NLPIP Lighting Answers

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Dynamic Outdoor Lighting

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Abstract

Dynamic outdoor lighting varies light level (or other characteristics) automatically and precisely in response to factors such as vacancy or the type of use of an outdoor space. Topics addressed in *Lighting Answers: Dynamic Outdoor Lighting* include: strategies for implementing dynamic outdoor lighting installations; technologies used; energy, environmental, and cost benefits; and potential liabilities and barriers. The applications discussed in this report include parking lots, parking garages, outdoor walkways, and streets, which are the most common places where dynamic outdoor lighting might be found.

Introduction

The National Lighting Product Information Program (NLPIP) defines **dynamic outdoor lighting** as outdoor lighting that varies light output, spectral content, intensity distribution or other characteristics of the light automatically and precisely in response to factors such as ambient light levels, vacancy or the type of use of the outdoor space. Recently, there has been an interest in dynamic outdoor lighting because enabling technologies are becoming more cost-effective and because dynamic outdoor lighting has the potential to reduce energy use and **light pollution**.

While dynamic lighting can include many different control schemes, most new dynamic outdoor lighting installations reduce light levels and electric power through switching or dimming during periods of low occupancy, so this report focuses on these types of installations. Dynamic outdoor lighting systems could also temporarily increase light levels, such as after sports events or concerts when pedestrian and vehicle traffic around a stadium are substantially increased. Temporary increases in light levels could be useful for public safety, for example, following an accident or crime, or during nighttime road repair work. In addition to varying light levels, dynamic outdoor lighting could also vary other characteristics of light, such as its spectral or intensity distribution, but because NLPIP did not identify any installations of this nature, they are not discussed in this report. Outdoor lighting installations that use photosensor or time clock controls for dusk-to-dawn operation are not discussed in detail either because they are already in widespread use.

There are two factors that may hinder a greater use of dynamic outdoor lighting. One is the lack of familiarity with cost-effective technologies, especially given the prevalence of **high-intensity discharge (HID)** lamps, which are widely perceived as difficult to modulate over time. HID lamps are used in most outdoor lighting systems (Navigant Consulting 2002) and are likely to continue to be the dominant outdoor light source technology for many years. Uncertainty about the economic and technological feasibility of dynamically controlling this family of technologies is probably a major reason that dynamic outdoor lighting with HID lamps is not widely used. The legal liability of dynamic outdoor lighting is another factor hindering the widespread use of this technology. Because dynamic outdoor lighting generally involves reductions in light levels, the subsequent reduced visibility might become a liability to property owners, depending on the jurisdiction.

This *Lighting Answers* summarizes NLPIP's findings about dynamic outdoor lighting technologies, control strategies, and potential benefits and drawbacks. The applications discussed in this report include parking lots, parking garages, outdoor walkways, and streets, which are the most common places where dynamic outdoor lighting is found.

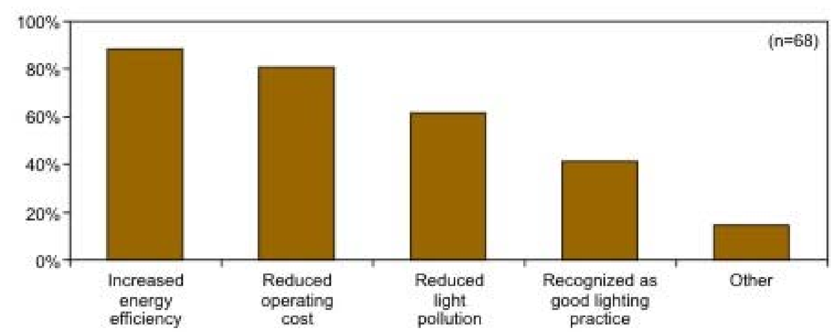
What do lighting specifiers believe about dynamic outdoor lighting?

In January and February 2010, NLPIP surveyed individuals who had previously downloaded NLPIP's *Specifier Reports: Parking Lot and Area Luminaires* and attendees of the Illuminating Engineering Society's 2009 Street and Area Lighting Conference. The survey consisted of several questions that had multiple-choice answers. NLPIP received 68 responses to the survey.

NLPIP asked the lighting professionals if they were familiar with the concept of dynamic outdoor lighting, described as outdoor lighting that automatically changes in light level or spectral distribution in response to certain conditions. Most respondents (87%) were familiar with this concept. When asked whether they believed that dynamic outdoor lighting is technologically feasible, 98% responded that it is.

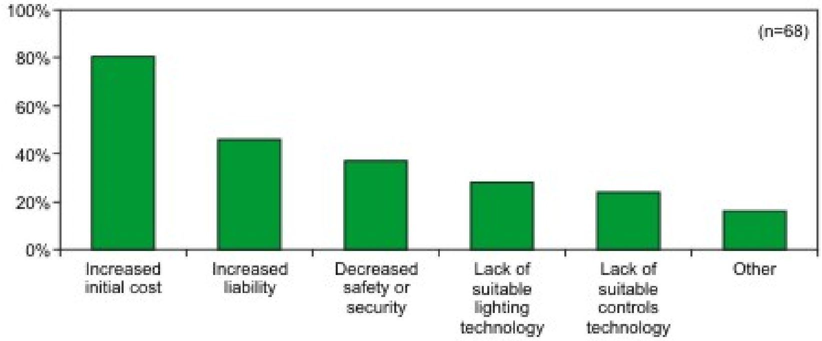
When asked what factors make dynamic outdoor lighting beneficial, the majority of respondents cited increased energy efficiency, reduced operating cost, and reduced light pollution, as shown in Figure 1. Some respondents indicated that dynamic outdoor lighting is recognized as good practice and some mentioned other factors, primarily citing the potential to improve visibility or safety and the ability to tailor lighting to customer and user preferences.

