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This guide was prepared by the California Lighting Technology Center (CLTC) at the University of California, Davis, for the National Park Service. CLTC is a research, development and demonstration facility dedicated to accelerating the development and commercialization of energy-efficient lighting and daylighting technologies. The center develops technological innovations, conducts demonstrations of new and emerging technologies, and carries out education and outreach activities in partnership with utilities, lighting manufacturers, end users, builders, designers, researchers, academics, and government agencies.

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Lighting constitutes a large portion of energy use at national parks. This guide provides assistance to facility managers who want to reduce lighting energy use while making parks safer and more visually appealing for visitors.

Proper outdoor lighting increases safety and security, minimizes light pollution, and makes visitors’ experience of national parks more memorable. Illuminating key attractions with the right luminaires, equipped with the right lighting controls, can also reduce energy consumption. This guide is intended to make the selection of appropriate, energy-efficient outdoor lighting solutions easier and improve project outcomes.

This guide provides an overview of outdoor lighting best practices as well as information on lighting technologies that can optimize energy, cost and maintenance savings. It offers guidance for evaluating light sources, performing a lighting audit, and pairing lamps with lighting controls. In many cases, following best practices allows facilities to exceed federal standards for outdoor lighting energy efficiency.

While some traditional outdoor lighting products are relatively energy-efficient, most sacrifice light quality and control for the sake of energy savings. This compromise is no longer necessary. Many new types of high-quality, outdoor lighting solutions are both highly energy-efficient and compatible with advanced lighting controls. Lighting retrofits that utilize these new technologies can reduce lighting energy use immediately, often by 50% or more as compared to traditional solutions.
Part 1

Reasons for Outdoor Lighting Retrofits
After the sun sets, people rely on outdoor lighting for safety, security, wayfinding, and recreational activities, but excessive lighting often obstructs views of the night sky and can negatively impact ecosystems. Recent advances in light sources, controls and luminaires have made it possible to focus lighting only where and when it is needed, reducing light pollution.

Advances in outdoor lighting technologies are also increasing energy savings, reducing maintenance costs, improving visual environments, and enhancing safety. These improvements, coupled with a nationwide push to increase energy efficiency, have prompted the development and deployment of many lighting retrofit programs.

**Energy Efficiency**

Lighting retrofits can lower energy use and costs without sacrificing light levels or quality. Switching to more advanced technologies may also allow users to implement lighting controls more successfully, which further increases energy savings.

Outdoor lighting presents an excellent opportunity for national parks to reduce their energy use. Case study summaries presented throughout this guide illustrate the energy savings that can be achieved with outdoor lighting retrofits.

When replacing older technologies, it is important to select fixtures, light sources and controls suited to each site. Proper selection requires consideration of many factors. This guide is intended to assist facility managers during the process. It includes instructions for conducting a lighting audit and guidelines for determining which lighting system components might be best suited to different applications.

**Figure 1.** Satellite imagery of the Earth at night reveals the density of electric lighting in developed areas.
Reduced Maintenance Costs

A lighting retrofit can often deliver reduced maintenance costs over the life of the new lighting system as compared to costs to maintain old or outdated components. For example, improvements in lighting technologies have led to increased lifetimes for many types of products. This lengthens the time between maintenance tasks such as lamp replacement, which reduces labor costs and other expenses. In addition, implementing a routine maintenance program simplifies maintenance and further reduces operational costs associated with sustaining lighting systems.

Maintenance savings may also help offset some of the initial cost of a lighting retrofit project. For example, prices for LED sources continue to decrease, as their efficacy continues to increase, resulting in greater energy savings and a better return on investment.

Improved Visual Environments

Lighting retrofits can help address general lighting quality problems. For example, new technologies can offer lighting with better color rendering characteristics and reduced flicker and audible noise. When discussing outdoor lighting characteristics, two metrics are commonly used: correlated color temperature (CCT) and color rendering index (CRI). In addition, surrounding visual conditions influence the way we perceive light in the outdoor environment.

Correlated Color Temperature (CCT)

Correlated color temperature (CCT) indicates the color appearance of a light source and is measured in Kelvin (K). CCT is calculated by measuring the apparent color of light emitted by a source then correlating that color to that of an idealized reference light 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, the color appearance of the light it emits varies. The higher the temperature of the blackbody radiator, the “cooler” the color appearance of the light it emits (see figure 2). High-pressure sodium lamps, for example, have a relatively 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 that is relatively cooler in appearance.

Figure 2. CCT indicates the warmth or coolness of a light’s apparent color. Note how the high-pressure sodium light on the left in this photo has a warm CCT while the metal halide lighting on the right has a cooler CCT.
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 (represented by the black line cutting through the middle of figure 3).

**Color Rendering Index (CRI)**

The color rendering index is used to describe how accurately a light source renders colors. CRI uses eight standard color samples to compare the color rendering ability of a light source (such as a fluorescent or HID lamp, etc.) to that of a reference light source. The color of each sample is measured under the test light source and the reference light source, both with the same CCT. The degree of color shift between the two sets of measurements is calculated and grouped as an average. This average is subtracted from 100 to produce the CRI value. CRI is expressed as a number on a scale with no units. CRI ratings range from 1 to 100. A CRI rating (above 80) denotes more accurate color rendering ability.

Any light source appears to emit a single color, but in reality, a light source emits a broad range of colors that the eye blends together. This spectrum deconstructed into its individual colors is called spectral power distribution, or SPD. SPD is usually represented as wavelengths in the visible spectrum. The visible spectrum of light wavelengths ranges from approximately 380–780 nm. CCT and CRI are two ways of distilling a light source’s SPD into a single number.
Visual Conditions: Scotopic, Photopic and Mesopic Efficiency Functions

How the human eye perceives the SPD of a light source is also critical. This perception is, in part, dependent on the SPD of the source and the surrounding visual conditions. There are three general types of visual conditions: photopic, scotopic and mesopic 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, such as occur in a forest on a cloudy night; and mesopic conditions occur somewhere in between. Mesopic conditions account for the majority of nighttime lighting conditions in suburban and urban outdoor environments.

Viewing-condition effects are captured through a luminous efficiency function, which is applied to the SPD to get a representation of what the human eye actually sees under real-world conditions. There are three different luminous efficiency functions, one for each of the three different visual conditions.

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. The mesopic luminous efficiency function is more complex. Work is ongoing to better define and account for visual conditions in the mesopic range.

Light level measurements are calculated based upon application of the luminous efficiency function to the SPD of a particular light source. Application of one function or the other has the effect of biasing the measured light level; thus, it is important to understand which function has been applied to obtain a particular light output value. The lighting industry usually provides light output values using the photopic luminous efficiency function. Figure 5 shows the scotopic and photopic luminous efficiency functions.

Safer Outdoor Areas

An outdoor lighting retrofit can improve the visual environment and make outdoor spaces feel safer and more secure. Many people assume that “brighter is safer,” but studies have shown that increased illuminance is not always beneficial.

Too often, excessive lighting can lead to glare and overillumination. When designing outdoor lighting systems, the quality of light, not just the quantity of light, is important for safety. Outdoor lighting designs should aim to reduce glare, employ appropriate contrast ratios, and create “zones of recognition” in order to increase safety and perceived security.

The visual needs of the area’s intended occupants should also determine what type of illumination is installed. The color temperature and quality of different light sources can also affect people’s perception of brightness. As a result, it is important to understand who will use the space being lit, when they will use it and for what tasks or purposes.

Minimal Light Pollution and Light Trespass

Light pollution and light trespass occur when nighttime lighting strays from its intended target, spreading into the sky or intruding on surrounding areas. Research continues to indicate the adverse effects of light pollution on people and wildlife. An important reason for completing an outdoor lighting retrofit is to reduce the negative environmental impacts of an existing lighting system. More on this topic, and the important role that national parks can play in reducing light pollution, is provided in the section on “Preserving Dark Skies,” presented in Part 6 of this guide.

Figure 5. Scotopic and photopic luminous efficiency functions
Figure 6. The constellation Orion, as viewed under dark-sky conditions near Mammoth, Utah (left) and amid the urban sky glow of Orem, Utah (right).
Part 2

Best Practice Strategies
A successful lighting installation delivers the right light, in the right amount, only where and when it is needed.

Basic Steps for a Lighting System Retrofit or New Lighting Installation

1. **Perform a lighting audit of existing systems.**
   Before beginning a lighting system retrofit, a lighting audit of the existing system should be performed to determine the system’s performance, how it meets the area’s lighting needs, opportunities for improvement, and requirements for replacement technologies. The lighting audit will also establish the physical dimensions of the space, as well as the mounting heights and locations of existing luminaires and lighting controls; this is essential information for a lighting retrofit project. Guidelines for performing a lighting audit are provided later in this guide.

2. **Establish goals for the retrofit or new lighting system design.**
   The results of the lighting audit will help identify which aspects of the existing system need improvement. These needs, in turn, will clarify the goals of the retrofit, e.g., to improve energy efficiency, reduce maintenance needs, reduce light pollution, etc.

3. **Identify appropriate light sources and lighting controls.**
   The needs of the outdoor space and the retrofit goals will determine which lamps, luminaires or lighting controls are best suited to the project. A section on light sources, light fixtures and lighting controls is provided in this guide. Federal codes and standards, as well as professional lighting resources, should also guide product selection.

4. **Obtain a code-compliant lighting design.**
   Lighting plans must meet, or exceed, the federally mandated standards set forth by ASHRAE 90.1 – 2010. Whether installing a new lighting system in a previously dark area or retrofitting an existing system, the new lighting design should be obtained through one of the following:
   - A reputable lighting system supplier
   - A professional computer-aided design package (e.g., AGI 32, Radiance, or Visual Pro)
   - IES Recommended Practice appendix calculations

5. **Verify application-specific light levels and distribution patterns meet best-practice guidelines.**
   Consult the Recommended Practice guides published by the Illuminating Engineering Society (IES) for each lighting application to ensure designed light levels and other lighting characteristics are sufficient without being excessive.

6. **Perform a lifecycle cost-benefit analysis.**
   Evaluate the long-term costs and benefits of different systems under consideration. Remember to factor in projected increases in energy costs, estimated energy savings from lighting controls, replacement and disposal costs, and environmental impact.
Lighting Design and 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 object or space being illuminated and the intended use of the space. Factors such as illuminance, luminance, surface reflectance, and the lighting zone of the site should be considered before beginning any lighting project. In addition, for every new lighting design, a lifecycle cost analysis should be performed for each potential technology, to evaluate its payback based on initial costs such as design, materials, installation, and commissioning. Annual energy savings and maintenance cost savings should also be compared to existing lighting or alternative options.

Illuminance (E)

Illuminance refers to the amount of light that strikes a surface from a light source. Illuminance is measured in footcandles (fc), or lumens per square foot (lm/ft²). Typically, the IES provides recommended, maintained illuminance values for specific applications. Illuminance values are also specified as minimum horizontal and vertical values for some applications.

Luminance (L)

Luminance is the measure of light reflected from a surface in a given direction. It indicates the intensity, or brightness, of lighting in that direction and is measured in candelas per square foot (cd/ft²). Luminance measurements indicate, for example, how much light is reflected from the paved surface of a road in the direction of a driver. The IES provides recommended luminance values for use with roadway lighting.

Surface Reflectance

Surface reflectance classifications are required to determine luminance. In the case of pavement reflectance, the IES follows CIE guidelines for the Four Class System (Table 1).

