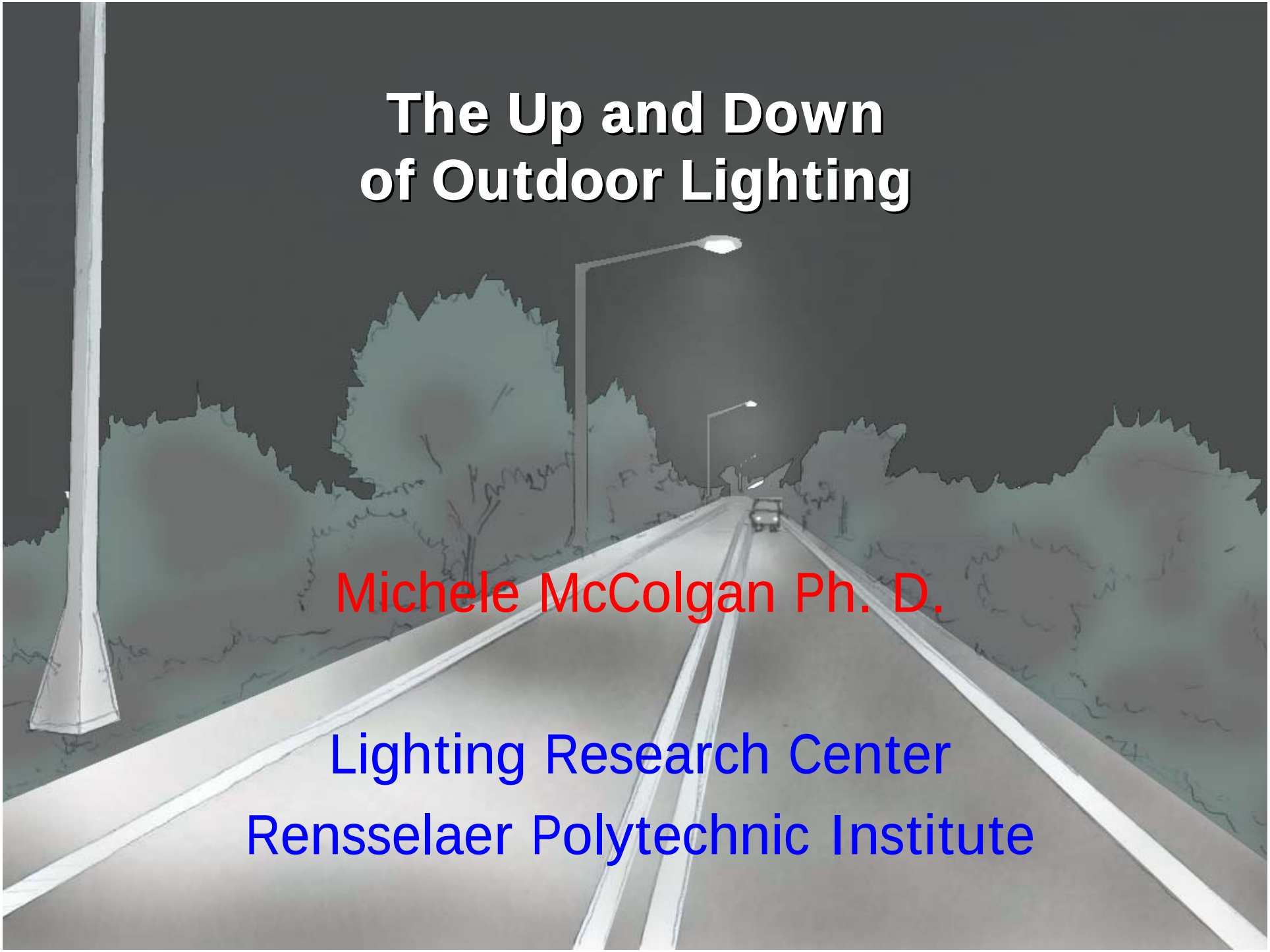

The Up and Down of Outdoor Lighting

Michele McColgan Ph. D.

Lighting Research Center
Rensselaer Polytechnic Institute

Scope of Presentation

- Introduction
  - Why light?
- Good outdoor lighting practice
  - Lighting considerations
- Light pollution
  - What is it?
  - What is being done about it
- Light Pollution Research
  - Defining the problem
  - Who's doing work in LP?
- NLPIP Specifier Report – new!
- Shoebox framework for light pollution – new!
- Spectrum
- Breast cancer and lighting
- Conclusions


www.nyseg.com

Introduction

- Why do we light our outdoor nighttime environment in the first place?
- To meet societal objectives!

The truth is: lighting that does not meet these objectives is of little use

- Outdoor lighting must meet application objectives as efficiently as possible with the least amount of wasted/offensive light
  - Follow good lighting practice
  - Develop new metrics and measurement methods to describe outdoor lighting

Lighting Objectives

- Safety
  - Drivers, pedestrians
- Security
- Economic Development
- Esthetics
  - Sending messages
  - Landmarks, historical areas

Safety

- Street lighting illuminates the roadway
  - Makes obstacles and the roadway surface more visible
  - Also acts to mitigate glare
- Street lighting lights more than just the road
  - Pedestrians
  - Cyclists
  - Children playing
  - Other non-motorists

http://www.morguefile.com

Security

- There is controversy about whether electric lighting improves security
  - One does feel safer walking or driving on well-lit streets and parking lots
- In order for security lighting to be effective, minimum light levels and uniformity ratios must be met

Economic Development

- Exterior lighting has a significant impact on economic development
  - Lighting may draw people to downtown or shopping areas by making the space inviting

- The appearance of a space (during nighttime as well as daytime) is an important consideration for many areas

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Esthetics

- Lighting sends a message
  - “Look here”
  - “Walk down this street”
  - “Don’t walk down this street”
  - “Come and window shop”
- Lighting enhances historic areas, landmarks and helps to promote an image

When to Light?

There are many valid reasons to light!

<u>However</u>, understanding how much is enough is important

- Awareness is the key to balancing the need for lighting while minimizing light pollution and increasing energy efficiency

http://www.morguefile.com

Lighting Considerations

Before any decisions about lighting are made, the objectives of the community must be considered

Questions to consider:

- Does the street or area in question need lighting?
  - *What are the objectives?*
- Are there other ways to accomplish the goals without installing lighting?
  - Marking, signaling, mechanical structures, educational programs, speed limits, etc.

Lighting Considerations

- Once lighting is deemed necessary:
  - Are minimum lighting levels being used to accomplish the objectives?
  - Is the current or proposed lighting installation energy efficient?
  - Does the lighting installation minimize light pollution?
  - Is the lighting installation cost effective?
  - Have lighting controls such as motion sensors or timers been considered?
  - Is a lighting curfew (turn lights off after a certain time) appropriate?

Lighting Considerations

- Lamp sources
- Light distribution
- System light loss
- Luminaire cutoff classification

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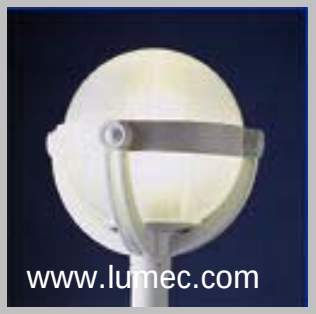
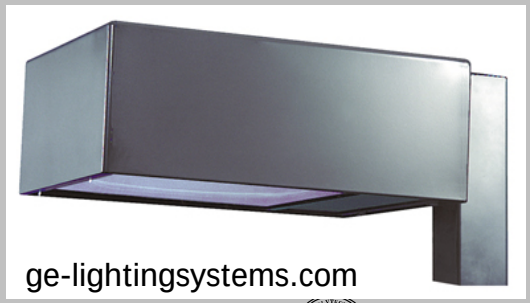
Review of Cutoff Classifications





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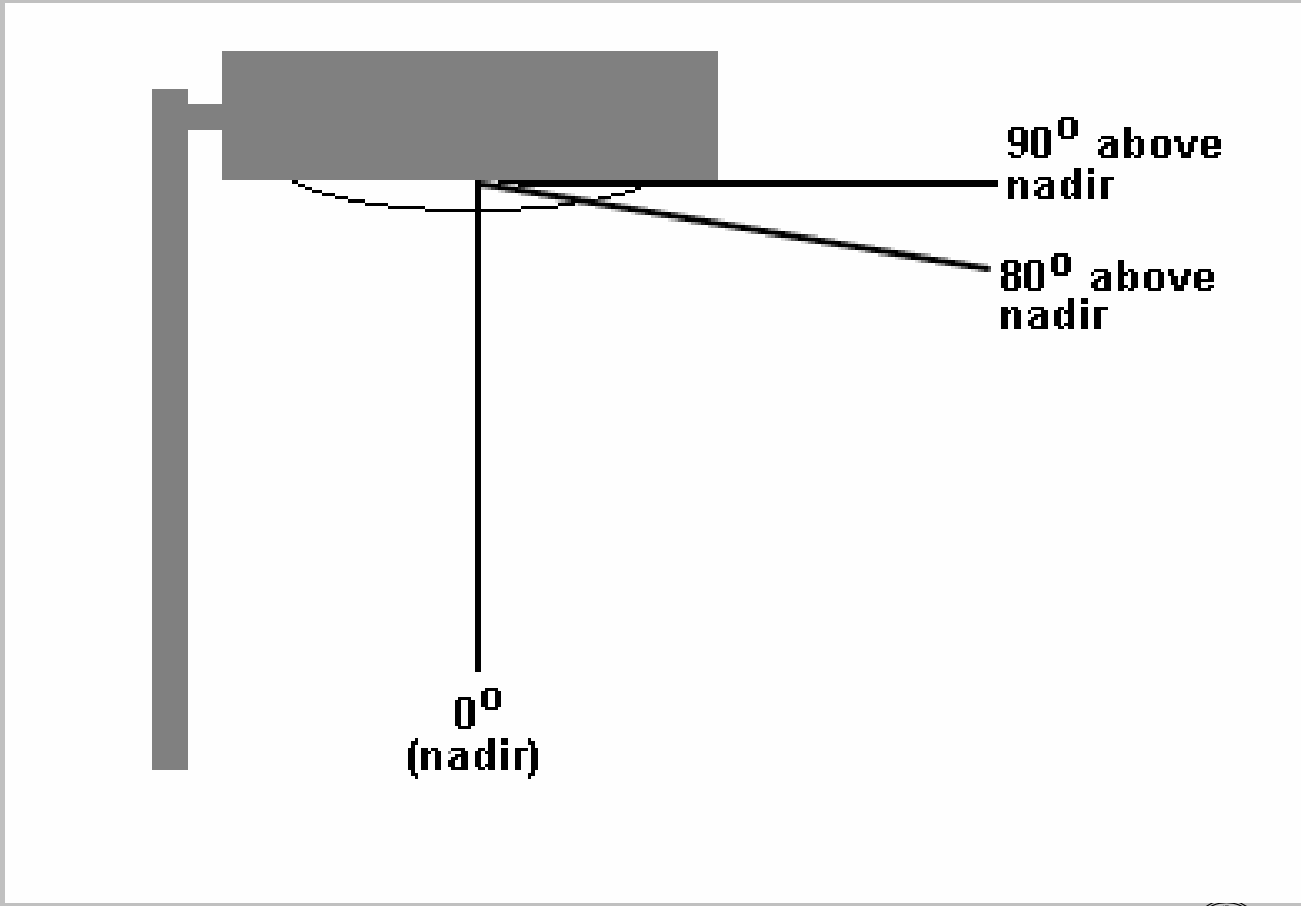
Angles Referenced by Luminaire Cutoff Classifications



IESNA Cutoff Classifications

Name	Description of intensity distribution
Full cutoff	A luminaire light distribution where zero candela intensity occurs at an angle of 90° above nadir, and at all greater angles from nadir. Additionally, the candela per 1000 lamp lumens does not numerically exceed 100 (10%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.
Cutoff	A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 25 (2.5%) at an angle of 90° above nadir, and 100 (10%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.
Semicutoff	A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 50 (5%) at an angle of 90° above nadir, and 200 (20%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.
Noncutoff	A luminaire light distribution where there is no candela limitation in the zone above maximum candela.

