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EXTERIOR LIGHTING GUIDE

FOR FEDERAL AGENCIES

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INTRODUCTION

Exterior lighting comprises a large portion of energy use at national parks. This guide should assist facilities managers in choosing the correct luminaires and practices for their spaces to reduce energy use and make their spaces more visually appealing and safe for visitors.

This document provides overviews of exterior lighting technologies that would best be integrated into national parks as retrofits or new designs, as well as tips for evaluating light sources, performing a lighting audit, and pairing lamps with lighting controls. The key issues to consider when performing a retrofit or new lighting design are energy, cost, and maintenance savings, and this guide is intended to help make these decisions easier.

Lighting in national parks plays a significant role in keeping visitors safe and enhancing their stays. For example, using the correct sources to light paths and trails can contribute to visitors' safety without upsetting the natural beauty of the park. And illuminating key attractions with energy-efficient luminaires can make their trips more memorable.

Exterior lighting often is on for extended periods of time, if not 24 hours a day. By combining high-quality sources with occupant-responsive controls, the energy use can be reduced with immediate results. In the past, high pressure sodium lamps were the most efficient choice. However, the quality of light was sacrificed for efficiency. Improved ballasts for induction lamps, emerging LED luminaires, and new improvements in HID sources broaden the scope of choices. When combined with the right sensors to maximize efficiency without compromising safety, exterior lighting can be vastly improved, typically saving more than 50% in retrofit applications.

REASONS FOR OUTDOOR LIGHTING RETROFITS

In the United states today, most residents seldom experience truly dark skies, no matter what time of night they find themselves outdoors.

© California Lighting Technology Center, UC Davis
CREDIT. Kathreen Fontecha

Pervasive outdoor lighting, which allows myriad activities to continue outside even after the sun goes down, obstructs the view of the night sky.

People rely on exterior lighting for safety, security, guidance, and recreation. Although traditional technologies and lighting designs initially met these fundamental needs, light sources, controls, and lighting designs have improved in recent years. These improvements, coupled with a nationwide push toward increased energy efficiency, have prompted widespread implementation of lighting retrofit programs. Advancements in exterior lighting technologies include increased energy savings, reduced maintenance costs, improved visual environment, enhanced safety measures, and reduced light pollution.

ENERGY SAVINGS

Lighting retrofits can lower energy use and costs without sacrificing light levels or quality. In addition, switching to more advanced technologies may allow users to implement lighting controls, which deliver increase functionality and energy savings.

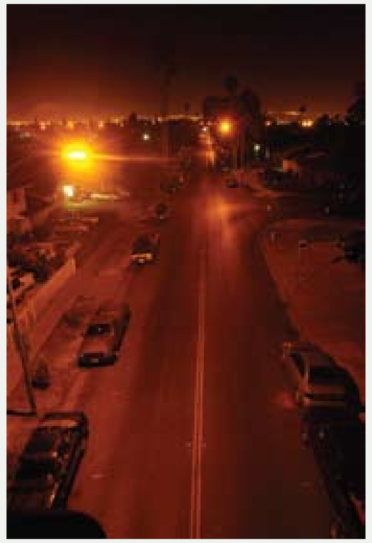
The Energy Information Administration estimates residential and commercial sectors used about 526 billion kilowatt-hours (kWh) of electricity for lighting in 2007—enough energy to power all homes in New York state for 107 years. This amount represents 19% of total electricity consumed by both sectors and 14% of total U.S. electricity consumption.[1]

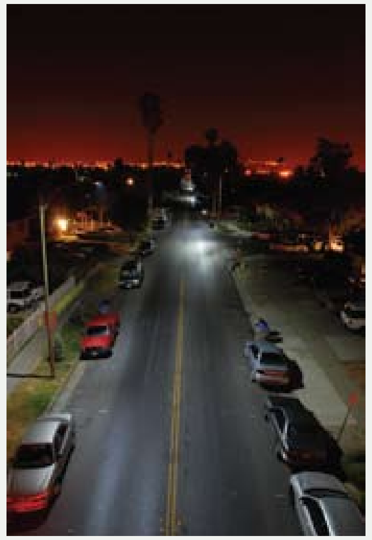
Residences consumed about 215 billion kWh—about 15% of residential electricity consumption.[2] The commercial sector consumed about 311 billion kWh for lighting, which is 23% of that sector's electricity consumption. Exterior lighting is included in this use and is an excellent opportunity for national parks to reduce electricity consumption.

[1] U.S. Energy Information Administration: http://tonto.eia.doe.gov/ask/electricity_faqs.asp.

[2] U.S. Energy Information Administration.

Figure 1. Low pressure sodium streetlights (top) were retrofitted with LED luminaires (bottom) in San Jose, CA, for 62% energy savings.





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CALIFORNIA: CASE STUDIES

Although California's energy use per capita is the third lowest in the nation, there is a growing movement to further reduce this use by implementing energy-efficient technology. Lighting is one sector targeted for improvement. California Assembly Bill 1109 (Huffman, Chapter 534, Statutes of 2007), in combination with federal lighting standards, requires inefficient exterior lighting technologies to be replaced with improved devices to reduce electricity use by no less than 25% from 2007 levels by 2018. To accomplish this goal, exterior lighting retrofits for public and private properties are increasing across the state.

CALIFORNIA COMMERCIAL AND INDUSTRIAL OUTDOOR LIGHTING	
Consumption	3067 GWh
Winter peak	7–8 p.m.
Summer peak	9 p.m.

www.fypower.org/bpg/module.html?b=institutional&m=Lighting&s=Outdoor_Areas

The following summaries of four California case studies provide tangible examples of the potential reductions in energy consumption that can result from exterior lighting retrofits.

In one California Lighting Technology Center (CLTC) exterior lighting demonstration, several exterior lighting systems were retrofitted with improved luminaire systems. The first retrofit involved replacing 18 compact fluorescent (CFL) bollards with nine bi-level light emitting diode (LED) bollards. Given the observed 10% occupancy rate, the LED bollards consumed 78% less energy than the original luminaires, while providing the same average light levels. In addition, lamp lifetime increased from 10,000 hours to 70,000 hours, which reduced maintenance costs.[3]

In the second study, eight 175W metal halide (MH) shoebox luminaires were replaced by eight 100W bi-level induction shoebox luminaires. The induction product consumed 67% less energy than the existing luminaires and produced similar average light levels. In addition, lamp lifetime increased from roughly 10,000 hours to 100,000 hours, again resulting in reduced maintenance costs.

[3] C. Jackson, P. Arani; LED Downlight and Bi-level Exterior Lighting Demonstration Project; California Lighting Technology Center and California Institute for Energy and Environment, January 2010.

In another notable case study by Pacific Gas and Electric Company (PG&E) for the Emerging Technologies Program, several low pressure sodium (LPS) streetlights in San Jose (Figure 1) were retrofitted with LED systems. Lighting retrofits consisted of a one-to-one replacement of 118 55W nominal LPS fixtures with continuously dimmable LED luminaires rated at 75W. The LED streetlight systems, operating at 50% power, had an energy savings of 62% over the incumbent LPS system.[4]

In a last case study by the San Diego Gas & Electric Company (SDG&E) for the city of San Diego, advanced street lighting technologies, including induction and LED lighting systems, replaced high pressure sodium (HPS) lighting systems. In this study, one-to-one replacements of HPS were made using induction and LED systems. The LED and induction streetlight systems had average energy savings of 31% and 43% over the incumbent HPS lighting systems.[5]

Implementing the knowledge from these case studies at national parks depends on the setting. Bollards could be effective outside park visitors centers and along trails and pathways. Choosing one new technology over another to replace older lamps will vary by location, and determining which light source will work best in a space is addressed later in the guide, in "Evaluating the Current Lighting System."

LOWERED MAINTENANCE COSTS

As observed in the previous case studies, improvements in lighting technologies have led to increased lifetimes for components in lighting systems. This, coupled with fewer failures, lengthens the time between maintenance activities, which reduces labor and other maintenance costs.

Implementing a routine maintenance program in addition to a lighting retrofit will simplify maintenance practices and reduce operational costs associated with sustaining lighting systems. Lifetimes of alternative sources are steadily growing, and life-cycle maintenance savings may alleviate some of the initial cost. Increasing efficacies of alternative light sources also are expected to reduce luminaire pricing and expand energy savings.

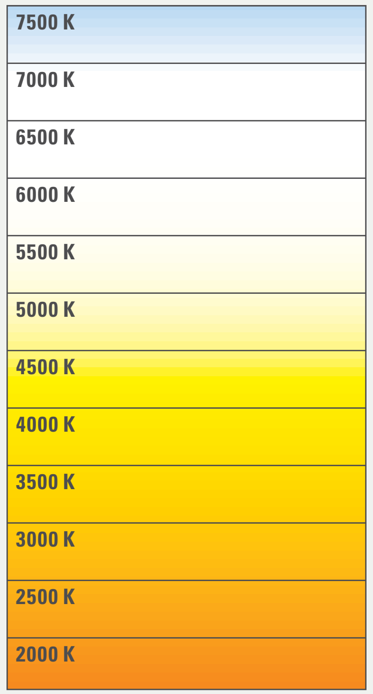
Lighting Energy Quick Facts

1. The United States Energy Information Administration reports that 19% of lighting is for residential and commercial use, and those sectors account for 14% of total U.S. electricity consumption.
2. Consumers who retrofit existing lighting systems, use more efficient luminaires, and use bi-level and occupancy control systems can expect energy savings of more than 50% compared to existing systems.
3. Many new lighting systems offer significant increases in system lifetimes, resulting in lower maintenance costs from less frequent lamp replacement.

[4] M. Bryan, J. Shackelford, M. Johnson, T. Cook, T. Pang; LED Street Lighting and Network Controls; Pacific Gas and Electric Company, Emerging Technologies Program, November 2009.

[5] M. Mutmansky, T. Givler, J. Garcia, N. Clanton; Advanced Street Lighting Technologies Assessment Project-City of San Diego; Clanton and Associates, Inc, and San Diego Gas & Electric Company, January 4, 2010.

Figure 2. Correlated color temperature scale



IMPROVED VISUAL ENVIRONMENT

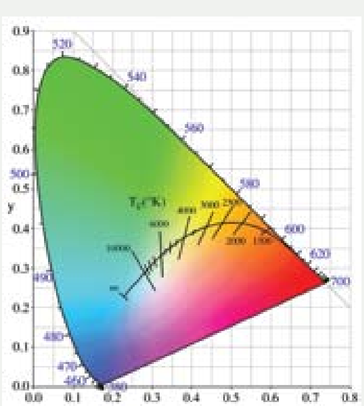
Lighting retrofits can help address general lighting quality problems, and new technologies have improved visual quality characteristics, such as color and flicker. When discussing lighting quality, two metrics commonly are used: correlated color temperature (CCT) and color rendering index (CRI).

CORRELATED COLOR TEMPERATURE (CCT)

Correlated color temperature is used to describe the color appearance of a light source. The light source (i.e., fluorescent, HID, etc.) is compared to a reference light source. The reference light source is taken to be an idealized source, called a blackbody radiator. The color of light emitted by a blackbody radiator depends exclusively on its temperature. As a blackbody radiator heats up or cools down, it emits light, according to Figure 2. When its temperature is low, a blackbody radiator will emit light with a "warmer" color appearance, and when its temperature is high, it will have a "cooler" color appearance. CCT is calculated by measuring the color of a light source, correlating that color to the blackbody radiator, and expressing that color as the temperature most closely matching that on the blackbody radiator temperature scale. CCT is stated in units of Kelvin (K). High pressure sodium lamps, for example, are considered to have low CCT (~2000 K), and deliver orange-yellow light. In contrast, most general illumination LED sources have high CCTs (5000–6000 K) and deliver white light.

A more in-depth perspective on color specification uses the International Commission on Illumination (CIE) 1931 x,y chromaticity diagram (Figure 3). Here, specific color matching can be achieved by plotting the chromaticity coordinates of light sources and comparing how close those points are to the reference light source (i.e., the long black line cutting through the middle of Figure 3).

Figure 3. CIE 1931 x,y chromaticity (color) space, with the chromaticities of blackbody light sources of various temperatures shown as the locus plot.



COLOR RENDERING INDEX (CRI)

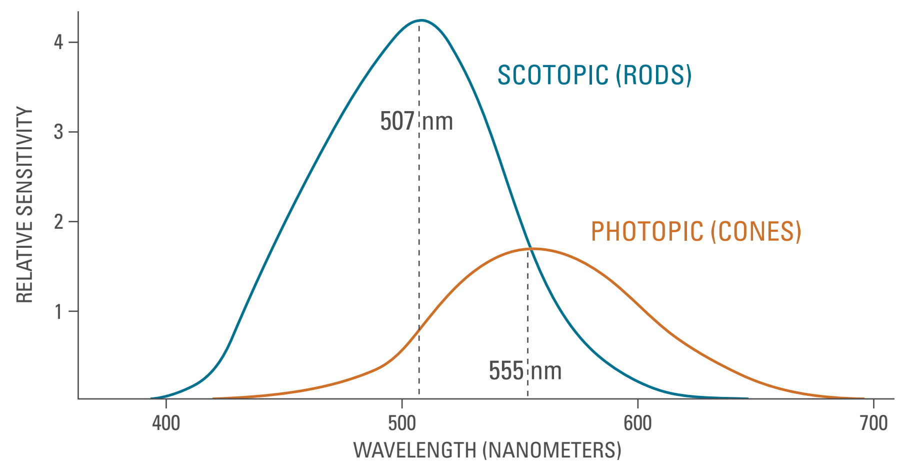
Color rendering index is used to describe the color rendering accuracy of a light source. The color rendering ability of a light source (i.e., fluorescent or HID lamp) is compared to that of a reference light source by using eight standard pastel color samples. The color of each sample is measured under the test light source and the reference light source with the same CCT as the test light source. The degree of color shift between the two sets of measurements is calculated and grouped as an average. This average is subtracted from 100, giving the CRI value. CRI is expressed as a number on a scale with no units ranging up to 100. High CRI value denotes good color rendering ability. While CRI is an official way to describe color accuracy, it is not the only way. Other metrics include color quality scale (CQS).

Any light source appears as a single color, but in reality, a light source is a conglomerate of colors that the eye blends together. When the color of a light source is deconstructed into its individual colors, the result is a light source's spectral power distribution, or SPD, and is usually represented in wavelengths in the visible spectrum, which ranges from approximately 380–780 nm. CCT and CRI are two ways of distilling a light source's SPD into a single number.