Figure 1. Survey response: Perceived benefits of dynamic outdoor lighting



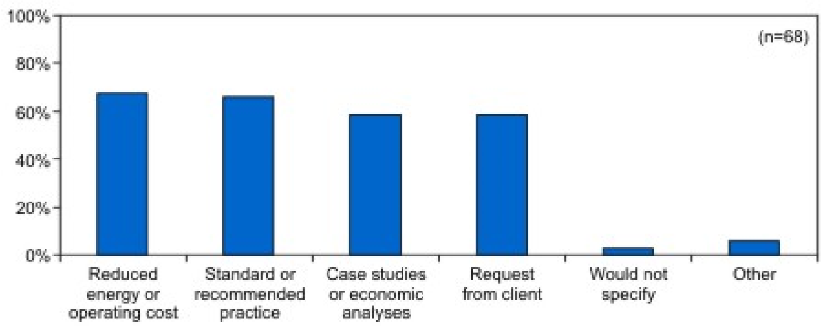
When asked which factors make dynamic outdoor lighting less beneficial (Figure 2), most respondents (81%) identified increased initial costs for a lighting system. Combined with the lack of suitable lighting and control technologies (28% and 24%, respectively), these answers are consistent with a more general concern about cost-effective technological solutions for implementing dynamic outdoor lighting. Many survey respondents also selected increased liability (46%) and decreased safety or security (37%). Sixteen percent of respondents identified other factors, including a lack of standards regarding visual requirements for dynamic outdoor lighting, increased maintenance requirements, lack of tariff structures, and the potential for increased complaints by occupants of the lighted area.

Figure 2. Survey response: Perceived barriers to implementing dynamic outdoor lighting



When asked what factors could reduce the barriers associated with dynamic outdoor lighting (Figure 3), the majority of respondents identified the potential for reducing operating and energy costs; a standard, code, or recommended practice; published case studies and benefit-cost analyses; and a specific request from a client. Other factors supplied by survey respondents included the potential to improve visibility or security and the ability to respond to environmental issues such as light pollution. Very few respondents (3%) stated that they would not specify dynamic outdoor lighting.

Figure 3. Survey response: Perceived solutions to overcoming the barriers associated with dynamic outdoor lighting



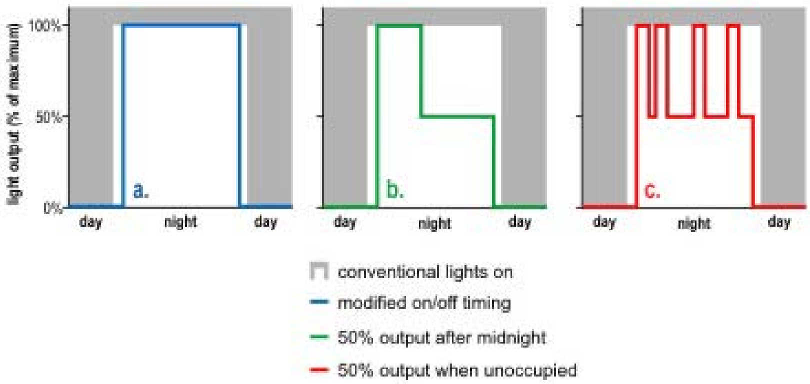
Approximately 37% of the survey respondents said they had participated in or were aware of a lighting project that utilized dynamic outdoor lighting.

The results of this short survey indicate that although there is a broad awareness of the concept of dynamic outdoor lighting, less than half the lighting professionals surveyed had direct experience with this concept. Most respondents agreed that dynamic outdoor lighting has a number of potential benefits including reduced energy use and reduced operating costs. The responses showed that the barriers to its use are related to concerns about initial costs, safety and liability, as well as perceived technological limitations.

What are some dynamic outdoor lighting strategies?

Figure 4 illustrates light output profiles as a function of time for three outdoor lighting strategies. The white box in each example represents conventional outdoor lighting control using a photosensor or time clock. Adjusting the timing of these simple controls to turn lighting on slightly later and switch it off slightly earlier when ambient light still exceeds levels from outdoor lighting could result in 5% less energy use (Institution of Lighting Engineers 2006), which is illustrated by the blue line in Figure 4a. Most outdoor lighting installations that use photosensors to detect ambient light levels orient the photosensors upward. This strategy does not always accurately estimate the amount of light in an area, especially when there is snow cover or high ground surface **reflectance** (Hawkins and Hallmark 2007; BSREC 2007). Orienting photosensors downward could therefore provide greater energy savings, thereby reducing the height of the blue line in Figure 4a.

Figure 4. Relative light output for three examples of outdoor lighting strategies: a) a conventional photosensor- or timer-based strategy with modified on/off timing, b) a dynamic strategy with reduced light output during periods of expected low use, and c) a dynamic strategy with reduced light output during periods of vacancy



Light levels can also be reduced based on actual usage patterns, based either on data collected over a period of time (Hawkins and Hallmark 2007) or through real-time systems such as traffic monitoring sensors embedded in the roadway (Wilken et al. 2001) or by motion sensors. Dynamic control of outdoor lighting through motion sensor technology appears to be one that is growing in use and acceptance in recent years, especially along pedestrian walkways and in parking facilities (PIER Program 2008; CLTC 2009; Edwards 2010; MJB Technologies 2010). NLPIP noted that with these systems, motion sensors are used to control output from each individual **luminaire**. The red line in Figure 4c represents a strategy whereby light is maintained at 50%, but when motion is detected, light levels are increased to 100% for a period of time (for example, 30 minutes). Although not identified in the literature on dynamic outdoor lighting, several of the respondents to NLPIP's survey of lighting professionals suggested that temporarily *increasing* light levels for special events, emergencies, or other circumstances could be useful. This strategy, which is similar to that illustrated in Figure 4c, could require designing the capability to produce higher light levels from a lighting system, such as additional lamps and luminaires, which in turn would result in increased equipment costs.

Most light sources gradually reduce light output over their operating life (Rea 2000). Dynamic outdoor lighting strategies can be used to maintain a constant luminous flux from a luminaire, with the potential for modest energy savings, perhaps about 10% over the life of the system (Guo 2008). Controls can counteract lumen depreciation by gradually increasing power to maintain the desired light level (Ji and Wolsey 1994; BSREC 2007; E-Street 2008).

How can specifiers select appropriate light levels for dynamic outdoor lighting?