Classification	Candelas at or above	
	90°	80°
Full Cutoff	0	<10%
Cutoff	<2.5%	<10%
Semicutoff	<5%	20%
Noncutoff	NA	NA

*Candelas are given as a function of lamp lumens

IESNA Lighting Handbook: Reference and Application, 9th edition (2000)

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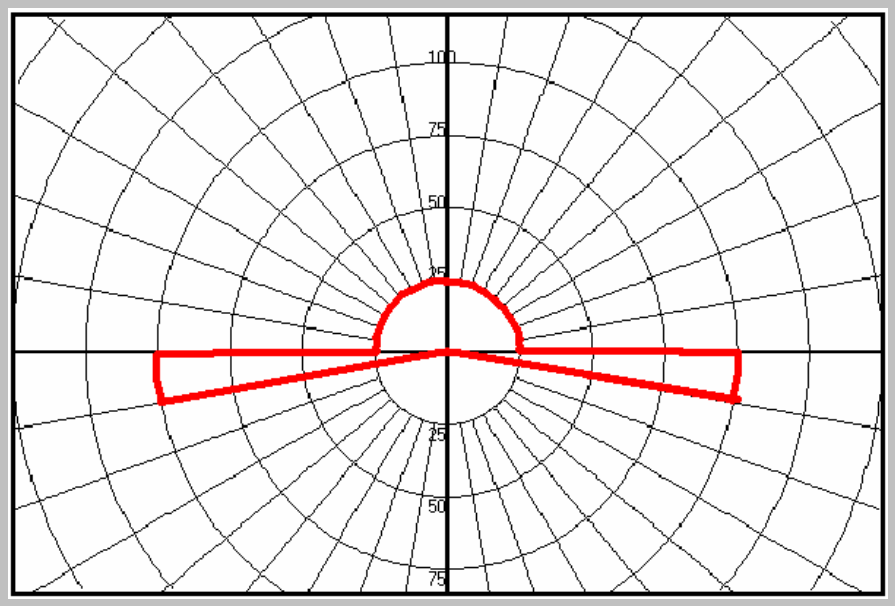
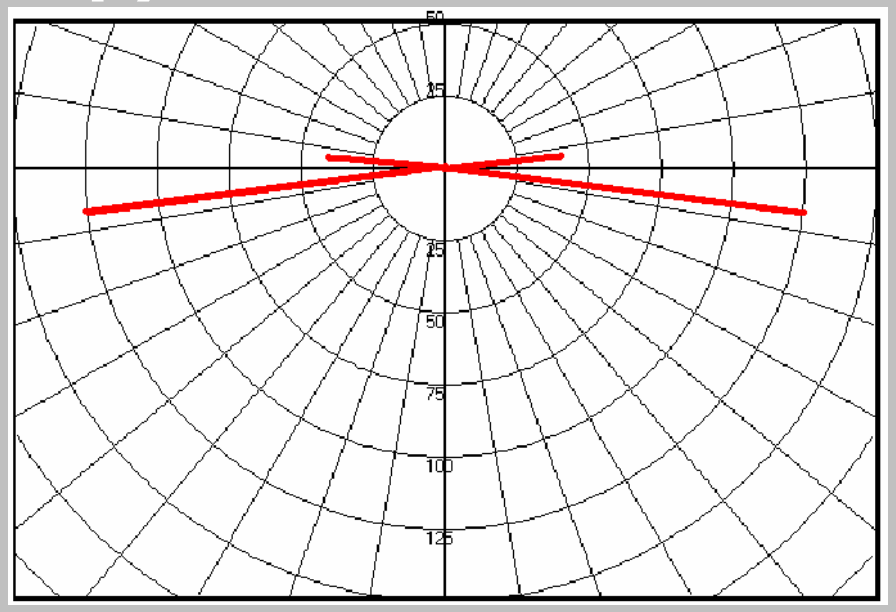
IESNA Cutoff Classifications

Hypothetical 1000 (Lamp)Lumen Luminaires





- Meets IESNA cutoff classification
- Nearly 16% of lamp lumens above 90°
- 11% of lamp lumens between 80° and 90°

- Does not meet IESNA cutoff classification
- About 1% of lamp lumens above 90°
- 3% of lamp lumens between 80° and 90°

(Bullough, 2002)

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IESNA Cutoff Classifications

Allowable Lamp Lumens for Given Cutoff Classifications

Luminaire classification	Range of allowable lumens emitted upward	Range of allowable lumens emitted between 80° and 90°
Full cutoff	0	0 - 11%
Cutoff	0 - 16%	0 - 11%
Semicutoff	0 - 31%	0 - 22%

(McColgan, 2003)

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Lamp Sources

High Pressure Sodium (HPS)
- Pinkish white, high efficiency, long life

Low Pressure Sodium (LPS)
- Yellow, very high efficiency, long life

Metal Halide (MH)
- White, good efficiency, good life

Mercury Vapor (MV)
- White, low efficiency, short life

Induction Lamp (QL)
- White, high efficiency, very long life

MV

MH

HPS

LPS

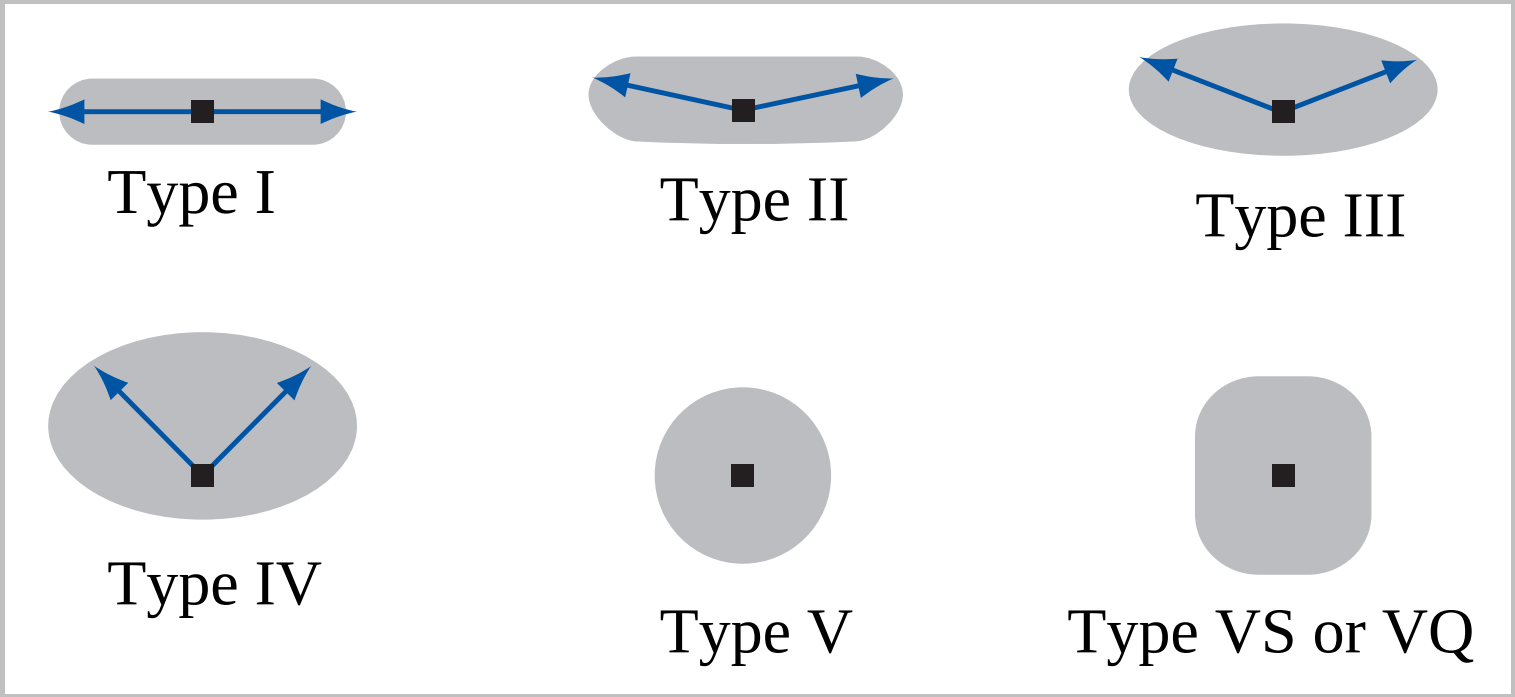
Table 1. Performance Characteristics of Lamps Used in Parking Lot and Area Luminaires [a]

Standard Lamp		Lamp Efficacy (LPW) [b]	Lamp Wattage	Life (hours) [c]	Luminous Flux (lumens) Initial	Luminous Flux (lumens) Mean	Correlated Color Temperature (K)	Color Rendering Index (CRI)
HPS		104–116	250	24,000+	26,000–29,000	23,400–27,000	2,000–2,100	21–22
MH (probe-start)	Vertical pos.	70–92	250	10,000	17,500–23,000	11,300–17,000	3,200–4,000	65–70
	Horizontal pos.	69–92	250	10,000–15,000	17,200–23,000	9,400–15,000	3,200–4,300	65–70
	Universal pos.	66–88	250	6,000–10,000	16,600–22,000	10,600–17,500	3,000–5,000	65–75
MV		44–52	250	24,000+	11,000–13,000	8,250–10,800	3,700–6,700	15–50
LPS		167–178	180	16,000–18,000	30,000–32,000	32,000 [d]	1,700–1,800	0
		163–167	135	16,000–18,000	22,000–22,600	19,140–22,600	1,700–1,800	0

(McColgan, 2004)

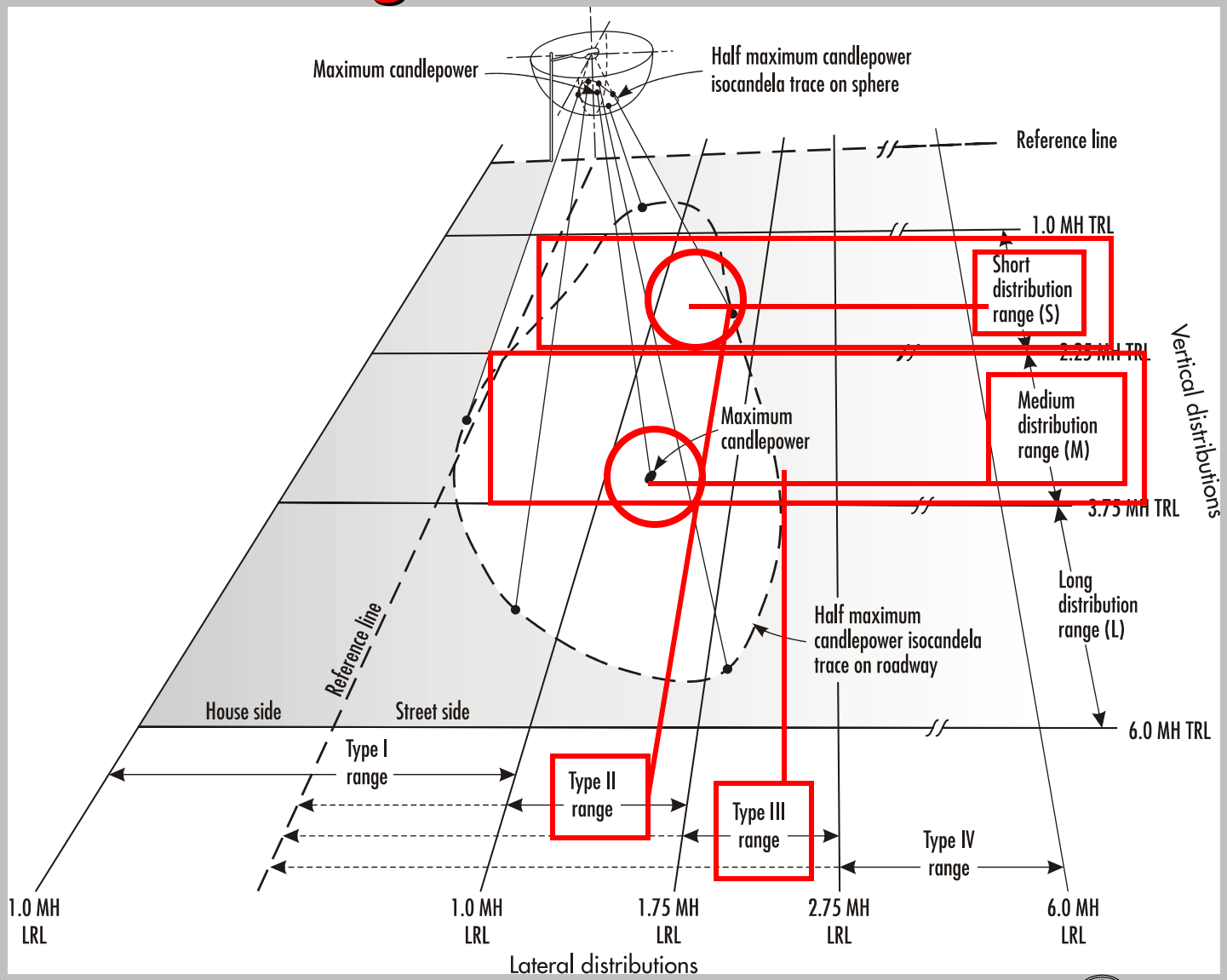
Light Distribution

- Lateral



- Vertical – short, medium, long

Light Distribution



Adapted from Rea 2000, Fig. 22-7

System Light Loss

- Optical performance determines luminaire efficiency
  - System light output also depends on the ballast
- Downward efficiency governs the number of luminaires needed
- System light output decreases with time
  - lamp depreciation
  - normal wear and tear of luminaire components
  - dirt and moisture in the housing

Good Lighting Practices

- Many installations of lighting on roadways fall short of IESNA recommendations
  - These recommendations form the basis for "good practice" in street and roadway lighting
- Once the decision is made to embark on a street lighting project, carrying it through requires care and attention to avoid:
  - Unwanted equipment costs
  - Complaints about poor visibility
  - Glare
  - Unnecessary use of energy
  - Excessive maintenance costs

Good Lighting Practices

- What are the objectives
- What are the existing conditions
- Are efficient technologies being used
- Are pole heights and pole spacings appropriate
- Are all attempts being made to minimize light pollution
- Have maintenance and component life been considered

Existing Conditions

- Understanding the area in question
  - What is the traffic density, posted and typical driving speeds and accident history of the location?
  - Is pedestrian traffic heavy throughout the day or only at certain times of the day?
  - What types of buildings are found in the area?
    - Residences, offices, neighborhood businesses, schools, restaurants?
  - What is the crime history?
  - Is the location perceived as safe or unsafe?

