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LED STREETLIGHTS – GENERAL SPECIFICATION

INTRODUCTION

Streetlights predominately uses high intensity discharge – HID bulbs, including LPS, HPS, Metal Halide, Mercury Vapor, etc. These are very inefficient light sources. The lumen-per-watt efficiency rating includes both bulb and ballast losses. Most part of the energy is not converted to light but dissipated heat. Moreover, most part of the energy converted in visible light is wasted for it does not go to the intended point of illumination but spread around in all directions. This is called “light pollution” term covered ahead in this paper, and has a number of implications on the environment. In addition, HID light sources are expensive to maintain due to the bulbs short life and ballast failures.

LED is a newer source light for commercial purposes, including streetlights. It has been said that LED does not put enough lumen to replace HID light sources. This is not totally correct. LED technology is evolving every day. LED is a directional source of light. It directs the light to where it is intended to be. By combining multiple LED arrays and light guides into one fixture, LED can achieve light distributions such as cosine or batwing, upward or downward as desirable. LED is much more efficient than HID as light source. In this regard, the lighting fixture design plays a big role. A main requirement for a fixture is to maximize the amount of light coming out of the fixture. Most existent fixtures are designed for HID lights. Therefore, we are herein introducing guidelines for identification and selection of LED fixture for streetlights.

This specification does not constitute innovation or modification of any existent ordinances or study. It also has no pretense to be complete or conclusive. The subject is vast and complex. There are a number of rules, regulation and ordinances on streetlights, made by institutions, government agencies, and utility companies, mostly addressing part of the requirements but not all, like light pollution and energy conservation. This specification aims to synthesize most requirements for streetlights including their impact on the environment.

The ideal light source and lighting fixtures for streetlights must meet at least 90% of this specification to be considered acceptable. Some of the requirements are interdependent of the lighting fixture manufacturing and it should be considered in this regard.

Light Pollution

Light pollution is a generic term that encompasses many different aspects of improper lighting. The effect of light pollution on the environment has been largely ignored. It is estimated that at least 50% of the light pollution is caused by roadway lighting. Lighting fixtures poor design contributes a lot to the side effect. Streetlights, besides illumination, are subject to broad term association with three major areas of potential concern:

1. Light trespass
2. Glare
3. Urban sky glow

A few others of minor problems consist of confusion caused by light sources, adverse aesthetic effects caused by clutter, energy waste, and general annoyance. All of these problems have adverse effects not only on the general public but also affect the safety of the motorists. Each one of these major areas is addressed ahead in this specification.

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LIGHT TRESPASS

Light trespass is described as the effects of light or illuminance that strays from its intended purpose. The light should be directed onto the roadway avoiding light falling on adjacent area. Light trespass can be quantifiable as a measure of illuminance and measured in the field by a light meter. Many cities and counties placed the limit of stray light at 0.21 lux on the horizontal and vertical planes at a point 1.5 meter inside a property line. Other cities and counties classify light falling on residences from a roadway lighting system in excess of 3 lux as a public nuisance.

GLARE

Glare, is defined by as the sensation produced by luminance in the visual field that is sufficiently greater than the luminance to which the eye has adapted to cause annoyance, discomfort, or loss of visual performance and visibility. Glare is described as unwanted source luminance, and it can be categorized into three areas:

Blinding Glare: It is a glare that so intense such way that, after the stimulus has been removed, no object can be seen or easily distinguished.

Disability Glare: Glare that causes reduced visual performance, also known as "veiling luminance". Disability glare can have serious repercussions on a roadway system as it reduces the driver's ability to distinguish objects clearly.

Discomfort Glare: Glare that produces discomfort or annoyance without necessarily interfering with visual performance. Discomfort glare may cause fatigue which may result in driver error. This effect is very subjective and not easily quantifiable although several jurisdictions have applied some limits to the amount of discomfort glare permissible from a lighting system.

URBAN SKY GLOW

Urban sky glow is the result of stray light being scattered in the atmosphere brightening the natural sky background level. Use full-cutoff luminaries that emit no light above 90 degrees. Refer to Figure 1 above.