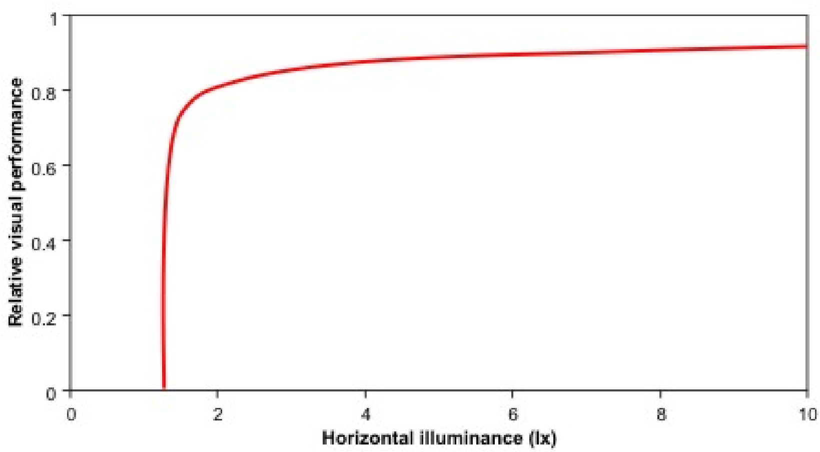
An important consideration for the implementation of dynamic outdoor lighting is the level of reduction relative to full light output. At present, there are few guidelines for identifying the appropriate light level when an area is usually unoccupied but may be occupied at any time. One approach is to rely on precedent. Some jurisdictions require that light levels be reduced by half during periods of less frequent use (for example, Fairfax County 2003). The basis for this level of reduction is not clear and may be related to the amount of dimming that is practical for HID light sources (see "*What light sources can be used with dynamic outdoor lighting?*").

A second approach to selecting the target light level is to base it on **visual performance**. For example, Rea and Ouellette (1991) developed the relative visual performance (RVP) method that estimates a person's ability to detect an object based upon its luminance, contrast, and size. Calculated levels of RVP are based on an arbitrary but high level of visual performance (reading black type on a white page under office lighting conditions). As an example, if there were a tripping hazard on a sidewalk or parking lot having the characteristics listed below, then a person’s expected RVP as a function of illuminance is shown in Figure 5.

- **shape:** cube, an arbitrary object shape
- **size:** 3 inches (in) (7.5 centimeters [cm]) along each side, defined as a critical tripping hazard size (Zeller et al. 2006)
- **viewing distance:** 10 feet (ft) (3 meters [m]), a typical distance ahead on the ground at which a pedestrian's attention might be focused while walking (Sammarco et al. 2010)
- **luminance contrast:** 0.7, typical of a shadowed portion of a three-dimensional object
- **ground reflectance:** 0.1, typical of asphalt (IES 1981)
- **age of observer:** 60 years, the upper age limit of the RVP model (Rea and Ouellette 1991)

As shown in Figure 5, the calculated RVP values exhibit a plateau characteristic: below 0.2 **footcandles (fc)** (2 **lux [lx]**), RVP values drop precipitously, but above 0.2 fc (2 lx), further increases would provide little improvement in visual performance. Estimates of visibility such as those in Figure 5 might be useful in establishing a minimum **illuminance** of 0.2 fc (2 lx) as adequate for providing visibility "coverage" (Rea et al. 2010) in a particular location.

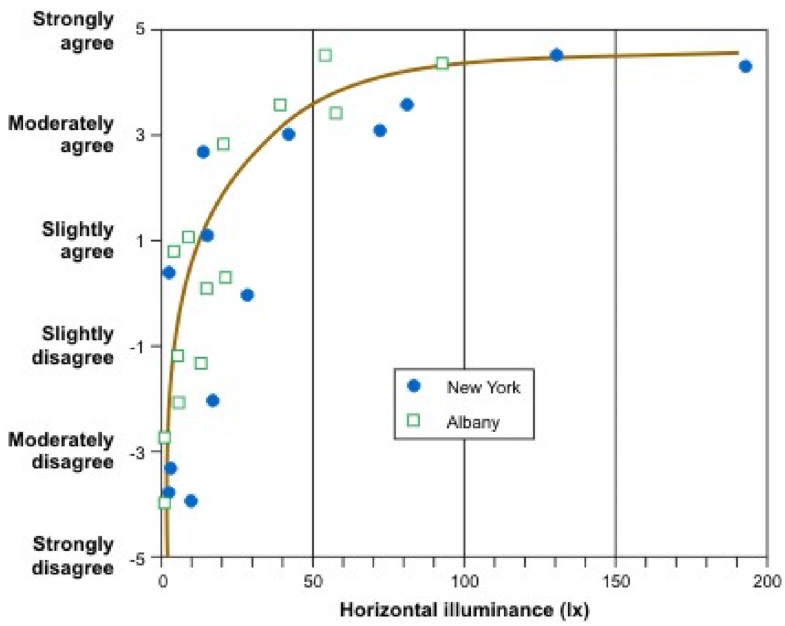
Figure 5. Relative visual performance for a tripping hazard as might be seen by a 60-year-old, as a function of horizontal illuminance (Rea and Ouellette 1991)



Another visual performance-based approach is to compare illuminances from electric lighting with those from moonlight. *Lighting Answers: Photovoltaic Lighting* (Zhou and Frering 2006) describes a unit of light called a "moonlight" that is equivalent to the typical illuminance produced by light from a full moon (0.01 fc [0.1 lx]). When electric street lighting systems were first developed and installed, for example, the lights might not have been switched on when a full moon was present (Hyde 1910) because electric light was thought to be redundant with the visibility benefits of full moonlight. Lighting of just a few moonlights (up to 0.05 fc [0.5 lx]) might be acceptable in applications where only basic visual orientation is required of occupants (Zhou and Frering 2006).

A third method of determining minimum illuminance levels is based on people's perceptions of safety and security from outdoor lighting, which can be quite different from an individual’s level of visual performance under the same lighting. Figure 6 illustrates the results of people’s perceptions of many different outdoor lighting installations in Albany, NY and New York City, NY (Leslie and Rodgers 1996; Boyce et al. 2000). Participants in those studies visited outdoor areas with various light levels and judged their agreement with the statement "This is an example of good security lighting." Although ratings of agreement tended to saturate for illuminances higher than 5 fc (50 lx), agreement was much lower at levels below 1 fc (10 lx). Lighting specifiers should be clear regarding their objectives in planning dynamic outdoor lighting; providing good visibility may result in different decisions about target light levels than providing *perceptions* of safety.

Figure 6. Average ratings of agreement with the statement "This is an example of good security lighting" by observers in Albany, NY and New York City, NY for outdoor areas illuminated to different light levels (Leslie and Rodgers 1996)



What light sources can be used with dynamic outdoor lighting?