Efficient Technologies

- There is not one single best technology for street lighting
  - Are efficient light sources and ballasts planned?
  - Mercury vapor lamps are relatively inefficient and should not be used in any new or retrofit installations
- Even the most efficient lamp and ballast can be made very inefficient by using luminaires that trap light inside
  - A luminaire that emits less than 60% of the light generated by the lamp and ballast should be avoided

Light Pollution

Light pollution is an unwanted consequence of outdoor lighting and includes such effects as skyglow, light trespass, and glare

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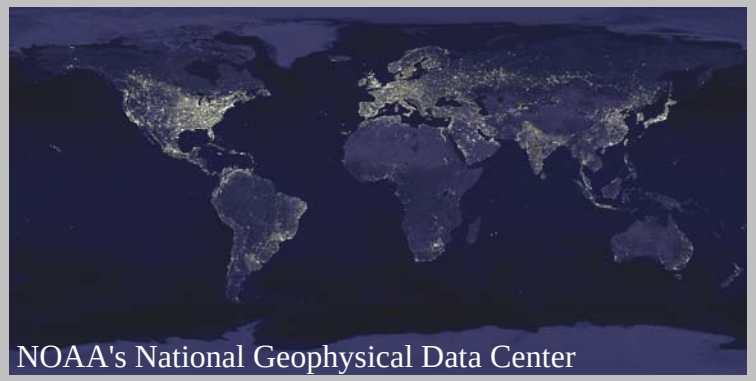
What is Light Pollution?

- ***Sky glow*** – brightening of the night sky caused by natural and human-made factors
- ***Light Trespass*** – light being cast where it is not wanted or needed
- ***Glare*** – objectionable brightness
  - *Disability glare* – loss of visibility from stray light scattered within the eye
  - *Discomfort glare* – sensation of annoyance or pain induced by overly bright sources


NOAA's National Geophysical Data Center

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Example of Sky Glow

Institution of Lighting Engineers and the Society of Light and Lighting

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Example of Light Trespass

David Fernández-Barba, Dep. d'Astronomia i Meteorologia, Universitat de Barcelona, SPAIN

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Example of Light Trespass

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Example of Glare

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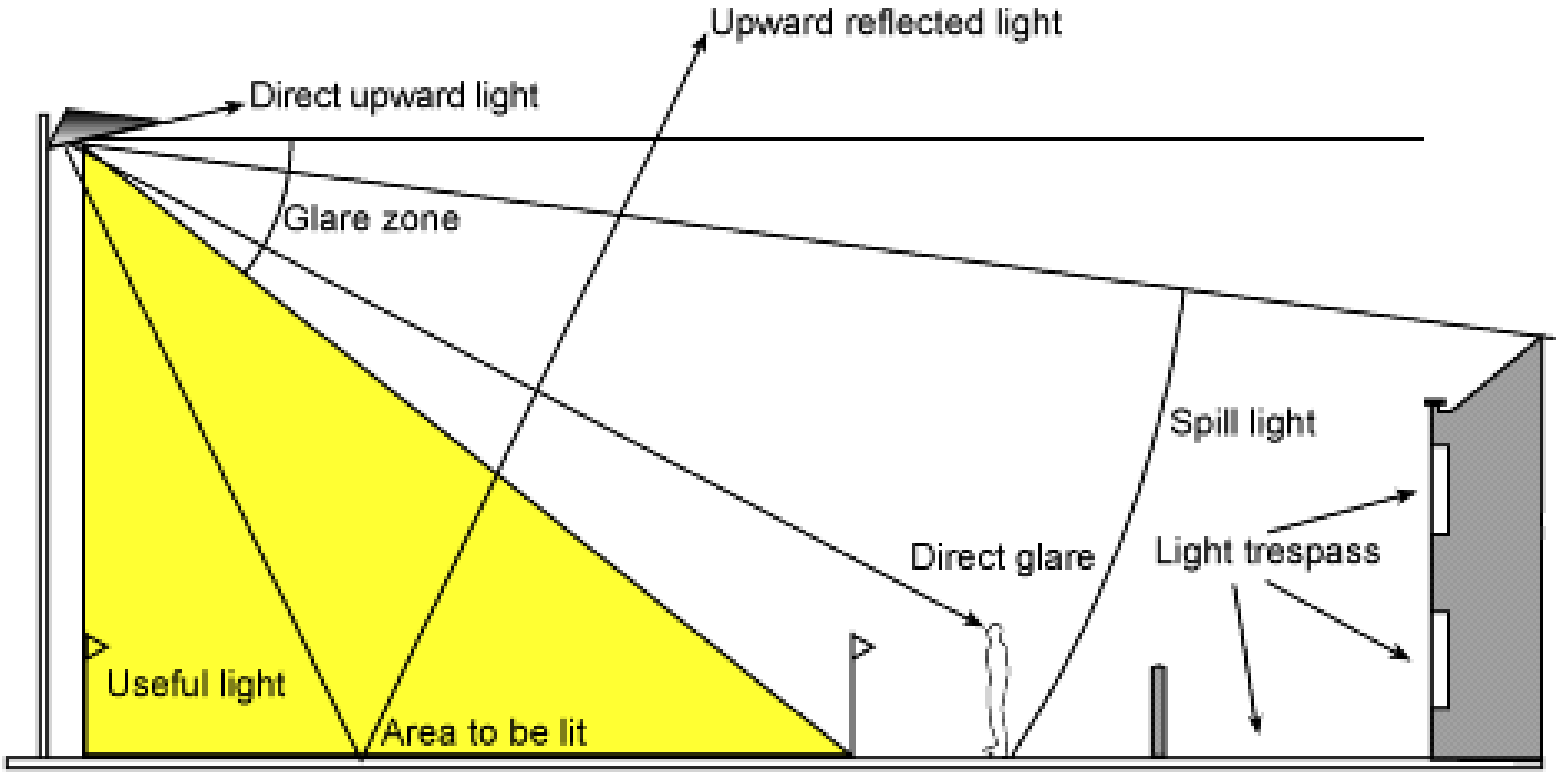
Useful Light and Light Pollution



Light pollution is often caused by the way light is emitted from lighting equipment. Choosing proper equipment and carefully mounting and aiming it can make a significant difference.

(McColgan, 2003)

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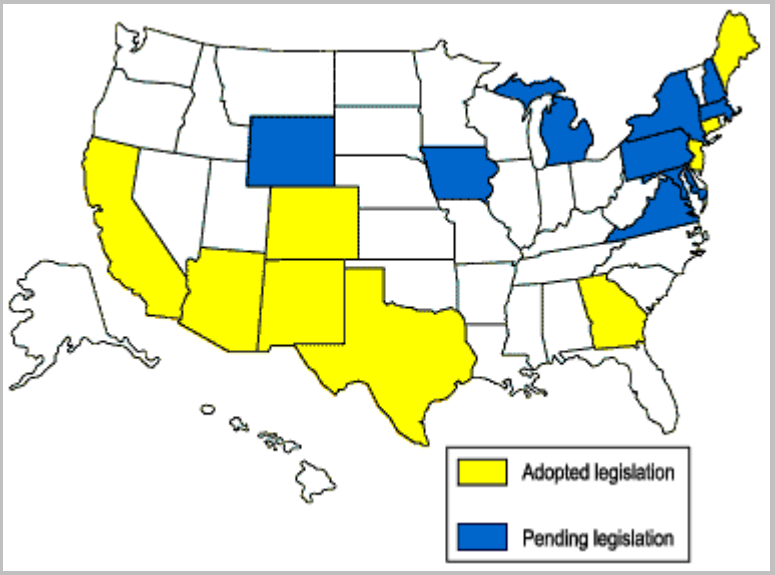
Results of Public Efforts

- Lighting ordinances
  - Equipment requirements
  - Minimum lighting levels
  - Lumen/acre limits
  - Eliminate lighting
- IDA membership almost 10,000 strong



Adopted: Arizona, California, Connecticut, Colorado, Maine, New Mexico, Texas, Georgia, New Jersey

Proposed or Introduced: New York, Iowa, Massachusetts, Michigan, New Hampshire, Maryland, Pennsylvania, Rhode Island, Virginia, Wyoming

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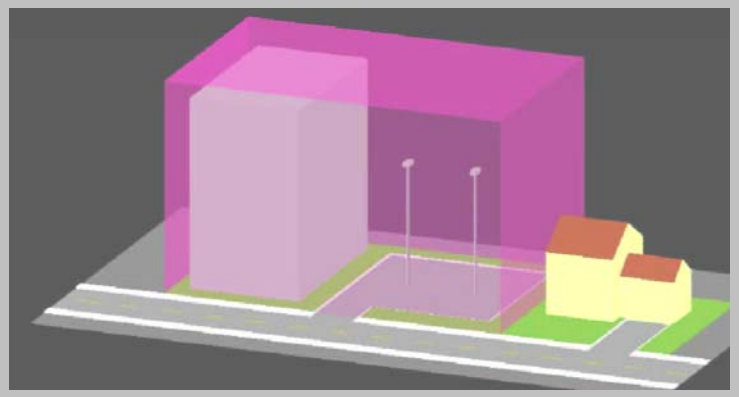
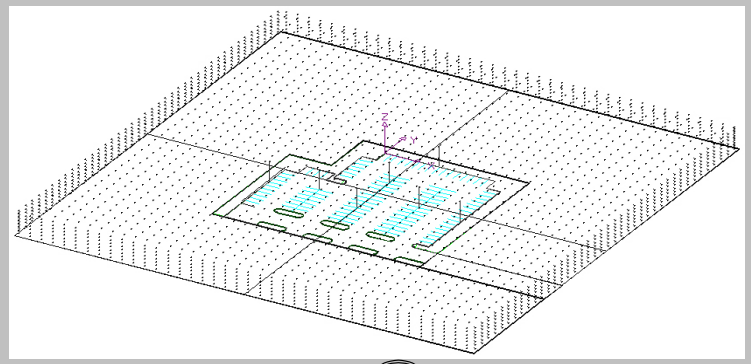
Light Pollution Research
What's Missing?