How the human eye perceives the SPD also is critical. Perception of a light source is a combination of the SPD of the source, and the surrounding visual conditions under which it is viewed. There are three general types of visual conditions. Photopic conditions account for the majority of applications including all applications occurring under moderate to well-lit conditions; scotopic conditions occur at very low light levels; and mesopic conditions are a combination of the two and account for the majority of exterior, nighttime lighting applications. Photopic and scotopic luminous efficiency functions are well defined, although the photopic luminous efficiency function is the only function accepted for use in standard lighting practice. Much work remains to be done on the definition of a mesopic luminous efficiency function.

Measurable light levels are relative quantities based upon application of the scotopic or photopic luminous efficiency function. Application of one function or the other has the effect of biasing the measurable light level depending on the source's spectral power distribution; thus, it is important to understand which function has been applied to obtain a particular value of light output. The lighting industry usually provides light output values using the photopic luminous efficiency function. Figure 4 shows the scotopic and photopic luminous efficiency functions.

Figure 4. Scotopic and photopic luminous efficiency functions



Winton FR, Bayliss LE: Human Physiology, 5th ed.Boston, Little, Brown, 1962.

Why this is important:

Understanding CCT, CRI, and types of vision will assist in making decisions about exterior lighting, about what color light the lamps should have, and how the luminaire type can affect people with different visual requirements.

Dark Sky Lighting Designs

According to the IDA, sky glow and light trespass should always be taken into consideration in dark-sky friendly lighting designs. To that end, the IDA recommends the following:

- Use full-cutoff or low-wattage luminaires.
- Aim façade/architectural lighting from the top down when possible, or avoid allowing uplight to shine past building lines.
- Shield landscape and security lighting so the light reaches only its intended target.
- Avoid overlighting areas by limiting reflected light.
- Keep lights off or in a lowered mode when they are not needed.

APPROPRIATE SAFETY MEASURES

Although it can be assumed that "brighter is safer," studies have shown that increased illuminance is not always beneficial. Too often, excessive lighting can lead to glare and overillumination — like at ATMs — sometimes making people more vulnerable to criminal activities.[6]

When designing exterior lighting systems, it is the quality of light instead of the quantity of light that typically is related to safety. For example, to increase safety and perceived security, the lighting design should aim to reduce glare, employ appropriate contrast ratios, and create "zones of recognition."

An additional concern for lighting safety is the spectral needs of the occupant. For example, different portions of the population may perceive areas to be brighter, depending on the type and color temperature of light sources used to illuminate a space. As a result, it is important to understand who, when, and why individuals will use the space being lit, and fit the lighting design to provide the type of illumination that suits the needs of the expected occupants.

REDUCED LIGHT POLLUTION & LIGHT TRESPASS

Expanding urban environments often lead to deterioration of people's view of the night sky. It is estimated that two-thirds of the U.S. population can no longer see the Milky Way with the naked eye.[7] According to the International Dark-Sky Association (IDA), "light pollution is any adverse effect of artificial light, including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste." In addition, ecological light pollution produces documented effects on the behavior of many wild species. Therefore, astronomical and ecological light pollution must be addressed, along with the public safety and maintenance in national parks. This can be an especially difficult task to address when trying to balance public safety and the maintenance of the natural state of national parks.

LIGHT POLLUTION

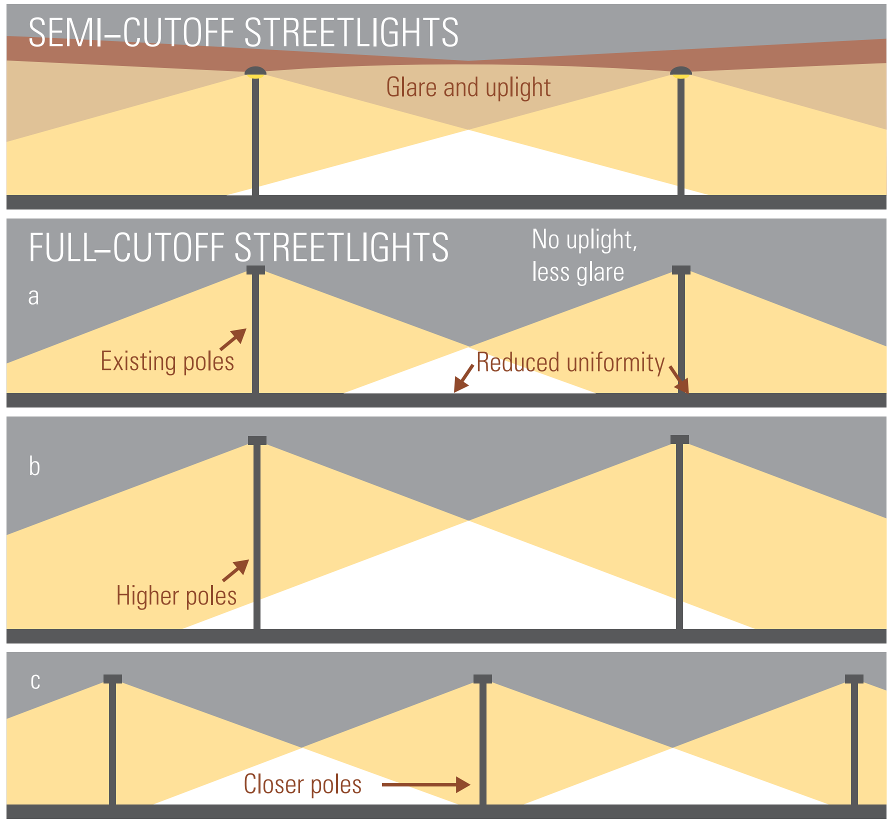
Sky glow occurs when artificial light is projected into the sky and spreads, causing a glow above populated areas. The lights of Las Vegas, for example, illuminate the night sky, and this sky glow is visible for miles to travelers entering the city by air or land. Such sky glow is common above all cities and towns, and anyone interested in an unobstructed view of the night sky must travel well beyond the city limits. In addition, according to the IDA, sky glow can interfere with astronomical instruments.

LIGHT TRESPASS

Similar to light pollution, light trespass results from fixtures that shine light beyond their intended target areas. This potentially undesired light can fall into neighboring buildings and infringe on people's outdoor activities.

In an effort to eliminate light pollution and light trespass, the IDA recommends preventing the projection of light above the horizon. This is achieved by using light fixtures with specifically designed optics (Figure 5).

Figure 5. Semi-cutoff and full-cutoff streetlights

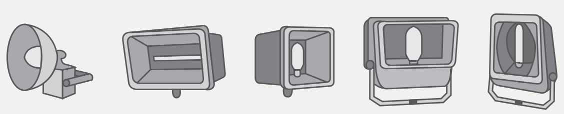
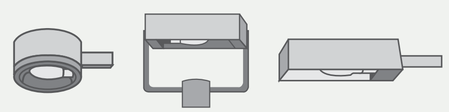
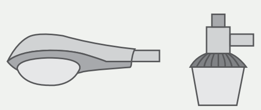
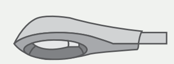
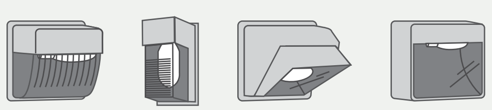
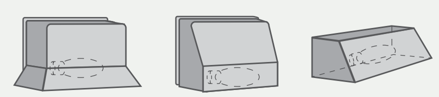
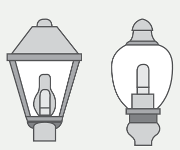
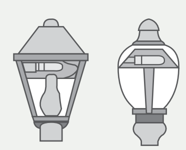
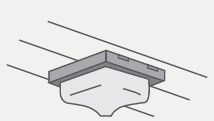
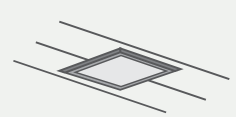
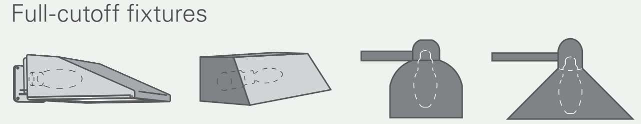


IES RP-8-00

[6] Lighting for Exterior Environments, IES Recommended Practice, RP-33-99.

[7] Cinzano, P., F. Falchi, and C.D. Elvidge. 2001. *The first world atlas of the artificial night sky brightness.* Mon Not R Astron Soc 328:689–707.

Figure 6. Traditional light fixtures (left) and new designs to reduce sky glow and light trespass (right)

UNACCEPTABLE/DISCOURAGED	ACCEPTABLE
Fixtures that produce glare and light trespass	Fixtures that shield the light source, to reduce glare and light trespass and to facilitate better vision at night.
Non-cutoff floodlights 	Full-cutoff fixtures 
Non-cutoff streetlight or dusk to dawn security fixtures 	Full-cutoff streetlights 
Non-cutoff wallpacks 	Full-cutoff wallpacks 
Non-cutoff Colonial-type fixtures 	Full-cutoff Colonial-type fixtures 
Drop-lens canopy fixtures 	Flush-mounted canopy fixtures 
Sag-lens/Drop-lens with exposed light source 	Full-cutoff fixtures 

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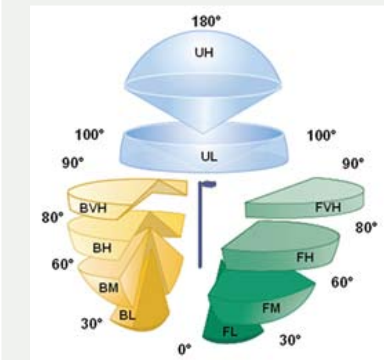
The lighting industry follows particular specifications to control the stray light from outdoor luminaires using the BUG System, an acronym for "Backlight," "Uplight," and "Glare."[8] This system, developed by the Illuminating Engineering Society of North America (IES), rates the amount of light a luminaire emits in specific directions. The BUG System helps lighting professionals determine appropriate lamp lumens for a given lighting zone: front, back, up (Figure 7). Today, many exterior light fixtures include BUG-rated zonal lumen distributions based on photometrics of the light fixture. These BUG ratings for light distribution can be used to estimate the fit of the lighting system within a desired application.

Many new light fixture designs optimize light output while reducing glare, light pollution, and light trespass (Figure 6).

Light pollution obscures the night sky and is especially troublesome for astronomical observatories. Specific light sources are more appropriate for use near observatories; for example, low pressure sodium lamps produce light with a small number of wavelengths, and this light is easily filtered out without substantially reducing or affecting astronomical observatories.

In contrast, white light of metal halides or some newer LED luminaires can be difficult for observatories to filter. This is because a broad spectrum of electric light emissions, often produced by white-light sources, may exist at the same wavelengths as the cosmic radiation often studied by astronomers. It is difficult to selectively filter the electric light from the starlight. Generally, astronomers prefer that major electric light emissions be reserved for LPS sources. If broad spectrum sources must be used, it is preferred that they are dimmed whenever possible and their spectrum be limited in short wavelength content, which is less likely to reflect off surfaces back into the atmosphere and interfere with celestial observations.

Figure 7. BUG System lighting zone specifications

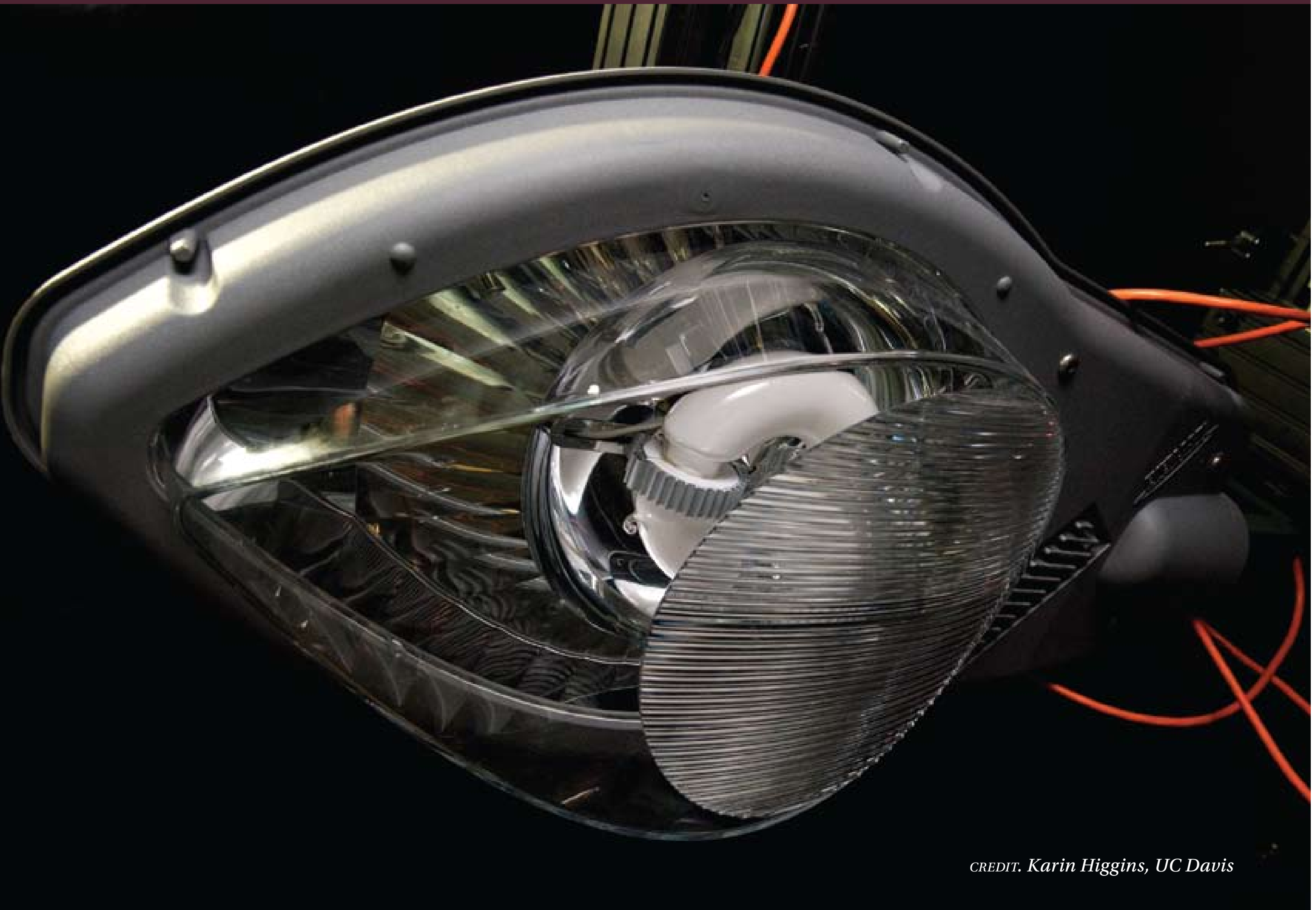


IES TM-15-07

[8] IES Luminaire Classification System for Outdoor Luminaires, TM-15-07.