Many respondents to NLPIP's survey about dynamic outdoor lighting noted that perceived technological barriers often prevent specifiers from considering dynamic outdoor lighting systems. A lack of awareness about technologies for dimming HID lighting systems contributes to these perceived barriers. Almost all outdoor lighting systems in the U.S. use HID lamps (Navigant Consulting 2002), and most of those HID lamps are **high pressure sodium (HPS)** like the ones shown in Figure 7. Although dynamic switching is rarely used with HID sources because of their long **restrike times** (up to five minutes [Rea 2000]), systems have been available for a number of years for dimming HID lamps down to about 50% of full power through **bi-level switching**, multi-step control, or **continuous dimming**. *Lighting Answers: Dimming Systems for High-Intensity Discharge Lamps* (Ji and Wolsey 1994) provides a description of the methods and technologies for dimming HID lamps. More recently, electronic **ballasts** for HID lamps have become available, and these appear to be useful for dimming (Echelon 2007; Hawkins and Hallmark 2007).

Figure 7. Most outdoor lighting systems use high pressure sodium lamps

However, dimming HID lamps, at least using non-electronic ballasts, can affect the spectral characteristics of the light emitted by the lamp. In 1994, NLPIP measured the **spectral power distribution (SPD)** from a **metal halide (MH)** lamp dimmed to 50% power and found that the **correlated color temperature (CCT)** shifted from 3850 kelvins (K) to 4310 K, with the SPD resembling that of a mercury vapor lamp, providing a lower **color rendering index**. An HPS lamp dimmed to 30% power shifted in CCT from 2070 K to 1990 K, and the SPD began to resemble that of a low pressure sodium lamp (Ji and Wolsey 1994), also providing a lower color rendering index.

HID lamp luminous **efficacy** is reduced when dimmed, and operating an HID lamp for extended periods of time while dimmed might reduce the **lamp life** (NEMA 2002). However, some studies of HID lamps in step-level dimming systems showed no reduction in lamp life (Smith and Zhu 1993; Gibson 1994). Dimming MH lamps may also accelerate lumen depreciation (Ji and Wolsey 1994), but dimming does not appear to affect lumen depreciation of HPS lamps.

Outdoor lighting can be provided by light sources other than HID lamps. For example, induction lamps have much faster restrike times than HID lamps (Rea 2000), and dimmable ballasts providing bi-level switching functionality for induction lamps have been used in some dynamic outdoor lighting applications (for example, Edwards 2010). Induction lamps typically contain mercury amalgams that reduce temperature variations in light output (Rea 2000). While linear **fluorescent lamps** have fast restrike times (Rea 2000), can be dimmed (O'Rourke 1999), and can be started and operated in very cold weather with appropriate selection of starting gear (Akashi et al. 2005), they are not commonly used in outdoor lighting installations (Navigant Consulting 2002). As described in *Lighting Answers: T5 Fluorescent Systems* (Akashi 2002), linear fluorescent lamps usually do not contain mercury amalgams and therefore are generally more sensitive to differences in **ambient temperature** than HID lamps. Akashi et al. (2005) reported that light output from linear fluorescent roadway luminaires was about one-third lower at 15ºF (-10º C) than at 32ºF (0ºC). Because induction and linear fluorescent lamps use phosphors to emit light, they have substantially larger optical source sizes than HID lamps, and require larger luminaire sizes to control the light distribution similarly to HID luminaires. Increased wind loads from larger luminaires could require stronger poles to ensure system durability.

Light-emitting diodes (LEDs) are being used in a growing number of outdoor lighting installations. LEDs have nearly instantaneous restrike times (Bullough 2003; Richman 2009), and dimming is relatively straightforward (Hawkins and Hallmark 2007; Richman 2009) using current control or, more commonly, pulse-width modulation (Bullough 2003). Even temporary *increases* in light output with LEDs are possible with appropriate control. A number of outdoor lighting installations using LEDs have incorporated dynamic lighting strategies using dimming technologies (PIER Program 2008; Brons 2009; CLTC 2009; Johnson et al. 2009). Dimming LEDs has no negative effects on life and may actually increase their life (Bullough 2003). Some methods of LED dimming result in spectral shifts; Dyble et al. (2005) reported that adjusting the current to dim **phosphor**-converted white LEDs resulted in small shifts toward a "greener" appearance (but within the allowable tolerance specified by the lighting industry for fluorescent lamp color [ANSI 2001; Narendran et al. 2004]) and that **pulse-width modulation** methods of dimming LEDs resulted in negligible spectral shifts.

What kinds of controls can be used with dynamic outdoor lighting?

In systems that reduce light levels after certain hours of operation (Ji and Wolsey 1994; BSREC 2007; Gray 2007; Echelon 2007; Hawkins and Hallmark 2007; Richman 2009; Brons 2009), timers are the most suitable and reliable control technology for turning off lights during periods of non-use (Institute of Lighting Engineers 2006). Photosensor controls can allow lighting systems to respond to ambient lighting conditions or changes in ground reflectivity due to snow cover (Watt Stopper 2006; BSREC 2007).

If the control system is to respond to real-time changes in traffic patterns, a control unit that can utilize input from in-pavement vehicle sensors or from other monitoring devices is needed (Wilken et al. 2001). These control units can also allow outdoor lighting systems to be operated remotely from a central location, for example, to turn low-level street lighting to full output temporarily following an accident. These controls can also communicate the status of the lighting system, such as lamp failures, to the central location (Echelon 2007; BSREC 2007). However, these systems can be expensive to monitor and difficult to operate and maintain compared to timers and other simple controls (Guo 2008).

Figure 8 illustrates wasted light and energy when a parking lot is lighted during hours when it is not being used, a problem that can be overcome with timers or motion sensors. A number of demonstrations of dynamic outdoor lighting have used motion sensors to adjust the light output from luminaires from dimmed to full output when the presence of a nearby pedestrian or vehicle is detected (PIER Program 2008; CLTC 2009; Johnson et al. 2009; Edwards 2010). Occupants of one such installation in the parking lot of a grocery store (Johnson et al., 2009) reported that they liked the dynamic system and felt that it could improve safety because the lighting alerted them to the presence of someone else in the parking lot. Published case studies did not describe how motion sensor-controlled outdoor lighting systems would perform if the motion sensor fails. Some recommendations state that full light output should be produced in case of sensor failure (BSREC 2007).

Figure 8. Motion sensor- or timer-based controls in parking lots are suitable for lots that are unused for periods of time during the night

Can dynamic outdoor lighting save money?