- Defining the issues of light pollution
  - Lack of data on the problem
  - No way to quantify the issues
  - Metrics and measurement methods need to be developed to provide a means to quantify light pollution, and ultimately, to help mitigate the associated problems

Light Pollution Research

- Uplight
  - Unit Uplight Density – Keith
  - Upward Flux – Gillet
  - Light Pollution Index - LRC
  - Uplight Metric – LRC
- Light Trespass
  - Vertical Illuminance – LRC
- Glare
  - Luminous Flux vs. Luminous Intensity – LRC
- Cutoff Classification – IESNA
- Shoebox Metric - LRC





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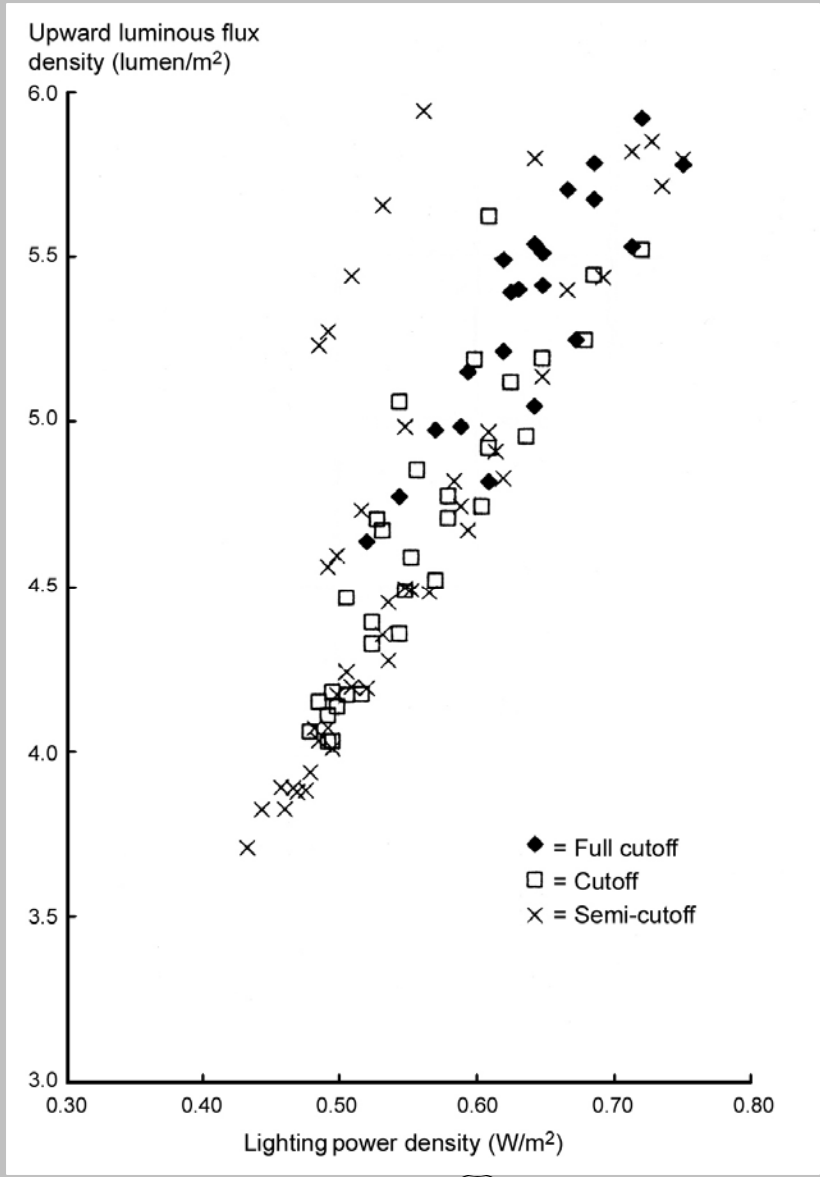
Unit Uplight Density (UUD)

- Keith, 2000
  - Analysis performed for roadways
  - Increasing the amount of light increases the uplight
  - Cutoff classification is not indicative of uplight



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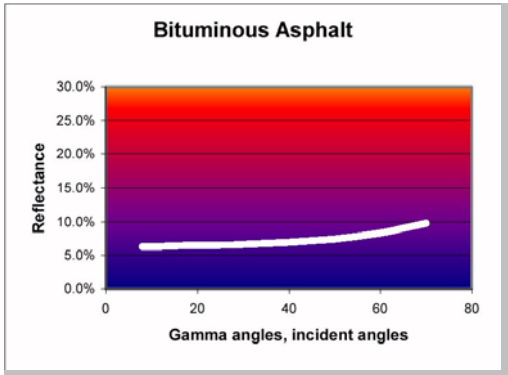
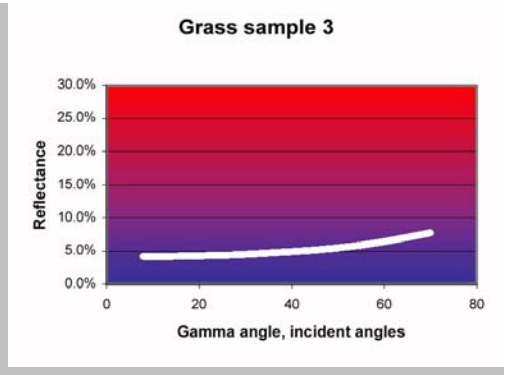
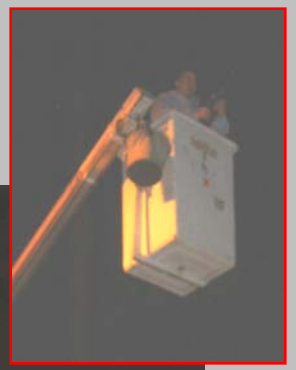


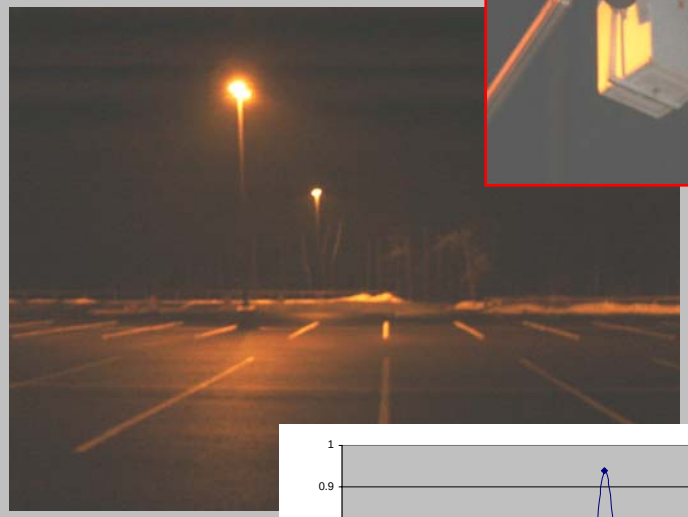
Upward Flux



- Laport, Gillet (2003)
  - Analysis performed for roadways
  - When grass is the ground surface, uplight is reduced
  - Sagged and flat lens resulted in less uplight than bowl lens
  - Very little difference in uplight between different cutoff classifications or lens types if the lighting designs are well optimized
  - Only the sag lens satisfies photometric efficacy as well as lower uplight
  - Regardless of lens type or cutoff classification, a luminance efficient solution (least amount of lumens to achieve 1 cd/m^2) results in less uplight than a less luminance efficient solution

LRC Research

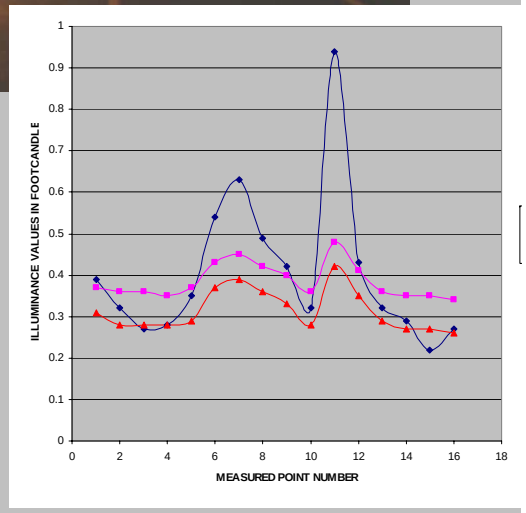




- Light Pollution Index
- NLPIP Specifier Report – new!
- Shoebox framework – new!

for light pollution

- Spectrum
- Breast cancer and lighting



(Sundaram, 2003)

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Uplight Metric

- A study was performed to examine the effects of different types of cutoff luminaires on local skyglow (Sundaram, 2003)
  - Exploring uplight of parking lot lighting designs meeting IESNA standards (RP-20-98) with similar:
    - Average illuminance values
    - Minimum illuminance and max/min ratio

Experimental Geometry

- Parking lot in Rensselaer Technology Park
- $R_{asphalt}$ = 7%
- Dimensions 135’ x 180’
- Grass surrounding parking lot extends 200’ in each direction
- 18 pole-mounted luminaires
  - 4 full cutoff, 7 cutoff, 7 semicutoff
  - different manufacturers
  - Different optics
  - Intensity data above 90˚

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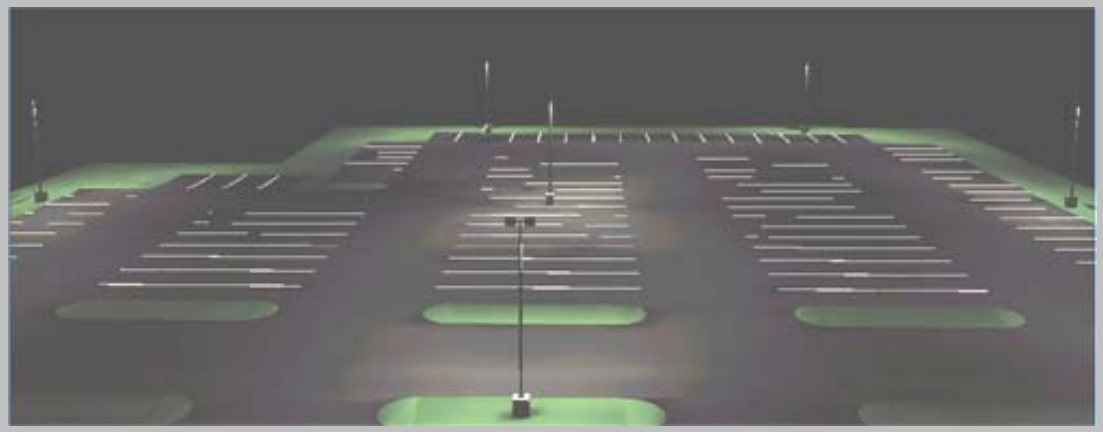
Analysis

- Constants
  - Height (30’), wattage (250W), and throw (Type III)
- Similar average ground illuminance (~ 25 lux)
  - In all cases recommendations of min illuminance (> 2 lux) and max/min ratio (< 1:20) were met
- Variables
  - Number of luminaires
  - Spacing



Number of Luminaires

Cutoff Type	No. of Luminaires
Manufacturer A	
Cutoff1	7
Cutoff2	7
Semicutoff1	8
Semicutoff2	8
Manufacturer B	
Full Cutoff1	7
Full Cutoff2	8
Cutoff1	8
Cutoff2	8
Semicutoff1	7
Semicutoff2	8

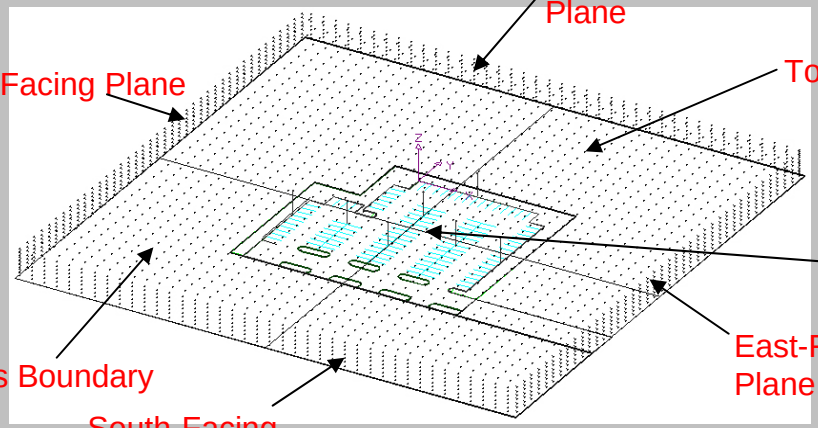
Cutoff Type	No. of Luminaires
Manufacturer C	
Cutoff1	8
Cutoff2	7
Semicutoff1	10
Semicutoff2	11
Manufacturer D	
Full Cutoff1	7
Full Cutoff2	7
Cutoff	8
Semicutoff	8

Light Pollution Index (LPI)

- "**Light pollution index**" or **LPI**
  - Ratio of the lumens on each plane by the lumens falling on the parking lot surface
- Total luminous flux (in lumens) on 5 virtual planes
- Pollutant lumens
  - Lumens falling on the top-down plane and on the top of the 4 vertical planes

LPI Calculations

- 1 horizontal ceiling plane pointing downwards located 35’ above the ground (5’ above luminaires)
- 35’ tall vertical wall planes on each side of the lot
  - Located about 200’ away from the edge of the lot



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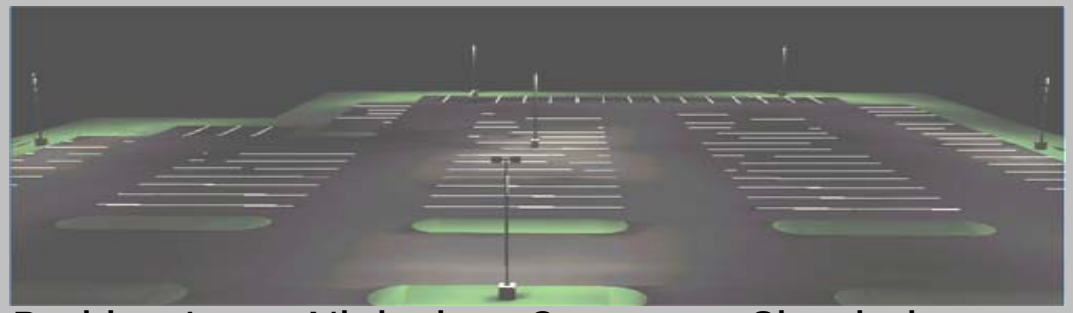
Light Pollution Index