EVALUATING THE CURRENT LIGHTING SYSTEM

Evaluate the current lighting system and what will be required for the future lighting system.



CREDIT. *Karin Higgins, UC Davis*

LIGHTING EVALUATION BASICS

Whether retrofitting an existing lighting system or designing a new one, a few issues should be addressed before any new lighting components are selected:

- What is the intended lighting application, and what are the required color temperature and color rendering requirements? In other words, how important is it to have colors appear naturally within the desired lighting space?
- Where will the light fixture be located, and what are the cutoff, glare reduction, and spectral considerations of the site? Are there any buildings, roadways, or walkways that would require shielding of direct light, and are any observatories nearby?
- How will the lighting system operate, and what control schemes are best for the application? Can lights be fully extinguished during certain parts of the night?
- What technologies are available to achieve the desired design? What are the costs?

CONDUCTING A LIGHTING AUDIT

WHY CONDUCT A LIGHTING AUDIT?

Lighting audits are essential to efficiently determine the current state of a particular lighting system or the need for a new one. An audit of the existing lighting system can determine what type of retrofit is proper. This includes deciding if adding occupancy-based controls, dimming capabilities, or daylight contributions into the new lighting design is appropriate. Lighting audits also allow for an accurate economic evaluation and light level comparison for the pre- and post-retrofit systems. These evaluations become important when seeking additional funding for the project.

HOW TO CONDUCT A LIGHTING AUDIT

Many organizations provide professional services for large-scale lighting system audits, and the processes for each individual audit vary. Several points recommended for a lighting audit are provided in "Lighting Audit Guidelines."

LIGHTING AUDIT GUIDELINES

To conduct a thorough evaluation of the existing lighting system, the following items are recommended for consideration:

- The age, condition, quality, and location of existing lighting fixtures, noting any lens discoloration, lens cracking, paint cracking, or burn marks.
- Model and manufacturer of lighting system to obtain existing photometrics.
- Lamp wattage and ballast type.
- Observe the operational environment of the lighting system, noting the possibility of particulate, moisture, or dirt buildup in or around lighting fixture.
- Note the activities of and the type of work being conducted in the space, as well as any special visual requirements.
- Observe how the lighting system is controlled and how often it is used.
- Note the perceived color of objects within the space to characterize color quality.
- Measure the physical layout of the existing lighting system noting luminaire height and spacing.
- Use an illuminance meter to measure the light intensity of the existing system during dark sky conditions to determine if the existing design is appropriate for the space. Readings should be taken on the ground and at even intervals to create a "grid" of measurements. These illuminance levels can be compared to the recommended levels for the application.

Once all this basic information has been recorded, it is possible to make some useful conclusions about the existing lighting system or space:

- Does the lighting system meet the original or proposed lighting needs of the space and occupants, given the required operations (energy use) and maintenance costs?
- Calculate the system efficacy of each type of luminaire. How efficient is each system at delivering light to its intended surface?
- Calculate the theoretical system illumination, determined from a rough lumen method or point-to-point calculation. Use lighting design software to determine if the theoretical measurements match the measured illumination values from the site. This will help determine the level of deterioration of the current lighting system as well as if the system meets code requirements.
- Calculate the existing lighting power density and determine if it meets any applicable codes or energy standards.

Lighting System Power and Energy Use Estimation

1. **COMPUTE THE TOTAL POWER (KW) USED BY THE EXISTING SYSTEM.**

EXISTING LAMP OR LUMINAIRE WATTAGE		NUMBER OF LAMPS		TOTAL POWER CONSUMED
______ W	x	______ lamps	=	W

2. **COMPUTE THE TOTAL ENERGY (KWH) CONSUMED ANNUALLY BY THE EXISTING SYSTEM.**

TOTAL POWER CONSUMED BY SYSTEM LUMINAIRE		HOURS OF USE PER DAY		DAYS OF USE PER WEEK		WEEKS OF USE PER YEAR		TOTAL ENERGY CONSUMED
______ W	x	______ hrs/day	x	______ days/wk	x	______ wks/yr	=	kWh/yr

3. **COMPUTE THE TOTAL ENERGY COST (DOLLARS) ANNUALLY FOR OPERATION OF THE EXISTING SYSTEM.**

TOTAL ENERGY CONSUMED		ENERGY RATE		TOTAL COST
______ kWh/yr	x	______ $/kWh	=	$/yr

LIGHTING AUDIT LOG

		FIXTURE/LENSES		LAMP						
ITEM NUMBER	LOCATION DESCRIPTION	AGE	CONDITION (soiled, cracked, etc.)	AGE	CONDITION (soiled, cracked, etc.)	SYSTEM WATTAGE	MODEL NUMBER	MANUFACTURER	PERCEIVED COLOR QUALITY (good, poor, etc.)	OCCUPANT TYPES (age, work activities, etc.)

LIGHTING LIFESPAN & MAINTENANCE PLANNING

Many decisions are involved when performing a lighting retrofit, especially when weighing cost versus benefit and seeking funding for the project.

RETROFIT ECONOMICS

SIMPLE PAYBACK

A simple payback is defined as the incremental cost of a new system over the existing system, divided by the incremental annual energy and maintenance cost savings received from the new system.

Examples of initial costs typically incurred for a lighting project (varies by project):

- Design
- Materials
- Installation
- Commissioning

LIFE-CYCLE ANALYSIS (LCA)

In general, life-cycle analysis attempts to capture all costs and benefits for the entire life of a product—cradle to grave. This differs from simple payback, which only considers the initial costs and the savings from energy and maintenance cost reductions. A true LCA starts from manufacturing and ends at disposal, including transportation costs and the related pollution effects. There are different approaches for implementing an LCA, depending on the project. For a more detailed description, please refer to the Economic Analysis of Lighting (IES RP-31-96).

LIFE-CYCLE COST-BENEFIT ANALYSIS

INITIAL COSTS	SYSTEM 1	SYSTEM 2
1. **LIGHTING SYSTEM—INITIAL INSTALLED COSTS, ALL PARTS AND LABOR (DOLLARS)** An estimate is prepared for material and labor of the installation.		
2. **TOTAL POWER USED BY LIGHTING SYSTEM (KW)** Connected load of the lighting system, including ballasts and transformers, if any.		
3. **UTILITY REBATES (ENTER A FINANCIAL INCENTIVE AS A NEGATIVE NUMBER) (DOLLARS)** To reduce peak demand, electric utility companies in the United States may offer incentives for end users who retrofit or install energy-efficient lighting equipment in their buildings.		
4. **OTHER FIRST COSTS GENERATED BY THE PRESENCE OF THE LIGHTING SYSTEMS (DOLLARS)** Include any other differential costs, such as insulation, solar power, or tax credits.		
5. **INITIAL TAXES (DOLLARS)** Usually 6–8% of the initial cost (Line 1).		
6. **TOTAL COSTS (DOLLARS)** The sum of lines 1, 3, 4, and 5.		
7. **INSTALLED COST PER SQUARE FOOT (DOLLARS)** The installed cost per square foot.		
8. **WATTS OF LIGHTING PER SQUARE FOOT (W/FT^2)** Watts per square foot, also known as the power density.		
9. **RESIDUAL (SALVAGE) VALUE AT END OF ECONOMIC LIFE (DOLLARS)** The amount the system will be worth at the end of its economic life (as scrap, for example). Use the same life for each system under comparison. Note that this value is negative if money is received for the salvage; it is positive if a cost is incurred to dispose of the system at the end of its life.		

ANNUAL POWER AND MAINTENANCE COSTS	SYSTEM 1	SYSTEM 2
1. **LUMINAIRE ENERGY (Operating hours x kW x $/kWh) (DOLLARS)** The number of operating hours and cost per kWh depends on occupancy schedules and local power rates. Ten hours a day, five days a week, 52 weeks per year represents 2,600 hours. In the United States, the average energy cost for commercial, institutional, and industrial customers is $0.08 to $0.09 per kWh.		
2. **OTHER ANNUAL COSTS GENERATED BY THE LIGHTING SYSTEM (DOLLARS)** Other costs may include costs for maintenance of the lighting system.		
3. **COST OF LAMPS ANNUALLY (DOLLARS)** The cost of lamps per year depends on the relamping strategy. If spot relamping is used, then the lamp cost per year is figured from this formula: $\text{lamp cost per year} = \frac{\text{(labor and lamp cost for spot replacement of one lamp)} \times \text{(number of lamps in the system)}}{\text{(lamp life)} / \text{(annual burning hours)}}$		
4. **OTHER ANNUAL COSTS GENERATED BY THE LIGHTING SYSTEM (DOLLARS)** To annualize ballast costs, use: $\text{ballast cost per year} = \frac{\text{(cost to replace one ballast)} \times \text{(number of ballasts in the system)}}{\text{(ballast life)} / \text{(annual burning hours)}}$		

IESNA Lighting Handbook, 9th ed. 25-4

Figure 8. Scheduled group relamping has proven to be more cost effective than spot relamping.

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RELAMPING BEST PRACTICES

When relamping lighting fixtures, two strategies can be used: group and spot relamping. The debate between the two generally is reserved for fluorescent and HID lamps.

Group relamping requires lamp replacement to occur on a fixed schedule to maximize lamp life while minimizing lamp outages. Oftentimes, group relamps occur at about the L70 life of the lamp (the length of time it takes the lamp to reach 70% of its initial light output). Depending on the size of the lighting installation and amount of time the relamping would take, the relamp normally occurs in phases. This strategy saves labor costs by reducing setup time and fixture cleaning. Furthermore, group relamping is easy to delegate to outside contractors who have special equipment and training, which increases the labor efficiencies.

Spot relamping requires a technician to replace a lamp every time it fails. As a result, lamps run until the end of their lives. This strategy saves material costs by allowing lamps to last longer, but increases labor costs by forcing a technician to replace and clean lamps regularly. Spot relamping may result in less constant illuminance levels because of delays between the lamp failures and replacement.

In general, a scheduled group relamping program has proven to be more cost effective than spot relamping (IESNA Lighting Handbook, 9th ed., 21-9). Page 26 of this guide contains a maintenance log that can be used to track relamping.

FUNDING YOUR PROJECT

Agencies can look to federal, state, and local sources to fund exterior lighting projects.

- Federal stimulus money is available through government-awarded grants.
- Local utilities offer incentives to support the use of energy-efficient technologies in various applications.
- Lighting manufacturers also can help find incentives; contact the exterior lighting manufacturer for more information.

RECYCLING TIPS

Fluorescent lamps contain a small amount of mercury and must be disposed of properly; a few states prohibit throwing fluorescent lamps in the trash. A growing number of home improvement stores recycle CFLs, including Home Depot and Ikea. For more information on where to recycle fluorescent lamps, visit www.earth911.com.

High intensity discharge lamps—including mercury vapor, metal halide, and high pressure sodium—contain various amounts of mercury. Fewer disposal sites and stricter laws exist to recycle these lamps. Two sets of laws govern HID's disposal: Section C of the Resource Conservation and Recovery Act, and each state's Hazardous Waste regulations. To find out more about both, visit www.epa.gov.

Fluorescent ballasts manufactured before 1978 might contain polychlorinated biphenyls and must be disposed of as hazardous waste.

CASE STUDIES

ARCADE CREEK RECREATION AND PARK DISTRICT

A recent CLTC case study demonstrated simple payback and LCA. LED bollards were installed at the Arcade Creek Recreation and Park District in Sacramento, CA, and were analyzed over a 15-year evaluation cycle. If the LED bollards replaced 42W CFLs, the simple payback would be more than 10 years, and the LCA showed a savings of $220 over the comparison time period. For a 70W HID base case, the simple payback is about five years and LCA showed a savings of $350; for a 100W HID base case, the simple payback is about two-and-a-half years and LCA returned a savings of $530.

Arcade Creek Recreation and Park Distric:

www.cltc.ucdavis.edu/content/view/667/353

BIG BEND NATIONAL PARK

Big Bend National Park in Texas recently upgraded a section of exterior lighting using American Recovery and Reinvestment Act funds, a Best Lighting Practices Grant, and a grant from the Friends of Big Bend National Park. The retrofit resulted in an estimated annual energy cost savings of $3,130 and a 98% reduction in watts, energy consumption, and greenhouse gas emissions. The goal is to retrofit all lights within the park to reduce light pollution and energy use, improve the lighting quality for park users, reduce energy costs, and make the park safer for visitors.

Big Bend National Park:

www.nps.gov/bibe/parknews/upload/Chisos Basin Best Lighting Practices Release.pdf

LIGHTING SYSTEM MAINTENANCE LOG

ITEM NUMBER	LOCATION OF FIXTURE	DATE OF RELAMP	ACTION TAKEN	EMPLOYEE NAME

Figure 9. Bear Valley Visitor Center at Point Reyes National Park at dusk

LIGHTING CONTROLS

Many options are available for implementing lighting controls, and they can make outdoor lighting systems much more energy efficient.

CREDIT. *Kathreen Fontecha*

Lighting controls in outdoor lighting systems reduce the number of operating hours, lower maintenance costs, and increase energy savings. Several types of exterior lighting controls are available, including photosensors, energy- and time-management systems, and occupancy or motion sensors. These technologies can be used either to dim the lights or extinguish them. Select manufacturers offer luminaires with integrated controls, while others can be paired with external options. They can be implemented with a variety of sources including LED, induction, fluorescent, and HID. When exterior lights are coupled with luminaire control packages, the end result is a smart lighting system that optimizes energy use, offers the right amount of light output for the application, and reduces operational costs.

Some lighting controls, such as photosensors, are useful in all exterior areas. Others, such as bi-level occupancy controls, are appropriate only for certain applications, such as spaces that are required to be illuminated but have low occupancy levels after dark. National parks and other federal properties with after-hours parking lots, garages, pathways, or exterior security lighting are ideal candidates for lighting controls projects.