Lighting Zones

The IES and the International Dark-Sky Association (IDA) developed the Model Lighting Ordinance (MLO) to minimize light pollution and keep light levels appropriate to the surrounding area. Released in 2011, the MLO classifies areas into five lighting zones, with guidelines for outdoor lighting in each of these zones. It is important to know which lighting zone a given project falls in, whether it is a new monument being installed in an urban setting or a retrofit of an existing wilderness area. This topic is discussed in more detail in Part 6 of this guide, on Preserving Dark Skies.

Table 1. Road Surface Reflectance

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Mode of Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Portland cement, concrete road surface. Asphalt road surface with a minimum of 12% of the aggregates composed of artificial brightener and aggregates.</td>
<td>Mostly diffuse</td>
</tr>
<tr>
<td>R2</td>
<td>Asphalt road surface with an aggregate composed of a minimum 60% gravel (size greater than 1 cm, or 0.4 in).</td>
<td>Mixed (diffuse and specular)</td>
</tr>
<tr>
<td>R3</td>
<td>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).</td>
<td>Slightly specular</td>
</tr>
<tr>
<td>R4</td>
<td>Asphalt road surface with very smooth texture.</td>
<td>Mostly specular</td>
</tr>
</tbody>
</table>
Luminaire Choice and Positioning
When replacing or retrofitting luminaires, the following are important characteristics to keep in mind:

- The energy efficiency of the light source technology
- Potential maintenance cost savings
- Distribution/beam width
- Compatibility with existing poles or other mounting apparatus
- Fixture aesthetic and consistency with the surrounding environment
- Opportunity to reduce light pollution (BUG rating)

See IES Recommended Practices or other reputable lighting guides for recommended spacing/aiming ratios applicable to the outdoor space. Factors to consider include:

- Setback
- Spacing
- Vertical/horizontal aiming

It is recommended that all lighting designs be modeled in a computer-based scenario program to validate the light levels and uniformity.

Structures and Monuments
Some structures or monuments call for uniform illumination, while others need a more striking approach to accentuate focal points. In general, uniform illumination leads to more light pollution, so this approach should be used for limited applications. Structures are typically lit through one of the following strategies:

- Floodlighting
- Spotlighting
- Outlining
- Silhouetting

More information on lighting design for outdoor monuments may be found in “Lighting for Exterior Environments,” IES Recommended Practice 33 (RP-33).
**Softscape**

Softscape lighting incorporates illumination of surrounding plants and natural landscaping materials into one unified lighting design. It is typically used for parks, gardens, entry markers, yards, or natural structures. When implementing a softscape lighting design:

1. **Identify focal points to be highlighted in the landscape and their material characteristics**
   - Shape
   - Height
   - Width
   - Age
   - Color
   - Reflectance
   - Texture
   - Density

For trees, branching pattern, bark condition, root depth and spread, growth rate, and whether the tree is evergreen or deciduous, can inform luminaire selection and placement.

2. **Choose appropriate luminaires to suit material characteristics and project goals**

Consider the following when making selections:
   - Light source choice for maximum energy efficiency benefits and lower maintenance costs
   - Cutoff visors and shielding to reduce light pollution
   - Beam width / distribution

3. **Determine best-practice guidelines for spacing**

For each point of interest, refer to IES Recommended Practices or other reputable lighting design sources for specific guidelines and best-practice recommendations.

**Hardscape**

Hardscape lighting applies to man-made elements of landscape, but involves similar considerations as softscape lighting.

1. **Identify whether the focal point is a structure or water**

   **Structure (sculpture, flat display, gazebo, etc.)**
   Considering critical viewing angles and position luminaire(s) to accentuate the structure from these vantage points.
   - Incorporate colored lighting so it is not dominated by other light sources
   - Use shadows and highlights to emphasize surface texture and shape
   - Avoid glare and “hot spots” by lighting the structure with IES recommendations in mind, from both above and below
   - Use shielded luminaires and correct beam shape

   **Water feature (fountain, pool, etc.)**
   Take the properties of light and water into consideration when positioning luminaires for this type of application.
   - Refraction: Known to cause rainbows in rough water
   - Reflection: Angle of incidence determines luminaire location
   - Diffusion: May add desired effects or obscure focal points under water with certain conditions

2. **Choose appropriate luminaires**

   - Choose technologies that increase energy efficiency and lower maintenance costs
   - Use cutoff visors and shielding to reduce light pollution
   - Consider beam width and distribution

3. **Determine luminaire spacing for each point of interest**

Refer to IES’s Recommended Practices or other authoritative sources for guidelines.
Vehicle Spaces
Good lighting for outdoor areas serving vehicle traffic allows both motorists and pedestrians to safely navigate the space. Roadways, tunnels, parking lots, and parking garages all have different lighting needs. Considerations for lighting each of these applications are explored below.

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

Roadway lighting designs are implemented following these basic steps:

1. Determine the classification of the roadway, area and pavement (see table 1)
2. Based on the roadway classification, determine the lighting codes and standards that must be met, including local ordinances
3. Choose luminaires that will satisfy lighting standards and provide appropriate distribution patterns for each area type along the roadway (see figure 9)
4. Implement lighting controls where appropriate to further improve energy savings and minimize light pollution

Figure 9. IES outdoor luminaire and light distribution patterns

![Figure 9. IES outdoor luminaire and light distribution patterns](https://example.com/image-url)
Parking Lots and Garages

Lighting in both parking lots and garages should provide ample lighting for safety and security while minimizing glare and light trespass. Parking garages are classified as indoor spaces under federal lighting regulations, but they utilize many of the same lighting technologies as outdoor parking lots, and they often provide excellent opportunities to reduce lighting energy waste. Unlike lots, parking garages have special lighting requirements for illuminating entrances and exits, ramps, perimeters, and stairways.

Follow these general guidelines when designing a lighting system for a parking lot or garage:

- Maintain illuminance levels at entrances to at least match surrounding public lighting. For parking garages, a daylight contribution is suggested.
- Select appropriate shielding / reflectors to reduce glare and obtrusive light.
- Choose adaptive luminaires with motion sensors to save energy and alert occupants when another person enters an area.
- Choose a luminaire with appropriate color rendering capabilities (i.e., high CRI where helpful to promote a sense of safety and security in the space).
- Design the geometry of the lighting system, including mounting height and spacing, according to the distribution of the luminaire selected and in order to achieve required uniformity levels.
- Incorporate safety lighting to abide by federal building ordinances (and any applicable at state or local codes and standards).
- Incorporate daylighting controls along parking garage perimeters, where daylight can supplement electric lighting, to reduce electricity use.

Tunnels

Vehicle tunnels are typically exempt from energy efficiency codes and standards. Several important factors influence tunnel lighting design:

- **Length and geometry of the tunnel**: These are the two primary factors to consider, as both will determine the spacing and mounting height of luminaires during installation.
- **Geographic location**: Surrounding area, type of landscape surrounding the tunnel, and the solar altitude / azimuth.
- **Climate factors**: Temperature, humidity, seasonal changes in landscape growth, type and levels of precipitation, and average cloud coverage.

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**Figure 10.** Adaptive parking garage lighting at UC Davis employs both occupancy and daylighting controls. In California, there are now requirements for both to be included in most lighting alterations for parking garages.

Photo: Kathreen Fontecha / CLTC, UC Davis
Pedestrian Spaces

Adequate lighting along walkways and other pedestrian paths can help to prevent accidents, assist police protection, and facilitate wayfinding. Energy-efficient lighting designs can support all these lighting goals. Table 2 provides illuminance recommendations for different areas with pedestrian traffic.

Table 2. Recommended Maintained Illuminance Levels for Pedestrians and Cyclists

<table>
<thead>
<tr>
<th>Minimum average horizontal illuminance levels on pavement (lux / footcandles)</th>
<th>Average vertical illuminance levels for special pedestrian security (lux / footcandles)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SIDEWALKS (ROADSIDE) AND TYPE A BIKEWAYS</strong></td>
<td></td>
</tr>
<tr>
<td>Commercial Areas</td>
<td>10/1</td>
</tr>
<tr>
<td>Intermediate Areas</td>
<td>5/0.5</td>
</tr>
<tr>
<td>Residential Areas</td>
<td>2/0.2</td>
</tr>
</tbody>
</table>

| **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 |

Outdoor Sports and Recreation Areas

Different guidelines apply, depending on the type of space and the specific activities it is designed to support (whether that space is a track, bike path, tennis court, ski run, etc.). In general, outdoor sports lighting should be designed to minimize sky glow, using luminaires with the appropriate BUG ratings for the site and the proper placement for the application. Countdown timers, timeclocks, and other control devices ensure lighting operates only when it is needed.
Part 3

Light Sources and Controls
Best Practices for Selecting Products

For over a century, 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 providing viable alternatives for general illumination. Selecting the right type of light source and the right lighting controls for a given application means comparing lumen output, efficacy, color quality, and spectral output. Factors such as cost, lamp life and controls compatibility are also important.

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 proper luminaire and controls for the specific application. When considering various lighting products, lumen output, efficacies, light quality, lifetimes, and cost all should be considered.

The following guidelines are helpful to keep in mind when selecting light sources and lighting controls:

- Luminaires should use long-life sources to reduce maintenance and recycling requirements
- Luminaires with the lowest appropriate BUG rating for controlling backlight, uplight and glare should be used whenever possible
- Sources should have a maximum CCT of 6000 K (or 4000 K in residential areas)
- Luminaires bearing the “IDA-approved Dark Sky Friendly” Fixture Seal of Approval (FSA) will help minimize light pollution
- Amber, orange or red light sources are available for sensitive habitats, such as coastal regions where sea turtles or threatened seabird populations nest, and spectrally tunable luminaires for use at different times of the year, such as migration seasons, may soon be more widely available
- Photocontrols and/or time clock devices should switch luminaires off entirely when sufficient daylight is available and operate lights at reduced power during dusk and dawn
- Occupancy controls should reduce luminaire power during vacant periods

The Statue of Liberty: 
Temporary LED solution speeds restoration while reducing energy consumption 65%

The National Park Foundation and the National Park Service partnered with Musco Lighting to relight the Statue of Liberty in the wake of Hurricane Sandy. Musco developed and installed a system of LED light fixtures powered by small generators and mounted on moveable structures that could be easily relocated as needed during restoration work. The LED lighting system reduced the energy used to light the iconic statue by an estimated 65% or more.

Light Sources
When planning a retrofit, keep in mind that not all sources are interchangeable. The new source may not perform the same way as the older source. For example, CFLs typically do not perform well in cold environments, and LED replacement lamps may not last as long as intended when operated for prolonged periods at very high temperatures.

Carefully evaluate the long-term goals of the retrofit. In some cases, replacing the whole luminaire is more cost-effective overall than replacing lamps, even though the up-front costs may be higher. It may be tempting to remove controls or dimmable luminaires from the purchasing plan to reduce initial project costs, but doing so will mean sacrificing the long-term savings associated with these measures. Understanding the benefits and limitations of light sources makes it easier to select the right technology for the application. Table 3 compares common source types used for outdoor lighting.