Parking Lot – Daytime

Parking Lot – Nighttime



Parking Lot – Nighttime Computer Simulation

$$\text{LPI} = \frac{\text{Lumens on virtual planes (pollutant lumens)}}{\text{Lumens on the ground (useful lumens)}}$$

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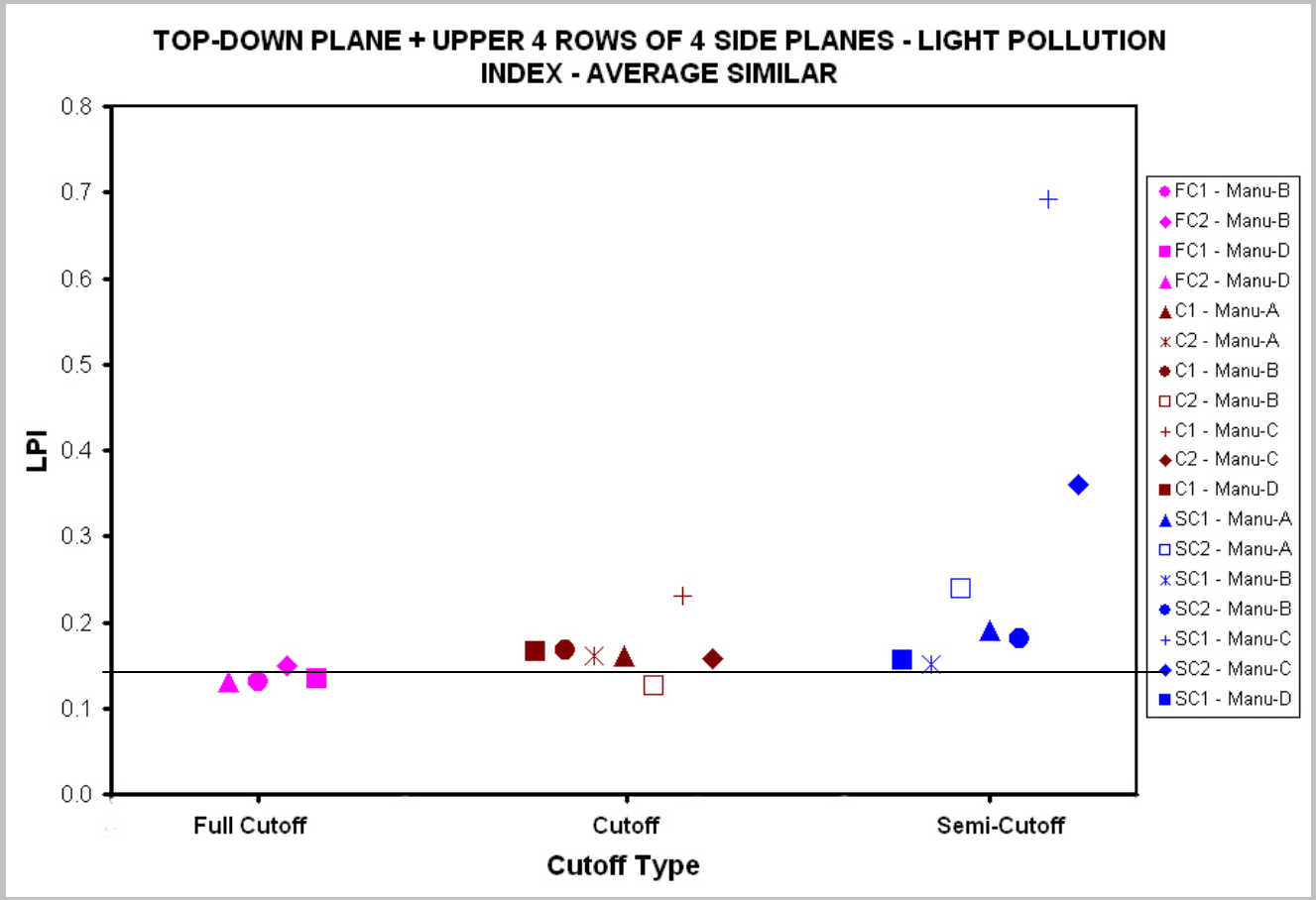
LPI vs. IESNA Cutoff Classification

- Luminaire cutoff classification is not predictive of installation uplight



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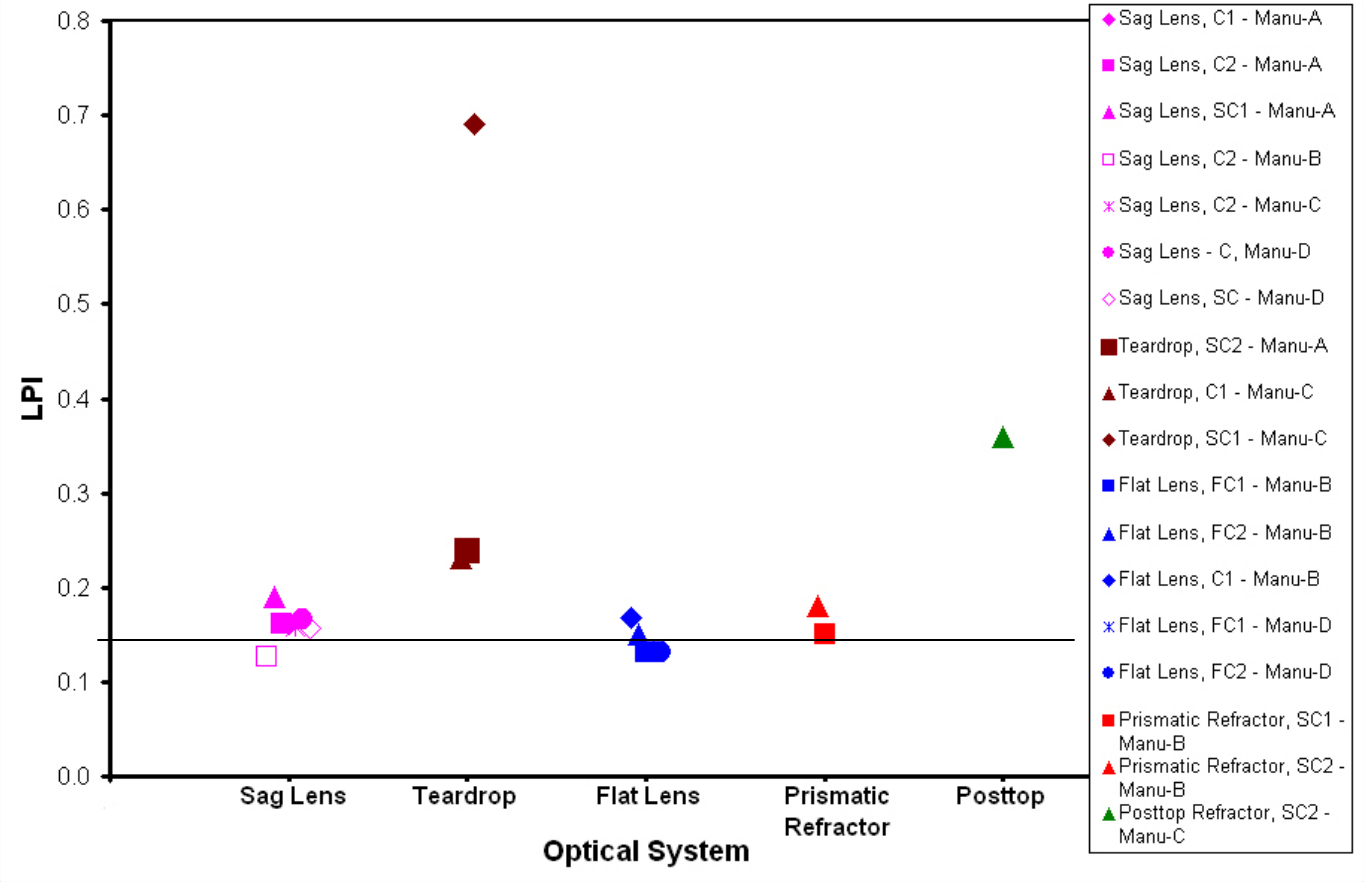
LPI vs. Optical System

- Optical type is also not predictive of installation uplight



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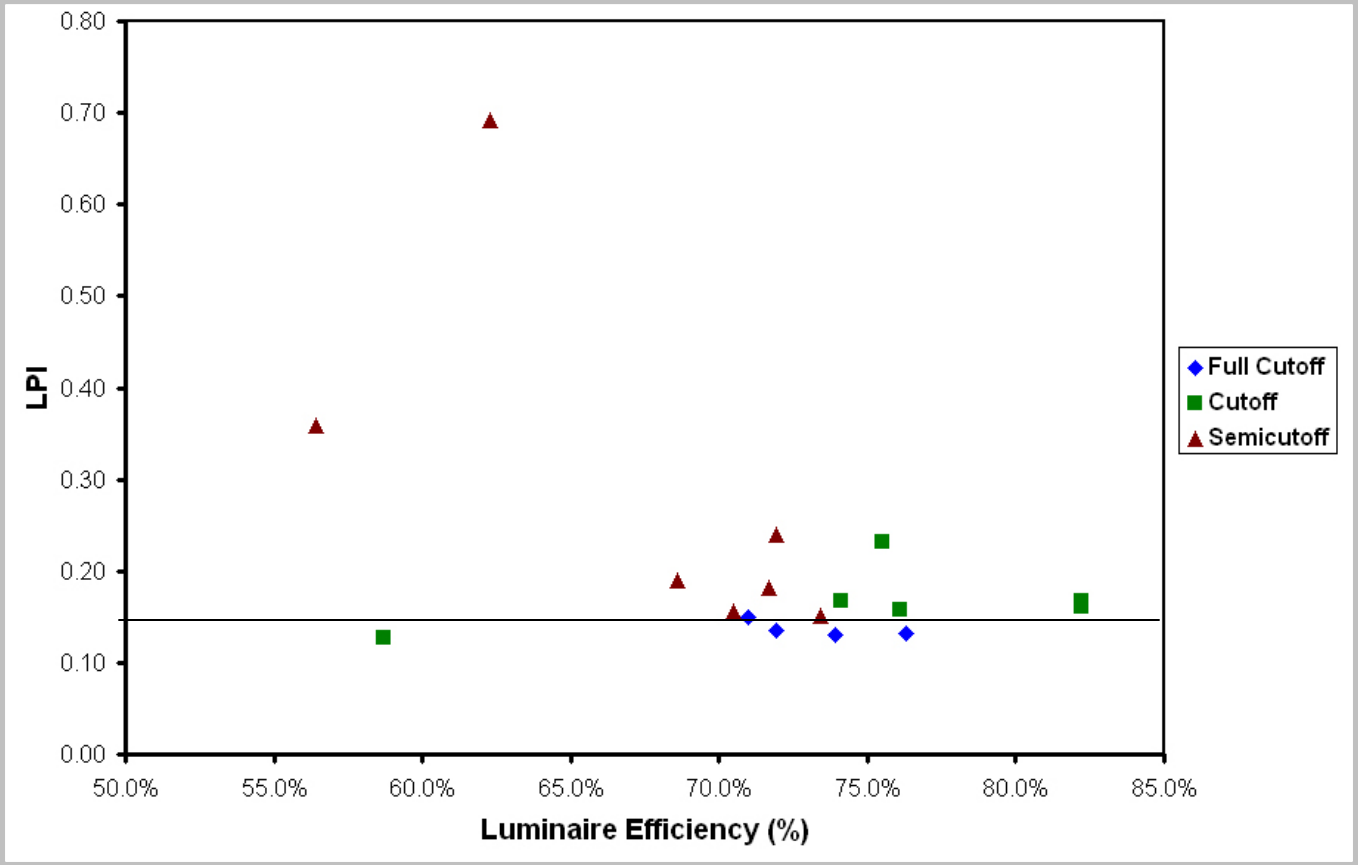
LPI vs. Luminaire Efficiency