The Institution of Lighting Engineers (2006) estimates that the amount of money saved by dynamic outdoor lighting because of reduced energy use is significant enough to create a net savings, despite higher initial costs. This finding is supported by an economic analysis conducted by NLPIP (Table 1) of a hypothetical parking lot lighted by ten luminaires, each containing a 250 watt (W) lamp, or 300 W after accounting for the ballast. In one scenario, the parking lot lighting system would operate each night at full output, and in the other scenario, motion-sensor control is assumed to dim the luminaires to 50% output during unoccupied periods (as illustrated in Figure 4c) with a resulting energy reduction of 30% overall. Cost data are based on published estimates (Leslie and Rodgers 1996; Leslie 1998; Southern California Edison 2007). The control system in this example is a bi-level switching controller with an integrated infrared motion sensor that is installed on each luminaire. The estimated costs can be applied to installations with fewer or more luminaires by scaling all costs relative to the ten luminaires in the example.

The increased initial cost of the motion-based control system is offset by operating cost savings with a resulting simple payback of nearly 4.5 years. In principle, reducing the target light output below 50% would result in further economic savings. Although this is not practical with many HID dimming systems, this strategy could also be cost-effective for other sources, such as LEDs.

Table 1. Cost comparisons between a conventional parking lot system and one using motion sensor controls to reduce light output by 50% during unoccupied periods (as illustrated in Figure 4c), resulting in 30% less energy use overall

Initial Costs	Baseline*	Occupancy Control*
Number of luminaires	10	10
Cost per luminaire ($)	300	300
Total luminaire cost ($)	3000	3000
Lamps per luminaire	1	1
Total number of lamps	10	10
Lamp cost ($)	54	54
Total lamp cost ($)	540	540
Number of poles	10	10
Pole cost ($)	940	940
Total pole cost ($)	9400	9400
Control system cost ($)	200	1085
Total equipment cost ($)	13,140	14,025
Labor ($)	13,140	14,025
Total installation cost ($)	26,280	28,050
Annual Costs		
Average daily use (hours)	12	12
Annual operating time (hours)	4380	3066**
Rated lamp life (hours)	24,000	24,000
Annual lamps used	1.83	1.83
Relamping labor cost ($)	23	23
Lamp replacement cost ($)	77	77
Annual maintenance cost ($)	141	141
Input power (W)	300	300***
Annual energy use (kWh)	13,140	9198
Electricity cost ($/kWh)	0.10	0.10
Annual energy cost ($)	1314	920
Annual operating cost ($)	1455	1,060

** All monetary units are in U.S. dollars.*
*** Motion-control system assumed to be equivalent to 30% reduction in energy use, equivalent to a 30% reduction in operating time.*
**** Input power at full output.*

Dimming HID lamps such as HPS or MH can reduce luminous efficacy, whereby a reduction in light level is proportionally greater than the reduction in input power (Ji and Wolsey 1994; NEMA 2002; Guo 2008). However, this potential effect is not included in the above analysis because of differences among lamp types. There is conflicting evidence on whether or not dimming HID lamps reduces their lifetimes. To understand the potential economic impact of the reduced operating life, NLPIP calculated the simple payback period for the scenario in Table 1, but with a reduced lamp life in the occupancy-controlled system of 16,000 hours (an arbitrary, but substantial reduction in lamp life of 33%). This reduction in lamp life would increase the simple payback period from 4.5 years to 5.5 years.

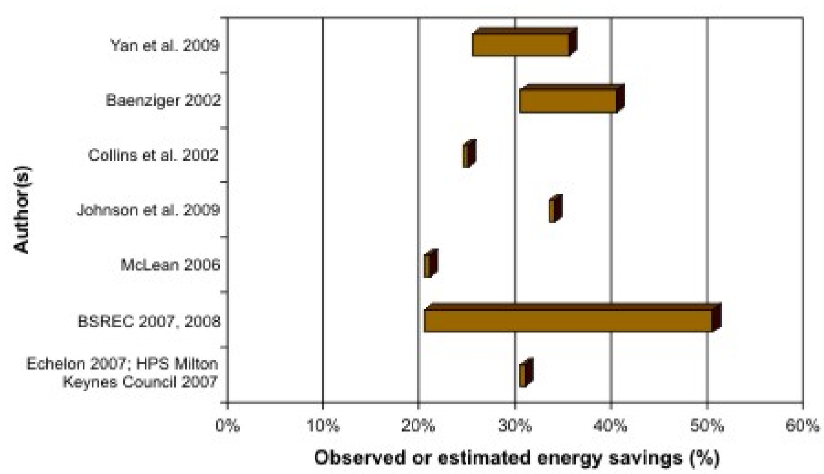
Can dynamic outdoor lighting save energy and benefit the environment?

Yes, but the amount of energy savings varies.

Many conventional outdoor lighting installations use simple timer- or photosensor-based control of lighting to reduce wasted energy during the day. If light levels are reduced for part of the nighttime period, there will be even greater energy savings.

A review of the literature on dynamic outdoor lighting found claims of energy savings between 20% and 50%, as summarized in Figure 9. For example, reducing street lighting levels from 0.5 fc (5 lx) to 0.2 fc (2 lx) between the hours of 10 p.m. and 5 a.m. was reported to result in a 30% average reduction in energy use from the lighting system (Echelon 2007; HBS Milton Keynes Council 2007).

Figure 9. Energy savings observed or estimated with different dynamic lighting scenarios



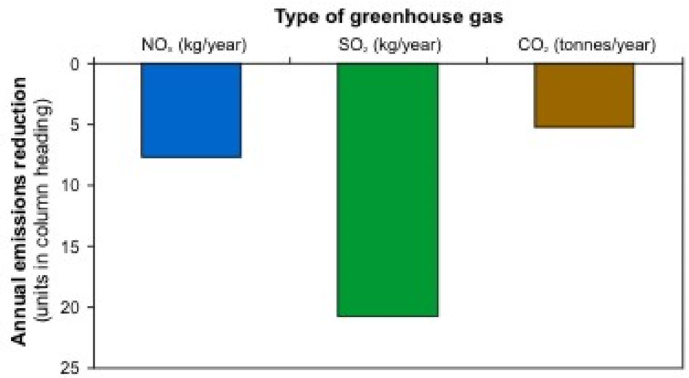
Other sources of information include substantially higher estimates of energy savings than those offered in the reports listed above. For example, replacing HPS lamps with:

- an LED system with bi-level switching capability had a savings of 66% (Johnson et al. 2009)
- LED luminaires controlled by motion sensors in a bi-level switching system in a parking structure had a savings of 80% (CLTC 2009)
- LED luminaires controlled by motion sensors in a bi-level switching system along a pedestrian walkway had a savings of 50-70% (PIER Program 2008)
- induction lamp systems with bi-level switching had a savings of 65% (Edwards 2010)

However, these larger energy savings estimates reflect combinations of improved lamp efficacy, luminaire efficiency, and *reduced light levels*, even at full output. NLPIP recommends that claims of energy savings through the use of dynamic outdoor lighting be evaluated carefully to assess the contribution of each of these factors.