Table 3. Common Light Sources Used in Outdoor Applications

<table>
<thead>
<tr>
<th>LAMP TYPE</th>
<th>DEMAND (W)*</th>
<th>SOURCE EFFICACY (LPW)**</th>
<th>CCT (K)</th>
<th>CRI</th>
<th>LIFETIME (HOURS)</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pressure sodium</td>
<td>70–400</td>
<td>80–120</td>
<td>1,900–2,200</td>
<td>22–70</td>
<td>20,000–40,000</td>
<td>$$</td>
</tr>
<tr>
<td>Low pressure sodium</td>
<td>55–180</td>
<td>130–170</td>
<td>1,700–1,800</td>
<td>—</td>
<td>16,000–20,000</td>
<td>$$</td>
</tr>
</tbody>
</table>
| Ceramic metal halide | 20–400    | 75–110                  | 3,000–4,200 | 80–94 | 10,000–30,000     | $$–$$$
| Metal halide         | 70–400     | 40–70                   | 3,000–4,200 | 60–80 | 10,000–20,000     | $$    |
| Mercury vapor***     | 75–1,000   | 20–40                   | 4,000–6,000 | 15–50 | 16,000–24,000     | $$    |
| CFL                 | 20–70      | 80–85                   | 2,700–5,000 | 80–85 | 6,000–12,000      | $     |
| Induction            | 70–250     | 50–85                   | 3,500–5,000 | 80–85 | 100,000          | $$–$$$
| LED                 | 40–250**** | up to 130               | 2,700–6,000 | 50–85 | up to 35,000 or more | $$–$$$

Note: The ranges listed in this table reflect typical values for light sources commonly used in outdoor lighting applications. These numbers were compiled when this guide was created and are subject to change as technologies improve.

Selection of a particular product should be made only after carefully considering the lighting needs of the site. Some outdoor applications may be best served by products with characteristics that fall outside of the ranges listed in this table.

* Typical size of lamps used in exterior applications.
** Based on initial lumens, system efficacy should be determined and is dependent on the specific luminaire style, as well as the ballasts or drivers employed.
*** Manufacture and import of mercury vapor lamp ballasts and luminaires has been banned since 2008; this is included for comparison purposes only.
**** Typical size of LED luminaires used in exterior applications, luminaire contains multiple LEDs.
Filament-Based Light Sources
Filament-based light sources produce light by passing current through a fine filament wire, causing it to glow. Incandescent and halogen lamps are both filament-based light sources, but they have unique differences.

INCANDESCENT sources produce light from a filament heated by an electric current to the point of 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.

HALOGEN lamps, sometimes called tungsten halogen or quartz halogen, 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 incandescent lamps and allows the lamps to burn hotter and brighter. Higher operating temperatures can pose a fire hazard in some applications.

HALOGEN INFRARED REFLECTING (HIR) Lamp is a type of halogen parabolic aluminized reflector (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
A fluorescent lamp is a type of low-pressure gas discharge lamp. Visible light is produced by phosphor coatings on the inside of the glass tube. The entire light-production process involves many reactions and requires proper voltage and current regulation.

A variety of phosphors can be used to provide fluorescent lamps in various color temperatures and with various color rendering qualities. Fluorescent lamps are also 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 and modulate the current during operation.

PREHEAT LAMP AND BALLAST 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 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 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 is designed to operate with a ballast that uses low-voltage windings to preheat the electrodes and initiate the arc. This is done without a starting switch or the application of high voltage. Rapid-start lamps require a bi-pin configuration.

PROGRAM-START BALLAST warm the electrodes before high voltage is applied. Once the arc is struck, the ballast stops the warming circuit.
MAGNETIC AND ELECTRONIC FLUORESCENT 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 because electronic ballasts deliver higher efficacy than magnetic ballasts and use improved electronic components to control the current more precisely. Electronic ballasts do not emit a notable humming noise, but they may have shorter lifespans than magnetic ballasts.

COMPACT FLUORESCENT LAMPS (CFLS) are a type of fluorescent lamp designed to replace incandescent A-lamps. CFLs are available in three base types with many different geometries, wattages, and color temperatures. Most CFLs are designed for use with a standard screw-base socket. These are commonly known as screw-in or screw-base CFLs. Screw-in CFLs are also known as self-ballasted CFLs because the ballast is integrated into the base of the lamp.

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

The third type of CFL has a GU-24 base. GU-24 CFL lamps are installed using the same screw-in motion as a screw-base CFL but with a modified twist-and-lock connector instead of threads. Some lamp styles contain integrated ballasts while others have separate, detachable ballasts that allow for replacement.

INDUCTION LAMPS are a type of fluorescent lamp 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 the standard ballast and electrode system, 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, but because induction lamps do not have electrodes, they have much longer lifetimes. Because of their longevity, induction luminaires are well suited for outdoor areas where reducing lamp replacement and maintenance would provide an advantage.

High-Intensity Discharge (HID) Lamps
HID lamps are a type of gaseous discharge lamp. 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.

MERCURY VAPOR (MV) LAMPS are an older technology that generally underperforms in efficacy and lamp life compared with metal halide or sodium lamps. For this reason, sales of mercury vapor lamp ballasts were banned in the United States in 2008. Metal halide and high-pressure sodium (HPS) sources have replaced many MV lamps.

METAL HALIDE (MH) LAMPS, similar in construction to mercury vapor lamps, provide white light at higher efficacies and have longer lifetimes. Metal halides in the arc tube contribute to the improved light output over time. MH lamps are commonly used for commercial, industrial, sport, building façade, and high-ceiling architectural purposes. MH is the most suitable HID source when good color rendering is required.

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, called an igniter, to generate a high-voltage pulse to the operating electrodes.

CERAMIC METAL HALIDE (CMH) LAMPS are similar to pulse-start MH lamps, 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) LAMPS produce light by exciting sodium atoms contained in the arc tube. The outer glass of an HPS lamp is made of borosilicate hard glass to withstand high operating temperatures. 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 other outdoor lighting applications.

LOW-PRESSURE SODIUM (LPS) LAMPS, similar to HPS sources, produce light from sodium vapor. This arc discharge produces a monochromatic yellow light (CCT 1800 K); 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 deliver extremely high efficacy, but because of their poor color characteristics, LPS lamps are rarely used except near astronomical observatories, where their limited spectral output causes minimal interference with analysis of cosmic radiation.

Light Emitting Diodes (LEDs)
A wide number of LED replacement options are now available to suit a variety of outdoor lighting applications. Long-life, energy-efficient LED luminaires and lamp replacement kits are achieving considerable energy and maintenance savings as a growing number of sites replace incandescent and HID sources with LED options. LEDs have also long been a popular source for exit signs and traffic signals. As the most rapidly developing type of source technology today, LED efficacy and quality continue to improve, and the technology continues to become more affordable.

Made from solid-state materials that emit light when a current is passed through them, the light output and characteristics of LEDs depend on the specific material, chemistry, size, color, and thermal environment used for their production. 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, emitting primarily one wavelength on the visible spectrum.

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. This configuration effectively combines the light emissions on the different spectra 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.
Lighting Controls

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

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

Some lighting controls, such as photosensors, are useful in all outdoor areas. Others, such as bi-level motion sensor controls, are appropriate only for certain spaces, such as those that must remain illuminated after dark but have low, intermittent occupancy rates. National parks and other federal properties with after-hours parking lots, garages, pathways, or outdoor security lighting are ideal sites for motion sensors.

The first step in any lighting controls project is to define control zones and control resolution within each zone. Exterior lighting control zones can vary depending on the application and occupancy patterns.

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

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 amount of daylight available and the type of daylighting controls used. Daylighting control systems may include time scheduling, which can maximize energy savings.

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 (i.e., dimmers and switches), photosensors can help reduce the number of operating hours for outdoor 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 shut off the electric light. A photosensor is often integrated in the luminaire, or placed in a location free from shadows or direct sunlight. Properly installed photosensors will require little maintenance, perhaps just occasional dusting of the surface to keep operation optimal.

Time Clocks and Energy Management Control Systems

An energy management control system (EMCS) or a time-clock can be used to limit lighting to specific scheduled hours. An EMCS is often used to control lighting both indoors and outdoors at a site such as a visitor center with an adjacent parking lot. Energy management control systems can also be used to monitor energy use, adjust luminaire light levels remotely, and indicate when repairs are needed.

Pairing or layering controls usually achieves the best results. For example, daylight controls or photosensors can adjust lights as the sky darkens and more light is needed; a time-clock or EMCS can then increase or decrease their power later in the evening depending on scheduling needs.
Occupancy Controls (Motion Sensors)

Passive infrared (PIR) and microwave technologies are the primary types of occupancy control devices used in outdoor applications. Ultrasonic and audio-based occupancy sensor technologies are inappropriate for outdoor use because they can be triggered unintentionally by small animals, wind, rain, etc.

Standard (on/off) occupancy controls enable lighting systems to operate at full power and light output when an area is occupied and shut lights off completely when the area is unoccupied. This strategy is best suited to secondary-use areas where lighting is rarely needed at night.

Step-dimming occupancy controls consist of a lighting system that operates at multiple steps, or dimming levels. Luminaires operate at full power and light output when the space is occupied and at a reduced power level and light output when unoccupied. Dimming levels can often be adjusted to increase energy savings or increase light based on the needs of the site. This design method balances energy savings with safety, security and comfort. It is a suitable solution for primary-use areas and yields the greatest savings where occupancy rates are low or occupancy patterns are irregular.

Care should be taken when installing lighting control systems as most sensors are visible to the public and can potentially be manipulated, damaged or stolen. To function correctly, sensors must also be carefully positioned and commissioned. Follow these steps to ensure sensors are properly installed and maintained:

1. Refer to the sensor manufacturer’s instructions for proper installation
2. Include building personnel in planning stages
3. Position sensors to minimize false triggers
4. Train staff on sensor maintenance

When adding controls to existing lighting:

- Assess 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
Emerging Technologies

Networked Lighting
Several network lighting control systems are now commercially available. These allow authorized users to remotely access a system’s detailed energy-use profile, receive automated maintenance alerts as soon as an outage occurs, and view or edit operating schedules, from a desktop or laptop computer with the system software. 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 automated monitoring and instant control of every light is now possible, maintenance issues can be quickly and precisely addressed, saving money and energy. Some of the features of networked lighting include:

- Remote monitoring and data assessment, including maintenance tracking and outage detection, via Web connection
- Demand response (DR) control
- Power metering to take advantage of power savings from dimming
- Compatibility with motion sensors for increased energy savings
- Easily adjustable light dimming profiles
- Scheduling, as an alternative to photocell control

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.

Because of their high power density, plasma systems are currently being developed for exterior lighting applications typically illuminated with HID lamps, such as roadways, parking lots and outdoor sports facilities. With further performance and cost validation, plasma lighting could potentially increase the energy efficiency of lighting in these outdoor applications.

Photovoltaic (PV) Systems
A photovoltaic (PV) system may serve as a stand-alone source of energy or be connected to a utility-owned electricity grid. Grid-connected PV systems are less costly and require less maintenance than stand-alone systems. In some areas, grid-connected systems qualify for more government incentives. For these reasons, grid-connected PV systems are more common in North America.

When a grid-connected PV system generates more power than the customer can use, the surplus power is fed to the utility grid, and the customer earns credit for that unused electricity. When power use exceeds what the system can produce, the customer draws electricity from the grid and is charged for that power.

Lighting loads installed underneath PV structures, such as solar-paneled carports, should be minimized by pairing high-efficacy sources with photosensors and motion sensors.

Stand-alone PV systems are less common than grid-connected systems. These are not connected to the electrical grid; instead, they store excess electricity in batteries, which are then used for power when the sun is not shining. Batteries, however, incur additional initial costs and maintenance costs, and they must be replaced every few years.