DAYLIGHTING CONTROL SYSTEMS

Daylighting control systems detect available sunlight and adjust electric light output accordingly. Electric lights may dim or turn off completely, depending on the type of daylighting controls used. Daylighting control systems may include time scheduling, which can maximize energy savings.

PHOTOSENSORS

A photosensor is an electronic component that detects the presence of visible light, infrared (IR), and/or ultraviolet (UV) energy. Used in conjunction with lighting controllers (e.g., dimmers, switches), photosensors can help reduce the number of operating hours for exterior lighting. If the amount of light that strikes the photosensor is greater than the preset threshold, a signal is sent to lighting controllers to dim or extinguish the electric light. Photosensors often are integrated in the fixture, or placed in a location free from shadows or direct sunlight. Properly installed photosensors will require little maintenance, such as occasional wiping to remove dust from the surface.

ENERGY MANAGEMENT CONTROL SYSTEMS AND TIME CLOCKS

EMCS and timers limit lighting to specific scheduled hours. EMCS often is used to control lighting in an interior and exterior space, for example, a visitor center and adjacent parking lot. Because spaces may need more light as the sky darkens, daylight controls or photosensors can adjust lights on to reduced output, then timers can increase their power later in the evening on a preset schedule. Energy management control systems also can be used to monitor energy use, adjust luminaire light levels remotely, and indicate repair needs.

OCCUPANCY SENSORS

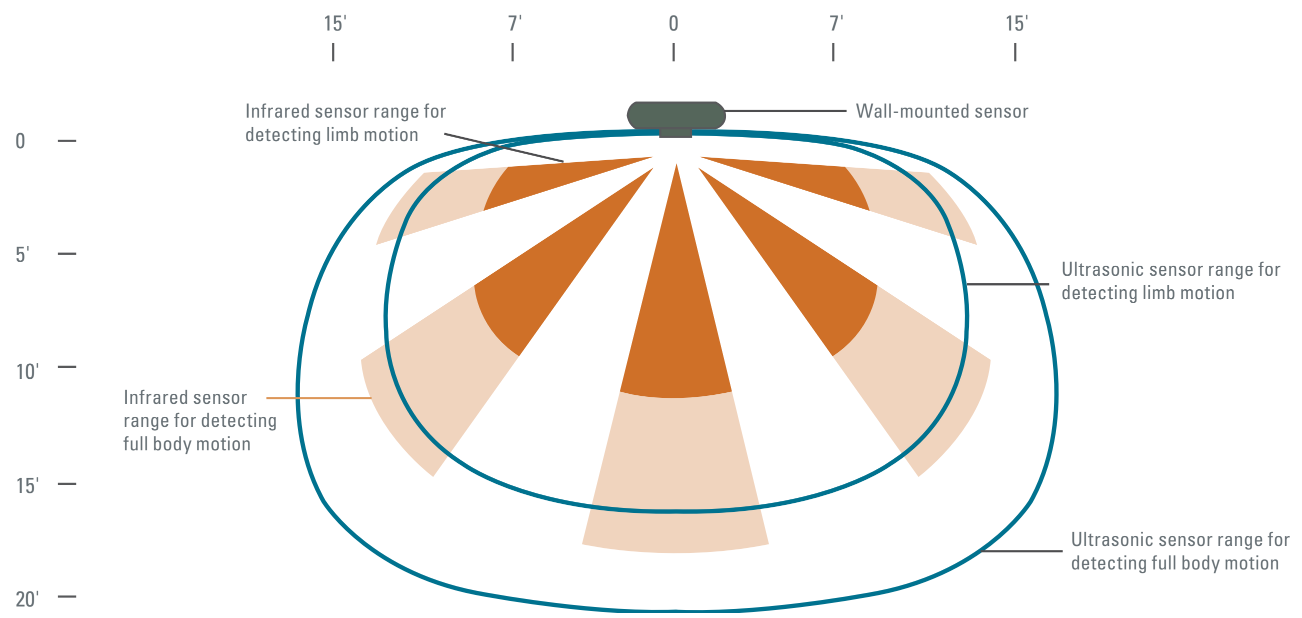
There are four types of occupancy sensor technologies that are available on the market—passive-infrared, ultrasonic, microwave, and audio-based. Audio and ultrasonic technologies are inappropriate for exterior use because they can be triggered unintentionally by small animals, wind, rain, etc.

ON/OFF VS. STEPPED-DIMMING OCCUPANCY CONTROLS

On/off occupancy controls consist of a lighting system that operates at full power and light output when the space is occupied and at zero power and light output when unoccupied. This function is appropriate for secondary use areas that are not used at night.

Stepped-dimming occupancy controls consist of a lighting system that operates at full power and light output when the space is occupied and at a reduced power level and light output (the level can be design or product specific) when unoccupied. This design method balances energy savings and safety. This function is appropriate for primary use areas.

Figure 10. Various occupancy sensor configurations and ranges



www.reliant.com/en_US/Page/Generic/Public/esc_purchasing_advisor_occupancy_sensors_bus_gen.jsp

ZONAL VS. INDIVIDUAL OCCUPANCY CONTROLS

A zonal occupancy control design involves occupancy sensors controlling groups of luminaires. For example, a single occupancy sensor located at the entrance to a small parking area could activate all parking area luminaires when traffic enters the lot. Zonal occupancy controls can be cost effective and provide desired performance features, but they may produce "blind" spots (i.e., it is possible to occupy the controlled zone without being detected).

Individual occupancy control design involves each controlled fixture having an integral occupancy sensor. This increases reliability and minimizes "blind" spots but can increase incremental cost.

PASSIVE-INFRARED OCCUPANCY SENSOR

Passive-infrared sensors require a direct line of sight to function properly. This means any obstructions such as buildings or trees between the sensor and the intended target will keep the sensor from activating luminaires.

Passive-infrared sensors have varied coverage ranges and patterns. An appropriate range and coverage pattern should be determined based on application and traffic patterns.

MICROWAVE OCCUPANCY SENSOR

Microwave occupancy sensors can detect motion through some, but not all, mediums. These sensors can be useful when integrating an exposed sensor into the luminaire is not possible. Exposing the sensor to open air or through a thin acrylic sheet can reduce blind spots due to unforeseen obstructions. However, it is not typical for a microwave sensor to detect reliably through fixture housings. Unless a fixture is offered with an integral microwave sensor and a detailed coverage pattern, beware of specifying a sensor to be integrated into a housing.

LIGHTING CONTROLS / IMPLEMENTATION

- Lighting controls implementation methods can vary depending on the application. The first step in any lighting controls project is to define control zones and control resolution within each zone. Exterior lighting controls zones can vary from a residential walkway to an industrial parking lot.
- Control resolution can be as fine as fixture-integrated photosensors for all area luminaires or as coarse as one timeclock for an entire facility. Lighting controls often are installed at the circuit or fixture level, and specific configurations will vary according to each lighting controls system type and manufacturer.

INSTALLATION AND COMMISSIONING OF LIGHTING CONTROLS

Care should be taken when installing lighting control systems as most sensors are visible to the public and can easily be manipulated, damaged, or stolen. To function correctly, sensors must be positioned and set up correctly. Consult the sensor manufacturer for installation and commissioning procedures.

TIPS FOR ADDING CONTROLS AS A RETROFIT

- Determine the needs and usage patterns of occupants to determine the best lighting control system.
- Evaluate sensor upgrade costs versus estimated energy savings using first- and second-level economic analyses.
- Ensure the sensor is physically compatible with the space considering sensor ranges, ambient light, and sensor delays.

STEPS FOR SUCCESSFUL SENSOR POSITIONING AND COMMISSIONING

- Refer to the sensor manufacturer's instructions for proper installation.
- Include building personnel in planning stages.
- Position sensors to minimize false triggers.
- Train building occupants on sensor maintenance.

SOURCE TECHNOLOGIES

Many light sources exist for exterior lighting applications. This section describes various lighting products and provides a comparison of technologies to assist in selecting the appropriate lighting technology.

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Light sources come in myriad types, shapes, sizes, colors, light output, and watts. Choosing the right lamp for the application can depend on factors such as cost, lamp life, controls, and efficacy. The rapidly changing marketplace makes the decision challenging: CFLs are replacing incandescents, and LEDs are poised for tremendous growth.

When selecting a light source, keep in mind that each technology will be paired with other elements to create an effective system. The source should be selected in combination with the luminaire and proper controls for the specific application.

When planning a retrofit, not all fixtures are designed to seamlessly replace one source with another. The new source may not perform the same way as its predecessors. For example, compact fluorescent lamps typically do not perform well in cold environments, and LED replacement lamps may not last as long as intended when exposed to prolonged periods of heat. Careful evaluation of the long-term goals of the retrofit may indicate, in some cases, that replacing the whole fixture is more cost-effective than replacing the lamps, even though the up-front costs may be higher.

For the past 150 years, electric light was mainly produced by a glowing filament in a glass bulb or by the fluorescence of a gas-filled tube. Now, solid-state lighting is a viable alternative for general illumination. Understanding the benefits and limitations of the most prevalent light sources will aid in the selection of the right technology for the application.

FILAMENT-BASED LIGHT SOURCES

Incandescent and halogen lamps both are filament-based light sources that operate by a similar principle but have unique differences. In these lamps, current flows through a fine filament wire, causing it to glow.

INCANDESCENT

Incandescent sources produce light from a filament heated by an electric current to incandescence. Traditionally, incandescent lamps have been used in nearly every application. These sources are known for their warm color appearance and high color rendering ability. Incandescent lamps are available in many different lamp shapes and sizes to fit almost any application, although they are one of the least efficient sources available. Incandescent lamps are the most common type of lamp used in residential applications.

HALOGEN

Sometimes called tungsten halogen or quartz halogen, halogen lamps are another type of incandescent filament-based light source. This lamp uses halogen gas inside a small quartz capsule that encloses the filament. The gas provides some protection for the filament and redirects filament particles back to the filament itself, which results in a longer lamp life than standard incandescents and allows the lamps to operate at a higher temperature. Higher operating temperatures also can increase the probability of fire or heat applications.

HALOGEN INFRARED REFLECTING (HIR) LAMP

This is a type of halogen PAR lamp with a coating on the inside of the lamp. The coating not only absorbs ultraviolet (UV) radiation but also redirects heat (infrared radiation) back onto the filament, which allows for a slight increase in efficacy over standard halogen lamps.

FLUORESCENT LIGHT SOURCES

Fluorescent technology is a low-pressure gas discharge source in which light is produced by the fluorescence of a phosphor coating when excited by ultraviolet (UV) radiation from a mercury arc. The phosphor coating on the inside of the glass tube transforms the UV radiation into visible light. A variety of phosphors can be used to provide fluorescent lamps in various color temperatures and with various color rendering qualities. Fluorescent lamps are available in many shapes, sizes, wattages, and colors. Ballasts are essential to the operation of fluorescent lamps. Ballasts are electrical devices that provide proper starting voltage to initiate the arc between the electrodes and then control current during operation.

PREHEAT LAMP AND BALLAST

Preheat (switch start) fluorescent lamps are designed to operate in a circuit requiring a manual or automatic starting switch to preheat the electrodes to start the arc. Preheat lamp and ballast circuits heat the cathode using a variety of starter mechanisms before the high voltage is applied. The preheating takes a few seconds and then the ballast attempts to strike the lamp; if the lamp does not strike, the preheating process starts over. When using a starter that cannot recognize a lamp failure, it is important to remove the lamp as soon as possible, or the ballast will continue to attempt to strike the lamp until the ballast and/or starter fail. Lamp flicker is usually an indication of lamp failure.

INSTANT-START LAMP AND BALLAST

An instant-start fluorescent lamp is designed to start by a very high voltage without preheating the electrodes. The high voltage in instant-start lamp and ballast circuits causes the electrodes to discharge electrons through field emission.

RAPID-START LAMP AND BALLAST

A rapid-start fluorescent lamp is designed to operate with a ballast that uses low-voltage windings to preheat the electrodes and initiate the arc without a starting switch or the application of high voltage. Rapid-start lamps require a bi-pin configuration.

PROGRAM-START BALLAST

Program-start ballasts warm the electrodes before the high voltage is applied. Once the arc is struck, the ballast stops the warming circuit.

ELECTRONIC BALLASTS VS. MAGNETIC BALLASTS

Magnetic and electronic ballasts provide the proper starting voltage and regulate the amount of current flowing through the lamp. The magnetic ballast is an older technology that uses coiled wire as an inductor to regulate current. It is less efficient and larger than an electronic ballast, and may create a humming noise during operation. The magnetic fluorescent ballast is currently being phased out of the market. The electronic ballast delivers higher efficacy than the magnetic ballast and uses improved electronic components that more precisely control the current. The electronic ballast does not emit a notable humming noise, but may have a shorter lifespan than the magnetic ballast. Different lamps require different ballast technologies. It is important to check lamp and ballast compatibility before any retrofit or maintenance project.

COMPACT FLUORESCENT LAMP (CFL)

CFLs are a type of fluorescent lamp designed to fit into roughly the same space as incandescent lamps. CFLs are available in three base types with many different geometries, wattages, and color temperatures. Most CFLs for residential applications are designed to fit into standard Type-A (arbitrary lamp) screw-base sockets. These are commonly known as screw-in or screw-base CFLs. Screw-in CFLs also are known as self-ballasted CFLs because the ballast is integrated into the lamp as a nonremovable part. The ballast is enclosed in the plastic shell in the base of the lamp.

On the other hand, pin-based CFLs have small, plastic bases that do not contain integrated ballasts. Pin-based CFLs are designed with two or four pins and are used with specially designed fluorescent fixtures that have the ballast remotely mounted to part of the housing.

Finally, there is a new type of CFL known as a GU-24 lamp. This lamp is geared toward using strengths of both screw- and pin-based technology. There are few GU-24 lamp styles that are shallower than traditional CFLs for decorative fixture applications. All GU-24 lamp styles will keep the same screw-in motion as a screw-base CFL but with a modified twist-and-lock installation. Some styles will contain integrated ballasts, while others will have separate, detachable ballasts within the lamp configuration, allowing for easier ballast replacements.

INDUCTION LIGHT SOURCES

Induction lamps are similar to fluorescent lamps and generate light in the same way: The flow of electricity creates a gas discharge that is converted into visible light by the white phosphor inside the lamp. Instead of using a standard ballast and electrode system that is essential to fluorescent lamps, induction systems use a high-frequency electromagnetic wave produced by a special ballast (also called a generator) to induce a current in the lamp. Fluorescent lamps have electrodes that degrade over time and eventually fail. Induction lamps do not have electrodes, which is the primary reason for their long life. Because of their longevity, induction luminaires are well suited for outdoor areas where lamps would be inconvenient to maintain or replace.