- Luminaire efficiency is also not predictive of installation uplight



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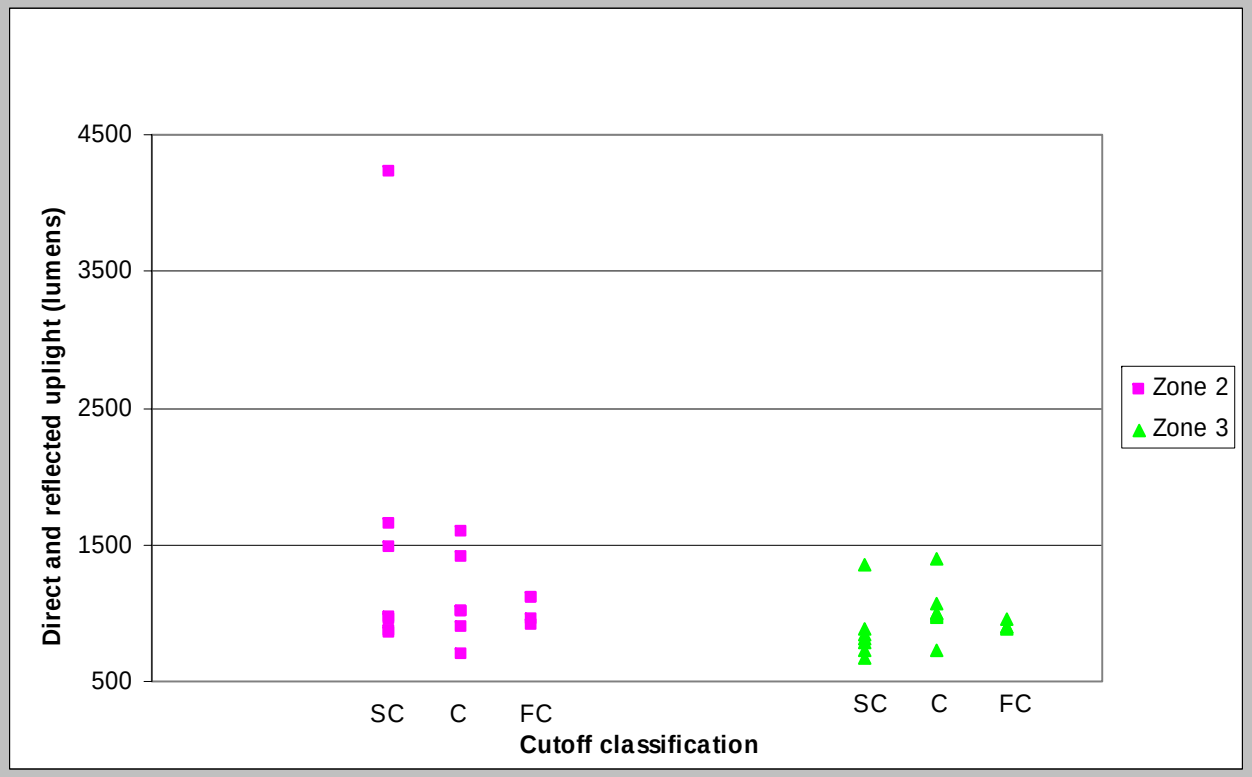
Direct and Reflected Uplight Metric

- Luminaire cutoff classification is not predictive of luminaire uplight



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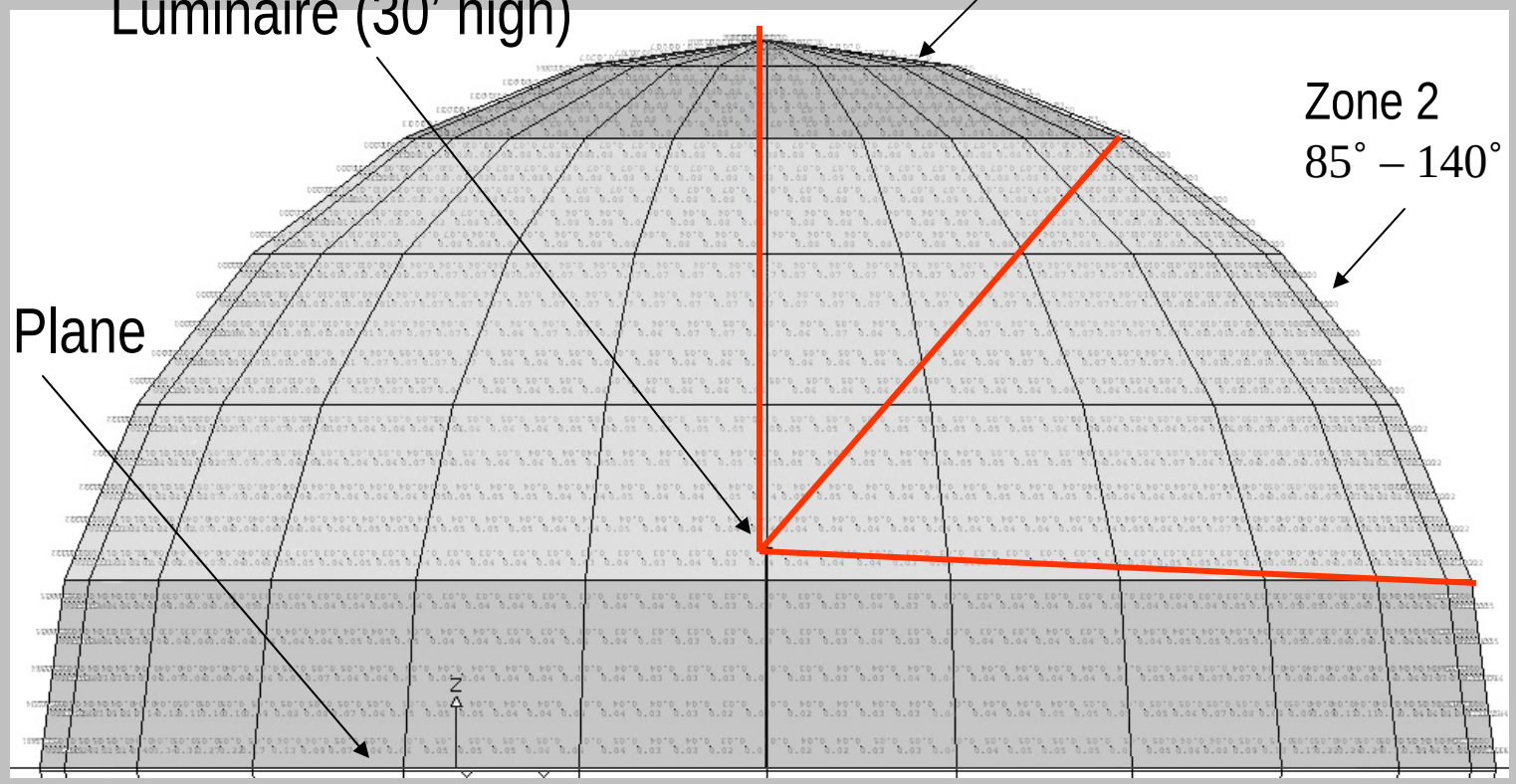
Uplight Metric



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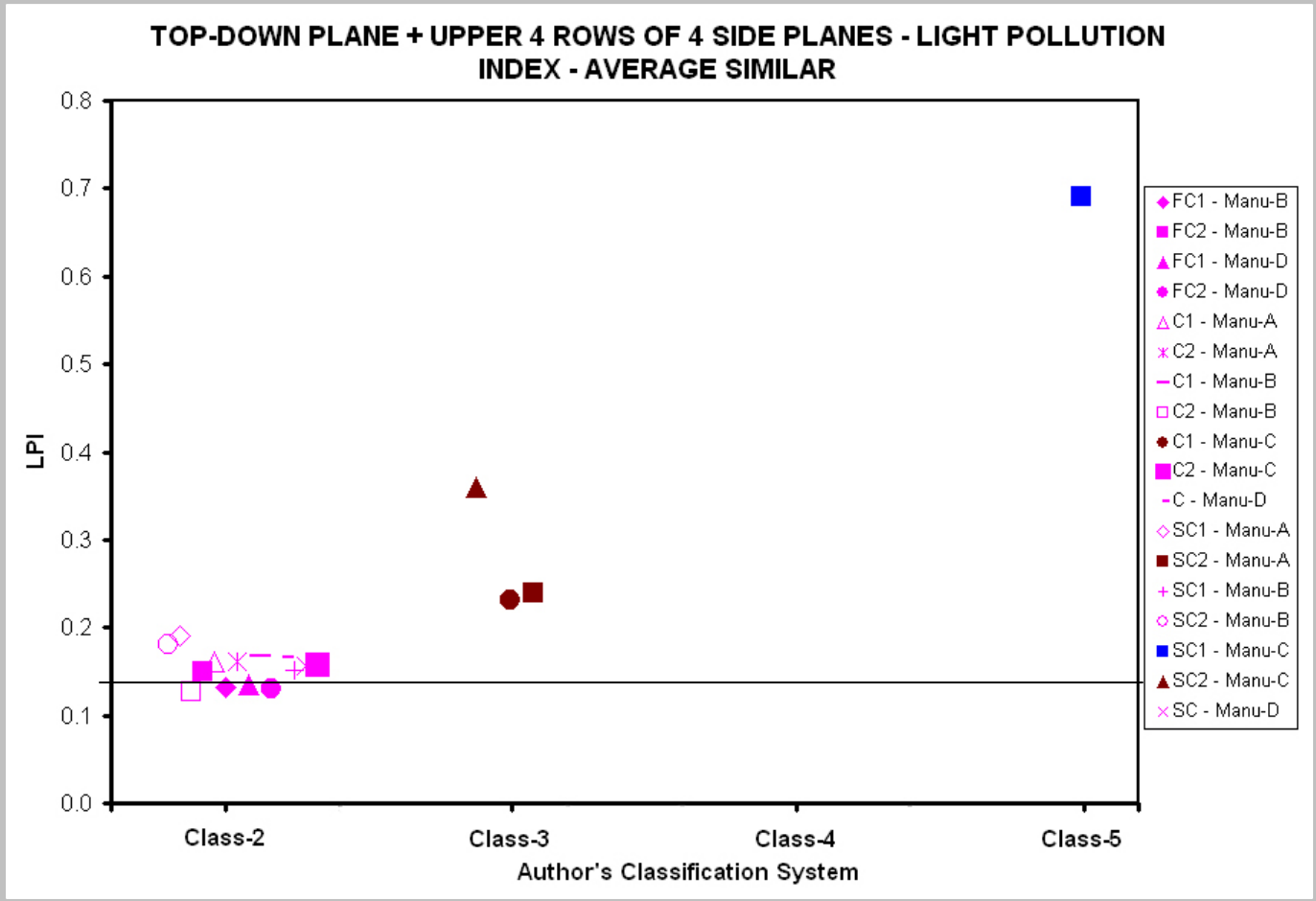
Reclassification

- The LPI metric can lead to a new luminaire classifications that is predictive of uplight



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New Specifier Report
Parking Lot and Area Luminaires

- The report lists the luminaire types, components, classifications, considerations, performance characteristics, and application issues
- Tables of luminaires from 34 manufacturers
- Testing of 23 luminaires (250-watt MH lamps with same IES classification (type III).
- Manufacturer-supplied information and test reports compared regarding type and cutoff classification.
- Luminaires analyzed using new metrics and compared in terms of luminaire efficiency, glare, light trespass, and sky glow.

www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRParking.pdf

Manufacturer Info

- Product family
- Lamp type, wattage
- IES Type
- Cutoff classification
- Optical and Mechanical

Table 11. Manufacturer-Supplied Information

Cobra Head Luminaires

Manufacturer	Product	Lamp	Wattage	Lamp Pos.	IES Lat. Dist.	Cutoff Class.	Reflector Type	Rotatable Optics	Gasket
American Electric Lighting	DuraStar 20	HPS, MH	35–175	—	II, III	—	—	—	—
American Electric Lighting	DuraStar 30	HPS, MH	200–400	—	II, III	—	—	—	—
American Electric Lighting	Roadway 115 ●	HPS, MH	35–250	—	II, III	*	—	—	—
American Electric Lighting	Roadway 315	HPS, MH	35–400	—	II, III	*	—	—	—
American Electric Lighting	Roadway 125	HPS, MH	175–400	—	II, III, IV	*	—	—	—
American Electric Lighting	Roadway 325	HPS, MH	175–400	—	II, III, IV	*	—	—	—
American Electric Lighting	Roadway 327	HPS, MH	310–400	—	I, II, III, IV	—	—	—	—
American Electric Lighting	Roadway 413	HPS, MH	35–150	—	II, III	—	—	—	—
GE Lighting Systems	M-250	HPS, MH	50–250	H	II, III, IV	NC, SC, C	—	—	—
GE Lighting Systems	M-400 ●	HPS, MH	100–400	H	II, III, IV	NC, SC, C	—	—	—
GE Lighting Systems	Solaris	HPS	70–150	H	II, III, IV	SC, C	—	—	—
Hubbell Lighting	Roadway	HPS, MH	70–400	—	II, III	NC, C	—	—	poly, silic
Lithonia Lighting	CHE	HPS	35–150	H	II, III	FC	—	—	poly
Lithonia Lighting	CHL, CHLD	HPS, MH	50–250	H	II, III	FC	—	—	poly
Lithonia Lighting	CHM, CHMD	HPS, MH	175–400	H	II, III	C, FC	—	—	poly
Lithonia Lighting	CHX	HPS	310–400	H	II, III	—	—	—	poly
Lumark	Roadway	HPS, MH	50–400	H	II, III	—	hydro	—	rubber
Lumec-Schréder	Helios	HPS, MH	70–400	H	II, III	NC, SC, C	hydro	—	silic
Streetworks	OV ●	HPS, MH	50–400	H	II, III, IV	NC, SC, C	hydro	—	—

