Promotion Facts Brochure

PFB 1 - Luminance, Illuminance and Concrete Pavement (1/12)

It is widely accepted within our industry that a concrete parking area can lower lighting costs due to its lighter color and higher surface reflectivity. However, it is not often that we see designers take advantage of this opportunity. While it is important that an interior lighting system provide enough light for the individuals who live or work within the space, it is just as important that exterior lighting be as effective to provide adequate visibility. Improper or poor exterior lighting can be a safety hazard. Perhaps a better understanding of the lighting industry and its needs can "shed some light" on the topic and allow the concrete promoter to better assist lighting engineers with their design process.

There are several terms that are essential in a discussion of lighting. ***Lumen*** is the unit used to indicate the total amount of light given off by a single light source. ***Candela*** is the basic unit for measuring luminous intensity from a light source in a particular direction. As a point of reference, a common candle emits light with a luminous intensity of roughly one candela. In the past, candela was also known as "candle" or "candlepower." Understanding the next two terms, ***illuminance*** and ***luminance***, is critical to interpreting lighting design. An untrained person may use these terms interchangeably but, in fact, they have distinctly different meanings.

In simplest terms, ***illuminance*** is the amount of actual light that strikes a surface. The density of the illuminance is measured in ***lux*** (lumens per square meter, abbreviated ***lx***) or ***foot-candles*** (lumens per square foot, abbreviated ***fc***), and is directly related to the proximity of the light source to the surface. The foot-candle is a non-SI* unit of measure and is mainly used only in the United States, particularly in construction-related engineering and in building codes. For purposes of conversion, one foot-candle equals 10.764 lux. Illuminance should not be confused with ***illumination***, which is defined as the deliberate application of light to achieve some aesthetic or practical effect.

Luminance is the light that is reflected by a surface, or transmitted through it, in the direction of the observer. Measured in candelas per square meter (cd/m^2) or candelas per square foot (cd/ft^2), luminance is directly related to illuminance, factoring in the reflectivity of the surface. For a lambertian (uniformly reflective) surface, luminance is calculated using the equation $\mathbf{L = (E / \pi) \times \rho}$ where **L** equals luminance, **E** equals illuminance and **ρ** equals reflectivity of the surface. Luminance should not be confused with brightness, which is strictly a subjective estimate.

Several aspects of the lighting fixture, or ***luminaire*** are taken into consideration when designing for exterior lighting. Type of lamp, reflector, height of pole and number of fixtures per pole all play a role in determining required luminaires for a given area. A single luminaire has one light fixture per pole, a dual luminaire, two fixtures, and a quad luminaire has four fixtures.

Most lamps used in exterior lighting can be grouped as ***High Intensity Discharge*** (HID) lamps. HID lamps produce light by means of an electric arc between tungsten electrodes that are housed in a gas and metal salt filled tube or globe. There are four distinct types of HID lamps: mercury vapor, metal halide, high-pressure sodium (HPS) and low-pressure sodium (LPS). Each of these lamp types has its preferred application, with HPS and metal halide being used most frequently for landscape, security, roadway and parking area lighting. Both HPS and metal halide lamps have good efficacy, with ratings of 80 to 130 lumens per watt, and average life expectancy for both is between 25,000 and 30,000 hours. HPS lamps were once the most widely used lamp for exterior lighting, but more recently

Concrete's high reflectivity allows owners to take advantage of greater luminance, with increased safety and reduced energy consumption.

SI** *refers to the International System of Units, commonly known as the modern metric system. The abbreviation SI comes from the French le* ***S*ystème* ***i****nternational d'unités.*

have been replaced by the metal halide type, due to its wide wattage range (20W - 2000W) , slightly better efficacy, and more natural color rendition.