Reduced energy use benefits the environment through reduced greenhouse gas emissions from fossil fuels. The U.S. Environmental Protection Agency (2009) estimated that on average nationwide, each kilowatt hour (kWh) of electricity saved corresponds to reductions of 0.9 grams (g) of nitrogen oxide (NOX), 2.4 g of sulfur dioxide (SO2) and 603 g of carbon dioxide (CO2). Using the example given in Table 1, for a parking lot with ten HPS luminaires (each using 300 W), the reduction in energy use of nearly 4000 kWh per year with dynamic outdoor lighting results in the emissions reductions illustrated in Figure 10.

Figure 10. Annual greenhouse gas emission reductions associated with reduced energy use for ten luminaires with the scenario described in Table 1



In addition to these environmental effects, step-level dimming of lighting in parking lots has been identified as a means of reducing **light trespass** (Ji and Wolsey 1994), **sky glow** and **glare**. These light pollution impacts can be assessed quantitatively using the outdoor site-lighting performance method of evaluating trespass, glow and glare (Brons et al. 2008).

Will reduced light levels through dynamic lighting reduce safety and security?

Lowering the light levels during part of the nighttime will reduce visibility during those periods. For example, light levels provided by street lighting do not always provide high levels of visual performance (see Figure 5), so reductions in illuminance can correspond to meaningful reductions in visibility. Perhaps for this reason, some guidelines for dynamic outdoor lighting recommend that outdoor lighting only be dimmed or only some of the luminaires be switched off (Echelon 2007; Richman 2009).

On the other hand, some locations, particularly urban areas, can have high ambient light levels for commercial enterprises that reduce the incremental benefit of outdoor lighting. Rea et al. (2010) evaluated the impact of different levels of street lighting on RVP in areas with varying ambient light conditions, including the effects of lighting from vehicle headlamps. The study determined that higher ambient light levels in urban areas resulted in improved visibility even without street lighting, whereas in rural areas with lower ambient light levels, visibility without street lighting was lower.

Despite the logical relationship between light levels and visibility, which would seem to have important implications for safety, there is no published evidence that reducing outdoor light levels during off-peak hours through dimming has reduced safety or security (Kevin Poulton and Associates et al., 2005). This is not unexpected because reductions in dynamic outdoor lighting would usually occur when usage or occupancy is infrequent and because very small samples are involved, limiting the validity of statistical conclusions.

Aside from any functional impacts of dynamic lighting on safety and security, outdoor lights can play an important role in an individual's *perceptions* of safety (Boyce et al. 2000). Outdoor locations that appear brighter tend to be perceived as safer (Rea et al. 2009). One way to make scenes appear brighter is through selection of the light source spectral power distribution. There is a growing body of field research that suggests that streets and parking areas illuminated by whiter light sources (for example, fluorescent, induction, MH or LED, having more short-wavelength content) appear to provide similar or better perceptions of safety and security than those lighted by yellowish HPS lamps, even if the light levels under the whiter source are 25% to 50% lower than under the yellowish source (Akashi et al. 2005; Morante et al. 2007; Morante 2008; Rea et al. 2009). Again, although safety perceptions are not the same as actual safety, improving perceptions of safety can be an appropriate outdoor lighting design objective in some applications.

Are there any maintenance related benefits of dynamic outdoor lighting?

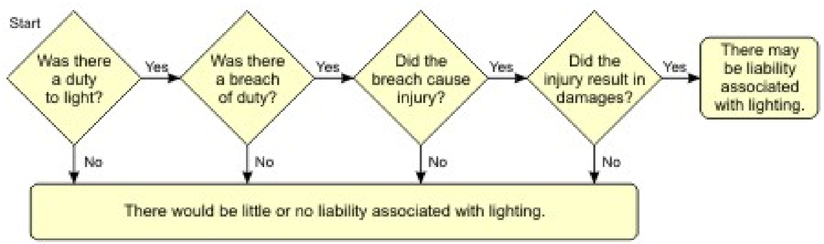
The potential maintenance benefits of dynamic lighting strategies are rarely discussed in related literature. Some commercially-available dynamic lighting and control system packages can notify a central location that a lamp failure has occurred (BSREC 2007; Echelon 2007); this type of notification would presumably improve the maintenance of an outdoor lighting system. **Lumen maintenance** strategies can also be used with outdoor lighting to account for reduced light output as a lighting system ages (BSREC 2007; MJB Technologies, 2007).

Are there any legal liabilities associated with dynamic outdoor lighting?

Put simply, the answer is yes, but the specific legal issues will vary among jurisdictions and will depend upon the specific circumstances. NLPIP conducted informal interviews with several trial attorneys in the U.S. and researched legal cases in U.S. federal and state courts that involved outdoor lighting as a possible factor relating to safety or security. NLPIP does not provide legal advice. Consulting an attorney familiar with the statutes and laws of the local, state/provincial, and federal jurisdictions is an important and useful course of action for a municipality or property owner considering use of a dynamic outdoor lighting strategy. The information in this section is provided to help facilitate, but not to replace, that consultation.

To demonstrate a legal liability related to dynamic outdoor lighting, several factors would need to be established such as whether the municipality or property owner had a duty to provide lighting for safety or security, whether there was a breach of this duty by the municipality or property owner, whether the breach of duty was in fact a cause of an injury, and whether the injury resulted in damages (*Pinsonneault et al. v. Merchants and Farmers Bank and Trust Company et al.* 2002). These factors are illustrated in Figure 11. The latter two factors are based on the circumstances surrounding a particular incident; therefore only the first two factors are discussed further.