HIGH INTENSITY DISCHARGE (HID) LAMPS

HID lamps are also gaseous discharge lamps. Typical HID lamps contain an electrode within an inner arc tube that is mounted on a supporting frame. The frame and support assembly are connected to a base, which provides the electrical contact. The entire assembly is surrounded by a hard glass outer jacket that has been exhausted of air to protect the arc tube and lamp components from contamination and oxidation. The light-producing element of HID lamps is the electric arc discharge contained within the arc tube.

Unlike fluorescent lamps, which provide visible light by the fluorescence of phosphor coating along the tube wall, HID lamps emit light directly from the electric arc. The efficacy and color characteristics of HID lamps are dependent upon chemical components present in the arc tube.

The arc tube chemical composition determines the classification of the lamp (e.g., mercury vapor, metal halide, high pressure sodium, and low pressure sodium).

MERCURY VAPOR (MV)

Mercury vapor is one type of HID technology in which a major portion of the light is produced by radiation from mercury. The outer glass envelope of mercury lamps is made of borosilicate hard glass, which is needed to withstand the high operating temperature. The outer glass shell absorbs much of the UV radiation emitted by the mercury arc.

MV lamps emit a greenish-blue light at efficacies of 30 to 65 lm/W and a CRI of 15. Under this light, blues, greens, and yellows are emphasized, making the lamps suitable for landscape lighting. However, orange and yellow spectrums are lacking, which makes the lamps undesirable for areas occupied by people.

In general, MV lamps are an older technology that generally underperforms in efficacy and lamp life compared with metal halide or sodium lamps. Thus, in retrofit applications, mercury vapor lamps often are replaced with metal halide or high pressure sodium lamps. In addition, sales of mercury vapor lamp ballasts were banned in the United States in 2008.

METAL HALIDE (MH)

Similar in construction to mercury vapor lamps, metal halide lamps provide white light at higher efficacies and longer lifetimes than mercury vapor sources. Metal halides present in the arc tube contribute to the improved light output over time. MH lamps commonly are used for commercial, industrial, retail, sport, building façade, and high-ceiling architectural purposes. High CRI metal halide PAR lamps are used in downlighting, accent, and display lighting in architectural and retail applications. MH is the most suitable HID source when good color rendition is required.

MH technology is available in these three types of lamps:

- Probe-start metal halide lamps contain a special "starting" electrode within the lamp to initiate the arc when the lamp is first lit. This generates a slight flicker when the lamp is turned on.
- Pulse-start metal halide lamps do not require a starting electrode and instead use a special starting circuit referred to as an igniter to generate a high-voltage pulse to the operating electrodes.
- Ceramic metal halide lamps allow for an increase in color quality and are similar to the pulse start, except the arc tube is made of aluminum oxide instead of quartz. These lamps have better color rendering, lumen maintenance, and color consistency over their lifetimes than metal halide lamps because of the improved arc tube material.

HIGH PRESSURE SODIUM (HPS)

The high pressure sodium lamp is a type of HID lamp in which light is produced by radiation from sodium vapor. The outer glass of a high pressure sodium lamp is made of borosilicate hard glass, which is needed to withstand the high operating temperature of the lamp. The arc discharge is produced by a mixture of xenon and sodium-mercury amalgam in the arc tube. HPS lamps are available with clear and diffuse coatings. They produce an amber light and are widely used in outdoor and industrial applications where color appearance and color rendering are not critical. The lamps' long life and high efficacy have made them popular for parking lots, street lighting, and exterior lighting.

LOW PRESSURE SODIUM (LPS)

Similar to high pressure sodium, low pressure sodium lamps produce light by radiation from sodium vapor. This arc discharge produces a monochromatic "yellow" light at a color temperature of 1800K; the lamps are not CRI rated. Not only does the light appear yellow, but also any object whose color is not yellow appears yellow or gray under this source. LPS lamps have the highest efficacy of any lamp family, but because of their poor color characteristics, LPS lamps are rarely used. However, the limited LPS spectrum lends itself well to exterior lighting near astronomical observatories, where it can easily be filtered out.

LIGHT EMITTING DIODES (LED)

The light emitting diode is one of the newest source technologies in lighting today. LEDs are made from solid-state materials that emit light. Light output quantity and characteristics depend on the specific material, chemistry, size, color, and thermal environment of the LED. The color of the emitted light depends on the chemical composition of the material used and can be near-ultraviolet, visible, or infrared. Red LEDs are the most efficient at producing light in the visible spectrum. LEDs can be monochromatic (one wavelength of visible spectrum) emitters. To make white light, there are two general approaches: color mixing or phosphors. Color mixing is typically denoted as RGB (Red-Green-Blue). The RGB LEDs are placed close together (typically with a diffusing lens), which combine to make white light. The other approach to making white light with LEDs requires a yellowish phosphor coating over the top of a blue LED. The resulting mix gives the appearance of white light.

LEDs have been used for decades as indicators in most electronic equipment and more recently in exit signs and traffic signals. White LED technology has improved significantly and has begun to find niches in the general lighting market with the potential of considerable energy and maintenance savings. Rapid improvements in LED efficacy along with the development of white LED sources with very good color characteristics make LEDs a viable lighting source to consider in many exterior applications.

Figure 11. Full-cutoff luminaire in Tucson, Arizona.

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BEST PRACTICES FOR SELECTING PRODUCTS

When selecting various lighting products, the lumens, efficacies, light quality, lifetimes, and cost all should be considered. On the next page is a technology selection chart.

- Luminaires should reduce power during vacant periods.
- Photocontrols should switch luminaires off high mode when sufficient daylight is available.
- Photocontrols or time clocks should extinguish the entire luminaire when sufficient daylight is available.
- Luminaires should use long life sources to reduce maintenance and recycling requirements.
- Cutoff or full-cutoff luminaires should be used whenever possible.
- Sources should have correlated color temperatures below 6000 K (or 4200 K in residential areas).

EXTERIOR LIGHTING: SOURCE TECHNOLOGIES

LAMP TYPE	DEMAND (W)*	SOURCE EFFICACY (LPW)***	CCT (K)	CRI	LIFETIME (HOURS)	PRICE
HIGH PRESSURE SODIUM	70–400	80–120	1,900–2,200	22–70	15,000–40,000	$$
LOW PRESSURE SODIUM	55–180	130–170	1,700–1,800	–	16,000–18,000	$$
CERAMIC METAL HALIDE	70–400	75–110	3,000–4,200	80–94	10,000–24,000	$$–$$$
METAL HALIDE	70–400	40–70	3,000–4,200	60–80	10,000–20,000	$$
MERCURY VAPOR	75–1,000	20–40	3,200–6,700	15–50	16,000–24,000	$$
CFL	20–70	80–85	2,700–5,000	80–85	6,000–20,000	$
INDUCTION	70–250	50–85	3,500–5,000	80–85	100,000	$$–$$$
LED	40–250**	up to 130	2,700–10,000	50–80	35,000–50,000	$$$–$$$$

NOTE: The numbers in this chart were compiled when this guide was created and change as the technology improves.

* Typical size of lamps used in exterior applications.
** Typical size of LED luminaires used in exterior applications, luminaire contains multiple LEDs.
*** Based on initial lumens, system efficacy should be determined and is dependent on the specific fixture style, ballasts, and drivers employed.

EMERGING TECHNOLOGIES

Within exterior lighting, emerging technologies have the potential to further increase energy efficiency.

© Luxim Corporation

PLASMA LIGHTING

Plasma technology has the potential for high efficacy, high lumen density, and long life. These characteristics, combined with plasma's small form factor, show promise for a future high-performance light source. Plasma lighting systems use an electrodeless lamp that emits light as a result of an interaction of gas inside the lamp and precisely focused radio frequency power. Because there is no electrode, which is a common cause of failure for many HID lamps, plasma lighting systems have the potential for longer lifetimes.

Plasma systems, because of their high power density, currently are being developed for exterior lighting applications typically occupied by high intensity discharge lamps for roadways, parking lots, and outdoor sport lighting. With further performance and cost validations, these emerging plasma applications potentially could increase lighting-related energy efficiencies.

NETWORKED LIGHTING

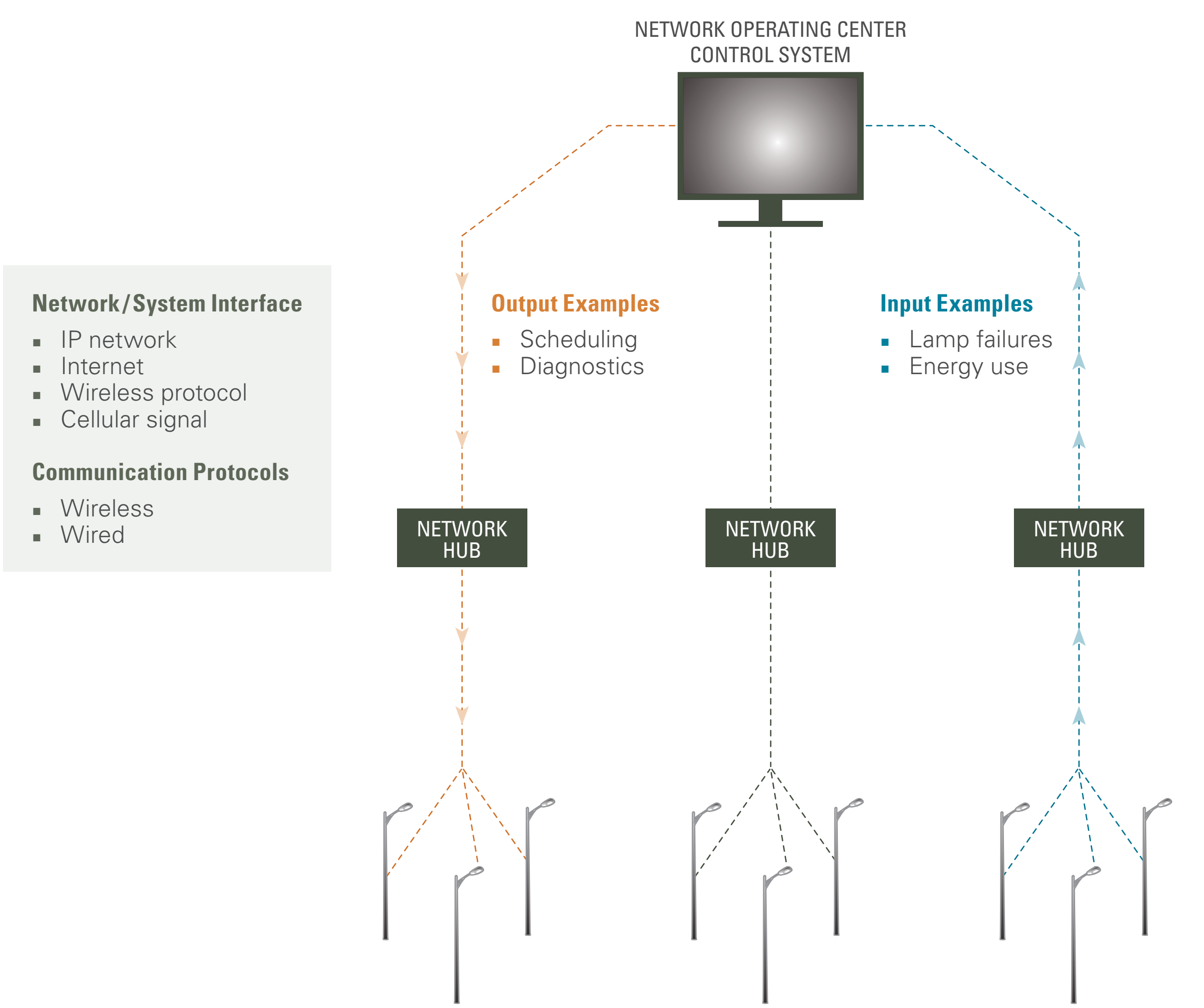
An area with potential to increase energy savings and lighting performance is networked lighting controls. Several networked lighting controls technologies exist that allow stakeholders to access a system's detailed energy-use profile, identify maintenance needs, and view or edit operating schedules, all from a central access point. Networked lighting control systems are quickly expanding to incorporate new features and improved technologies.

Networked lighting is a fundamental improvement in how lights are managed. Because instant control of every light is now possible, maintenance issues can be quickly addressed and light can be delivered and maintained with precision, saving money and energy. Some of the features of networked lighting include:

- Remote data assessment, via Internet connections, including maintenance tracking and outage detection.
- Demand response control for future electrical utility load-leveling.
- Power metering to take advantage of power savings from dimming.
- Easily adjustable light dimming profiles.
- Interoperable with motion sensors to create well-lit areas of light.
- Scheduling to replace photocell control.

Networked luminaires can be connected in various ways: via a separate cable stringing lines together, through pre-existing power or network lines using power line carrier communication, or via wireless radios. Direct cable connection from light to light can be more expensive to install and difficult to retrofit. Power line carrier communication can be effective but can suffer signal loss depending on the existing wiring. Wireless radio communication offers easy installation and adaptable mesh networking, but the materials and commissioning can be excessively costly. A wireless network allows the radio in each luminaire to work together to reliably communicate messages across the network. Networked lighting controls provide a user with enhanced access to all parts of a lighting system, which can lead to decreased costs and improved quality.

Figure 12. Network-controlled system



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PHOTOVOLTAIC (PV) LIGHTING & SYSTEMS

A single solar cell produces only 3–4W of power, so cells are connected to form units called modules, which can be joined to form larger groups called arrays. These arrays then are connected to other electrical components to create a photovoltaic system, which may be grid-tied or serve as a stand-alone source of energy generation.

Grid-tied PV systems are connected to the power grid. When the system creates excess power, it is fed to the grid, and the customer earns credit for the electricity. When the building uses more power than the system can produce, the customer draws electricity from the gird and is charged for that power. Grid-tied PV systems are less costly and require less maintenance than stand-alone systems.

Stand-alone PV systems are not connected to the electrical grid, but store excess electricity in batteries, which then are used for power when the sun is not shining. Batteries, however, add initial costs and maintenance costs to the system and must be replaced every few years. Also, in many areas, stand-alone systems do not receive the same kind of government incentives provided for grid-tied systems.