The newest technology in solid-state lighting, the Light Emitting Diode (LED) is now making its mark in exterior lighting. LED's offer improved directionality, better color rendition, instant-on capability and potential energy savings. Estimates from the Department of Energy (DOE) claim that adoption of LED's for down-lighting, streetlights and other miscellaneous exterior lighting could remove twenty-two 1000MW coal burning power stations from the nation's power grid. LED life expectancy is greater than HID lights, with claims of 80,000 to 100,000 hour lamp life, based on the reliability of the diode. One downside to LED's is that, while they consume considerably less energy than HID lamps, their efficacy is much lower, as they produce as little as 25 to 45 lumens per watt. As a result, LED lighting may not appear as bright to the eye as traditional lighting. However, a recent DOE study at the Leavenworth, KS Wal-Mart demonstrated that when used in conjunction with concrete pavement, LED efficacy is improved. Initial response from customers and Wal-Mart personnel indicate that the luminance of the LED-lit concrete parking lot was acceptable, even though it has significantly lower illuminance than a similar asphalt lot with a traditional 1000W metal halide lighting design. The DOE reported, "Typical concrete has a higher reflectance value than asphalt, along with a smoother, more reflective texture. The higher reflectance values from concrete play as much of a role in the visibility and apparent brightness of the site as the lighting."
(www1.eere.energy.gov/femp/technologies/solid_state_lighting.html)

Light Emitting Diode (LED) lighting is now becoming more popular for exterior lighting due to the potential energy savings.

Induction lamps are another newcomer to the exterior lighting market. The principle of the induction lamp dates back to the late 1800's. Technological advancements created a new interest in the early 1990's. Induction lamps have seen wider acceptance over the past 15 years, and they are now getting a closer look because of their long lifespan and energy efficiency. Induction lamps are similar to fluorescent lights in that they are gas filled and produce light as the excited gas emits UV radiation which is converted to white light by the phosphor coating on the inside of the bulb. However, unlike the standard fluorescent lamp, induction lamps have no internal electrical connection and energy is transferred by electromagnetic induction. Also unlike conventional fluorescent lights, induction lamps are operable at temperatures as low as –40 degrees F.

One of the benefits of induction lights is their long life. In other conventional gas discharge lamps, the electrodes are the part with the shortest life, limiting the lamp lifespan severely. Since an induction lamp has no electrodes, it can have a very long service life. In fact, service life for an induction lamp can be as long as 100,000 hours. That is equal to 11.4 years of continuous (24/7) operation or 25 years if operated 10 hours per day. Induction lamps have been used since 1990 and their track record supports this claim.

Another popular feature of the induction lamp is its energy efficiency. Studies have shown that an induction lamp will use approximately 50% less wattage than either HPS or metal halide lights to produce the same lumens. Combining the lower wattage required for operation with the long lifespan, an induction lamp emits less than half of the CO2 of an HPS or metal halide light.

With sustainability as the driving force behind development, there have been several recent legislative actions that require reductions in energy consumption to be incorporated in new design and construction. For example, ***Executive Order #13423, Strengthening Federal Environmental, Energy, and Transportation Management*** (January 26, 2007) requires all federal agencies to reduce energy intensity by 30% by 2015. More recently, passage of the ***Energy Independence and Security Act of 2007*** **(EISA 2007)** mandates specific measures related to energy reduction that apply to all federal agencies. Among the new requirements for federal facilities are:

- 25% greater efficiency for light bulbs, to be phased in from 2012 to 2014.
- 200% greater efficiency for light bulbs, or similar energy savings, by 2020.
- All new and renovated federal buildings must implement 55% reduction in fossil fuel use by 2010 and 80% reduction by 2020.
- All new federal buildings must be carbon neutral by 2030.

Many of the energy efficient lamps available today can contribute to achieving these goals. When coupled with a concrete parking lot, the increased luminance can enhance their performance.

Exterior Lighting Design

International lighting engineers calculate their requirements based on both illuminance and luminance, taking the reflectivity of appropriate surfaces into consideration.

Type of Area	FC
Primary Walkways - Commercial	0.9 - 2.0
Secondary Walkways - Residential	0.2 - 0.5
Major Streets (Arterial)	
Commercial	1.2 - 1.7
Intermediate	0.9 - 1.3
Residential	0.6 - 0.9
Parking Lots	
High Traffic	3.6 avg. 0.9 min.
Medium Traffic	2.4 avg. 0.6 min.
Low Traffic	0.8 avg. 0.2 min.