Figure 11. Factors associated with the legal liability of outdoor lighting (based on *Pinsonneault et al. v. Merchants and Farmers Bank and Trust Company et al.* 2002)



Different jurisdictions impose different levels of duty. There may also be different levels of duty placed upon governmental agencies than on private property owners within the same jurisdiction. One court in California stated that unless there is a special circumstance that makes lighting absolutely necessary for safety, municipalities in that state have no duty to illuminate their streets (*Antenor v. City of Los Angeles* 1985). In Illinois, a court decision stated that municipalities have no duty to provide lighting for pedestrian safety except in crosswalks (*Hough v. Kalousek and Village of Oak Lawn* 1996), and another Illinois court stated that it is up to the municipality to decide if a street should be illuminated (*Baran v. City of Chicago Heights* 1968). Some local jurisdictions actually require reduced outdoor light levels after business hours (Fairfax County 2003). On the other hand, a court in Michigan ruled that illuminating a parking lot was part of a property owner's duty in order to maintain a safe place for employees (*Sleeman v. Chesapeake & Ohio Railroad Company v. Barnaby and Parker* 1968). There can be broadly varying interpretations in different jurisdictions about how the duty to provide nighttime **illumination**, if it is imposed, should be carried out. Standards and recommendations from organizations such as the Illuminating Engineering Society (IES) have been cited in Michigan cases as a basis for defining the appropriate level of duty (*Sleeman v. Chesapeake & Ohio Railroad Company v. Barnaby and Parker* 1968; *Lane and Lane v. Ekrem Bardah of Fenton, Inc. and McDonald's Restaurants of Michigan, Inc.,* 2003). In at least one case in Illinois, a jury was permitted to consider IES recommendations in its deliberations about whether the duty was properly met (*Baran v. City of Chicago Heights,* 1968). In one Michigan case where a question arose of whether the outdoor lighting at a restaurant was on during an accident, lighting measurements made by an expert revealed that the light levels still conformed to IES recommendations even when the lights were turned off, and the court subsequently stated that because of these sufficient ambient conditions, the property owner did not breach its duty to provide lighting for safety (*Lane and Lane v. Ekrem Bardah of Fenton,* *Inc. and McDonald's Restaurants of Michigan, Inc.,* 2003).

In a different case in California, a court determined that municipalities were not required to conform to IES standards in the provision of street lighting (*Stathoulis et al. v. City of Montebello* 2008). Furthermore, a court in Washington state ruled that darkness or low light levels alone did not excuse occupants from exercising ordinary care when walking or driving in an outdoor area (*Roppo v. Motor Cargo and Unterwegner* 1998).

Reliance on expert opinions regarding lighting and visual performance were also used in cases in order to help identify whether there was a breach of duty regarding lighting (*Roppo v. Motor Cargo and Unterwegner* 1998; *Lane and Lane v. Ekrem Bardah of Fenton, Inc. and McDonald's Restaurants of Michigan, Inc.* 2003). In at least one case, a court in Illinois stated that although there was not automatically a duty of municipalities to illuminate streets, once the duty was assumed by a municipality, the municipality was required to ensure that lighting was "reasonably safe and done skillfully" (*Baran v. City of Chicago Heights* 1968).

These issues suggest that a municipality or property owner should research whether there is a legal duty to provide lighting and if so, how to demonstrate that the duty is being properly carried out. Local ordinances requiring lighting may call for specific light levels or may be written in more general language. Local requirements generally supersede industry standards and recommendations, such as those published by the IES. The attorneys interviewed by NLPIP noted that having a written plan for lighting to provide safety, using assessments by experts in lighting and visibility during the design phase, and providing documentation explaining any deviations from standards or recommendations could reduce a property owner's legal liability.

Not all reasons for implementing dynamic outdoor lighting would be treated equally in a court case. The attorneys interviewed by NLPIP suggested that the desire to reduce operating costs and energy use would not necessarily excuse a property owner from a duty to provide lighting for safety. Environmental factors such as mitigation of light pollution (for example, light trespass onto a residential neighbor's property) could be perceived as a reasonable basis for reducing light levels through dynamic outdoor lighting, but it is unlikely that this factor would be considered as important as safety in a legal case.

Liability issues will continue to be a barrier to implementing dynamic outdoor lighting. Local ordinances that require light levels to be reduced after certain hours, such as those in Fairfax County (2003), Virginia, are not widespread, and depending upon the local jurisdiction, reduction of light levels could create exposure to legal liability. Municipalities and property owners can take specific actions to reduce exposure to liability, including the preparation of written plans for lighting and safety, visual assessments of reduced light levels (if used) and documentation of factors, such as reducing light trespass, that could justify lower light levels. Again, NLPIP recommends that municipalities and property owners who wish to consider dynamic outdoor lighting consult an attorney familiar with the local, state, and federal requirements for lighting during the lighting planning and design stages.

What are other barriers to dynamic outdoor lighting?

In addition to potential issues of reduced visibility and legal liabilities, several other potential barriers to more widespread use of dynamic outdoor lighting exist, including lack of technical information, higher initial costs, lack of financial structures to support dynamic lighting (for example, utility tariffs that recognize reduced energy use), and lack of standards (Walraven 2006). These are generally similar to the barriers identified by NLPIP's survey respondents, assuming the survey responses regarding a lack of suitable lighting and control technologies are based on insufficient technical information about dynamic outdoor lighting. Importantly, perceived technological barriers for dynamic outdoor lighting, including the availability of equipment suitable for dimming HID lamps, are not a significant concern because technical liabilities have been largely overcome.

Current standards and recommendations for outdoor lighting can also be barriers to dynamic lighting. Standards-making organizations are seeking to resolve these problems and reduce the barriers preventing technologies like dynamic outdoor lighting from gaining wider acceptance. Research on the visual impacts of reduced light levels (or of increased light levels for strategies involving temporary increases in light level) could be used by standards-making organizations to develop consensus-based recommendations for dynamic outdoor lighting. The simple visual performance calculation approach described elsewhere in this publication could be applied systematically to evaluate impacts of different light levels on visual performance in street and outdoor lighting (Rea et al. 2010). The Commission Internationale de l'Éclairage (CIE) has a technical committee (TC 4-44, *Management and Maintenance of Road Lighting*) that is investigating the inclusion of dynamic lighting guidance for streets and roadways into future roadway lighting recommendations (E-Street 2008). NLPIP expects that efforts such as these will lead to more widespread demand and justification for dynamic outdoor lighting.