Arm Mount Luminaires

Manufacturer	Product	Lamp	Wattage	Lamp Pos.	IES Lat. Dist.	Cutoff Class.	Reflector Type	Rotatable Optics	Gasket
American Electric Lighting	AVL	HPS, MH	250–400	V	II, III, IV	*	—	—	silic
Architectural Area Lighting	Mitre	HPS, MH	70–400	H	II, III, IV, V	FC	die, seg	—	silic
Architectural Landscape Lighting	AL-01	HPS, MH	100–400	H	II, III, V	—	seg	yes	poly
Architectural Landscape Lighting	AL-02	HPS, MH	100–400	H	II, III, V	—	seg	yes	poly
Architectural Landscape Lighting	AL-04	HPS, MH	70–175	—	II, V	—	—	—	poly
Architectural Landscape Lighting	AL-05	HPS, MH	100–400	—	II, III, V	—	seg	yes	poly
Architectural Landscape Lighting	AL-11	HPS, MH	100–400	H, V	II, III, V	—	seg	yes	poly
Architectural Landscape Lighting	AL-12	HPS, MH	100–400	—	II, III, V	—	—	yes	silic
Bega	8071, 8171	HPS, MH	100–175	H	—	*	—	—	*
Bega	8141, 8145	MH	70–150	H	—	—	—	—	silic
Bega	8381, 8383, 9372	HPS, MH	70–175	V	—	—	—	—	*
Bega	8821, 8881	HPS, MH	100	V	—	—	—	yes	—
Bega	9804, 9900, 9998	HPS, MH	50–175	V	—	*	—	—	*
Bieber Lighting	Arlington	HPS, MH	35–400	—	III, V	—	seg	—	rubber
Bieber Lighting	Century	HPS, MH	70–400	H, V	III	—	seg	—	—
Bieber Lighting	Denver	HPS, MH	50–400	H	II, III, V	—	seg	—	rubber
Bieber Lighting	Geodome	HPS, MH	70–400	H, V	II, III, V	—	seg	—	*
Bieber Lighting	Le Mans	HPS, MH	70–400	H, V	II, III, V	—	hydro, seg	—	*
Bieber Lighting	Orlando Select	HPS, MH	70–400	H, V	II, III, V	—	hydro, seg	—	rubber
Bieber Lighting	Park Circle	HPS, MH	50–400	H	II, III, V	—	seg	—	rubber

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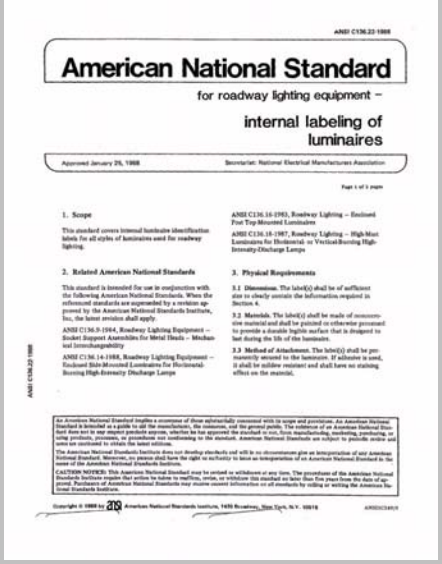
Luminaire Labeling

- Product information was incomplete or missing
  - on the luminaire
  - on the shipping box
- Some luminaires did not include
  - the model number
  - lamp type or wattage
  - name of the manufacturer
  - product family of the luminaire
- Requiring luminaires to comply with ANSI C136.22 would eliminate this problem



ANSI C136.22-1988

American National Standard

for roadway lighting equipment –

internal labeling of luminaires

Approved January 29, 1988 | Secretariat: National Electrical Manufacturers Association

Page 1 of 3 pages

1. Scope

This standard covers internal luminaire identification labels for all styles of luminaires used for roadway lighting.

2. Related American National Standards

This standard is intended for use in conjunction with the following American National Standards. When the referenced standards are superseded by a revision approved by the American National Standards Institute, Inc., the latest revision shall apply.

ANSI C136.9-1984, Roadway Lighting Equipment – Socket Support Assemblies for Metal Heads – Mechanical Interchangeability

ANSI C136.14-1988, Roadway Lighting Equipment – Enclosed Side-Mounted Luminaires For Horizontal-Burning High-Intensity Discharge Lamps

ANSI C136.15-1985, Roadway Lighting – Enclosed Post Top-Mounted Luminaires

ANSI C136.18-1987, Roadway Lighting – High-Mast Luminaires for Horizontal- or Vertical-Burning High-Intensity-Discharge Lamps

3. Physical Requirements

3.1 Dimensions. The label(s) shall be of sufficient size to clearly contain the information required in Section 4.

3.2 Materials. The label(s) shall be made of noncorrosive material and shall be painted or otherwise processed to provide a durable legible surface that is designed to last during the life of the luminaire.

3.3 Method of Attachment. The label(s) shall be permanently secured to the luminaire. If adhesive is used, it shall be sublime resistant and shall have no staining effect on the material.

ANSI C136.22-1988

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. An American National Standard is intended as a guide to all the manufacturers, the consumers, and the general public. The existence of an American National Standard does not in any respect preclude anyone, whether he has approved the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standard. American National Standards are subject to periodic review and users should ensure that they have the latest edition.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation of any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute.

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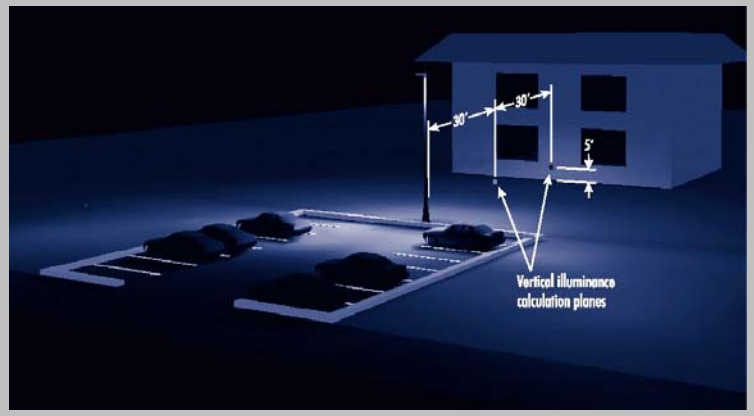
NLPIP Testing

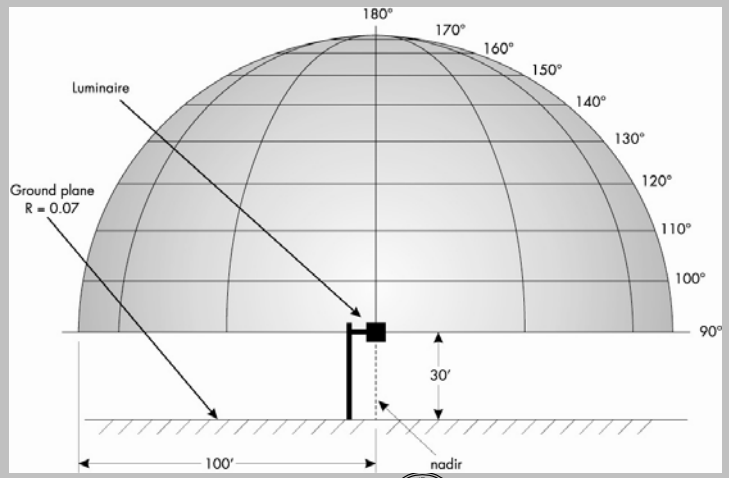
- Testing Conducted at Luminaire Testing Laboratory (LTL), Inc. located in Allentown, PA.
- The testing and reporting was based on the *IESNA Approved Method for Photometric Testing of Roadway Luminaires* (LM-31-95) and other pertinent IESNA procedures.

- Full 360° goniometric measurements were performed on the luminaires.
- The goniometric center was selected based on LM-31 guidelines.
  - flat lens luminaire or a clear drop lens luminaire, the center position was located at the center of the opening in the reflector.
  - For a luminaire with a refractor, such as a cobra head, the center position was located at the center of the refractor, both vertically and horizontally.

Analysis

- Compared manufacturer supplied data with tested data
  - Type
  - Cutoff
  - Downward efficiency
- Developed new metrics for
  - Light trespass
  - Glare
  - Uplight





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Independent Testing

- 250 watt
- Metal Halide
- IES Type III
- Luminaire Selection
- Purchased through typical distribution chains

Table 13a. NLPIP-Tested Information
Type III Luminaires with 250-W MH Lamps

Key to Abbreviations, p. 32

	Manufacturer	Product	Lamp Pos.	Cutoff Classification: Mfr. Claim	Cutoff Classification: Mfr. IES File	Cutoff Classification: Test Report	Max. Lum. Inten. ≥ 90° (%)	GZ Max. Lum. Inten. (%)	GZ Lum. Flux (%)	IES Lat. Dist.	IES Vert. Dist.	Efficiency: Down (%)	Efficiency: Up (%)	Efficiency: Total (%)
Cobra Head	American Electric Lighting	Roadway 115	H	–	C	C	2.1	6.4	2.7	II [a]	S	83.8	3.1	86.9
	GE Lighting Systems	M-400 (cutoff opt.)	H	FC	FC	FC	0.0	1.6	0.3	III	M	88.6	0.0	88.6
	GE Lighting Systems	M-400	H	SC	SC	SC	1.6	11.6	2.1	III	S	80.2	2.0	82.2
	Streetworks	OV (F Flat Glass)	H	C	C [a]	FC	0.0	1.7	0.1	I	M	88.7	0.0	88.7
Arm Mount	Gardco Lighting	Gullwing	H	–	FC	FC	0.0	1.3	0.2	III	S	80.3	0.0	80.3
	GE Lighting Systems	Dimension	H	C	FC	SC [d]	0.0	10.5 [d]	0.4	III	M	77.9	0.0	77.9
	Kim Lighting	Archetype	H	C	FC	FC	0.0	1.1	0.2	III	S	81.4	0.0	81.4
	Kim Lighting	Curvilinear	H	C	FC	FC	0.0	1.5	0.2	III	S	83.3	0.0	83.3
	LSI Lighting Systems	Hilton	V	FC	FC [c]	FC	0.0	4.2	0.4	III	S	54.8	0.0	54.8
	Lumark	Hammer	H	–	C [c]	FC	0.0	7.8	0.6	II [f]	S	79.5	0.0	79.5
	Lumec-Schréder	Citea	V	C	C	SC [d]	0.2	10.1 [d]	1.0	III	M	72.9	0.1	73.0
	Ruud Lighting	S3V (2)	V	–	FC [b]	FC	0.0	2.8	0.4	III	S	75.6	0.0	75.6
	Spaulding Lighting	Proformer	V	FC	C [b]	FC	0.0	4.4	0.2	II	S	58.4	0.0	58.4
	Stonco Lighting	SVL	V	–	FC [b]	FC	0.0	1.1	0.2	II	S	76.2	0.0	76.2
	Visionaire Lighting	Toronto	H	–	C [b]	FC	0.0	1.7	0.0	II	S	88.6	0.0	88.6
	Wide-Lite	Effex	H	FC	C	FC	0.0	1.9	0.1	IV [g]	S	75.1	0.0	75.1
Post-top	Bieber Lighting	PCV	V	–	NC [b]	FC	0.0	3.4	0.5	II [h]	S	60.7	0.0	60.7
	Emco Lighting	Ecoround (ERP)	H	C	FC	FC	0.0	7.8	0.4	III	M	69.8	0.0	69.8
	ExceLine	VertiLyte Tenon	V	–	SC [b]	SC	1.9	10.7	1.0	III	S	67.6	0.1	67.7
	Holophane	PoleStar II	H	C	C	C	0.3	2.1	0.4	III	S	75.0	0.4	75.4
	Stemer Lighting Systems	Berkley-21	H	FC	SC	SC	0.1	15.0	0.5	III	M	71.6	0.2	71.8
	U.S. Architectural Lighting	SVLPT222	V	–	C	FC	0.0	9.3	1.3	III	S	66.7	0.0	66.7
	Wide-Lite	Effex	V	C	FC	NC	0.9	34.5	4.5	IV	M	74.3	0.1	74.4

