LED Application Series:

Outdoor Area Lighting

LED technology is rapidly becoming competitive with high-intensity discharge light sources for outdoor area lighting. This document reviews the major design and specification concerns for outdoor area lighting, and discusses the potential for LED luminaires to save energy while providing high quality lighting for outdoor areas.

Introduction

Lighting of outdoor areas including streets, roadways, parking lots, and pedestrian areas is currently dominated by metal halide (MH) and high-pressure sodium (HPS) sources. These relatively energy-efficient light sources have been in use for many years and have well-understood performance characteristics. Recent advances in LED technology have resulted in a new option for outdoor area lighting, with several potential advantages over MH and HPS sources. Well-designed LED outdoor luminaires can provide the required surface illuminance using less energy and with improved uniformity, compared to HID sources. LED luminaires may also have significantly longer life (50,000 hours or more, compared to 15,000 to 35,000 hours) with better lumen maintenance. Other LED advantages include: they contain no mercury, lead, or other known disposal hazards; and they come on instantly without run-up time or restrike delay. Further, while MH and HPS technologies continue to improve incrementally, LED technology is improving very rapidly in terms of luminous efficacy, color quality, optical design, thermal management, and cost.

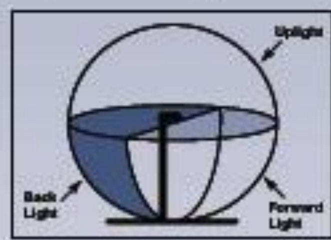
Current LED product quality can vary significantly among manufacturers, so due diligence is required in their proper selection and use. LED performance is highly sensitive to thermal and electrical design weaknesses that can lead to rapid lumen depreciation or premature failure. Further, long-term

Figure 1. Several HPS fixtures (left) were replaced with LED pole-top mounted luminaires (right) to illuminate a pedestrian area at a Federal Aviation Administration facility in Atlantic City, NJ. A full report on this installation is available at www.netl.doe.gov/ssl.

Photo Credit: GE Lighting Systems

Terms

LCS – luminaire classification system for outdoor luminaires, published as an IESNA technical memorandum, TM-15-07. Addresses three zones of light distribution from outdoor area luminaires: forward light (F), backlight (B), and uplight (U).



IESNA

Glare – sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted causing annoyance, discomfort, or loss in visual performance and visibility.

Light trespass – effect of light that strays from the intended purpose and becomes an annoyance, a nuisance, or a determent to visual performance.

Sky glow – the brightening of the night sky that results from the reflection of radiation (visible and non-visible), scattered from the constituents of the atmosphere (gaseous molecules, aerosols, and particulate matter), in the direction of the observer.

performance data do not exist given the early stage of the technology's development. Interested users should continue to monitor available information sources on product performance and lifetime, such as CALiPER test results and GATEWAY demonstration program reports, available on the DOE Solid State Lighting website (www.netl.doe.gov/ssl).

Design and Specification Considerations

Many issues enter into design and specification decisions for outdoor lighting. Energy efficiency is especially a priority in this application due to the long running hours and relatively high wattages typically involved. This section looks in detail at energy efficiency factors, as well as issues related to durability, color quality, life and lumen maintenance, light distribution, glare, and cost.

Energy efficiency

Energy effectiveness encompasses luminous efficacy of the light source and appropriate power supply in lumens per watt (lm/W), optical efficiency of the luminaire (light fixture), and how well the luminaire delivers light to the target area without casting light in unintended directions. The goal is to provide the necessary illuminance in the target area, with appropriate lighting quality, for the lowest power density. One step in comparing different light source and luminaire options is to examine luminaire photometric files. Look for photometry in standard IES file format from qualified independent or qualified manufacturer-based laboratories.[1] The photometry should be based on an actual working product, not a prototype or computer model.

Table 1 provides photometric data for several outdoor area luminaires, to illustrate basic comparisons. Lumen output and efficacy vary greatly across different outdoor area luminaires, so these data should not be used to generalize the performance of all luminaires using the listed lamp types.

Table 1. Examples of Outdoor Area Luminaire Photometric Values

	150W HPS	175W MH	LED
Luminaire (system) watts	183W	208W	153W
CCT	2000 K	4000 K	6000 K
CRI	22	65	75
Rated lamps lumens, initial	16000	11700	n/a
Downward luminaire efficiency	70%	81%	n/a
Downward luminaire lumens, initial	11200	9477	10200
Luminaire efficacy	61 lm/W	46 lm/W	67 lm/W

Sources. HPS and MH: published luminaire photometric (.ies) files. LED: manufacturer data.