DEFINITIONS AND TERMS

USUAL TERMS

Candela: The luminous intensity of a lighting source is measured in candelas. This is the basic unit of photometric quantity. Candela is "the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 X 10 12 Hz and that has a radiant intensity in that direction of 1/683 watts per steradian".

Foot-candle (fc): is a unit of measure of illuminance. A unit of illuminance on a surface that is one foot from a uniform point source of light of one candle and equal to one lumen per square foot. Foot-candle values can be measured directly with handheld incident light meters. One foot-candle is equal to 1 lumen cast per sq. ft. of surface. One foot-candle equals 1.76 lux.

Lumen (lu): The lumen is the unit of luminous flux produced by the source and is directly related to the candela. A point source of one candela intensity will produce a luminous flux of one lumen through a solid angle of one steradian. (A sphere has a total area of 4 steradians. Therefore a point source of one candela has a total luminous flux of 4 or 12.57 lumens). The lumen can be loosely interpreted as the amount of light emitted from a source with certain intensity.

Lux (lx): It is defined as the amount of light on a surface of one square meter all points of which are one meter from a uniform source of one candela. One lux equals .0929 foot-candle.

Illuminance: Illuminance (or illumination level) is defined as the amount of light being transmitted upon a certain area. Illuminance is the lux, which is equal to one lumen per square meter. The Imperial unit for illuminance is the foot-candle, which is equal to one lumen per square foot. Illuminance is governed by the inverse square law. The illuminance of an area or object diminishes as the square of the distance.

Horizontal illuminance: The measure of brightness from a light source, usually measured in foot-candles or lumens, which is taken through a light meter's sensor at a horizontal position on a horizontal surface.

Vertical illuminance: The measure of brightness from a light source, usually measured in foot-candles or lumens, which is taken through a light meter's sensor at a vertical position on a vertical surface.

Average Maintained Illuminance: The average level of horizontal illuminance on the roadway pavement when the output of the lamp and luminaire is diminished by the maintenance factors; expressed in average foot-candles (lux) for the pavement area.

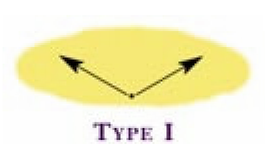
Uniformity ration: describes the uniformity of light levels across an area. This may be expressed as a ratio of average to minimum or it may be expressed as a ratio of maximum to minimum level of illumination for a given area.
Example: U. ratio maximum to minimum = 4:1 for the given area, the lowest level of illumination (1) should be no less than 1/4 or "4 times less" than the maximum (4) level of illumination.

Luminance: Luminance is the brightness of an object that has been illuminated by a source. The luminance of an object depends on its material characteristics and reflectance. For example, under the same illuminance conditions a dark object will look less bright that a light object. Since luminance refers to the amount of light reflected back by an object, this object in effect acts as a new source. There is a direct relationship between the luminance of a viewed object and the resulting illuminance of the image on the retina of the eye. The unit of luminance is the candela per square meter.

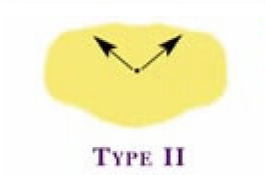
Foot-Lambert (fl): is a unit of photometric brightness (luminance). It is equal to 1/pi candela per square foot. One foot-lambert equals 3.426 candelas per square meter.

Ingress protection (IP): The degree of protection assigned to a lighting fixture, is given by the IP code, and defined by two digits such as: IP 65 - Describes a particular dust and water protection level**.** IP 6X - The '6' stands for a particular level of protection dust tight. IP X5 - The '5' stands for a particular level of protection against liquid intrusion meaning jet-water proof in all directions. IP X6 means powerful jet-water proof in all directions. Acceptable IP level for streetlights is IP 65.

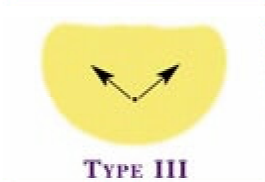
Light distribution:



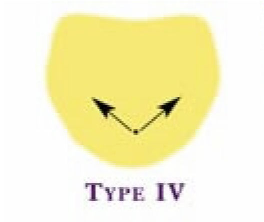
The type I distribution is ideal for narrow walkways or bike paths. It's intended to be located at or near the center of the pathway, approximately two mounting heights in width.