Solar street and area lights can be used in stand-alone outdoor lighting applications where wiring, trenching, or metering is not feasible. The solar panel and battery pack can be placed in many locations on the luminaire— 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 luminaire converts solar energy into electricity, which is stored in a battery to be used during the night. Bollards have a variety of uses, including marking pathways, increasing security and serving as traffic barriers.
Networked Adaptive LED Wall Packs at UC Davis

In 2012, the University of California, Davis, upgraded 101 of its wall packs as part of a campus-wide outdoor lighting retrofit. The campus selected full-cutoff, dimmable LED fixtures, controlled by motion sensors and wireless network control modules that integrated the wall packs into a campus-wide networked lighting control system. These replaced 56 high-pressure sodium (HPS) fixtures and 45 metal halide (MH) fixtures. The networked system was a first-of-its-kind, best-practice solution.

The California Lighting Technology Center (CLTC) participated in the project and conducted a case study of the wall packs to measure results. Occupancy rates averaged just 20% during the nighttime hours when the fixtures were on. The LED fixtures use 45 watts at full brightness and just 14 watts for the nine and a half hours or so that they are not needed; this is compared to the 189 watts consumed throughout the night by the HPS fixtures that lacked motion-sensing lighting controls. Electricity use and electricity costs for the wall packs were reduced 89%.

The fixtures emit a white light (4100K) with a CRI of 70, factors that improved visibility and lighting quality on campus. The network control system allows facility managers to create pre-set lighting profiles, adjust lighting schedules, directly control individual fixtures or groups of fixtures, monitor energy use patterns, and receive automatic alerts when a fixture needs maintenance.

More information on this project is available online: cltc.ucdavis.edu/sites/default/files/files/publication/speed-case-study-ucd-wall-packs.pdf
Part 4

Project Planning
**Lighting Evaluation Basics**

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

- Where will the luminaires be located, and what lighting control measures are required for the site, in terms of limiting light pollution, light trespass and glare?
- 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 measures can be taken to minimize the impact of nighttime lighting on any wildlife in the surrounding ecosystem?
- How important is accurate color rendering, relative to other factors, within the given area?
- What technologies are available to achieve the desired design?
- What are the costs and benefits associated with different options?

**Conducting a Lighting Audit**

Lighting audits are essential to efficiently determine the current state of a lighting system and the need, if any, for a new one. An audit of the existing lighting system can determine what type of retrofit is best suited to the site, and it will allow for an accurate economic evaluation and light level comparison of the pre-retrofit and post-retrofit systems. The measurements gathered through an audit often play an important role in funding and financing lighting retrofit projects.
Lighting Audit Guidelines

Many organizations provide professional services for large-scale lighting system audits. The process varies for each individual audit, but a thorough evaluation of the existing lighting system will include assessment of the following:

- Age, condition and quality of the existing luminaires (e.g., lens discoloration, lens cracking, paint cracking, or burn marks)
- Model and manufacturer of the existing lighting system, to obtain photometrics
- Lamp wattage and ballast type
- Operational environment of the lighting system, noting the possibility of particulate, moisture, or dirt buildup in or around luminaires
- Activities and type of work being conducted in the area, as well as any special visual requirements
- Lighting system controls and time of use
- Colors of objects within the space (to characterize color rendering)
- Physical layout of the existing lighting system, including luminaire height, spacing and number

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 and measurements should be taken on the ground and at even intervals, following a grid pattern. These illuminance levels can then be compared to IES recommended levels for the application.

Once all this basic information has been recorded, it is possible to draw conclusions about the existing lighting system and answer some important questions:

- Does the lighting system meet the original or proposed lighting needs of the area and its occupants?
- How cost-effective is the lighting system, given its operational costs for energy use and maintenance?
- Calculate the system efficacy of each type of luminaire. How efficient is each system at delivering light to its target 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 existing lighting system and if the system meets code requirements.
- Calculate the existing lighting power density and determine if it meets the applicable codes or energy standards.
<table>
<thead>
<tr>
<th>Item Number</th>
<th>Location, Description</th>
<th>LUMINAIRE / LENSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Condition (soiled, cracked, etc.)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>Condition (soiled, cracked, etc.)</td>
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<tr>
<td>System Power (W)</td>
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<tr>
<td>Model Number</td>
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<tr>
<td>Manufacturer</td>
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<tr>
<td>Perceived Color Quality (good, poor, etc.)</td>
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</tr>
<tr>
<td>Occupants, Tasks (age, work activities, etc.)</td>
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</table>
Relamping and Maintenance
There are two strategies for addressing this aspect of lighting maintenance: group and spot relamping. Each has its own advantages, but scheduled group relamping has generally proven to be more cost effective than spot relamping.

Group Relamping
Using this strategy, lamp replacement occurs on a fixed schedule, minimizing lamp outages. Depending on the size of the lighting installation and amount of time the relamping would take, group relamping normally occurs in phases. This strategy saves labor costs by reducing setup time and luminaire cleaning. Group relamping is also easy to delegate to outside contractors who have special equipment and training, further increasing labor efficiency.

Spot Relamping
Lamps are replaced as they fail with this strategy. This approach saves material costs since lamps run until the end of their useful lives, but it entails higher labor costs as a technician must replace and clean lamps according to their individual life-cycles rather than systematically. Spot relamping can also result in inconsistent light levels with delays between lamp failure and replacement.

Tracking Maintenance
Keeping a maintenance log allows facilities to track relamping, regardless of which strategy is selected. Logs should allow employees performing relamping or other maintenance tasks to note their names, identify the item number addressed, its location, the date the maintenance was performed and the action taken. See the example provided on this page.

Maintenance Log

<table>
<thead>
<tr>
<th>Item Number</th>
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</thead>
<tbody>
<tr>
<td>Location of Fixture</td>
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<tr>
<td>Date of Relamp</td>
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<tr>
<td>Action Taken</td>
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<td></td>
</tr>
<tr>
<td>Employee Name</td>
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</table>
Recycling

Fluorescent lamps contain a small amount of mercury and therefore require careful disposal. The vast majority of lamps that contain mercury are considered hazardous waste under federal regulations and cannot simply be thrown in the trash. Fluorescent ballasts manufactured before 1978 might contain polychlorinated biphenyls; these must also be disposed of as hazardous waste. Lamps not tested and proven non-hazardous must be assumed hazardous and handled accordingly.\(^1\) State requirements may also apply.

A growing number of home improvement stores recycle CFLs, including Home Depot and IKEA. For more information on specific state regulations, contact the appropriate state environmental agency. These agencies are listed on the EPA’s website.\(^2\)

HID lamps

High-intensity discharge lamps—including mercury vapor, metal halide, and high-pressure sodium sources—contain various amounts of mercury. Fewer disposal sites and stricter laws exist regarding disposal or recycling of these lamps. Two sets of laws govern the disposal of HID lamps: 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](http://www.epa.gov).

LED sources

LED lighting products must be treated as electronic waste. A DOE study released in March 2013 stresses the importance of properly recycling this equipment, as one would do with cell phones, computer equipment or other e-waste. A report on the research concludes that the hazardous materials in these products come mainly from components other than the LEDs themselves. The same report indicates the recycling of aluminum components would be particularly effective in reducing the environmental impact of LED lighting products, many of which contain aluminum heat sinks. Study results also indicated that the value of recovering aluminum can offset the cost of recycling.

Reports on all three parts of the DOE study, and guidelines for meeting stringent regulations for hazardous waste disposal, are available at [www.ssl.energy.gov/tech_reports.html](http://www.ssl.energy.gov/tech_reports.html).

Cost-benefit Analysis

Funding Sources

Agencies can look to federal, state and local sources to fund outdoor lighting projects. Sources of assistance include:

- Federal grants
- The National Park Foundation, charitable partner of the National Park Service
- Local utilities offering incentives and rebates
- Lighting manufacturers or distributors with information on financing programs and incentives

In addition to securing outside funding, weighing the costs and benefits of various retrofit options makes planning a successful project easier.

Simple Payback

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 gained from the new system.

Initial costs vary by lighting project but typically include:

- Design
- Installation
- Materials
- Commissioning

Simple payback often drives project decisions, but this can yield poor results in the long term. Following best practices means looking beyond short-term payback opportunities and focusing on strategies and technologies that will produce deeper, more sustained energy savings as well as greater economic benefits in the long term. Forward-thinking project planners base their decisions on a cost-benefit analysis that spans the full life of the lighting system and includes projected rises in the cost of energy and the cost of maintenance.

Lifecycle Analysis (LCA)

A lifecycle 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 with 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.

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2. EPA: [http://www2.epa.gov/home/state-and-territorial-environmental-agencies](http://www2.epa.gov/home/state-and-territorial-environmental-agencies)
The following worksheet provides for a simplified economic analysis of outdoor lighting systems. It does not include equations for factoring in inflation or calculating the present value of future costs or benefits. Chapter 18 of the *IES Lighting Handbook, 10th edition*, covers economic analysis in more detail and provides tables that support more complex calculations. The IES’s Recommended Practice for the Economic Analysis of Lighting (IES RP-31-96) is also helpful.

**Economic Analysis Worksheet**

<table>
<thead>
<tr>
<th>PROJECT METRICS</th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Total power used by each lighting system (kW)</strong>&lt;br&gt;Note connected load, including any ballasts and transformers.</td>
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</tr>
<tr>
<td><strong>2. System life (years)</strong></td>
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<tr>
<td><strong>3. Interest rate (%)</strong>&lt;br&gt;Determine the interest rate associated with borrowing funds, alternative investments, or simple escalation over the life of the lighting system.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>INITIAL COSTS</th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4. Equipment</strong>&lt;br&gt;Sources for cost estimates might include: RSMeans, contractors, manufacturers, distributors, and past projects.</td>
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<td></td>
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</tr>
<tr>
<td><strong>5. Labor</strong></td>
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<td></td>
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</tr>
<tr>
<td><strong>6. Utility rebates</strong>&lt;br&gt;Utilities sometimes offer incentives for energy-efficient lighting retrofits or installations. Enter rebates as negative numbers.</td>
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</tr>
<tr>
<td><strong>7. Other first costs</strong>&lt;br&gt;Include differential costs, such as design fees or tax credits.</td>
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<tr>
<td><strong>8. Initial taxes</strong>&lt;br&gt;Usually 6–8.5% of initial material and equipment costs (line 4). Include taxes for labor if not included in line 5.</td>
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<tr>
<td><strong>9. Total initial costs</strong>&lt;br&gt;Enter the sum of lines 4–8.</td>
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</tr>
</tbody>
</table>
### ANNUAL COSTS

<table>
<thead>
<tr>
<th></th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. <strong>Energy costs (annual kWh x $/kWh)</strong></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Annual energy use depends on operating hours, lighting controls, and occupancy rates. Multiply the annual energy use for each system by the average utility rate.</td>
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</tr>
<tr>
<td>11. <strong>Maintenance costs (equipment and labor)</strong></td>
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<tr>
<td></td>
<td>Annual maintenance costs for SSL luminaires will reflect longer lifetimes. For HID and fluorescent sources, include both lamp and ballast replacement costs, and consider whether a group or spot relamping strategy will be followed. Annual relamping costs can be calculated as follows:</td>
<td></td>
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</tbody>
</table>
|   | \[
|   | \frac{\text{cost for replacement (number of replacements required)}}{\text{lamp life / annual operating hours}}
|   | \]
|   | Annual ballast replacement costs can be calculated similarly, with ballast life in place of lamp life. | | |
| 12. **Cleaning costs** | | | |
|   | Estimate average costs per year. If cleaning will occur only during lamp replacement, these costs may be included in line 11. | | |
| 13. **Other annual costs** | | | |
| 14. **Total annual costs** | Enter the sum of lines 10–13. | | |

### FINAL COSTS

<table>
<thead>
<tr>
<th></th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>15. <strong>Residual (salvage) value at end of economic life</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>This value is negative if money is received for the salvage; it is positive if a cost is incurred to dispose of the system.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. <strong>Final total for system costs</strong></td>
<td>Enter the sum of lines 9, 14 and 15.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part 5

Meeting Federal Building Energy Standards
The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) develops technical standards and performance criteria for building systems. Federal buildings designed on or after July 9, 2013 must meet the requirements of ASHRAE Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings. To comply, outdoor lighting systems and equipment must meet the requirements specified in Section 9 of the ASHRAE 90.1-2010 Standard and summarized in this part of the guide.