Luminaires differ in their optical precision. Photometric reports for outdoor area luminaires typically state downward fixture efficiency, and further differentiate downward lumens as "streetside" and "houseside." These correspond to forward light (F) and backlight (B), respectively, referenced in the Luminaire Classification System (LCS). How does luminaire photometry translate to site performance? The next step is to analyze illuminance levels provided to the target areas, both horizontal and vertical. This is done through lighting design software and actual site measurements.

Table 2 compares measured illuminance data from the recent installation of LED outdoor luminaires referenced in Figure 1, in which existing 70W HPS luminaires were replaced with new LED luminaires.[2] The LED luminaires installed used three arrays containing 20 LEDs each. An option using two arrays was also modeled in lighting software

[1] National Voluntary Laboratory Accreditation Program (NVLAP) accreditation for LED luminaire testing is not yet available, but is in development. In the meantime, DOE has pre-qualified several independent testing laboratories for LM-79 testing.

[2] Kinzey, BR and MA Myer. Demonstration Assessment of Light Emitting Diode (LED) Walkway Lighting at the Federal Aviation Administration William J. Hughes Technical Center, in Atlantic City, New Jersey. March 2008. PNNL-17407. Available for download from http://www.netl.doe.gov/ssl/techdemos.htm.

(see Table 2, last column). Note that in this installation, the uniformity was improved by more than a factor of two with the LED luminaires. The maximum illuminance decreased and the minimum illuminance was the same or slightly higher than the HID, which led to a lower uniformity ratio. These results cannot be generalized for LEDs, but indicate a potential benefit possible with well-designed LED luminaires for outdoor area lighting.

Since HID lamps are high-intensity near-point sources, the optical design for these luminaires causes the area directly below the luminaire to have a much higher illuminance than areas farther away from the luminaire. In contrast, the smaller, multiple point-source and directional characteristics of LEDs can allow better control of the distribution, with a resulting visible improvement in uniformity. This difference is evident in Figure 2, where "hot spots" are visible under the HPS luminaires. This overlighting represents wasted energy, and may decrease visibility since it forces adaptation of the eye when looking from brighter to darker areas.

Table 2. Comparison of HPS and LED Outdoor Luminaires for Demonstration Site

	Existing 70W HPS	LED 3-array Luminaire	Optional LED 2-array Luminaire
Total power draw	97W	72W	48W
Average illuminance levels	3.54 fc	3.63 fc	2.42 fc
Maximum illuminance	7.55 fc	5.09 fc	3.40 fc
Minimum illuminance*	1.25 fc	1.90 fc	1.27 fc**
Max/Min Ratio (uniformity)	6.04:1	2.68:1	2.68:1
Energy consumption per luminaire***	425 kWh/yr	311 kWh/yr	210 kWh/yr
Energy savings per luminaire	--	114 kWh/yr (**26.8%**)	215 kWh/yr (**50.6%**)

* Lowest measured or modeled for each luminaire. IESNA guidelines call for at least 0.5 fc.

** Modeled results.

*** Energy consumption for the HPS system is based on manufacturer-rated power levels for lamps and ballasts, multiplied by 4380 hours per year. Energy consumption for the 3-bar LED unit is based on laboratory power measurements multiplied by 4380 hours per year. Energy consumption for the 2-bar unit is based on manufacturer-rated power levels multiplied by 4380 hours per year.

Durability

Outdoor lights often become perches for birds and the debris that comes with them. The luminaire should not collect and retain dirt or water on the top side, and the optical chamber should remain clean for the LED luminaire to truly reduce maintenance. Ingress Protection (IP) ratings describe the luminaire's resistance to dust and moisture penetration. Look for an IP rating appropriate to the conditions in which the luminaire will be used. For example, a rating of 65 indicates "dust tight, and protected from water jets from any direction." Ask the manufacturer about the long-term reliability of gaskets and seals relative to the expected useful life of the LEDs, and make sure the manufacturer will replace the product if it fails before 5 years, similar to the warranty for an HID luminaire. A quick disconnect point between the light engine and the drivers will allow for field maintenance on the power supply. Keeping the maintenance contact points to this level reduces the opportunity for installation mishaps that create reliability issues during normal use.