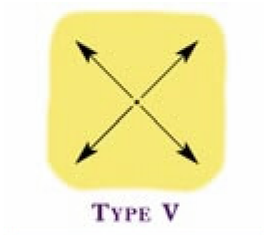
The type II distribution is ideal for wider walkways, entrance roadways, bike paths and other long and narrow roads. It is intended to be located near the side of a roadway, approximately 1.75 mounting heights in width.



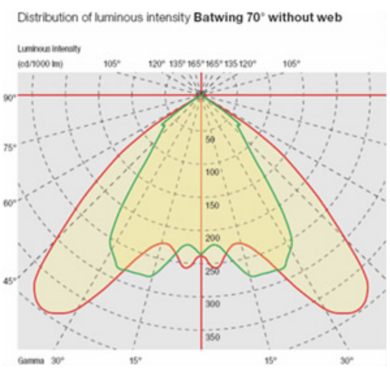
The type III distribution is ideal for wider roadway, general parking, and other area lighting applications. It is intended to be located near the side of the area, approximately 2.75 mounting heights in width.



The type IV distribution is especially suited for wall mounting applications and for illuminating the perimeter of parking areas. It is intended to be located near the side of the area, which are over 2.75 mounting heights in width. It produces a semicircular distribution with essentially the same candlepower at lateral angles from 270 to 0 to 90 degrees.



The type V distribution is ideal for general parking and area lighting applications. It is intended to be located at or near the center of an intersection or in a large area, since it has no beams but produces a circular distribution with essentially the same candlepower at all lateral angles.



Batwing distribution: This is usually defined as a distribution that produces the highest intensity around 45 degree angle. The following diagram illustrates. This distribution seems to be the most appropriate for streetlights for it puts the hot spot or the spot of highest intensity away from the light source.

Efficacy, Luminous Efficacy: The quotient of the total luminous flux delivered from a light source divided by the total power input to the light source. It is expressed in lumens per watt.

Ballast: A device used with an electric-discharge lamp to obtain the necessary circuit conditions (voltage, current and wave form) for starting and operating.

Luminaire: A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.

Bracket or Mast-arm: An attachment to a lighting standard or other structure used for the support of a luminaire.

Mounting Height (MH): is the vertical distance between the roadway surface and the center of the apparent light source.

Spacing: The distance between successive lighting units measured along the centerline of the roadway.

Luminaire and Light Distribution Terms - Terms relating to data on luminaires and on light distributions include the following:

ISO foot-candle diagram: This diagram is available from the manufacturer of the light source
Coefficient of Utilization Curve (CU): This curve shows that percentage of the total light output which will fall on the roadway. Mounting height (fixture position relative to the edge of roadway) and width of roadway must be known to apply the curve.

Lump Lumen Depreciation Curve (LLD): This curve gives information on the relationship between length of service and light output. All lamps deteriorate with time, and total light output becomes less.

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Luminaire Dirt Depreciation (LDD): These curves assist in planning maintenance so that depreciation due to accumulated dirt does not become excessive.

Equipment Factor (EF): Relates the actual field performance of a new luminaire to laboratory performance data. Generally, an EF of 0.90 to 0.95 is used for roadway lighting computations.

Maintenance Factor: A depreciation factor which is the product of the **Lamp Lumen Depreciation Factor (LLD)** and the **Luminaire Dirt Depreciation Factor (LDD)**. This factor is applied to the initial average foot-candles to account for dirt accumulation and lamp depreciation at some predetermined point after installation.

Transverse Roadway Lines (TRL): One set of lines which establish a coordinate system for roadway lighting analysis. This set runs perpendicular to the curb line or edge of pavement.

Longitudinal Roadway Lines (LRL): Another set of lines used in the coordinate system. This set runs parallel to the curb line of the roadway.

ISO candela Diagram: A series of lines plotted in Cartesian coordinates showing directions in space at which the candlepower is the same.

Glare Control Mark (G): The Glare Control Mark scale the discomfort from glare:

G=1 unbearable glare
G=2 disturbing glare
G=5 admissible glare
G=7 satisfactory glare
G=9 unnoticeable glare

For streetlights G7 is the minimum acceptable.