Solar street and parking lights can be used in off-grid exterior lighting applications where wiring, trenching, or metering is not feasible. The solar panel and battery pack can be placed in many locations on the fixture—at the top, middle, bottom, or with the battery pack underground—and several options are available for pole height and lamp style.

Additionally, PV bollards are well suited for stand-alone systems. PV bollards can be programmed to turn on at dusk and off when the sun rises. A solar panel on the fixture converts solar energy into electricity, which is stored in a battery to be used during the night. Bollards have myriad uses, including marking pathways, increasing security, and creating traffic barriers.

Figure 13. Pathway lighting throughout Juan Pablo II Park, an environmental green space centrally located in the municipality of Las Condes in Santiago, Chile.

© Carmanah

EXTERIOR LIGHTING RETROFIT & DESIGN BEST PRACTICES

When planning for a lighting retrofit or new design, establish the project's goals and consider factors based on the type of space that will be lit.

© California Lighting Technology Center, UC Davis
CREDIT. Kathreen Fontecha

The exterior lighting retrofit and design best practices listed in this section are derived from both professionals in the lighting industry and the IES recommended practice guides for each lighting application.

NEW LIGHTING SYSTEM DESIGN

When considering new designs for lighting systems, it is important to establish goals for the new designs. These goals could include, for example, energy efficiency, light characteristics, and light distributions.

Once the goals have been established for the new lighting system design, the physical dimensions of the space must be determined. Following that, it is important to verify application-specific light levels using the appropriate IES recommended practices. A code-compliant lighting design should be obtained from one of the following:

- The lighting system supplier
- A professional computer-aided design package (e.g., AGI 32, Radiance, or Visual Pro)
- IES recommended practice appendix calculations

LIGHTING SYSTEM RETROFIT

Before beginning a lighting system retrofit, a lighting audit of the existing system should be performed to determine the system performance and ability to meet the needs of the space. Begin by establishing the goals of the retrofit. These goals could be similar to or the same as the new lighting system design described above (improved energy efficiency, light characteristics, and light distribution), but the goals will be determined by the needs.

After establishing the retrofit goals, once again determine the physical dimensions of the space while also considering any existing light fixture heights and locations. That step will be followed by the same final steps described under the New Lighting System Design subheading above:

- Verify application-specific light levels using the appropriate IES recommended practices
- Obtain a code-compliant lighting design

LIGHTING DESIGN & RETROFIT ELEMENTS

There are several elements that are common to both the design of a new lighting system as well as to the retrofit of an existing system. These elements are specific to both the subject or space being illuminated and the intended use of the space. The following are elements of lighting design and retrofits that should be considered before beginning a lighting project.

ILLUMINANCE (E)

Also known as light level, illuminance refers to the amount of light incident on a surface from a lighting system and is measured in units of footcandles (lumens/ft^2) or lux (lumens/m^2). Typically, IES illuminance method tables specify recommended values of maintained illuminance for specific applications. Illuminance values also are specified as minimum horizontal and vertical values in some applications.

LUMINANCE (L)

Luminance is the measure of reflected or diffuse light emitted from a surface. Typically, IES luminance method tables are used in roadway lighting design to determine the level of "brightness" of a roadway surface by determining the amount of light reflected from the pavement in the direction of the driver. Values for luminance are based on candelas per square meter (the SI units of light).

SURFACE REFLECTANCE

The calculation of reflectance is used to determine luminance, particularly in the area of pavement reflectance for road designs. In the case of pavement reflectance, the IES follows CIE guidelines for the Four Class System.

ROAD SURFACE CLASSIFICATIONS

CLASS	DESCRIPTION	MODE OF REFLECTANCE
R1	Portland cement, concrete road surface. Asphalt road surface with a minimum of 12% of the aggregates composed of artificial brightener and aggregates.	Mostly diffuse
R2	Asphalt road surface with an aggregate composed of a minimum 60% gravel (size greater than 10 millimeters).	Mixed (diffuse and specular)
R3	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly specular
R4	Asphalt road surface with very smooth texture.	Mostly specular

IES RP-33-99, Table 5

FIGURE 14. High pressure sodium exterior structure lighting of a building

© California Lighting Technology Center, UC Davis, CREDIT. Kathreen Fontecha

AREA CLASSIFICATION

For some exterior lighting designs, the area classification of the application environment is required for the appropriate level of illuminance. The table below lists the definitions of these area classifications.

AREA CLASSIFICATIONS	
COMMERCIAL	A business area of a municipality where ordinarily there are many pedestrians during some of the night hours. This definition applies to densely developed business areas outside, as well as within, the central part of a municipality. The area contains land use, which frequently attracts a heavy volume of night time vehicular and pedestrian.
INTERMEDIATE	Those areas of a municipality characterized by frequent, moderately heavy nighttime pedestrian activity. This definition applies to blocks having libraries, community recreation centers, large apartment buildings, industrial buildings, or neighborhood retail stores.
RESIDENTIAL	A residential development, or a mixture of residential and small commercial establishments, characterized by few pedestrians at night. This definition includes areas with single-family homes, town houses, and small apartment buildings.

IES RP-33-99, Table 4

STRUCTURE LIGHTING

Exterior structure lighting is accomplished through floodlighting, spotlighting, outlining, and silhouetting. The strategic use of these structure lighting techniques develops an improved nighttime atmosphere.

Structural lighting design and implementation is guided by several key principles. Some scenarios call for uniform illumination, while others need a more striking approach to accentuate focal points. In general, uniform illumination leads to more lighting pollution and should be used in appropriate applications only.

When designing and implementing a "Structure Lighting" plan, luminaire choice and positioning of the luminaire should be considered

LUMINAIRE CHOICE

Important characteristics to keep in mind: lamp technology choice for increased energy efficiency and lower maintenance costs, cutoff visors and shielding to reduce lighting pollution, beam width/distribution.

LUMINAIRE POSITIONING

- Including, but not limited to: setback, spacing, vertical/horizontal aiming.
- See IES Recommended Practices or other reputable lighting guides for recommended spacing/aiming ratios applicable to your space.

It is recommended that all lighting designs be modeled in a computer-based scenario program to validate the light levels and uniformity. Life-Cost Analysis should be performed for each potential technology to evaluate its payback based on initial costs such as materials, installation, commissioning, and design as well as annual savings based on energy savings and reduced maintenance costs compared to incumbent lighting or alternate designs.

SOFTSCAPE LIGHTING

Softscape lighting is the incorporation of surrounding plant and natural landscaping materials into one unified lighting design. Softscape lighting can occur in the following areas: private yards, parks, gardens, boulevards, entry markers, earth markers (i.e., water), etc.

When implementing a softscape lighting design, the following characteristics of the space should be considered:

- Identify focal points to be highlighted in landscape and corresponding material characteristics (shape, height, width, age, color, reflectance, texture, density, branching pattern, bark condition, root depth/spread, growth rate, evergreen/deciduous, etc.).
- Choose appropriate luminaires to accommodate material characteristics (important to keep in mind: lamp technology choice for increased energy efficiency and lower maintenance costs, cutoff visors and shielding to reduce lighting pollution, beam width/distribution).
- Refer to IES Recommended Practices or other reputable lighting guides to determine suggested lighting spacing for each point of interest.

Codes and Standards

Always consider local building codes and restrictions when implementing a lighting design. It is recommended that all lighting designs be modeled in a computer-based scenario program to validate the light levels and uniformity. Life-Cost Analysis should be performed for each potential technology to evaluate its payback based on initial costs such as materials, installation, commissioning, and design as well as annual savings based on energy savings and reduced maintenance costs compared to incumbent lighting or alternate designs.

HARDSCAPE LIGHTING

Hardscape lighting applies to man-made elements of landscape such as fountains, outdoor sculptures, flat displays, and gazebos. All hardscape lighting follows these guidelines:

1. **CHOOSE A FOCAL POINT (I.E., STRUCTURE OR WATER)**

   STRUCTURE: SCULPTURE, FLAT DISPLAY, GAZEBO

   - Place lighting to accentuate structure focal point by considering critical viewing angles and location of luminaire.
   - Incorporate colored light effectively so it is not dominated by other lighting.
   - Use shadows and highlights to emphasize surface texture and shape.
   - Avoid glare and "hot spots" by lighting structure to IES specifications: Light from both above and below.
   - Use shielded luminaires and correct beam shape.

   WATER

   - Take light/water properties into consideration when placing luminaire in landscape.
   - Refraction: Known to cause rainbow in rough water.
   - Reflection: Angle of incidence/reflection determines luminaire location.
   - Diffusion: Potentially will obscure focal points under water in right conditions or add desired effects.

2. **CHOOSE APPROPRIATE LUMINAIRES TO ACCOMMODATE MATERIAL CHARACTERISTICS**

   Important to keep in mind: lamp technology choice for increased energy efficiency and lower maintenance costs, cutoff visors and shielding to reduce lighting pollution, beam width/distribution.

3. **REFER TO IES RECOMMENDED PRACTICES OR OTHER REPUTABLE LIGHTING GUIDES TO DETERMINE SUGGESTED LIGHTING SPACING FOR EACH POINT OF INTEREST.**

AUTOMOBILE SPACES

Lighting in automobile spaces is a safety measure, allowing for information transfer between motorists and pedestrians. It is recommended that all lighting designs be modeled in a computer-based scenario program to validate the light levels and uniformity. Life-Cost Analysis should be performed for each potential technology to evaluate its payback based on initial costs such as materials, installation, commissioning, and design as well as annual savings based on energy savings and reduced maintenance costs compared to incumbent lighting or alternate designs.

ROADWAY

Designing and implementing a roadway lighting system requires evaluating many factors: visibility, economics, aesthetics, safety, environmental conditions, materials, space geometry (width of roadway, curb location, etc.), pavement reflective properties, extreme grades and curves of roadway, intersections, landscaping, etc.

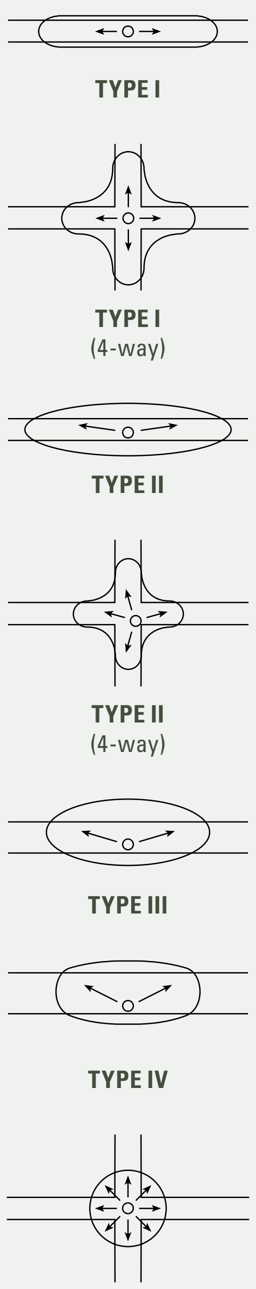
A general guideline to follow when implementing a roadway lighting design:

- Determine the classification of roadway, area, and pavement to establish the set of lighting standards/local codes that needs to be followed (Refer to charts on pgs. 51–52).
- Choose luminaires that fit into space geometry and design. "Light Distribution Types" apply to different geometries of spaces being addressed.
- Per luminaire choice, design geometry of space including mounting height and pole spacing, etc.

Figure 15. Roadway lighting in a neighborhood in Danville, CA

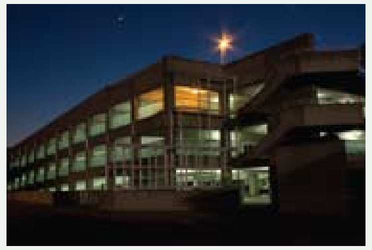
© BetaLED

Figure 16. IES Standard light distribution patterns



IESNA Lighting Handbook, 9th ed. 22-7

Figure 17. Bi-level induction parking garage luminaires at the University of California, Davis North Entry Parking Structure



© California Lighting Technology Center, UC Davis, Credit: Kathreen Fontecha

PARKING LOTS AND GARAGES

Parking lots and garages share similar characteristics that should be considered when implementing a lighting design. These include traffic locations, security/emergency lighting locations, vertical/horizontal illuminance levels, color rendition, uniformity, glare, and obtrusive light. Lighting specific to parking garages is for ramps, entrances, and stairways, as well as incorporating daylight into the space.

General guidelines to follow when designing a parking lot/garage lighting system:

1. Maintain illuminance levels at entrances to at least match surrounding public lighting. For parking garages, a daylighting contribution is suggested.
2. Choose an appropriate luminaire that has proper color rendering capabilities according to local ordinances and appropriate shielding/reflectors to reduce glare and obtrusive light.
   - Bi-level luminaires are recommended for parking lots and garages because they act both as an energy saver and a safety precaution, letting users know when the space is occupied.
3. Per distribution of chosen luminaire, design geometry of parking lot/garage light system including mounting height and spacing to achieve required uniformity.
4. Incorporate safety lighting into design to abide by local and building ordinances.

Figure 18. LED lighting for the Crocina Tunnel in Arezzo, Italy

© BetaLED

TUNNELS

When designing lighting for tunnels, the two main considerations to keep in mind are the length and the geometry of the tunnel. These will affect the spacing and mounting height of luminaires during installation.

Other important factors that will influence tunnel lighting design:

- Geographic location: surrounding area, type of landscape surrounding the tunnel, and the solar altitude/azimuth.
- Climate factors: temperature, humidity, change in landscape growth per season, precipitation type, and average cloud coverage.

PEDESTRIAN SPACES

A common use of lighting is to illuminate spaces designated for pedestrian use. Adequate lighting can prevent accidents, assist police protection, and facilitate pedestrian traffic flow. Ideally, these things can be achieved while allowing for energy savings through the effective application of light. Below are site-specific recommendations for several spaces designated for pedestrian use.

RECOMMENDED MAINTAINED ILLUMINANCE LEVELS FOR PEDESTRIAN WAYS

	MINIMUM AVERAGE HORIZONTAL ILLUMINANCE LEVELS ON PAVEMENT (lux/footcandles)	AVERAGE VERTICAL ILLUMINANCE LEVELS FOR SPECIAL PEDESTRIAN SECURITY (lux/footcandles)
SIDEWALKS (ROADSIDE) AND TYPE A BIKEWAYS		
Commercial Areas	10/1	20/2
Intermediate Areas	5/0.5	10/1
Residential Areas	2/0.2	5/0.5
WALKWAYS DISTANT FROM ROADWAYS AND TYPE B BIKEWAYS		
Commercial Areas	5/0.5	5/0.5
Intermediate Areas	5/0.5	10/1
Residential Areas	20/2	55/0.5

IES RP-33-99, Table 6

Sidewalks

Sidewalk spaces typically are paved areas for pedestrians that extend along roadways for vehicular traffic.