By following best practices, facilities can often exceed the minimum lighting requirements listed in ASHRAE Standard 90.1-2010 and the updated ASHRAE Standard 90.1-2013, released in October, 2013.

**General Outdoor Lighting Guidelines**

The standards for outdoor lighting apply to exterior building features, including facades, illuminated roofs, architectural features, entrances, exits, loading docks, and illuminated canopies, as well as lighting for outdoor building grounds supplied through the building’s electrical service.

The exceptions to this are:

- Emergency lighting that is automatically off during normal building operation
- Lighting that is specifically required by a health or life safety statute, ordinance or regulation
- Decorative gas lighting systems

**Lighting Alterations**

Alterations to lighting systems in any outdoor area must comply with the lighting power density (LPD) requirements applicable to that area and the automatic shutoff requirements of Section 9.4.1.1. Alterations include the addition, replacement and removal of luminaires, as well as replacement of lamps and ballasts.

Alterations do not include:

- Routine maintenance or repairs
- Alterations involving less than 10% of the connected lighting load in an area, provided that such alterations do not increase the installed LPD

**Installed Lighting Power**

ASHRAE Standard 90.1-2010, Section 9.1.3 states luminaire power (total watts) for outdoor lighting applications is calculated as all power used by the luminaires, including:

- Lamps
- Ballasts
- Transformers
- Control devices

Exceptions include those previously noted (emergency lighting, etc.) and those specified in Section 9.4.3, Exterior Building Lighting Power. If two or more independently operating lighting systems in an area are capable of being controlled to prevent simultaneous user operation, the installed lighting power is based on whichever lighting system uses the most power.

**Luminaire Power**

To calculate installed outdoor lighting power, determine luminaire power (watts) based on the manufacturer’s maximum labeled wattage for the luminaire. For luminaires with permanently installed or remote ballasts, transformers, or similar devices, the operating input power of the maximum lamp/auxiliary combination may also be used (this is based on values from the auxiliary manufacturers’ literature or recognized testing laboratories).

Lighting power calculations for ballasts with adjustable ballast factors are the exception. These are based on the ballast factor that will be used in the space, provided that the ballast factor is not user changeable.

**Miscellaneous Lighting Equipment Power**

Refer to the specified power (watts) of the lighting equipment for all other lighting equipment.

---

Lighting Controls Requirements
The following requirements are based on those listed under Section 9.4.1.7 of ASHRAE 90.1–2010. They apply to building exteriors and grounds lighting:

• Lights must be equipped with a device that automatically turns them off when sufficient daylight is available
• Building façade and landscape lighting must automatically shut off between the hours of midnight or business closing, whichever is later, and 6 a.m. or business opening, whichever is earlier (or alternate times established by the authority with jurisdiction)
• Other outdoor lighting, including sign lighting, must have controls that automatically reduce lighting power at least 30% during the same period described above or any time the surrounding area is vacant (with sensor switching set up to a maximum of 15 minutes)
• Time-switch controls must be able to retain programming for at least 10 hours in the event of a power failure, using a back-up battery or other means

Functional Testing
Commissioning and testing are absolutely necessary if lighting control devices are to function properly and perform as intended. ASHRAE 90.1-2010, Section 9.4.4 lists requirements designed to ensure that control hardware and software are calibrated, adjusted, programmed, and in proper working condition in accordance with manufacturers’ installation instructions and any construction documents for the project.

When the following controls are installed, these minimum procedures are required:

• Photosensors: Confirm that photosensor controls reduce electric light levels based on the amount of usable daylight in the space as specified.
• Occupant sensors: Confirm placement, sensitivity and time-out adjustments for occupant sensors yield acceptable performance; lights should turn off only after the space is vacated and should not turn on unless the space is occupied.
• Time switches and programmable schedule controls: Confirm devices are programmed to turn the lights off and function as programmed.

Certification
Construction documents must state who will conduct and certify the functional testing. The party responsible for testing must not be directly involved in either the design or construction of the project. The responsible party must also provide documentation certifying exactly how the installed lighting controls meet or exceed all documented performance criteria.
Lighting Power Allowances

To comply with Section 9 of ASHRAE 90.1–2010, the total installed outdoor lighting power must not exceed the outdoor lighting power allowance specified by the standards. Lighting power allowances for building exteriors are determined by lighting zone (described below). Many national parks are located in zones designated as LZ-0 or LZ-1. In some areas, local lighting ordinances may limit outdoor lighting power allowances more than ASHRAE standards.

Lighting Zone 0
LZ-0 requirements preserve dark skies in wilderness areas, parks and preserves, forest land, rural regions, areas near astronomical observatories, and other undeveloped areas.

Lighting Zone 1
LZ-1 pertains to parks and preserves in developed areas, low-density residential districts, and developed rural areas.

Lighting Zone 2
LZ-2 applies to areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas.

Lighting Zone 3
LZ-3 pertains to areas with moderately high lighting levels. It is the recommended default zone for business districts in large cities.

Lighting Zone 4
LZ-4 is not a default zone. It should only apply in dense commercial districts of major metropolitan areas or heavy industrial zones.
The total outdoor lighting power allowance for all outdoor building applications is the sum of the base site allowance plus the individual allowances for areas listed in Table 9.4.3B (see pages 44 and 45). These allowances are determined according to the site’s lighting zone designation.

** Tradable Surfaces**

Trade-offs are allowed for the following outdoor lighting applications (listed in Table 9.4.3B as “Tradable Surfaces”):

- Uncovered parking areas
- Building grounds
- Building entrances and exits
- Canopies and overhangs

**Exceptions:** Lighting used for the following exterior applications is exempt when it is controlled independently from the nonexempt lighting and complies with the lighting controls requirements discussed earlier (Section 9.4.1.7):

- Specialized signal, directional, and marker lighting associated with transportation
- Lighting integral to equipment or instrumentation and installed by the manufacturer
- Advertising signage or directional signage

**Parking Garages**

Lighting for parking garages must comply with indoor lighting requirements specified in Section 9.4.1.1, but guidelines are included here because retrofits for these spaces can yield deep energy savings and they are often included in outdoor lighting retrofit projects.

**Automatic shutoff controls**

One of the following is required:

- Time-of-day operated control device that turns lighting off at specific programmed times
- Occupant sensor that turns lighting off within 30 minutes of an occupant leaving
- A signal from another control or alarm system that indicates the area is unoccupied

**Exceptions:** Exceptions include spaces where 24-hour lighting is required or where automatic shutoff would endanger the safety or security of occupants.

**Automatic dimming controls**

Lighting must be controlled by one or more devices that automatically reduce the lighting power of each luminaire by at least 30% when there is no activity detected within a lighting zone for a set period of time (maximum: 30 minutes). Lighting zones for this requirement shall be no larger than 3,600 ft².

**Exceptions:** Daylight transition zones and applications using induction lamps or HID sources of 150 W or less are exempt from this requirement.

**Automatic daylighting controls**

Power must be automatically reduced in response to daylight for luminaires within 20 ft of any perimeter wall structure that has a net opening-to-wall ratio of at least 40% and no exterior obstructions within 20 ft.

**Exception:** Daylight transitions zones are exempt from this requirement.

**Transition lighting zones**

Lighting in parking garage transition zones (not to exceed 50 ft in width and a depth of 66 ft) must be separately controlled by a device that automatically turns lighting on during daylight hours and off at sunset. This helps visitors’ eyes to adjust as they enter or exit the parking garage.
### Table 9.4.3B: Individual Lighting Power Allowances for Building Exteriors

<table>
<thead>
<tr>
<th>Zone 0</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BASE SITE ALLOWANCE</strong> (base allowance may be used in tradable or non-tradable surfaces)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Base Site in Zone 0</td>
<td>500 W</td>
<td>600 W</td>
<td>750 W</td>
<td>1,300 W</td>
</tr>
</tbody>
</table>

**TRADABLE SURFACES** (LPDs for uncovered parking areas, building grounds, building entrances and exits, canopies and overhangs, and outdoor sales areas may be traded.)

#### Uncovered parking areas

| | | | | |
| --- | --- | --- | --- | |
| Parking areas and drives | No allowance | 0.04 W/ft² | 0.06 W/ft² | 0.10 W/ft² | 0.13 W/ft² |

#### Building grounds

| | | | | |
| --- | --- | --- | --- | |
| Walkways less than 10 ft wide | No allowance | 0.7 W/linear foot | 0.7 W/linear foot | 0.8 W/linear foot | 1.0 W/linear foot |
| Walkways 10 ft wide or greater Plaza areas Special feature areas | No allowance | 0.14 W/ft² | 0.14 W/ft² | 0.16 W/ft² | 0.2 W/ft² |
| Stairways | No allowance | 0.75 W/ft² | 1.0 W/ft² | 1.0 W/ft² | 1.0 W/ft² |
| Pedestrian tunnels | No allowance | 0.15 W/ft² | 0.15 W/ft² | 0.2 W/ft² | 0.3 W/ft² |
| Landscaping | No allowance | 0.04 W/ft² | 0.05 W/ft² | 0.05 W/ft² | 0.05 W/ft² |

#### Building entrances and exits

| | | | | |
| --- | --- | --- | --- | |
| Main entries | No allowance | 20 W/linear foot of door width | 20 W/linear foot of door width | 30 W/linear foot of door width | 30 W/linear foot of door width |
| Other doors | No allowance | 20 W/linear foot of door width | 20 W/linear foot of door width | 20 W/linear foot of door width | 20 W/linear foot of door width |
| Entry canopies | No allowance | 0.25 W/ft² | 0.25 W/ft² | 0.4 W/ft² | 0.4 W/ft² |

#### Sales canopies

| | | | | |
| --- | --- | --- | --- | |
| Free standing and attached | No allowance | 0.6 W/ft² | 0.6 W/ft² | 0.8 W/ft² | 1.0 W/ft² |

#### Outdoor sales

<p>| | | | | |
| | | | | |
| --- | --- | --- | --- | |
| Open areas (including vehicle sales lots) | No allowance | 0.25 W/ft² | 0.25 W/ft² | 0.5 W/ft² | 0.7 W/ft² |
| Street frontage for vehicle sales lots in addition to “open area” allowances | No allowance | No allowance | 10 W/linear foot | 10 W/linear foot | 30 W/linear foot |</p>
<table>
<thead>
<tr>
<th>Building facades</th>
<th>Zone 0</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>No allowance</td>
<td>0.1 W/ft² for each illuminated wall or surface 2.5 W/linear foot for each illuminated wall or surface length</td>
<td>0.15 W/ft² for each illuminated wall or surface 3.75 W/linear foot for each illuminated wall or surface length</td>
<td>0.2 W/ft² for each illuminated wall or surface 5.0 W/linear foot for each illuminated wall or surface length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Automated teller machines and night depositories**: No allowance, 270 W per location plus 90 W per additional ATM per location.