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ROADWAY LUMINAIRES

Roadway luminaries are classified by the way the light is transmitted and distributed. Luminaries' classifications are defined in terms of light distribution, horizontal and vertical and the control of distribution above maximum candlepower, known as cutoff. Vertical and lateral light distributions apply primarily to the shape of the roadway area. Light distribution is important to determining the amount of light trespass from the source.

A good lighting fixture is to get the maximum light output at an angle of say 65° to 70°, thus getting a good light throw out away from under the light fixture (avoiding a "hot spot" under the fixture), while at the same time getting a sharp cutoff at an angle of 75° to 80. In his regard, a batwing shape light distribution seems to be the most appropriated to meet this criterion.

CUTOFF

The control of the distribution above the maximum candlepower, known as the cutoff, is important for determining the amount of glare emitted by a fixture. A non-cutoff roadway fixture typically has a dropped lens (a refractor). This allows the light to be more easily distributed from the fixture and permits the illumination design to be less precise, however it produces more undesirable glare. A full cut-off fixture typically has the dropped refractor replaced with a flat glass, while the reflecting elements inside the fixture are designed to provide control of the light output. Figure 2 illustrates the effect of non-cutoff and full cut-off luminaries.

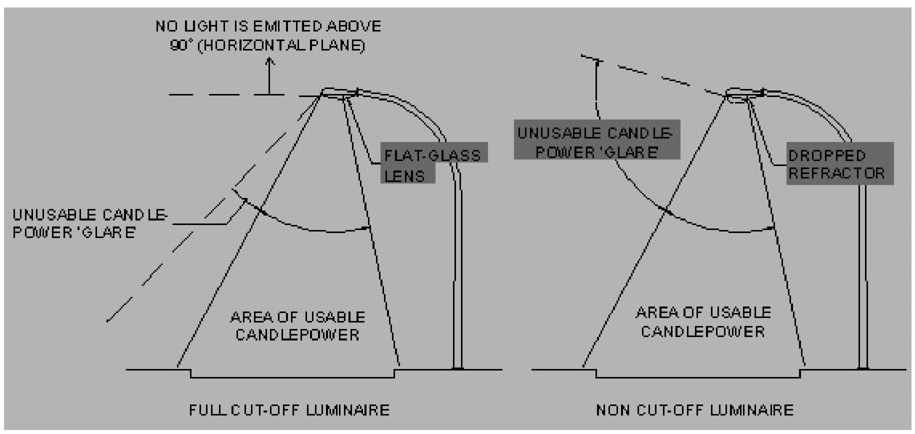

Figure 2 - Effects of Full Cut-off and Non Cut-off Luminaries

LIGHT SOURCES

Mercury vapor (MV) produce a bluish white light. The problem with mercury vapor luminaries is that they are very energy inefficient compared to some of other sources.

Metal halide luminaries are more energy efficient white light.

High pressure sodium (HPS) luminaries produce amber or pinkish light used by most roadway lighting installations today. This light is more monochromatic than mercury vapor and has poor color rendition. The HPS luminaries are about twice as energy efficient for the same lumen output as mercury vapor.

Low pressure sodium (LPS) lamps have no coloring rendering at all.

Metal halide (MH) luminaries produce a full spectrum light similar to mercury vapor and give good color rendition. Their energy consumption per lumen is about half way between that of HPS and MV. The lamp life for metal halide is shorter than the other lamps and they fall out of favor with maintenance personnel.

Mercury vapor or metal halide is suitable for downtown and people oriented areas and high pressure sodium for arterial routes and highways.

VISUAL INTRUSION AND ROADSIDE HAZARDS

Lighting structures add to the visual intrusion and negatively impact the aesthetics of an area.

This is a very subjective matter and difficult to quantify. As a rule of thumb a 30ft high pole fits in almost all applications. Exceptions such as for sport lighting installations or other high mast designs such as expressways are acceptable.