Figure 2. Installation of LED parking lot lights (left) compared to HPS lights (right) shows the difference in color appearance and distribution. Photo credit: Beta Lighting.

Color

The most efficient white LEDs at this time emit light of 4500K to 6500K correlated color temperature (CCT). This makes them white to bluish-white in appearance. Some LED luminaire manufacturers mix LEDs of various color temperatures to reach a target CCT for the array or luminaire, balancing the highest efficacy sources with warmer LEDs. Color rendering varies according to the make, model, and CCT of the LEDs, but generally is better than HPS (usually around 22 CRI) and standard MH (around 65 CRI), but somewhat lower than ceramic MH (80 to 90 CRI). The nominal CRI for neutral (4000K to 4500K) and cool white (5000K or higher) LEDs is typically 70 to 75. In most street and area lighting applications, CRIs of 50 or higher are adequate for gross identification of color.

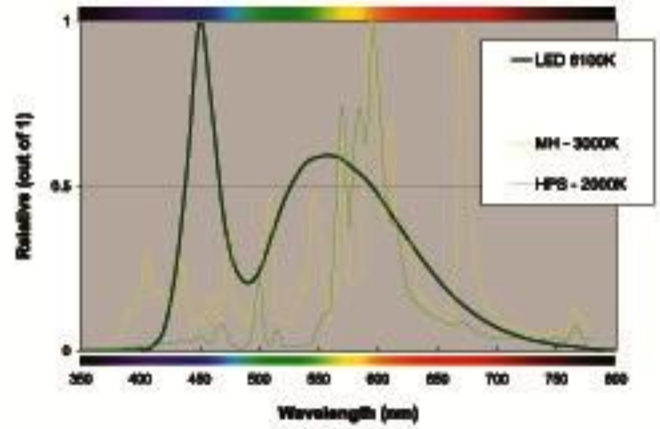


Figure 3. Comparative spectral power distributions for HPS, MH, and LED. Colors shown along top and bottom are approximations provided for reference.

In addition to CCT and CRI, it is useful to see the spectral power distribution (SPD) for the light source, to evaluate relative output in each area of the visual spectrum. See Figure 3 for a comparison of several sources, including the LED luminaire cited in Table 1.

Life and lumen maintenance

Estimating LED life is problematic because the long projected lifetimes make full life testing impractical, and because the technology continues to evolve quickly, superseding past test results. Most LED manufacturers define useful life based on the estimated time at which LED light output will depreciate to 70% of its initial rating; often the target is 50,000 hours for interior luminaires, but some outdoor luminaires are designed for much longer useful lives of 100,000 to 150,000 hours. Luminaire manufacturers typically determine the maximum drive current and LED junction temperature at which the LEDs will produce greater than 70% of initial lumens for at least the target useful life in hours. If the LEDs are driven at lower current and/or maintained at lower temperatures, useful life may be greatly increased. In general, LEDs in well-designed luminaires are less likely to fail catastrophically than to depreciate slowly over time, so it may be difficult for a utility or maintenance crew to identify when to replace the luminaire or LED arrays. In contrast, poorly-designed LED luminaires may experience rapid lumen depreciation or outright failure.

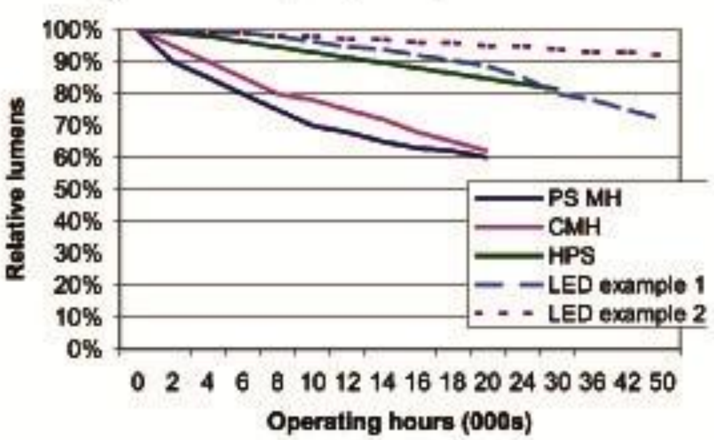


Figure 4. Typical lumen maintenance curves for HID sources, and estimated curves for LED.