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Credits

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Glossary

ambient temperature	The temperature of the surrounding air that comes into contact with the lamp and ballast. Ambient temperature affects the light output and active power of fluorescent lamp/ballast systems. Each fluorescent lamp-ballast system has an optimum ambient temperature at which it produces maximum light output. Higher or lower temperatures reduce light output. For purposes of lamp/ballast tests, ambient temperature is measured at a point no more than 1 meter (3.3 feet) from the lamp and at the same height as the lamp.
ballast	A device required by electric-discharge light sources such as fluorescent or HID lamps to regulate voltage and current supplied to the lamp during start and throughout operation.
bi-level switching	Control of light source intensity at two discrete levels in addition to off.
color rendering index (CRI)	A rating index commonly used to represent how well a light source renders the colors of objects that it illuminates. For a CRI value of 100, the maximum value, the colors of objects can be expected to be seen as they would appear under an incandescent or daylight spectrum of the same correlated color temperature (CCT). Sources with CRI values less than 50 are generally regarded as rendering colors poorly, that is, colors may appear unnatural.
continuous dimming	Control of a light source's intensity to practically any value within a given operating range.
correlated color temperature (CCT)	A specification for white light sources used to describe the dominant color tone along the dimension from warm (yellows and reds) to cool (blue). Lamps with a CCT rating below 3200 K are usually considered warm sources, whereas those with a CCT above 4000 K usually considered cool in appearance. Temperatures in between are considered neutral in appearance. Technically, CCT extends the practice of using temperature, in kelvins (K), for specifying the spectrum of light sources other than blackbody radiators. Incandescent lamps and daylight closely approximate the spectra of black body radiators at different temperatures and can be designated by the corresponding temperature of a blackbody radiator. The spectra of fluorescent and LED sources, however, differ substantially from black body radiators yet they can have a color appearance similar to a blackbody radiator of a particular temperature as given by CCT.
dynamic outdoor lighting	Outdoor lighting that varies light level or other characteristics automatically and precisely in response to factors such as vacancy or the type of use of an outdoor location.
fluorescent lamp	A low-pressure mercury electric-discharge lamp in which a phosphor coating on the inside of the glass tubing transforms most of the ultraviolet energy created inside the lamp into visible light.
footcandle (fc)	A measure of illuminance in lumens per square foot. One footcandle equals 10.76 lux, although for convenience 10 lux commonly is used as the equivalent.
glare	The sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility.

high-intensity discharge (HID)	An electric lamp that produces light directly from an arc discharge under high pressure. Metal halide, high-pressure sodium, and mercury vapor are types of HID lamps.
high-pressure sodium (HPS)	A high-intensity discharge lamp type that uses sodium under high pressure as the primary light-producing element. HPS lamps produce light with a correlated color temperature (CCT) of approximately 2000 kelvins, although CCTs for lamps having higher CRI values range from 2200 to 2700 kelvins. Standard lamps have a CRI value of 22; others have CRI values from 60 to 80. HPS lamps are among the most efficacious light sources, with efficacies as high as 150 lumens per watt, although those with higher CRI values have efficacies as low as 25 lumens per watt.
illuminance	The amount of light (luminous flux) incident on a surface area. Illuminance is measured in footcandles (lumens/square foot) or lux (lumens/square meter). One footcandle equals 10.76 lux, although for convenience 10 lux commonly is used as the equivalent.
illumination	The process of using light to see objects at a particular location.
lamp life	The median life span of a very large number of lamps (also known as the average rated life). Half of the lamps in a sample are likely to fail before the rated lamp life, and half are likely to survive beyond the rated lamp life. For discharge light sources, such as fluorescent and HID lamps, lamp life depends on the number of starts and the duration of the operating cycle each time the lamp is started.
light pollution	An unwanted consequence of outdoor lighting that includes such effects as sky glow, light trespass, and glare.
light trespass	A undesirable condition in which exterior light is cast where it is not wanted.
light-emitting diode (LED)	A solid-state electronic device formed by a junction of P- and N-type semiconductor material that emits light when electric current passes through it. LED commonly refers to either the semiconductor by itself, i.e. the chip, or the entire lamp package including the chip, electrical leads, optics and encasement.
lumen maintenance	The ability of a lamp to retain its light output over time. Greater lumen maintenance means a lamp will remain brighter longer. The opposite of lumen maintenance is lumen depreciation, which represents the reduction of lumen output over time. Lamp lumen depreciation factor (LLD) is commonly used as a multiplier to the initial lumen rating in illuminance calculations to compensate for the lumen depreciation. The LLD factor is a dimensionless value between 0 and 1.
luminaire	A complete lighting unit consisting of a lamp or lamps and the parts designed to distribute the light, to position and protect the lamp(s), and to connect the lamp(s) to the power supply. (Also referred to as fixture.)

lux (lx)	A measure of illuminance in lumens per square meter. One lux equals 0.093 footcandle.
metal halide (MH) lamp	A high-intensity discharge lamp type that uses mercury and several halide additives as light-producing elements. Metal halide lamps have better color properties than other HID lamp types because the different additives produce more visible wavelengths, resulting in a more complete spectrum. Metal halide lamps are available with CCTs from 2300 to 5400 K and with CRI values from 60 to 93. Efficacies of metal halide lamps typically range from 75 to 125 LPW.
phosphors	Materials used in a light source to produce or modify its spectral emission distribution. In fluorescent and high intensity discharge lamps, the phosphors fluoresce (emit visible light) when excited by ultraviolet radiation produced by mercury vapor inside the lamp when energized by an electric arc. In a light emitting diode, phosphors convert short-wavelength light or ultraviolet radiation produced by a semiconductor die into longer-wavelength light, usually with the goal of producing white illumination.
pulse-width modulation	Operating a light source by very rapidly (faster than can be detected visually) switching it on and off to achieve intermediate values of average light output; the frequency and the duty cycle (percentage of time the source is switched on) are important parameters in the modulation.
reflectance	A measure of the ability of an object to reflect or absorb light, expressed as a unitless value between 0 and 1. A perfectly dark object has a reflectance of 0, and a perfectly white object has a reflectance of 1.
restrike time	The time required for a lamp to restrike, or start, and to return to 90% of its initial light output after the lamp is extinguished. Normally, HID lamps need to cool before they can be restarted.
sky glow	Brightening of the sky caused by outdoor lighting and natural atmospheric and celestial factors.
spectral power distribution (SPD)	A representation of the radiant power emitted by a light source as a function of wavelength.
visual performance	The quantitative assessment of the performance of a visual task, taking into consideration speed and accuracy.

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