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Designers should be aware of using particularly large lighting structures, such as high-mast lighting poles near residential areas. The large number of lighting poles along roadways significantly adds to the hazards for the driver. From a safety aspect, it is preferable to use fewer taller poles with higher wattage lighting sources. A trade off should be made, however, with visual intrusion, light trespass, and glare. When the lighting design principles are properly applied, the increased visibility provided on the roadways can provide social and economic benefits to the public, including:

Reduction of nighttime accidents
Aid to police protection
Facilitation of traffic flow
Promotion of businesses
Inspiration of community growth
Safety for pedestrians

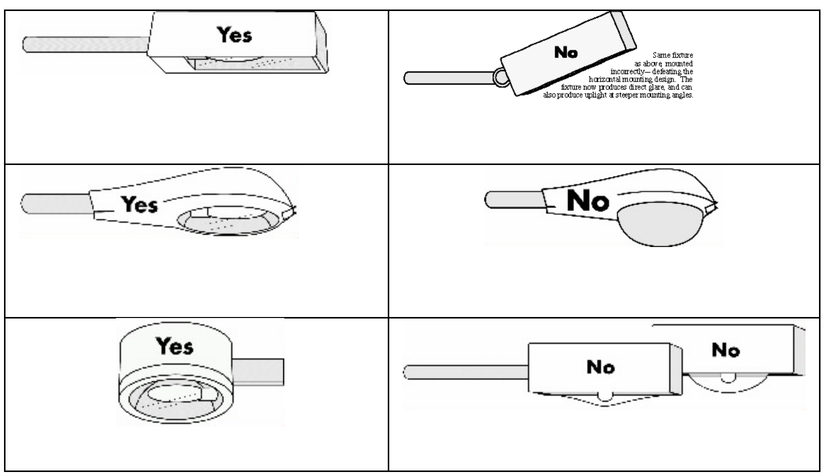
ROAD TYPE ILLUMINANCE IN LUX

Road Type	Illuminance (Lux)
Urban Freeway	10
Freeway interchange	14
Commercial arterial	12
Residential collector	8
Local	6

Table 1 - Illuminance for various roadway types source: ANSI/IES RP-8

TYPES OF HEADS

Any fixture that does not produce full cutoff shall not be considered.



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LED COMPARED TO OTHER LIGHT SOURCES

Type	Lumens per watt	Avg life (hours)
Incandescent	8 – 25	1000 – 2000
Mercury vapor	13 - 48	12000 -24000
Fluorescent	60 – 110	10000 – 24000
Metal halide	60 – 100	10000 – 15000
High Pressure Sodium	45 – 110	12000 – 24000
Low Pressure Sodium	80 - 180	10000 – 18000
LED	60 - 130	50000 - 100000

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LED COMPARED TO MH (METAL HALIDE)

The comparison is not easy as it is to compare to other light sources. LED has different characteristics than HID lights, therefore to compare, requires some understanding of how it operates. In summary, LED is a direction light. It concentrates the light in a cone about 120 degree provide better an illumination where it is suppose to be. Below is an excellent article explaining how to compare LED to MH.

LED vs Metal Halide

June 20, 2008 by Al

We recently had this question sent to us via the Hadco web site. I thought the response should be posted and shared to cut through some of the hype and get to some basic facts:

As engineers, we need some very specific decumentation regarding all of the wild efficiency claims for LED lighting for exteriors — from what we can tell, NO led is more efficient on lumens delivered to he pavement per watt consumed than the better Metal halide systems - we need this data FIRST, before we then factor in the lumen depreciation of MH, the lamp life issues, etc etc —- most vendors roll every thing into one over-simpllified blanket statment - -misleading owners, architects, etc - then lighting consultants have to dis prove the negative — please help us out here !!

Our response:
The explanation you have requested is somewhat lengthy and deals specifically with the inherit design issues surrounding todays luminaries and how we deal with those issues. The Average Rated Lamp Life, Initial Lamp Lumens, Mean Lamp Lumens, Lumen Maintenance at rated lamp Life, Ballast Factor, Ballast Efficiency, Thermal management, Optical System Losses and of Course Dirt Depreciation of the Optical System and the Degradation of the Materials that make up the optical system are the main issues of concern.
Normally these issues would be addressed in more of a training type session that would last several hours either here at Hadco or at a remote location and would at best accomplish only a very basic understanding of how all these work together. I have read many published articles by different LED manufacturers, LED Integrators and LED Luminaire Manufacturers. At best the LED manufacturers only understand the physics of how they make the LED and the integrators only understand how to power up and heat sink the LED but not how an LED should function and perform as a system so uniquely described as a LED Light Engine and or SSL Engine.