Walkways

Pedestrian walkways are within the right-of-way for vehicular traffic and include skywalks, subwalks, walkways for access to parks or block interiors, and midblock street crossings.

Bikeways

Bikeways are any path that is specifically designated for bicycle travel.

OUTDOOR SPORT LIGHTING

Outdoor sport lighting follows different guidelines for each specific sport area. In general, outdoor sport lighting should be designed to minimize sky glow through the use of cutoff fixtures and proper geometrical placement of luminaires.

OUTDOOR RETAIL LIGHTING

Proper lighting in an outdoor retail atmosphere is important for the customer and the merchant. The customer will be drawn to storefronts that offer a secure environment in addition to a pleasing aesthetic.

TABLE OF CONTENTS

CONCLUSION

An exterior lighting design or retrofit should make a space more energy efficient and visually pleasing to visitors. When planning for exterior lighting, ensure all decisions are best for the space.

Energy-efficient lighting technology is improving and changing rapidly, meaning any retrofits or new construction should not only meet the baseline and conform to state codes and guidelines, but facilities managers also should strive to be forward thinking as they plan their designs. Too often simple paybacks drive decisions and trap enormous savings. The focus should be on the deepest and most sustained energy-saving approaches as opposed to short-term payback opportunities. These decisions should be based on life-cycle analysis.

This guide was intended to assist facilities managers and others who are planning to install or replace exterior lighting. It addressed these issues:

- How to save the most energy and money through lighting design
- How to improve the light in a space
- How to determine the best technology for a space
- How to pay for the project
- How to recycle lamps
- How to implement lighting controls
- The differences between source technologies
- What emerging technologies have to offer
- Best practices for a retrofit and design

An exterior lighting project should be easier to plan and manage by following these tips and guidelines, making the facility more energy efficient when the project is finished. As more consumers, businesses, and agencies choose energy-efficient lighting sources, technologies will become more affordable, more options will be available, and more energy will be saved.

RESOURCES

Resources included in this section are intended to be used as a preliminary guide for information on exterior lighting. Though it is not a complete list, each of the resources included here provides links to a wide range of materials on this subject as well as related topics. The information contained here is up to date at the time this guide was created.

U.S. DEPARTMENT OF ENERGY | www.energy.gov

The Department of Energy's overarching mission is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex.

U.S. NATIONAL PARK SERVICE | www.nps.gov

Since 1916, the American people have entrusted the National Park Service with the care of their national parks. With the help of volunteers and park partners, the National Park Service is proud to safeguard these nearly 400 places and to share their stories with more than 275 million visitors every year.

NATIONAL PARK SERVICE NIGHT SKY TEAM | www.nature.nps.gov/air/lightscapes/team.cfm

The National Park Service Night Sky Team was formed in response to the alarming increase of light pollution even in national parks. The team works across the country to document the effects of light pollution.

LAWRENCE BERKELEY NATIONAL LABORATORY | www.lbl.gov

Berkeley Lab is a member of the National Laboratory System supported by the U.S. Department of Energy through its Office of Science. It is managed by the University of California (UC) and is charged with conducting unclassified research across a wide range of scientific disciplines.

CALIFORNIA LIGHTING TECHNOLOGY CENTER | cltc.ucdavis.edu

The California Lighting Technology Center's (CLTC) mission is to stimulate, facilitate, and accelerate the development and commercialization of energy-efficient lighting and daylighting technologies. This is accomplished through technology development and demonstrations as well as outreach and education activities in partnership with utilities, lighting manufacturers, end users, builders, designers, researchers, academics, and government agencies.

ILLUMINATING ENGINEERING SOCIETY | www.iesna.org

The Illuminating Engineering Society seeks to improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefit the public.

INTERNATIONAL DARK-SKY ASSOCIATION | www.darksky.org

A nonprofit member organization that teaches others how to preserve the night sky through fact sheets, law references, pictures, and web resources.

DARK SKY SOCIETY | www.darkskysociety.org

The Dark Sky Society supports educational and legislative efforts to eliminate light pollution.

NATIONAL RENEWABLE ENERGY LABORATORY | www.nrel.gov

National Renewable Energy Laboratory (NREL) is the only federal laboratory dedicated to the research, development, commercialization, and deployment of renewable energy and energy-efficiency technologies. Backed by 32 years of achievement, NREL leads the way in helping meet the growing demand for clean energy.

PACIFIC NORTHWEST NATIONAL LABORATORY | www.pnl.gov

Pacific Northwest National Laboratory (PNNL) is one of the U.S. Department of Energy's (DOE) 10 National Laboratories, managed by DOE's Office of Science. PNNL also performs research for other DOE offices as well as government agencies, universities, and industry to deliver breakthrough science and technology to meet today's key national needs.

RENSSELAER POLYTECHNIC INSTITUTE | www.lrc.rpi.edu

The Lighting Research Center is the world's leading university-based research and education organization devoted to lighting—from technologies to applications and energy use, from design to health and vision.

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION | www.nema.org

NEMA is the trade association of choice for the electrical manufacturing industry. Founded in 1926 and based near Washington, D.C., its approximately 450 member companies manufacture products used in the generation, transmission and distribution, control, and end-use of electricity.

CASE STUDIES

LIGHTING OF THOMAS JEFFERSON MEMORIAL |
www.nps.gov/partnerships/lighting_jefferson_memorial.htm

The National Park Service retrofitted the exterior and portions of the interior of the Thomas Jefferson Memorial, one of Washington's most recognized landmarks.

UC DAVIS SMART ENERGY INITIATIVE |
www.cltc.ucdavis.edu/content/view/560/334

The California Lighting Technology Center, Energy Efficiency Center, and Facilities Management at UC Davis launched the California Parking Garage Lighting Project as part of the UC Davis Smart Energy Initiative. This project is directed at increasing safety, reducing maintenance costs, and achieving 50% or greater energy savings in standard parking garage lighting applications.

INTERNATIONAL DARK-SKY ASSOCIATION EXTERIOR LIGHTING |
www1.eere.energy.gov/femp/pdfs/29267-5.4.5.pdf

Exterior lighting improves security, enhances safety, and directs pedestrians and vehicles. The IDA gives tips on how to improve exterior lighting.

LANSING BOARD OF WATER & LIGHT AND MIDWEST CIRCUITS |
www.philipslumileds.com/pdfs/CS11.pdf

The Lansing Board of Water & Light provides outdoor area lighting for its customers, and installs, operates, and maintains about 34,000 street lights throughout the greater Lansing area.

CITY OF LOS ANGELES LED STREET LIGHTING |
www.mwcog.org/environment/streetlights/downloads/
CCI Case Study Los Angeles LED Retrofit.pdf

Los Angeles' street lighting system is owned and maintained by the Los Angeles Bureau of Street Lighting—part of the Los Angeles Department of Public Works. With more than 209,000 street lights in its control, the city boasts the second largest municipally owned street lighting system in the United States. The goal is to replace 140,000 city street light fixtures with LED fixtures and install a remote monitoring system.

ARTICLES

FORT BENNING SAVES ENERGY WITH WIRELESS CONTROL OF OUTDOOR LIGHTS |
http://www.lonmark.org/connection/case_studies/
documents/FortBenning_OutdoorLights.pdf

Fort Benning, GA, updates its Energy Management and Control System to improve performance and reliability and, ultimately, to save on energy costs.

GUIDANCE NOTES FOR THE REDUCTION OF OBTRUSIVE LIGHT |
www.britastro.org/dark-skies/pdfs/ile.pdf

All living things adjust their behavior according to natural light. Man's invention of artificial light has done much to enhance the nighttime environment but, if not properly controlled, obtrusive light (commonly referred to as light pollution) can present serious physiological and ecological problems.

LIGHT DONE RIGHT |
www.libraryjournal.com/article/CA6696205.html

The haphazard lighting currently used to support 24/7 lifestyles affects humans' natural rhythm, physical and spiritual well-being, and the ability to see and study the stars. Continuous illumination also relates to the natural rhythms of animals, birds, reptiles, bugs, and plants. More conscious lighting design can help address these issues.

LEDS, CENTRALIZED CONTROL ILLUMINATE ANCHORAGE'S GREEN INITIATIVES |
www.govtech.com/gt/583194?topic=290183

Anchorage, Alaska, sought a way to make its 16,500 streetlights more energy efficient. What the city found was a plan to replace current streetlights—or high pressure sodium (HPS) lamps—with light-emitting diodes (LEDs) that are connected to a centralized control system.

LIGHT EMITTING DIODE STREETLIGHT SYSTEMS HELP CITIES SAVE ENERGY |
www.govtech.com/gt/628240

State and local governments looking to improve efficiency and cut costs are casting their gaze skyward—at streetlights— for an answer.

REPORTS & GUIDES

LED EXTERIOR LIGHTING: ABOVE GROUND PARKING GARAGE |
www.etcc-ca.com/images/stories/pdf/ETCC_Report_435.pdf

Light-emitting diode (LED) lights are emerging as a viable alternative for outdoor locations such as parking lots, parking garages, and streets, which typically use wallpacks and bollards lit with high wattage, high intensity discharge (HID) or fluorescent lights. In addition to increased energy efficiency, LEDs offer longer bulb life, reliability, and cool operating temperatures. LED sources are currently considerably more expensive than fluorescent, but prices are expected to drop as demand increases.

OREGON DOE OUTDOOR LIGHTING REPORT |
www.oregon.gov/ENERGY/CONS/Codes/docs/MLO_report.pdf

Excessive outdoor lighting can have a number of harmful consequences. Glare from high intensity light sources can be hazardous, light pollution can be disruptive to the nighttime aesthetic, and unnecessary artificial light is a waste of natural resources. There are simple measures that can be implemented to mitigate these problems. Use of shielded outdoor lighting fixtures that direct light appropriately is a simple remediation of the adverse consequences of excessive outdoor lighting.

LED LOW-BAY GARAGE LIGHTING SOUTH SAN FRANCISCO, CA |
www.etcc-ca.com/images/stories/pdf/ETCC_Report_435.pdf

Energy Solutions provided monitoring, data collection, and data analysis services for an LED Low-Bay Garage Lighting Demonstration project under contract to the Emerging Technologies Program of Pacific Gas and Electric Company. The project replaced low-bay metal halide fixtures of 175 W lamps with new low-bay LED Fixtures from Lighting Science Group Corporation of nominal 85 W and 6,000 K color temperature.

LED LUMINAIRES FOR EXTERIOR, PORCH, AND PERIMETER LIGHTING |
www.etcc-ca.com/component/content/article/33/2567-light-emitting-diode-led-luminaires-for-exterior-porch-and-perimeter-lighting

The overall goal of this project is to reduce energy consumption by researching and developing a series of high-performance, energy-efficient, LED-based alternatives to incandescent exterior, porch, and perimeter lighting in residential, commercial, and institutional applications.

ACTION ENERGY: ENERGY EFFICIENCY IN LIGHTING — AN OVERVIEW |
www.cibse.org/pdfs/energylight.pdf

This publication provides an overview of energy efficiency in lighting considering all the elements and how they interrelate with one another. It is aimed at people who are concerned with improving lighting energy efficiency without inhibiting the quality of the lit environment. This includes architects, lighting designers, and installers as well as building developers, facility managers, and building users.

LED STREET LIGHTING - PHASE III CONTINUATION, OAKLAND, CA |
www.etcc-ca.com/index.php?option=com_content&task=view&id=2422&Itemid=72

This report summarizes the third phase of an LED street lighting assessment project conducted to study the applicability of LED luminaires in a street lighting application. In Phase II, fifteen 78 W LED luminaires replaced 121 W high pressure sodium (HPS) luminaires (nominal 100 W) in a residential area of Oakland. In Phase III, the luminaires on one of the Phase II streets were replaced with next generation LED luminaires (58 W) from the same manufacturer. Four of the LED luminaires installed in Phase II were replaced. The same suite of lighting performance, electrical power measurements, and economic analyses performed in Phase II were performed for the Phase III LED luminaires.

SECTION 5.4.5 EXTERIOR LIGHTING: GREENING FEDERAL FACILITIES; SECOND EDITION |
www1.eere.energy.gov/femp/pdfs/29267-5.4.5.pdf

Federal Energy Management Program (FEMP) Greening Guidebook: This section discusses exterior lighting as it relates to greening federal facilities.

LIGHTING FUNDAMENTALS HANDBOOK:
LIGHTING FUNDAMENTALS AND PRINCIPALS FOR UTILITY PERSONNEL |
my.epri.com/portal/server.pt?Abstract_id=TR-101710

This comprehensive EPRI handbook provides basic information on lighting principles, lighting equipment, and issues related to lighting design. It is intended as a primer and reference for utility personnel involved in commercial and industrial lighting programs as well as customer assistance.

EXPLANATION OF LAMP IDENTIFICATION ORDERING ABBREVIATIONS

All lamps are designated by a code that provides information about operating characteristics and physical dimensions. Note that manufacturers' codes may vary. Information on how to read lamp label ordering abbreviations is available in most product catalogs relative to a particular manufacturer. Two examples of lamp labels are listed below.

EXAMPLE 1: F40 T12/735/RS/ES	
F	This is a fluorescent lamp.
40	Indicates nominal wattage, although this is a 34 W lamp
T	Tubular lamp shape
12	Indicates diameter in eighths of an inch
735	Color; the lamp has triphosphor, with a CRI over 70 and a CCT of 3500 K
RS	Mode of starting; the lamp is a rapid-start lamp. Note that preheat lamps do not have "RS" as a suffix.
ES	This is an energy-saving lamp, a generic designation; actual manufacturer designations may be "SS" for SuperSaver, "EW" for Econ-o-watt, "WM" for Watt-Miser, or other variations.

EXAMPLE 2: CF20EL/830/MED	
CF	This is a compact fluorescent lamp.
20	Indicates nominal wattage
EL	Electronic ballast lamp
830	Color; CRI over 80 and a CCT of 3000 K
MED	Medium screw base

GLOSSARY

A

ACCENT LIGHTING: Lighting used to emphasize or draw attention to a special object or building.