- **Entrances and gatehouse inspection stations at guarded facilities**: No allowance, 0.75 W/ft² of uncovered area (covered areas are included in the “Canopies and overhangs” section of “Tradeable surfaces”).

- **Loading areas for law enforcement, fire, ambulance, and other emergency service vehicles**: No allowance, 0.5 W/ft² of uncovered area (covered areas are included in the “Canopies and overhangs” section of “Tradeable surfaces”).

- **Drive-through windows/doors**: No allowance, 400 W per drive-through.

- **Parking near 24-hour retail entrances**: No allowance, 800 W per main entry.

- **Roadway/parking entry, trail head, and toilet facility, or other locations approved by the authority having jurisdiction**: A single luminaire of 60 W or less may be installed for each roadway/parking entry, trail head, and toilet facility, or other locations approved by the authority having jurisdiction.

Part 6  Preserving Dark Skies
In the United States today, most residents seldom experience truly dark skies, no matter what time of night they find themselves outdoors. This is because light pollution is now a common problem around cities and towns. The expansion of urban environments has made the problem more acute in recent decades, diminishing the visibility of stars and planets in the night sky for astronomers and casual observers alike. Light pollution can also adversely affect the health and well-being of people and animals.

Light pollution is arguably the easiest environmental hazard to remedy. Simple retrofits and changes to lighting designs can dramatically limit the amount of light spilling into the atmosphere and surrounding ecosystem—with immediate results. And advanced lighting controls make it easy to further minimize light pollution without compromising safety or security.

**Light Pollution**

Outdoor light pollution occurs when electric lighting alters the photic habitat of an outdoor environment. Light pollution is also commonly defined as any excessive, misdirected or obtrusive light emitted by a man-made source. Sky glow is one form of light pollution. It occurs when light is projected into the sky and spreads, causing a glow above populated areas. The sky glow above some cities is visible from as far as 100 miles away. Consequently, more than two-thirds of the U.S. population can no longer see the Milky Way with the naked eye\(^3\), and anyone interested in an unobstructed view of the night sky must travel well beyond city limits. Sky glow is also a serious impediment to astronomical research. The annual cost of all these negative effects, including energy waste, has been estimated at nearly $7 billion in the U.S.\(^4\)

**Light Trespass**

As with light pollution, light trespass results when luminaires shine light beyond their intended target areas. This potentially disruptive light can fall into neighboring buildings, inhibiting people’s ability to sleep. Likewise, nighttime lighting that spreads into surrounding ecosystems or across migratory paths can impact the health of a variety of species and even endanger populations.

A variety of species have evolved in sync with the diurnal patterns of light and darkness characteristic of our planet. Insects, fish, reptiles, amphibians, birds, and mammals—including humans—all depend on dark night skies to keep their circadian systems in alignment and support patterns of rest and activity. A number of species also depend on dark skies to provide cover from predators and allow for nighttime navigation by natural light sources such as the moon and stars.

In an effort to eliminate light pollution and light trespass, the International Dark-Sky Association (IDA) recommends preventing light from projecting above the horizon. More guidance on how to select dark sky-friendly luminaires is provided at the end of this section.

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Spectral Power Distribution

In addition to the intensity and directionality of light, the spectral characteristics of light emitted from different sources can impact biological function to greater or lesser degrees. Research indicates shorter wavelengths of light, particularly in the 400–550 nm range, are more disruptive to circadian function, with wavelengths shorter than 500 nm having particularly adverse impacts. This light would fall along part of the green band and across the entire blue, indigo and violet bands of the visible light spectrum.

While correlated color temperature (CCT) is useful for describing the color quality of white light as our eyes perceive it, CCT does not indicate how much energy a white light source emits along each aspect of the spectrum. This is why an metal halide (MH) source and an LED source could have identical CCTs, yet the spectral power distribution of one might be significantly higher in the range below 500 nm, compared to the other.

It is important to understand that a light source can emit a strong concentration of short-wave radiation, often referred to as “blue-rich light,” but when mixed with other wavelengths of light energy, the blue-rich character of the light is not discernible to the naked eye. Nevertheless, it can still have a physiological impact.

HPS light sources (550–650 nm) are still the most prevalent type of light source installed for roadway and area lighting in the U.S., but a growing number of facilities are replacing HPS lamps with solid-state white light sources, including LEDs. Along with energy efficiency and improved life, white-light LEDs provide better color rendering than HPS sources. This is because the spectral output of white light sources differs from that of HPS sources. Facilities undergoing retrofits should examine the spectral power distribution of potential replacement lamps and weigh any potential ecological impact along with the advantages of broad-spectrum lighting.

Not all LED sources are the same. Some LED manufacturers offer LED products with reduced blue content for outdoor lighting. Amber LEDs designed for sensitive habitats are also available.

Broad-spectrum electric light emissions, often produced by white light sources, can also interfere with astronomical research and activities at observatories. This is because some emissions from broad-spectrum sources match the wavelengths of cosmic radiation often studied by astronomers. It is difficult to selectively filter this electric light from starlight.

Low-pressure sodium (LPS) sources emit yellow light in a narrow range of wavelengths that are easier for astronomers to filter out during research. For this reason, LPS sources are often preferred in areas near observatories. If broad-spectrum sources must be used, the problem can be mitigated by dimming lights whenever possible and limiting light sources’ spectral output to shorter wavelength content, which is less likely to reflect off of surfaces.

Big Bend National Park: A park-wide relight project restores dark skies and cuts lighting energy use 98%

In February 2012, Big Bend National Park in Texas was designated a Dark Sky Park by the International Dark-Sky Association. It is only the second national park in the U.S. (after Natural Bridges National Monument in Utah) to earn the distinction, thanks to a four-phase, park-wide retrofit project that has improved outdoor lighting and drastically reduced light pollution in the area.

Phase two of the project introduced LED lighting along park buildings and outdoor paths within the Chisos Basin. Estimated annual energy cost savings so far total $3,130. The project has also reduced energy consumption and cut greenhouse gas emissions for lighting by 98%.

Appropriately shielded to limit light trespass, the new light fixtures have improved the quality of lighting along paths and walkways while reducing sky glow so effectively that the spectacular night skies over Big Bend are once again visible. In fact, Big Bend is now thought to have one of the darkest measured skies in the lower 48 states, conditions which also benefit the McDonald Observatory, a leading center for astronomical research located just 150 miles from the park.

The collaborative effort was undertaken with support from the National Park Service, funding from the American Recovery and Reinvestment Act, and a grant from the Friends of Big Bend National Park. A Best Lighting Practices Grant also aided the effort. The grant is administered through the National Park Foundation and the National Park Service’s Denver Service Center. Musco Lighting provided services and Forever Resorts, Inc. also made contributions.

More information, photos and video of the project are available online: www.nps.gov/bibe/parknews/upload/ChisosBasinBestLightingPracticesRelease.pdf
Human Factors

Outdoor lighting allows us to safely and comfortably navigate at night. Like any light processed through the optic nerve, nighttime lighting also elicits a physiological response in the human brain and body. The same bright, white light that helps people feel alert and awake during the day can potentially disrupt sleep cycles at night and, over time, impair metabolic function.

In June 2012, the American Medical Association (AMA) adopted a new policy recognizing the adverse health effects of nighttime lighting. The AMA concluded: “Exposure to excessive light at night, and blue-rich light in particular, has been linked to sleep disturbances and sleep disorders, impaired metabolic function, and suppression of the hormone melatonin.”5 The most adverse health effects are more common among those who experience chronic and long-term exposure to excessive light at night, such as overnight shift workers.

The AMA also stated its support for lighting technologies that minimize circadian disruption. Park facilities can do this by selecting light sources with limited blue-rich spectral content, by selecting dark sky-friendly luminaires, and by further reducing light pollution through the use of lighting controls that enable scheduling, tuning and automatic dimming when lights are not in use.

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Protecting Wildlife

Circadian science continues to reveal the ways that light exposure and dark periods influence hormone production and even affect gene expression. Researchers have observed light pollution disrupting feeding, migration, reproduction, and other behaviors essential to species’ health and survival.

Outdoor lighting can disorient migrating species, spur wakeful behavior when animals should be resting, inhibit activities associated with feeding and reproduction, and otherwise disturb normal, healthy behavior patterns, increasing animals’ risk of exhaustion and death. Insofar as light pollution inhibits successful reproduction, it can even result in extinction for small, isolated populations. For all these reasons, lighting that preserves dark skies is vital to the protection of wildlife.

Mammals

Research shows light pollution affects both diurnal and nocturnal mammals, including bats, raccoons, deer, moose, coyotes, and mountain lions. The endangered lesser long-nosed bat is just one example of mammal species that favor areas managed for lower light intensity, such as national parks. Research has demonstrated the bats avoid zones where light intensity is greater, favoring relatively darker flight paths instead. The endangered species is a primary pollinator in Arizona’s Organ Pipe Cactus National Monument, located west of Tucson in the Sonoran Desert. The bat species’ flight corridors and foraging areas encompass other parts of the state as well, where state and local agencies are working together to minimize light pollution and protect populations.

Birds

Outdoor light sources can also disrupt bird migration patterns, and because birds often become fixated on bright light beams, improperly shielded lights can make birds vulnerable to predators. Some birds will circle certain light sources to the point of exhaustion and collapse. One million birds die every year throughout North America from collisions with lighted towers and buildings, according to the International Dark-Sky Association (IDA). During stormy weather, in particular, when low cloud ceilings obscure the moon and stars, birds are more likely to be negatively impacted by nighttime lighting.

Fish

Research shows light and darkness affect every aspect of fish species’ lifecycle, from egg development, hatching and emergence to feeding, migration and spawning. Controlled aquarium research published in 2013 demonstrated that ecologically relevant light intensity levels from broad-spectrum street lamps can delay the emergence and dispersal of Atlantic salmon fry. This disruption desynchronized the population’s emergence and caused a significant proportion to disperse during daylight hours. In the wild, these factors would leave young salmon more vulnerable to predation and at a disadvantage to establish feeding territories among other species. The weight of salmon fry exposed to street-lit conditions was also significantly lower.

Field research confirms that bright light at night near rivers and streams can slow, stop or alter the migration patterns of young salmon. Light avoidance behaviors have been observed as some fish seek cover from predators in darker parts of the water. For other species, bright lighting along water ways acts as a fish trap, attracting predators and arresting movement along rivers and streams.

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Figure 16. A lesser long-nosed bat, covered in pollen from Sonoran Desert flowers. Data shows the endangered species favors low lighting zones.

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Washington researchers who have contributed to these observations recommend keeping light levels on rivers and other water habitats below 0.1 lux and implementing shielding and motion controls, so lighting is limited to where and when it is needed. Other requirements and guidelines may apply where state measures, such as the California Environmental Quality Act (CEQA), and local ordinances apply.