A) To make things a bit easier let's start with eliminating some of these variable and base this discussion on 32watt - 175 watt Metal Halide:
1) Dirt Depreciation, assuming we have a clean optics system that is sealed from dust and moister
2) Materials Degradation, assuming we are working with a glass optical system that is not affected by the harmful 300-400nm wavelengths of Metal Halide
3) Ballast Efficiency, assuming the HID Ballast and the LED Driver System is at least 90%, remember that a standard 175 Watt Probe Start Metal Halide lamp/ballast system consumes 210 Watts on a standard constant wattage auto-transformer ballast, that calculates to be a ballast efficiency of only 83%, of course there are more efficient electronic ballast systems today which provide as much as 90%)
4) Ballast Factor and Driver Factor is "1", assuming the HID ballast and the LED Driver can drive the lamp and or light engine to 100% of it's rated watts
5) Initial Lamp Lumens, assuming we understand that in less than one year the Metal Halide Lamps have settled to 75% of their initial lumen output where as measurable losses of an LED System are in most cases insignificant.
6) Rated Lamp Life, assuming we understand that most Probe Start Metal Halide lamps at best have 2 years of reliable lamp life and that the newer Pulse Start Systems can provide up to 15000 hours (3.4 years at a 12 hr per day ontime) of lamp life. Remember Metal Halide rated lamp life is based on a mortality rate of 50%, or 5 out of 10 lamps still running at the rated lamp life.

B) Now that leaves us with the effects of Lamp Lumen Maintenance, Mean Lamp Lumens, Thermal Management and Optical System Losses:
1) Lamp Lumen Maintenance "varies" from one lamp manufacturer to the next and so does LEDs. You would really have to dig for this information since the real data is normally proprietary to the manufacturer, I have recently in my research discovered that Metal Halide lamp Lumen Maintenance is as low as 60% at rated life, once again depending on the lamp manufacturer and the ballast manufacturer. The Philips Lumileds are the LEDs that we prefer to use in our products are guaranteed a 70% LM to 50,000 hours, that's about 11.4 years at 12 hours per day on time. The dilemma here is that how do you compare a 3.4 year lamp life at best for Metal Halide to the 11.4 year Lumen Maintenance cycle of LEDs. Remember, the LED does not have a rated life that the Lumen Maintenance is based on. The LED Lumen Maintenance is based on where the LED lumen output actually dims down to 70%. It is possible that LEDs can continue to operate for many more years rather than the Metal Halide 50% mortality rate at 3.4 years? We prefer to compare the LED Lumen Maintenance curve to the Metal Halide Lumen Maintenance curve which is roughly about 91% at 3.4 years which is where Metal Halide is rated. Given this comparison, if we were comparing an HID source and an LED source lumen to lumen, LED units would provide a 23% higher lumen output at 3.4 years than the Metal Halide Lamp.

Example: Bare 175 Watt Pulse Start MH Lamp/Ballast verses bare LED light Engine/Driver
a) GE Pulse Arc Lamp rated at 12,500 Mean Lumens with 90% efficient electronic Advance Ballast uses 194 watts at 120 Volts AC, that an efficacy of 12,500/194 = 64.43 lumens per watt