Thermal management is critical to the long-term performance of the LED, since heat can degrade or destroy the longevity and light output of the LED. The temperature at the junction of the diode determines performance, so heat sinking and air flow must be designed to maintain an acceptable range of operating temperature for both the LEDs and the electronic power supply. Ask the luminaire manufacturer to provide operating temperature data at a verifiable temperature measurement point on the luminaire, and data explaining how that temperature relates to expected light output and lumen maintenance for the specific LEDs used.

All light sources experience a decrease in light output (lumen depreciation) over their operating life. To account for this, lighting designers use mean lumens, usually defined as luminous flux at 40% of rated life, instead of initial lumens. For HPS lamps, mean lumens are about 90% of initial lumens. Pulse-start MH mean lumens are about 75% of initial lumens, while ceramic MH lamps have slightly higher mean lumens, around 80% of initial lumens. See Figure 4 for typical lumen maintenance curves for these HID light sources and two example curves for LEDs: one designed for 50,000-hour useful life (LED example 1) and one designed for longer life (LED example 2).

Light distribution and glare

LED luminaires use different optics than MH or HPS lamps because each LED is, in effect, an individual point source. Effective luminaire design exploiting the directional nature of LED light emission can translate to lower optical losses, higher luminaire efficacy, more precise cutoff of backlight and uplight, and more uniform distribution of light across the target area. Better surface illuminance uniformity and higher levels of vertical illuminance are possible with LEDs and close-coupled optics, compared to HID luminaires.

Polar plots given in photometric reports depict the pattern of light emitted through the 90° (horizontal) plane and 0° (vertical) plane. In general, look for a reduction in luminous intensity in the 70° to 90° vertical angles to avoid glare and light trespass; zero to little intensity emitted between 90° and 100°, the angles which contribute most seriously to skyglow; and much reduced light between 100° and 180° (zenith) which also contribute to skyglow. Figures 5 and 6 illustrate the forward light and uplight angles referenced in the Luminaire Classification System (LCS). Luminaires for outdoor area lighting are classified in terms of the light patterns they provide on the ground plane. Figure 7 shows IESNA outdoor fixture types classifying the distributions for spacing luminaires.

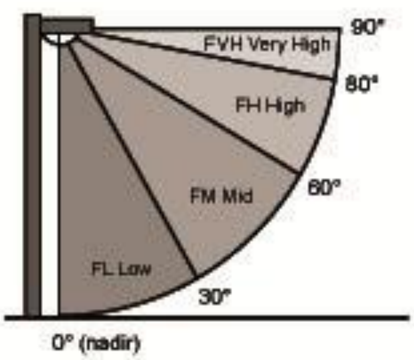


Figure 5. Section view for forward (F) solid angle. Light emmitted at high and very high angles can cause discomfort and disability glare for roadway users. Used with permission of IESNA.

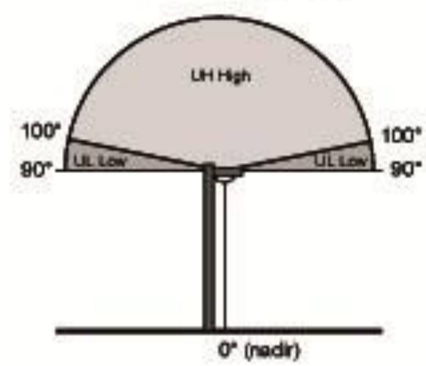


Figure 6. Section view for uplight (U) solid angle. Uplight contributes to light trespass and skyglow. Used with permission of IESNA.

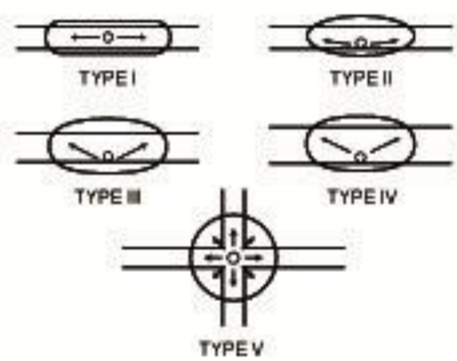


Figure 7. IESNA Outdoor lighting distribution types I - V. Used with permission of IESNA.