Figure 1: Recommended Illuminance Levels for Exterior Areas, adapted from IES RP-33-99: Lighting for Exterior Environments, Illuminating Engineering Society of North America, 1999.

They look at the aesthetic, ergonomic and energy efficient utilities of a lighting system and utilize the ambient light provided by luminance to maximize those utilities. In the United States, however, recommendations for lighting are set by the **Illuminating Engineering Society of North America** (IESNA) and are based strictly on illuminance. Specific lighting levels are recommended for various applications. IESNA recommendations for street and parking area lighting can be found in their ***IES RP-33-99; Lighting for Exterior Environments*** (see Figure 1).

Lighting engineers have computer software programs to assist their design needs. Two very popular programs in the U.S. are **Visual** and **Lite Pro 2.0**. Based on IESNA recommendations, neither program considers surface type or color in the calculations. IESNA reluctance to design with regard to luminance *may* be based on the theory that luminance can be affected not only by the color of the surface, but also by its texture and contour. Additionally, a factor in the perception of luminance is brightness which, as previously stated, is very subjective and cannot be measured. Illuminance, on the other hand, is less variable and is affected by the type and position of the lighting fixture. Rules of thumb for general area lighting suggest that mounting height of the lamp should not exceed 1/2 of the distance to be lighted and poles should be spaced apart no more than four times the mounting height.

Considering that most parking lots are relatively flat, the issue of contour should play little role in calculating luminance. Due to its lighter color and uniform surface texture, the high reflectivity of a concrete pavement provides greater luminance than other typical pavements. A study by the Portland Cement Association supports this. Conducted in 2005, the PCA study compared the lighting performance of concrete and asphalt surfaces with regard to the reflective characteristics of each pavement. The results showed a concrete pavement's average luminance to be 1.77 times higher than asphalt.

Armed with this information, lighting installations for parking lots were evaluated, again comparing concrete and asphalt surfaces. Calculating a standard lighting design for a 5,000 m^2 parking lot with single and quad 400 watt luminaires and a mounted pole height of 10 m, a total of 22 luminaires were required. The illuminance for this lighting pattern calculated to be 29.025 lux (2.69 fc) for both the asphalt and concrete pavements. However, luminance calculations for the two pavements were significantly different. The asphalt pavement had an average luminance of 3.4 cd/m^2 while concrete's average luminance was 6.03 cd/m^2.

Further calculations showed that comparable luminance could be achieved on the concrete parking lot with a reduction in illuminance, thus providing a significant reduction in energy consumption. In fact, if the wattage in each of the 22 luminaires on the concrete lot was reduced from 400 W to 250 W, the average luminance of 3.62 cd/m^2 was still greater than the original design with asphalt pavement. The reduction in wattage equates to an average annual savings of 6,027 kilowatt hours. That is a 37.5% reduction in energy requirements per year! (See Figure 2).

Pavement	Power (Watts)	L_B = Pavement Background Luminance (cd/m^2)				E_V = Vertical Illuminance (lux)	L_T = Target Luminance (cd/m^2)
		Avg.	Min.	Max	Max: Min		
Asphalt	**400**	**3.40**	**1.06**	**11.14**	**10.40**	**29.025**	**4.619**
Concrete	**400**	**6.03**	**2.67**	**14.25**	**5.28**	**29.025**	**4.619**
Concrete	**250**	**3.62**	**1.60**	**8.55**	**5.27**	**17.415**	**2.772**
Concrete	**150**	**1.95**	**0.82**	**4.25**	**5.00**	**9.340**	**1.487**
Concrete	**100**	**1.16**	**0.49**	**2.43**	**4.60**	**5.545**	**0.833**

Figure 2: Results from Varying Lamp Power (Adapted from Adrian and Jobanputra, Influence of Pavement Reflectance on Lighting for Parking Lots, Portland Cement Association, Skokie, IL, 2005)

A similar savings could be received by maintaining the individual lamp wattage at 400 W but reducing the number of luminaires. A number of different pole configurations were considered, with the requirement that each provide geometric symmetry for the lighting while targeting the benchmark of 3.4 cd/m^2 average luminance. Several of the proposed lighting patterns showed excellent performance in reducing luminaires on the highly reflective concrete pavement. In particular, four different configurations provided average luminance of 3.45 cd/m^2 to 3.51 cd/m^2 with as few as 14 luminaires. The reduction in luminaires would not only result in a lower construction cost, but also an average savings of 5,844 kW-hr annually, a 36.4% reduction in energy requirements. (See Figure 3). The study's conclusive report can be found in PCA's publication SN2458, *Influence of Pavement Reflectance on Lighting for Parking Lots* (Portland Cement Association, Skokie, IL, 2005).