AMBIENT LIGHT: The general overall level of lighting in an area.

B

BAFFLE: An opaque or translucent element to shield a light source from direct view.

BALLAST: A device used with a discharge lamp to obtain the necessary voltage, current, and/or wave form for starting and operating the lamp.

BEAM SPREAD: The angle created by two points of equal light intensity on either side of the beam's axis and the point where the axis and lamp surface intersect.

BRIGHTNESS: Strength of the sensation that results from viewing surfaces from which the light comes to the eye.

BUG: System created by IES based on TM-15-07 to rate the amount of light emitted from a luminaire in unwanted directions. The methodology represents a comprehensive system that limits lamp lumens to values appropriate for the lighting zone. The BUG rating system replaces the older IES cutoff classification system.

BULB OR LAMP: The source of electric light. To be distinguished from the whole assembly (see luminaire). Lamp often is used to denote the bulb and its housing.

C

CANDELA (CD): Standard SI unit of luminous intensity, or candle power. One candela is one lumen per steradian. Formerly called the candle.

CANDLEPOWER DISTRIBUTION: The plot graph representation of the variation in light spread and intensity of a lamp or luminaire.

CENTER BEAM CANDLEPOWER (CBCP): The intensity of light produced at the center of a reflector lamp; expressed in candelas.

CIE: Commission Internationale de l'Eclairage. The international light commission. Determines most lighting standards.

COEFFICIENT OF UTILIZATION (CU): Ratio of luminous flux (lumens) from a luminaire received on the "work plane" (the area where the light is needed) to the lumens emitted by the luminaire.

COLOR RENDERING INDEX (CRI): The CRI rating indicates how well an object's color(s) are rendered by a light source. It is a comparison of eight specific test colors between an "ideal" light source (incandescent or daylight) and the light source in question. The apparent shifting of these test colors is measured to give an average color rendering ability of a lamp. The greater the apparent shift, the lower the CRI. The CRI scale ranges from 0 (does not render colors well) to 100 (matched color rendition to that of the ideal source). If color rendering is less important, a CRI in the mid 70s may be less expensive and/or more efficient and sufficient. On the other hand, if color rendering is extremely important, it might be appropriate to sacrifice cost and/or efficiency for a CRI in the 90s. A CRI in the 80s is standard and should be specified for most applications.

CONES AND RODS: Retinal receptors. Cones dominate the response when the luminance level is high, and provide color perception. Rods dominate at low luminance levels. No rods are found in the central part of the fovea. Rods have no color perception ability.

CONSPICUITY: The capacity of a signal to stand out in relation to its background so as to be readily discovered by the eye (as in lettering on a sign, for example).

CORRELATED COLOR TEMPERATURE (CCT): CCT is measured in Kelvin temperature, which is a reference to the color produced by blackbody emitters (such as stars) when they are heated to different Kelvin temperatures. As these emitters become hotter, they move from appearing orange to white to blue. In lighting, this can be confusing because light sources that are commonly referred to as "cool" are more blue and thus have a higher Kelvin temperature than "warm" — more orange light sources. Typically, an acceptable CCT range for indoor environments is between 2500K and 5000K. Warm lighting (which has a low CCT) helps to create a homey and cozy space, while cool lighting (with high CCT) is associated more with commercial environments. Refer to the typical correlated color temperature on the scale below.

CUTOFF ANGLE OF A LUMINAIRE: The angle, measured up from the nadir (i.e. straight down), between the vertical axis and the first line of sight at which the bare source (the bulb or lamp) is not visible.

CUTOFF FIXTURE: A fixture that provides a cutoff (shielding) of the emitted light.

D

DARK ADAPTATION: The process by which the eye becomes adapted to a luminance less than about 0.03 candela per square meter (0.01 footlambert).

DISABILITY GLARE: See "Glare."

DISCOMFORT GLARE: Glare that produces discomfort, but does not necessarily diminish visual performance.

E

EFFICACY: A measure of how effectively a desired effect is achieved, also called "luminous efficacy." For lighting, it is used to quantify how effectively lamps transform electrical power (watts) into visible light (lumens). A lamp that consumes 100W of power and produces 2000lm would have an efficacy of 2000lm/100W or 20 lm/W. For white, high-brightness LEDs, luminous efficacy published by LED manufacturers typically refers to the LED chip only, and doesn't include driver losses.

EFFICIENCY: A measure of the effective or useful output of a system compared to the input of the system, also called "luminaire efficiency." Often expressed as a percentage of how much energy a system provides compared to the amount of energy supplied to it.

ELECTROMAGNETIC (EM) SPECTRUM: The distribution of energy emitted by a radiant source, arranged in order of wavelength or frequency. Includes gamma-ray, X-ray, ultraviolet, visual, infrared, and radio regions.

ENERGY (RADIANT ENERGY): Unit is erg, or joule, or kWh.

F

FIXTURE: The assembly that holds the lamp in a lighting system. It includes the elements designed to give light output control, such as a reflector (mirror) or refractor (lens), the ballast, housing, and the attachment parts.

FLOODLIGHT: A fixture designed to "flood" a well-defined area with light with a beam angle of 30% or more.

FLUORESCENT LAMP: A low-pressure mercury electric discharge lamp in which a phosphor coating transforms some of the UV energy into visible light.

FLUX (RADIANT FLUX): The flow rate of energy moving a certain distance from a source. Unit is erg/sec or watts.

FOOTCANDLE: Illuminance produced on a surface one foot from a uniform point source of one candela.

FOOTLAMBERT: The average luminance of a surface emitting or reflecting light at a rate of one lumen per square foot.

FULL-CUTOFF FIXTURE: A fixture that allows no emission above a horizontal plane through the fixture.

G

GENERAL ILLUMINATION: A term used to distinguish between lighting that illuminates tasks, spaces, or objects from lighting used in indicator or purely decorative applications. In most cases, general illumination is provided by white light sources, including incandescent, fluorescent, high intensity discharge sources, and white LEDs. Lighting used for indication or decoration often is monochromatic, as in traffic lights, exit signs, vehicle brake lights, signage, and holiday lights.

GLARE: Intense and blinding light resulting in reduced visual performance and visibility, often accompanied by discomfort.

GROUP RELAMPING: Practice of replacing lamps on a routine scheduled basis determined by a percentage of estimated lamp life.

H

HIGH INTENSITY DISCHARGE (HID) LAMP: In a discharge lamp, the emitted energy (light) is produced by the passage of an electric current through a gas. HID lamps include mercury, metal halide, and high pressure sodium lamps. Other discharge lamps are low pressure sodium and fluorescent. Some such lamps have internal coatings to convert some of the ultraviolet energy emitted by the gas discharge into visual output.

HIGH PRESSURE SODIUM (HPS) LAMP: HID lamp where radiation is produced from sodium vapor at relatively high partial pressures (100 torr). HPS essentially is a "point source."

I

ILLUMINANCE: The amount of visible light that falls on a surface is referred to as illuminance. Technically, the illuminance on a surface is the density of luminous flux falling or striking that surface. The units of illuminance are lumens per square foot or footcandles (fc). The metric units for illuminance are lumens per square meter or lux. One fc is equal to 10.76 lux, although a 1 fc = 10 lux approximation is commonly made by lighting practitioners. Typical illuminance levels or footcandles are recommended for different visual activities. Recommended number of footcandles for a space refers to the average light level required for a particular task measured in the horizontal plane at desk height. Vertical footcandles is illuminance on vertical surfaces, such as walls. Recommendations for illuminance levels can vary greatly depending on location, types of tasks performed, etc. The following luminance levels are based on the Illuminating Engineering Society of North America recommended light level for a particular task or space.

ILLUMINATING ENGINEERING SOCIETY OF NORTH AMERICA (IES): The professional society of lighting engineers, including those from manufacturing companies, and others professionally involved in lighting.

INCANDESCENT LAMP: An electric lamp in which a filament gives off light when heated by an electric current.

INDIRECT FIXTURE: A fixture that directs the majority of its luminous flux in an upward direction.

INFRARED RADIATION: EM radiation just to the long wavelength side of the visual.

INTENSITY: The degree or amount of energy or light.

INTERNATIONAL DARK-SKY ASSOCIATION (IDA, INC.): A nonprofit organization whose goals are to build awareness of the value of dark skies and of the need for quality lighting.

IR LAMP: Infrared lamps feature a coating that recycles the wasted heat generated by the filament. This coating allows visible light to pass through it while reflecting infrared heat back to the filament, making the lamp more efficient.

K

KILOWATT-HOUR (KWH): A unit of energy equal to the work done by one kilowatt (1000W) of power acting for one hour.

L

LIGHT POLLUTION: Any adverse effect of manmade light. Often used to denote urban sky glow.

LIGHT TRESPASS: Light falling where it is not wanted or needed; spill light; obtrusive light.

LIGHT EMITTING DIODE (LED): An LED is a semiconducting device made of inorganic (noncarbon-based) material that produces light when an electric current flows through it. LEDs first were developed in the 1960s but were used only in indicator applications until recently.

LOW PRESSURE SODIUM (LPS) LAMP: A discharge lamp where the light is produced by radiation from sodium vapor at a relatively low partial pressure (about 0.001 torr). LPS is a "tube source." It is monochromatic light.

LUMEN DEPRECIATION FACTOR: Light loss of a luminaire with time because of the lamp's decrease in efficiency, dirt accumulation, and any other factors that lower the effective output.

LUMEN MAINTENANCE: Ability of a source to maintain a given percentage of its original lumen output expressed in percentage of total lifetime.

LUMEN: Unit of luminous flux; the flux emitted within a unit solid angle by a point source with a uniform luminous intensity of one candela. One footcandle is one lumen per square foot. One lux is one lumen per square meter.

LUMINAIRE: The complete lighting unit, including the lamp, the fixture, and other parts.

LUMINANCE: The amount of visible light coming off a surface is referred to as luminance. The luminance of a source or surface is defined as the intensity of the source or surface in the direction of an observer divided by the area of the source or surface seen by the observer. This directionality is important to consider, as a source or surface often will have a luminance that varies depending on the angle from which it is viewed. The units of luminance are candelas per square inch, or per square foot in the English (inch-pound) system, and candelas per square meter in the metric (SI) system.

LUMINOUS FLUX: Lumens are the unit of luminous flux, or visible light, produced by a light source. In a very simplistic model: A lamp receives power (watts) and emits light (lumens).

LUX: One lumen per square meter. Unit of illuminance.

M

MERCURY LAMP: An HID lamp where the light is produced by radiation from mercury vapor.

MESOPIC VISION: Visual with fully adapted eyes at luminance conditions between those of photopic and scotopic vision, that is, between about 3.4 and 0.34 cd/m^2.

METAL HALIDE LAMP: An HID lamp in which the majority of the light is generated through the radiation of metal halide vapors.

MOUNTING HEIGHT: The height of the fixture or lamp above the ground.

N

NANOMETER (NM): 10^{-9} meter. Often used as the unit for wavelength in the EM spectrum. Often used in office environment with intensive VDT use.

O

ORGANIC LIGHT EMITTING DIODE (OLED): OLEDs are based on organic (carbon-based) materials. In contrast to LEDs, which are small point sources, OLEDs are made in sheets, which provide a diffuse area light source. OLED technology is developing rapidly and is increasingly used in display applications such as cell phones and PDA screens. However, OLEDs are still some years away from becoming a practical general illumination source. Additional advancements are needed in light output, color, efficiency, cost, and lifetime.

P

PAR LAMP: Lamp with a parabolic aluminized reflector.

PHOSPHOR CONVERSION: A method used to generate white light with LEDs. A blue or near-ultraviolet LED is coated with a yellow or multichromatic phosphor, resulting in white light.

PHOTOMETRY: The quantitative measurement of light level and distribution.

PHOTOPIC VISION: Vision mediated essentially or exclusively by the cones. It is generally associated with adaptation to a luminance of at least 3.4 cd/m^2.

Q

QUALITY OF LIGHT: A subjective ratio of the pluses to the minuses of any lighting installation.

R

REFLECTOR LAMP: Lamp in which the outer blown glass bulb is coated with a reflecting material that helps direct the light.

REFLECTOR: Controlling light output by means of reflection (mirror).

REFRACTOR: Controlling light output by means of refraction (lens).

RGB: RGB stands for red, green, and blue, the three primary colors of light. When the primaries are mixed, the resulting light appears white to the human eye. Mixing the light from red, green, and blue in LEDs is one way to produce white light. The other approach is known as phosphor conversion.

S

SCOTOPIC VISION: Vision mediated essentially or exclusively by the rods. It is generally associated with adaptation to a luminance below about 0.034 cd/m^2.

SEMI-CUTOFF FIXTURE: A fixture that provides some cutoff, but less than a full-cutoff fixture.

SOLID-STATE LIGHTING (SSL): Technology that uses semiconducting materials to convert electricity into light. SSL is an umbrella term encompassing both light emitting diodes (LEDs) and organic light emitting diodes (OLEDs).

SPOT RELAMPING: Practice of replacing lamps as they burn out.

SPOTLIGHT: A fixture designed to light only a small, well-defined area with a beam angle of 12 degrees or less.

STRAY LIGHT: Emitted light that falls away from the area where it is needed or wanted. Light trespass.

T

T# (T8, T12, ETC.): T stands for tubular, the number pertains to the diameter of the tube in 1/8th of an inch increments. A T8 lamp is 8/8 of an inch or a one-inch diameter, a T12 lamp has a diameter of 12/8 or one and a half inches. 38 mm diameter fluorescent lamps include specialized models for work premises with low temperature applications (exterior lighting, refrigerated warehouse).

U

ULTRAVIOLET "LIGHT": The energy output by a source that is of shorter wavelengths than the eye can see. Some photographic films are sensitive to ultraviolet energy, as are many electronic detectors. "Black Light."

URBAN SKY GLOW: The brightening of the night sky as a result of manmade lighting.

V

VEILING LUMINANCE: A luminance produced by bright sources in the field-of-view superimposed on the image in the eye reducing contrast and hence visibility.

VISIBILITY: Being perceived by the eye. Seeing effectively. The goal of night lighting.

VISUAL ACUITY: Acuteness or clearness of vision, especially form vision, which is dependent on the sharpness of the retinal focus within the eye and the sensitivity of the interpretative faculty of the brain. Quantitatively, it is the reciprocal of the minimum angular size in minutes of the critical detail of an object that can just be seen.

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