Follow IESNA recommendations for designing roadway and parking lot lighting rather than just designing for average illuminance on the paving surface. Illuminance alone does not consider the disabling glare that reduces visibility for the driver. For example, although an IES Type I or Type II distribution may provide the most uniform spread of illuminance with the widest pole spacing along a roadway, the angles of light that allow the very wide spacing are often the angles that subject the driver and pedestrian to disability and discomfort glare.

Cost

As a new technology, LED luminaires currently cost more to purchase than traditional fixtures lamped with commodity-grade HPS or MH light sources. The reduction in relamping cost and potential power savings with LEDs may reduce the overall lifecycle cost. Economic evaluation of LED outdoor luminaires is highly site-specific, depending on variables including electric demand (kW) and consumption (kWh) rates, labor costs, which may be bundled in a broader maintenance contract for the site; and other options available for the site. LED outdoor lighting demonstrations documented by DOE to date have shown estimated paybacks from three years to more than 20 years, depending on the assumptions and options assessed.

In some cases, LED technology may address new requirements that change the comparison to traditional sources. For example, some jurisdictions have implemented mandatory reductions in nighttime illumination. LED luminaires can be designed with control circuits that reduce the light output by half after curfew, without affecting the uniformity of light on the street or parking lot. Compare this to a design where a single, high-wattage HID luminaire is replaced with two lower-wattage luminaires on the same pole, so that half the fixtures can be extinguished at curfew without affecting the light distribution.

Summary

Outdoor area lighting appears to be a promising application for LED technology. New products are being introduced regularly. As with all LED products, careful information gathering and research is needed to assess quality, performance, and overall value. The checklist below is provided as a quick summary of issues addressed in this document:

- ❑ Ask for photometric test reports based on the IESNA LM-79-08 test procedure.
- ❑ Ask about warranty; 3 to 5 years is reasonable for outdoor luminaires.
- ❑ Check ingress protection (IP) ratings, and choose an appropriate rating for the intended application.
- ❑ Ask for operating temperature information and how this data relates to luminaire efficacy and lumen depreciation.
- ❑ Check color temperature for suitability in the intended application.
- ❑ Assess glare, preferably with the luminaire at intended mounting height and under typical nighttime viewing conditions, compared to incumbent technology.
- ❑ Evaluate economic payback, based on applicable energy, equipment, maintenance, and control costs for the site.

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Acknowledgement:
U.S. DOE acknowledges the major contribution of Naomi Miller in the writing of this document.

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PNNL-SA-60645
June 2008

Printed on 30% post-consumer recycled paper.

High Pressure Sodium CLight vs LED Street Light		
Items	**High Pressure Sodium Light - HPS**	**LED Street Light**
Photometric Performance	Bad	Excellent
Radiator Performance	Bad	Excellent
Electric Performance	Electric Shock Easy (High Voltage)	Safe (Low Voltage)
Working Life	Short (5,000 hours)	Quite Long (>50,000 hours)
Working Voltage Range	Narrow (±7%)	Wide (±20%)
Power Consumption	Quite High	Quite Low
Startup Speed	Quite Slow (Over 10 minutes)	Rapid (2 seconds)
Strobe	Yes (Alternating Current Drive)	No (Direct Current Drive)
Optical Efficiency	Low	High
Color Index / Distinguish Feature	Bad, Ra <50 (The Color Of Object Is Faith, Boring, Hypnosis)	Good, Ra >75 (The Color Of Object Is Fresh, Veritable And Comfortable)
Color Temperature	Quite Low (Yellow Or Amber , Uncomfortable)	Ideal Color Temperature (Comfortable)
Bad Glare	Strong Glare (Dazzle)	No Harmful Glare
Light Pollution	Strong	No
Heating	Serious (>300°C)	Cold Light (<60°C)
Lampshade Turn Dark	Easy (Absorb Dust)	No (Static Proof)
Lamp Aging Turn Yellow	In A Short Time	No
Shockproof Performance	Bad (Fragile)	Good (No Filament Nor Glass)
Environment Pollution	Contains Lead Element Etc.	No
Maintenance Cost	High	Quite Low
Product Cubage	Big	Small (Slim Appearance)
Product Weight	Heavy	Light
Cost-Effective	Low	High
Integrated Performance	**Bad**	**Excellent**