**Amphibians and Reptiles**

Sea turtle hatchlings are perhaps the most famous example of reptile species adversely affected by light pollution. For millions of years, young turtles could follow the white glow of the surf and the moonlight reflected in the waves to find their way to the ocean, where they are protected from predation by sea birds and mammals. In the last century, as lighting became denser in turtle habitats, the glow of broad-spectrum lamps along the shore has drawn hatchlings off course, with adverse effects on the population. 9

Lizards and other reptiles are also affected by excessive light at night, and amphibians also exhibit unusual behavior in areas where the night never approaches normal levels of darkness. Salamanders, having evolved to forage and mate at night to avoid predators, will forage less and reproduce in smaller numbers where nighttime lighting interferes. Canadian scientists have also found male green frogs make fewer mating calls in brightly lit areas, affecting selection for females and potentially changing the dynamics and genetic diversity of the entire population. 10

**Insects**

In 2013 a research team published its findings that dung beetles navigate using the sun, the moon, and, on moonless nights, the Milky Way. 11 The team’s experiments were the first to conclusively demonstrate insects’ use of the starry night sky for orientation, and they underscore the importance of dark night skies for all aspects of the animal kingdom.

In addition, though lead researchers to consider it, allowing for navigation by celestial markers, dark night skies provide cover for many insects. Nighttime lighting attracts and distracts insects, interfering with their ability to evade detection and capture by predators. In this way, lights can effectively act as bird and bat feeders, disrupting the natural hunting and foraging behaviors of predators. Naturalists have observed that spiders, frogs, and toads also take advantage of insects’ vulnerability in lit areas.

Researchers have found nighttime lighting can also interfere with insects’ reproduction. A study of male moths found outdoor lights compete with females for males’ attention, thus inhibiting the insects’ reproductive success. 12 Nighttime lighting also inhibits pheromone release in female moths. Light sources that arrest and kill pregnant females before they can lay their eggs further diminish populations. Naturally, any impact on insect populations also impacts the species that depend on insects for food and the pollination of plants that provide sustenance.

Lighting manufacturers design light sources that minimize light output in the UV spectrum, for example, or otherwise limit the light’s attractiveness to most insect species. Selecting appropriate sources, and implementing proper shielding and lighting controls can protect ecosystems without compromising human safety or comfort. Fewer swarms around luminaires can also reduce maintenance needs.

**Plant Life**

Older studies have found many plant species are unaffected by continuous lighting, but certain species, including geranium and tomato plants require natural light-and-dark cycles to thrive and stay alive.

A more recent 2013 study by biologists from Rice University in Texas and the University of California, Davis, found that plants exposed to light-and-dark cycles (circadian entrainment) even after harvesting had higher levels of phytochemicals, including antioxidants. These phytochemicals bolstered the plants’ resistance to herbivores and enhanced their nutritional value. 13 The team demonstrated that the first phenomenon, of naturally enhanced pest resistance, is widespread among diverse crops.

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Selecting Dark Sky-Friendly Luminaires

Many new light luminaire designs optimize light output while reducing glare, light pollution and light trespass. Specifications developed by the lighting industry help lighting designers and installers select outdoor luminaires with the appropriate distribution for sites in different lighting zones (the same zones listed in Table 9.4.3A of the ANSI/ASHRAE/IES Standard 90.1-2010).

The BUG System

The Illuminating Engineering Society of North America (IES) developed the Backlight-Uplight-Glare (BUG) rating system to evaluate luminaires’ performance in relation to light trespass, sky glow, and high-angle brightness (see figure 18).14

A BUG system rating consists of a three-part code that indicates how well the luminaire controls backlight, uplight and glare. A code for a luminaire may look something like this:

B0-U2-G1

The numbers in the rating represent how well the luminaire performed in photometric testing, with 0 representing the best control and 5 indicating poorest performance. A luminaire rated with the example code above (B0-U2-G1) offers excellent control of backlight, mediocre control of uplight, and fairly good control of glare.

Today, a growing number of manufacturers will provide BUG-rated zonal lumen distributions for their outdoor luminaires. The appendix of this guide includes a demonstration exercise, “Finding the BUG Rating for a Type II Outdoor Lighting Fixture,” which explains in more detail how BUG ratings can be determined using the information in a standard photometric report.

The Model Lighting Ordinance (MLO) jointly developed by the IES and the International Dark-Sky Association (IDA) lists maximum allowable BUG ratings for various lighting zones (see table 4).

Parks, preserves, wilderness areas, and protected wildlife corridors are classified as Lighting Zone 0 (LZ-0) under the MLO. Dark periods constitute a critical part of the habitat in this category, so LZ-0 environments require the most stringent control of outdoor lighting. The MLO recommends luminaires match the following backlight-uplight-glare (BUG) rating: B0 or B1, U0, G0. (A maximum rating of B1 is recommended for certain applications over 1 mounting height.) Some sites may be in more populated zones where greater general illumination levels are appropriate. Local jurisdictions can petition to have their lighting zones, and their corresponding lighting allowances, made more or less stringent.

14 IES Luminaire Classification System for Outdoor Fixtures, IES TM-15-11.
<table>
<thead>
<tr>
<th></th>
<th>LZ-0</th>
<th>LZ-1</th>
<th>LZ-2</th>
<th>LZ-3</th>
<th>LZ-4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BACKLIGHT RATING</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 mounting heights from property line</td>
<td>B1</td>
<td>B3</td>
<td>B4</td>
<td>B5</td>
<td>B5</td>
</tr>
<tr>
<td>1–&lt;2 mounting heights from property line and ideally oriented</td>
<td>B1</td>
<td>B2</td>
<td>B3</td>
<td>B4</td>
<td>B4</td>
</tr>
<tr>
<td>0.5–1 mounting heights from property line and ideally oriented</td>
<td>B0</td>
<td>B1</td>
<td>B2</td>
<td>B3</td>
<td>B3</td>
</tr>
<tr>
<td>&lt; 0.5 mounting height to property line and properly oriented</td>
<td>B0</td>
<td>B0</td>
<td>B0</td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td><strong>UPLIGHT RATING</strong></td>
<td>U0</td>
<td>U1</td>
<td>U2</td>
<td>U3</td>
<td>U4</td>
</tr>
<tr>
<td>Allowed % light emission above 90% for street or area lighting</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>GLARE RATING</strong></td>
<td>G0</td>
<td>G2</td>
<td>G2</td>
<td>G3</td>
<td>G4</td>
</tr>
<tr>
<td>Any luminaire not ideally oriented with 1–&lt;2 mounting height to any property line of concern</td>
<td>G0</td>
<td>G0</td>
<td>G1</td>
<td>G1</td>
<td>G2</td>
</tr>
<tr>
<td>Any luminaire not ideally oriented with 0.5–1 mounting height to any property line of concern</td>
<td>G0</td>
<td>G0</td>
<td>G0</td>
<td>G1</td>
<td>G1</td>
</tr>
<tr>
<td>Any luminaire not ideally oriented with &lt;0.5 mounting height to any property line of concern</td>
<td>G0</td>
<td>G0</td>
<td>G0</td>
<td>G0</td>
<td>G1</td>
</tr>
</tbody>
</table>

*Joint IDA–IES Model Lighting Ordinance (MLO), 2011.*
Resources & Glossary
The resources included in this section are intended to serve as preliminary sources for information on outdoor lighting. Though it is not a complete list, each resource listed here provides links to a wide range of useful materials. The information contained here is up to date at the time this guide was created.

**U.S. Department of Energy**

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**

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.

**NPS Night Skies Resources**

nature.nps.gov/night
The National Park Service website has helpful pages on the “Science of Light,” “Light Pollution,” “Managing Lightscapes,” “Making a Difference,” and more.

**Lawrence Berkeley National Laboratory**

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 (CLTC) is a not-for-profit research, development and demonstration center dedicated to accelerating the development and commercialization of energy-efficient lighting and daylighting technologies. Part of the University of California, Davis, CLTC includes laboratories for technology testing, development and prototyping. CLTC also conducts education and outreach activities. The center works in partnership with utilities, lighting manufacturers, end users, builders, designers, researchers, academics, and government agencies.

**Illuminating Engineering Society**

ies.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**

darksky.org
IDA is a nonprofit member organization that teaches others how to preserve the night sky. It provides resources, including fact sheets, photos and guides. IDA co-developed the Model Lighting Ordinance (MLO) with the Illuminating Engineering Society, and it recognizes national and state parks that protect dark-sky environments.
Dark Sky Society
darkskysociety.org
The Dark Sky Society supports educational and legislative efforts to eliminate light pollution.

National Renewable Energy Laboratory
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
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
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
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
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
cltc.ucdavis.edu/project/uc-davis-smart-lighting-initiative
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
Outdoor lighting improves security, enhances safety, and directs pedestrians and vehicles. IDA gives tips on how to improve outdoor lighting and provides information and guidance to help facilities choose sustainable, ecologically responsible solutions.

Lansing Board of Water & Light and Midwest Circuits
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 luminaires with LED luminaires and install a remote monitoring system.

Reports and Guides

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/
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 luminaires of 175 W lamps with new low-bay LED Luminaires from Lighting Science Group Corporation of nominal 85 W and 6,000 K color temperature.

LED Fixtures for Exterior, Porch, and Perimeter Lighting | www.etcc-ca.com/component/
content/article/33/2567-light-emitting-diode-led-
fixtures-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 luminaries 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.

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.

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


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](http://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.


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.


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


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.


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 luminaires that direct light appropriately is a simple remediation of the adverse consequences of excessive outdoor lighting.


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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.
Demonstration Exercise: Finding the BUG Rating for a Type II Outdoor Lighting Luminaire

Step 1: Locate Photometric Information
Search the manufacturer’s website for the photometric report or summary on the luminaire in question.

Step 2: Consult IES for BUG Ratings
Next, find the most recent version of the BUG ratings. For this example, we will use the ratings from Addendum A for *IESNA TM-15-07*. Check the IESNA website, www.iesna.org, for the most recent rating available.

Step 3: Determine the Backlight Rating
To find the backlight (‘B’) classification of this luminaire, we must first identify the lumen output for the secondary solid angles of BH, BM and BL. Our photometric report includes this data:

- BH: 375.8 lumens
- BM: 1034.8 lumens
- BL: 508.3 lumens

These values are then compared to the backlight ratings in Table A-1 of Addendum A for *IESNA TM-15-07* in order to determine which rating each secondary solid angle receives. In this example, the secondary angles are classified as follows:

- BH: B1 (375.8 < 500 lumens)
- BM: B2 (1034.8 < 2500 lumens)
- BL: B2 (508.3 < 1000 lumens)

The highest rating for the three secondary angles is then selected as the backlight rating for the luminaire. In this case, B2 is the highest rating the secondary angles received, so for this luminaire, the **Backlight Rating is B2**.

Step 4: Determine the Uplight Rating
The same process is used to determine the Uplight (‘U’) rating of the luminaire.

- UH: 0.0 lumens = U0
- UL: 0.0 lumens = U0
- FVH: 16.7 lumens = U1
- BVH: 11.6 lumens = U1

**Uplight Rating is U1**

Step 4: Determine the Glare Rating
The process for finding the glare (‘G’) rating depends on the IES classification of the luminaire. Glare ratings differ for asymmetrical luminaire types (Type I, II, III, and IV) and symmetrical luminaire types (Type V, V Square). The manufacturer usually provides the IES Classification for a luminaire.

Our example is a Type II luminaire, so we will use Table A-3: Glare Ratings of *ESNA TM-15-07*, using the same process used to determine the backlight rating.

- FVH: 16.7 lumens = G1
- BVH: 11.6 lumens = G1
- FH: 1062.5 lumens = G1
- BH: 375.8 lumens = G1

**Glare Rating is G1**

Step 5: BUG Rating
Finally, we can determine that this luminaire has the following BUG rating:

**B2-U1-G1**
Glossary

A

Accent lighting: Lighting used to emphasize a building’s architectural features or draw visitors’ attention to certain objects.