Pavement	Number of Luminaires	L_B = Pavement Background Luminance (cd/m^2)				E_V = Vertical Illuminance (lux)	L_T = Target Luminance (cd/m^2)
		Avg.	Min.	Max	Max: Min		
Asphalt	22	3.40	1.06	11.14	10.40	29.025	4.619
Concrete	22	6.03	2.67	14.25	5.28	29.025	4.619
Concrete	20	5.02	2.61	11.03	4.25	24.828	3.951
Concrete	18	4.35	2.54	7.69	2.96	20.985	3.340
Concrete	18	4.78	2.31	10.80	4.76	22.815	3.631
Concrete	16	3.52	2.18	5.70	2.65	16.993	2.704
Concrete	16	3.94	2.25	7.47	3.29	18.973	3.020
Concrete	14	3.49	2.03	7.32	3.58	16.850	2.682
Concrete	14	3.50	2.04	7.32	3.58	16.893	2.689
Concrete	14	3.51	1.54	13.63	9.07	16.993	2.704
Concrete	14	3.45	2.34	5.86	2.45	16.593	2.641

Figure 3: Luminance Calculations for Alternate Luminaire Configurations (Adapted from Adrian and Jobanputra, Influence of Pavement Reflectance on Lighting for Parking Lots, Portland Cement Association, Skokie, IL, 2005)

Additional Benefits of Concrete

There are other benefits that owners can realize due to concrete's greater luminance. One is increased safety. IESNA's recommendations for security lighting suggest that effective security lighting should:

- Provide a clear view of an area from a distance
- Deny potential hiding places
- Permit facial identification at 30 feet
- Provide the minimum required illuminance (both horizontal and vertical)
- Afford uniform illumination
- Enhance public perceptions of safety

The enhanced visibility that is provided by concrete would address each of these points. Concrete's high reflectivity contributes to uniform illumination with fewer shadows and reduced glare. The negative contrast of target objects (traffic signs, vehicles, pedestrians, etc.) against the light background of concrete makes for a greater visibility level at night. In fact, while visiting a recently constructed concrete parking lot, one illuminating engineer commented that the enhanced visibility might actually augment the performance of the security cameras.

Effective parking lot illumination can also attract customers to a retail establishment. When it comes to building business traffic, exterior lighting plays three roles. Lighting first captures the attention, then holds it, and, lastly, sets expectations. Enhanced visibility gives the potential customer a feeling of welcome as well as one of safety. US Energy Capital is a Greensboro, GA-based consultant that specializes in providing financing to the Petroleum and Convenience Store Industry as well as working with the energy saving and lighting retrofit industries. According to USEC President Jim Borland, some of USEC's customer's have reported sales increases of 3% to 5% after interior and exterior lighting improvements.

The Other Side of the Story

The cover story of the November, 2008 National Geographic was titled, *"The End of Night"* and dealt with the increasing problem of light pollution. Light pollution is any adverse effect of artificial light, including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste. Light pollution wastes energy, affects astronomers and scientists, disrupts global wildlife and ecological balance, and has been linked to negative consequences in human health.

The International Dark-Sky Association (IDA) is a non-profit organization whose mission is to preserve and protect the nighttime environment through environmentally responsible outdoor lighting. With members from 70 countries, and all 50 states in the USA, IDA is active on local, national, and international stages, working to reduce total nighttime light (total lumens in use) through densities (lumens/ft^2 or /m^2), controls (time-of-night sensors), energy codes, and shielded/directional fixtures.

Some might argue that concrete's high reflectivity would add to the sky glow and glare. However, with proper design and landscaping, that down-side can be controlled and concrete can enhance the energy-saving technology that is being promoted by IDA.