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b) Cool White Lumiled Rebel Led rated 100 Lumens at 350 ma has an efficacy of 86.96 lumens per watt, lets be rally fair, we will deduct 5% for Junction Temperature losses then we have 82.61 LPW, and deduct
the 10% driver efficiency loss we have 74.35 LPW
c) In this simple comparison we have established that LEDs can provide 13.3% more lumen output bare lamp to bare light engine.
2) The next big concern is optical systems efficiency.
a) The typical HID lamp produces a toroidal luminous distribution out put pattern about the vertical axis of the lamp. Except for the typical 30 degree solid angle cone that is void of light at the ends of the lamp arctube luminous flux from the lamp radiates outwardly in all directions and not evenly.
b) The typical LED emits luminous flux from the silicon chip from the LED package outwardly in one direction into a solid angle of about 120 degrees. That makes LEDs "directional".
c) The HID Flux distribution pattern would be an excellent source if a toroidal light distribution pattern was all we needed, but we know that this is not the case. The upset in the comparison between LEDs and HID light sources is this difference. The "real" gain in efficiency of LEDs over HID lamps is almost always in the efficiency of the optical system that gathers the luminous flux from the light source and redistributes into a useable lighting distribution pattern for particular applications whether it be a roadway scenario or a task oriented Luminaire such as a flood light. This is an area of the Luminaire design that can deliver up to 30% more luminous flux onto the work surface, especially if the area is a complex geometrical shape, liken to softball, football, soccer and basketball fields and also type 1, 2, 3, 4 and 5 IESNA lighting distribution. Try maintaining a sharp cut off with a single source Luminaire.

The real winner here in LED luminaries is "illumination" and not how big the lumen package is. I recommend to our sales reps that we're selling illumination and not high lumen output lamps. A good example is gas mileage, I had a Dodge back in the 70's with a V-8 and a 4-Barrel Carburetor that developed about 225 HP and delivered about 12 miles to the gallon on fuel efficiency. Today I have a Buick with a V-6 and is fuel injected that delivers about 225 HP at about 25 miles to the gallon. The real need today in an automobile is transportation and fuel economy. Today's automobile manufacturers have figured out that "less" can be "more". Just like with LEDs, the real story here is illumination and how we apply lumens.

STREETLIGHTS – A GUIDELINES FOR LED DESIGN AND SELECTION

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This specification can be used to compare LED streetlight fixtures from different manufacturers and for different applications:

STREETLIGHTS SPECIFICATION

GENERAL FEATURES		
Model		Acceptable
Source		LED
LED chip		CREE, Luxeon, Osram
LED quantity		per manufacturer
Power (watts)		>80
Power factor (0 to 1) usually not applicable to LED		>0.8
Quick response (mille-seconds)		10
Junction temperature (Celsius)		<70
Lumens		>6400
LED luminous efficiency (Lu/w)		>80
Color Rendering Index (CRI or Ra)		>65
Color temperature		4500-6000
Voltage		120-240AC
Frequency		50-60Hz
Driver efficiency		>70%
Operating temperature (Celsius)		-30 ~ +50
Light level (local road - Lx)		8 ~10
Light trespass (at 10m) HLx		5
Direct glare (degree)		85
Glare control mark		7
Beam angle		120
Energy savings %		35
Average life (hours)		>25000
LED life		50000
FIXTURE AND MOUNTING		
Fixture design		flat lens
Cutoff (0cd above 90dg / 10%cd above 80dg)		full
Fixture material		aluminum alloy
Fixture lens		polycarbonate
Fixture color		silver or black
Fixture efficiency (%)		>80
Luminary emit light above 90 degree		No
Ingress protection (IP)		65
Mounting position		level
Mounting height (meter)		10
Fixture connection diameter (inches)		2.5
Fixture life (years)		25
Fixture warranty (month)		60
Fixture lens warranty (month)		12
LED array		replaceable
Optical distribution:	Type II	1 head
	Type III	2 heads
	Type IV	2 heads @ 90dg
	Type V	>=3 heads
OPERATIONAL FEATURES		
Photoelectric (PE) operated switch		yes

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Time programmable	desirable
Certification	UL or ETL

PHOTOMETRICS				
		Avg lux	**Avg/min**	
Freeway class A		6-8	3/1	
Freeway class B		4-6	3/1	
Expressway		6-13	3/1	
Major road	Commercial	16	3/1	include photometric
	Intermediate	12	3/1	
	Residential	8	3/1	
Collector road	Commercial	11	4/1	
	Intermediate	8	4/1	
	Residential	6	4/1	
Local road	Commercial	8	6/1	
	Intermediate	7	6/1	
	Residential	4	6/1	

REFERENCES

IESNA – The Illuminating Engineering Society of North America
IDA – International Dark-Sky Association
ANSI – American National Standards Institute