Ambient lighting: See “general lighting” and “lighting zones.”

Astronomical time-switch: An automatic lighting control device that switches lights on or off at specified times of the day, or during astronomical events such as sunset and sunrise, to prevent energy waste during periods when daylight is available. These devices can account for geographic location and calendar date. Multi-level astronomical time switch controls reduce lighting power in multiple steps between full light output and their off setting.

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

C

Candela (cd): Standard SI unit of luminous intensity, or candle power. One candela is one lumen per steradian (lm/sr). A candle flame emits light with a luminous intensity of approximately one candela.

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 Commission on Illumination), an independent nonprofit organization that determines most lighting standards.

Coefficient of utilization (CU): Ratio of luminous flux (lumens) from a luminaire received on the work plane to the lumens emitted by the luminaire.

Color Rendering Index (CRI): The standard scale used in the lighting industry to measure how accurately a light source renders colors in comparison to an ideal source (known as a blackbody radiator). The rating system uses eight specific test colors. The apparent shifting of these test colors is measured to determine a light source's average color rendering ability. The greater the apparent shift, the lower the CRI. The CRI scale ranges from 0 (poorest) to 100 (color rendition matching that of the ideal source). A CRI of 80 or higher provides good color rendering for outdoor applications where color rendering is important. If color rendering is less important, a CRI in the mid-70s may suffice.

Compact fluorescent lamp (CFL): See “fluorescent lamp.” CFLs are a type of fluorescent lamp with ballasts incorporated in the base. The fluorescent tube of a CFL is curved into a more compact shape to allow for direct replacement of incandescent lamps.

Cones and rods: Retinal receptors that allow humans and animals to see. The cones in the eye enable color perception and sharper focus. Cones are most active when light levels are high (photopic vision). Rods dominate at low light levels (scotopic vision); they detect motion well but perceive less detail and do not allow for the perception of colors. At intermediate light levels, both cones and rods actively contribute to vision by varying degrees (mesopic vision).

Correlated color temperature (CCT): Measured in Kelvins (K), CCT describes the color appearance of light emitted from a lamp. Low CCT indicates a warmer (more red) cast while high CCT denotes a cooler (more blue) appearance. Light sources with a CCT of 2700 – 3000K emit incandescent-like light. Lamps with cooler color temperatures, within the range of 5000 – 6500K emit light that more closely resembles bright daylight on a clear afternoon. A CCT diagram is included in the first section of this guide.

Cutoff fixture: A luminaire that provides a cutoff (shielding) for the light it emits. The old cutoff system of luminaire classification has been replaced by the more precise BUG (backlight, uplight and glare) rating system.
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).

Daylight control: An automatic lighting control device that uses one or more photosensors to detect changes in daylight contribution and automatically adjust electric lighting levels accordingly. A multi-level daylight control adjusts the light output (luminous flux) of the electric lighting system in either a series of steps or by continuous dimming in response to available daylight.

Dimmer: A lighting control device that varies the light output (luminous flux) of the electric lighting system by changing the power delivered to that system. Step dimmers decrease power by one or more distinct, predetermined steps between maximum and minimum light output. Continuous dimmers operate over a continuous range, from maximum to minimum light output, allowing for subtle, granular transitions between light levels.

Disability glare: See “glare.”

Discomfort glare: Glare that produces discomfort but does not necessarily diminish visual performance.

Efficacy: Also called “luminous efficacy,” this is the ratio of visible light emitted by a lamp relative to the amount of power it consumes. This is measured in lumens per watt (lm/W). A lamp that consumes 100 W of power and produces 2000 lm would have an efficacy of 2000 lm / 100 W or 20 lm/W. A lamp’s efficacy is calculated by dividing its rated initial lumens (lm) by the rated lamp power (watts) without including auxiliaries such as ballasts, transformers or drivers.

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 management control system (EMCS): A computerized control system designed to regulate energy consumption by controlling the operation of one or more building systems, such as lighting and HVAC. An EMCS can also monitor environmental and system loads, adjust system operations, optimize energy usage, and respond to demand response signals.

Fixture: See “luminaire.”

Floodlight: A luminaire 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: The flow rate of visible light emitted from a source over time (see also “luminous flux”).

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 (lm/ft²).

Full-cutoff fixture: A luminaire that allows no light emission above a horizontal plane. See “cutoff.”

General illumination: In outdoor lighting, this term describes lighting designed to generally enhance visibility throughout an area, as distinguished from decorative lighting, task lighting, or lighting designed to illuminate objects such as statues, monuments or signs.

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.

High-intensity discharge (HID): A class of lamps that emit light by passing an electric current through a gas. Types of HID lamps include mercury, metal halide, and high-pressure sodium (HPS) 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): A type of high-intensity discharge (HID) lamp that uses sodium in an excited state, along with other elements, to generate light. HPS lamps produce light with a yellow or amber color and provide poor color rendering.

Illuminance: The amount of visible light that falls on a surface, measured in 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. Different illuminance levels are recommended for different visual activities and environments.

Illuminating Engineering Society of North America (IES): The professional society of lighting engineers, IES is the authority on lighting design and specification for lighting professionals. IES produces print and electronic publications, including The Lighting Handbook, the Model Lighting Ordinance (MLO) for outdoor lighting, and Recommended Practice manuals.

Incandescent: A type of lamp with a
filament that gives off light when heated by an electric current.

**Indirect fixture:** A luminaire that directs the majority of its luminous flux in an upward direction.

**Induction:** A type of lamp that uses a special ballast or a generator to create the initial electrical current, much like fluorescent lamps. Induction lamps have a long lifespan due to the fact that they do not require electrodes to start.

**Infrared radiation:** Electromagnetic radiation on the long wavelength side of the visual spectrum.

**Intensity:** The degree or amount of energy or light.

**International Dark-Sky Association (IDA):** A nonprofit organization dedicated to reducing light pollution and energy waste, building awareness of the value of dark skies, and supporting lighting ordinances that conserve and protect dark-sky ecosystems.

**Infrared (IR) lamp:** A type of lamp with 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 (1000 W) of power acting for one hour.

**L**

**Lamp:** The lighting industry term for an electric light source, as distinguished from the whole assembly (see “luminaire”). Lamps are commonly referred to as “bulbs.”

**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 material that produces light when an electric current flows through it. The acronym is often used to describe a component, device or package that incorporates an array of light emitting diodes.

**Lighting zone (LZ):** One of the five zones identified for distinct light-level limits by the IES and IDA. Lighting zones are designed to curtail light pollution. They range from LZ-0, the most stringent, to LZ-3, the least stringent, or LZ-4 in some rare cases where even higher light levels are deemed necessary. Lighting zone requirements are determined by ASHRAE or the authority with jurisdiction, based on the environment and activities within each area.

**Low-pressure sodium (LPS):** 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” that produces 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 measurement for the amount of light emitted from a light source. Higher lumen output generally indicates a brighter light source.

**Luminaire:** The lighting industry terms for what is commonly referred to as a “light fixture.” A luminaire is a complete lighting unit, consisting of lamp(s) and the parts that distribute light, position and protect the lamp(s), and connect them to a power supply.

**Luminance:** The intensity of light reflected from a surface in a given direction. Measured in candelas per area unit (generally, cd/ft² or cd/m²). Luminance (L) often varies depending on the angle from which the reflected light is viewed.

**Luminous flux:** The intensity of light reflected from a surface in a given direction. Measured in candela per area unit (generally, cd/ft² or cd/m²). Luminance (L) often varies depending on the angle from which the reflected light is viewed.

**Lux:** SI unit of illuminance, equal to one lumen per square meter.

**M**

**Mercury vapor lamp:** An older type of HID lamp that emits a blue-green light. Sale of ballasts for these lamps has been banned in the U.S. since 2008, due to the fact that mercury vapor lamps are significantly less energy efficient than other HID sources, including metal halide and high-pressure sodium lamps.

**Mesopic vision:** Vision with fully adapted eyes at intermediate light levels, between photopic and scotopic conditions, or about 3.4 – 0.34 cd /m².

**Metal halide (MH):** A type of HID lamp in which the majority of the light is generated through the radiation of metal halide vapors.

**Motion sensor:** A device that automatically turns lights off soon after an area is vacated. “Motion sensor” applies to outdoor lighting controls. When the device is used to control indoor lighting systems, it is called an occupant sensor, occupancy sensor, occupant-sensing device, or vacancy sensor.

**Mounting height:** The height of the luminaire or lamp above the ground.

**N**

**National Park Foundation:** The official charity of America’s National Parks, the National Park Foundation raises private funds to support national park projects and programs.

**O**

**Occupant sensor:** A lighting control
device that automatically turns lights off soon after an area is vacated. When used for outdoor lighting systems, this type of device is called a motion sensor.

**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.

**Photocontrol:** A device that detects changes in daylight levels and controls electric lighting loads accordingly to maintain predetermined illumination levels (e.g., automatically turning luminaires on at dusk and off at dawn).

**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 high light levels, a luminance of at least 3.4 cd / m².

**R**

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

**Reflector:** A component, such as a mirror, that controls light output by means of reflection.

**Refractor:** An object, such as a lens, that controls light output by means of refraction.

**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:** Visual function under very low light levels. The rod cells of the human eye are activated under scotopic conditions. Scotopic vision is associated with “night vision” and is characterized by high light sensitivity (as the eyes adapt to the darkness), poor spatial acuity, and a lack of color perception. It is generally associated with adaptation to light levels below 0.034 cd / m².

**Semi-cutoff fixture:** A luminaire that provides some cutoff, but less than a full-cutoff luminaire. The cutoff system has been replaced by the more precise BUG (backlight, uplight and glare) rating system.

**Spectral power distribution (SPD):** Radiant power emitted by a light source at each wavelength across the visible light spectrum, 380-760nm. SPD curves provide a visual profile of the color characteristics of a light source.

**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:** The practice of replacing lamps as they burn out, as distinguished from the strategy of group relamping.

**Spotlight:** A luminaire 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**

**T5, T8, T12:** Fluorescent lamp types. The T stands for tubular; the number indicates the diameter of the tube in 1/8-inch increments. A T8 lamp is 8/8 of an inch or one inch in diameter, a T12 lamp has a diameter of 12/8 or one and one-half inches. Fluorescent lamps 38 mm in diameter include specialized models for work premises with low temperature applications, including exterior spaces.

**U**

**Ultraviolet (UV) light:** Light energy output of shorter wavelengths than the human eye can see. Some animals, including insects, birds and reptiles, can see UV light.

**Urban sky glow:** The brightening of the night sky over urban areas as a result of dense electric lighting.

**V**

**Vacancy sensor:** An occupant sensor that requires manual activation of lighting but automatically turns lights off soon after an area is vacated. The device also may be called a manual-on occupant sensor or manual-on/automatic-off sensor.

**Veiling luminance:** A luminance produced by bright sources in the field of view superimposed on the image in the eye, reducing contrast and hence decreasing visibility.

**Visibility:** The quality of being perceptible to those with typical vision. Effective nighttime lighting increases visibility.

**Visual acuity:** Acuteness or clearness of vision, especially form vision, which is dependent in part on the sharpness of the eye’s retinal focus.

**W**

**Watt:** Unit of measure for the electric power used by an appliance or device such as a lamp or luminaire.