Notes

[a] 250-W HPS
[b] 400-W MH
[c] 175-W MH
[d] May be cutoff fixtures. Measurement of the maximum intensity at or above 90° exceeds the 10% limit, but falls within the uncertainty of the measurement system.
[e] On boundary with Type III
[f] If categorized as very short, would be Type I
[g] If categorized as very short, would be Type III
[h] On boundary with Type I

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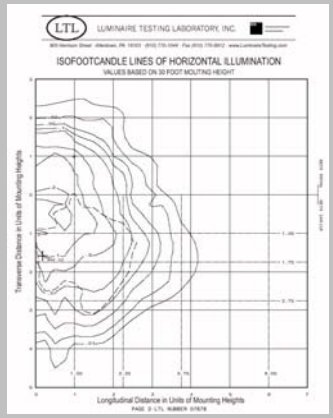
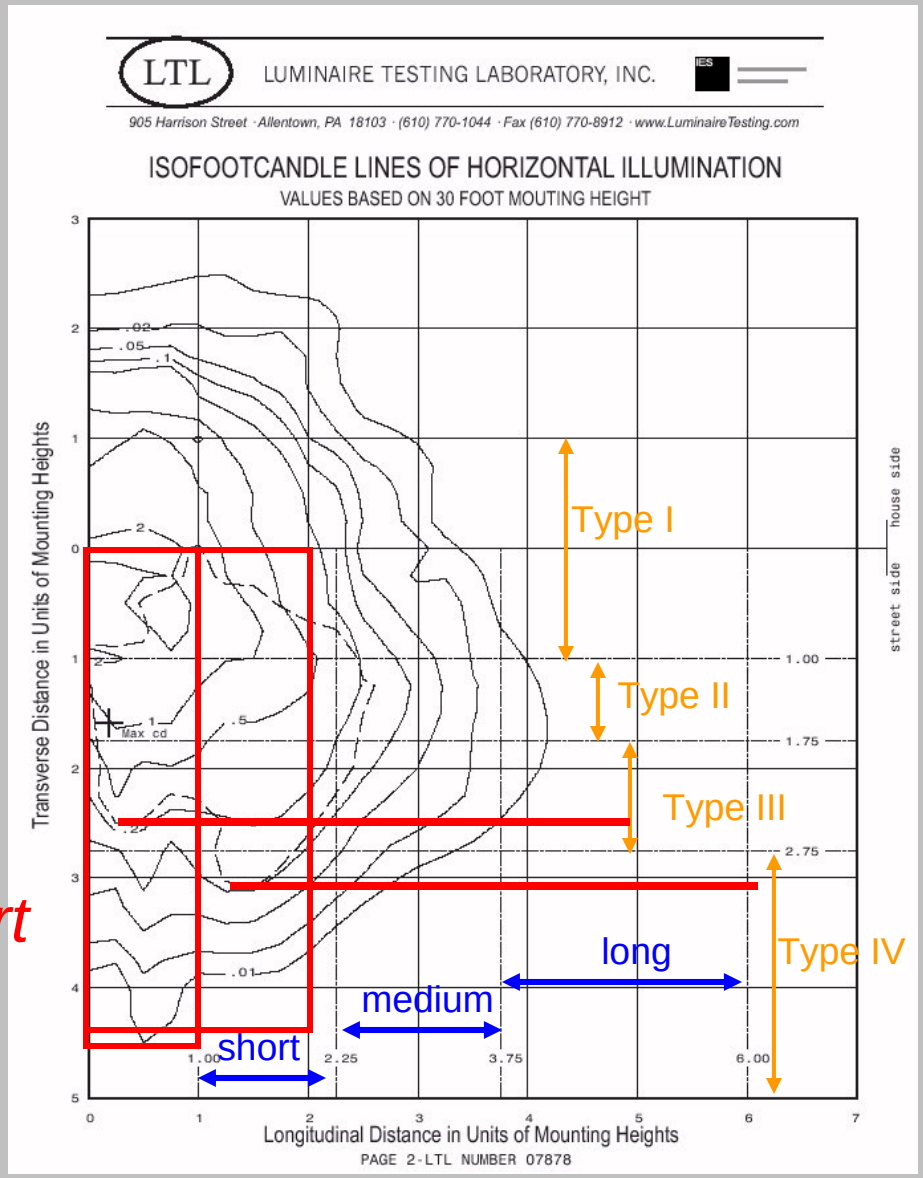
Light Distribution

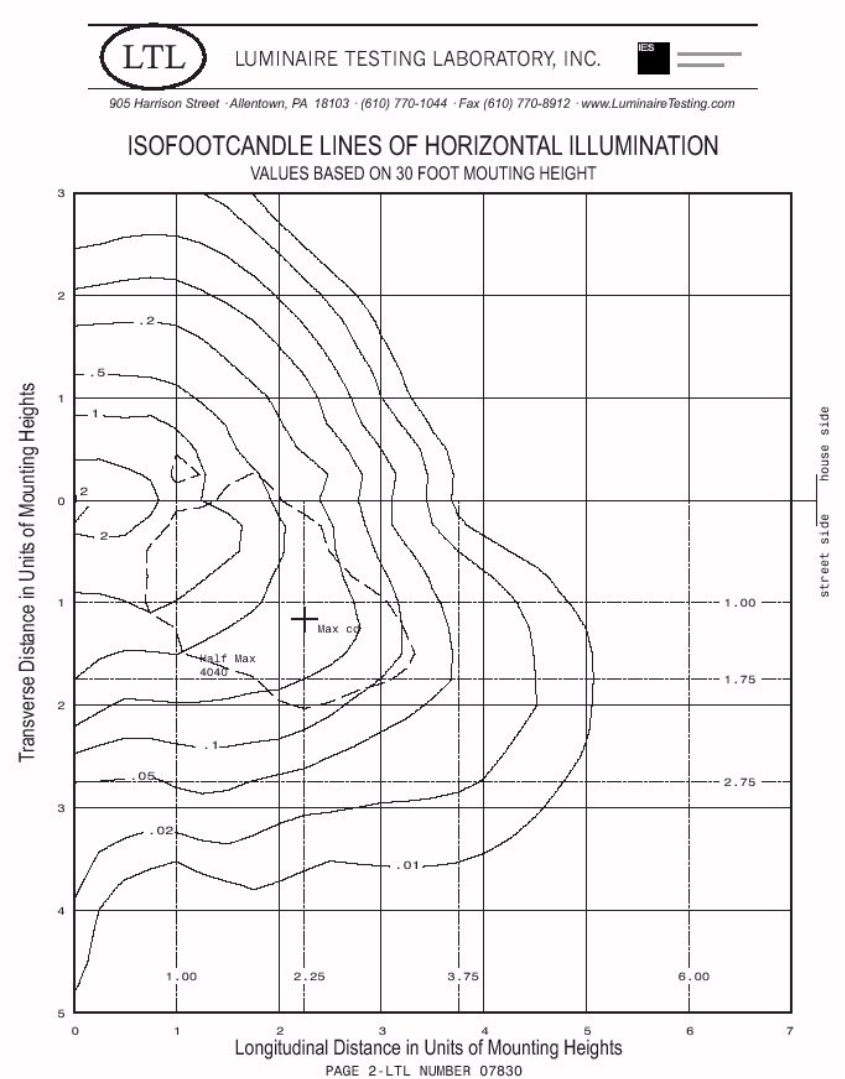


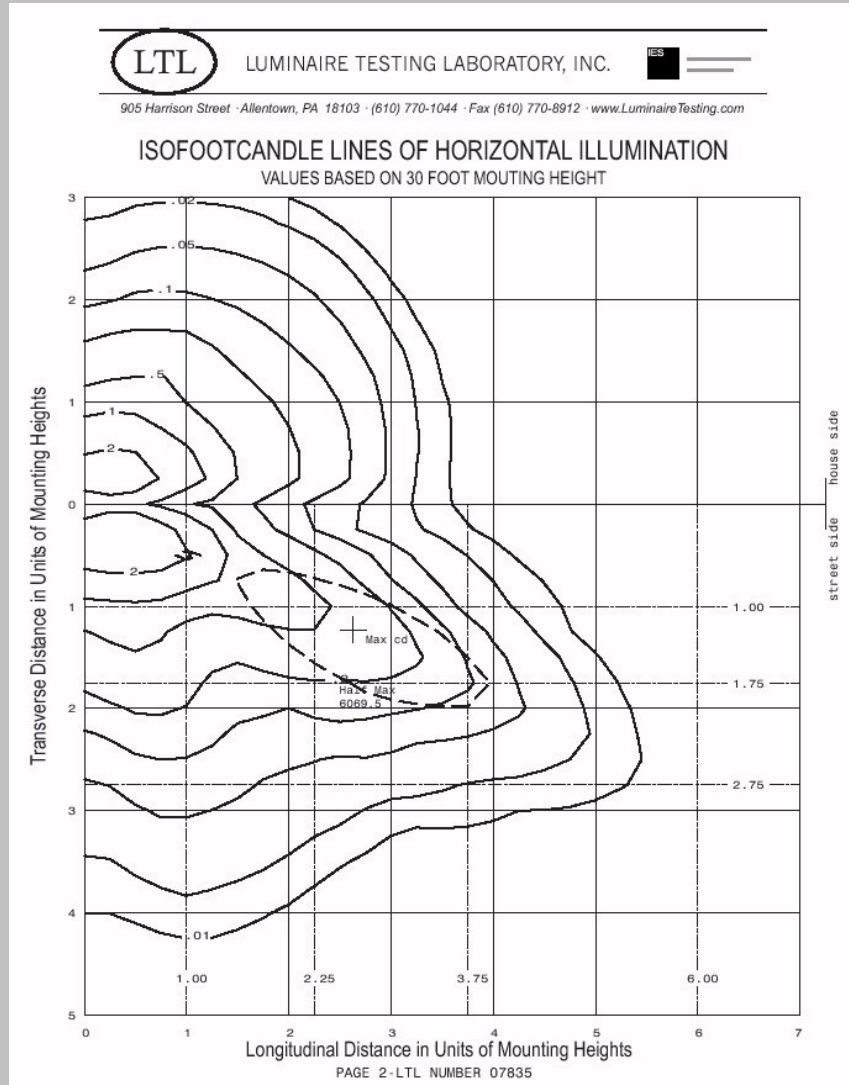
- Of the 23 luminaires tested, NLPIP found that 14 were Type III
  - When ordering the luminaire, the type is almost always in the product #
- 9 luminaires had distributions of Type I, II, and IV
- For 2 luminaires, the location of the half-maximum isointensity trace lies on the boundary with another distribution.
- No information to indicate whether a Type III, falls in the middle of the range or at the edge. It also provides no information about the vertical distribution used to make the determination.

Determining Type



Type III Medium





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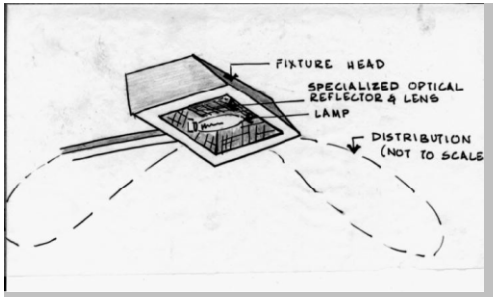
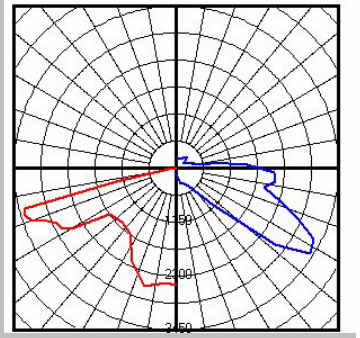


Cutoff Classification



- Three methods of determining cutoff classification:
  - manufacturer's claim in literature
  - manufacturer's photometric files
  - independent test report
- All three values agreed for only 4 luminaires
- Manufacturer photometric files and independent test reports agreed for 13 luminaires.
- Eight luminaires met a more stringent cutoff classification than the one claimed by either the manufacturers' literature or photometric files.
- Sometimes a photometric file for a 250-watt MH lamp luminaire was not available.
  - higher or lower wattage
  - different lamp type

Downward Efficiency

Table 2. Average Downward Efficiency (by luminaire type)

Luminaire Type	Average Downward Efficiency (% of lamp luminous flux)	Range of Downward Efficiency (% of lamp luminous flux)
Cobra Head	85	80–89
Arm Mount	75	55–89
Post-top	71	61–83

Table 3. Average Downward Efficiency (by lamp orientation)

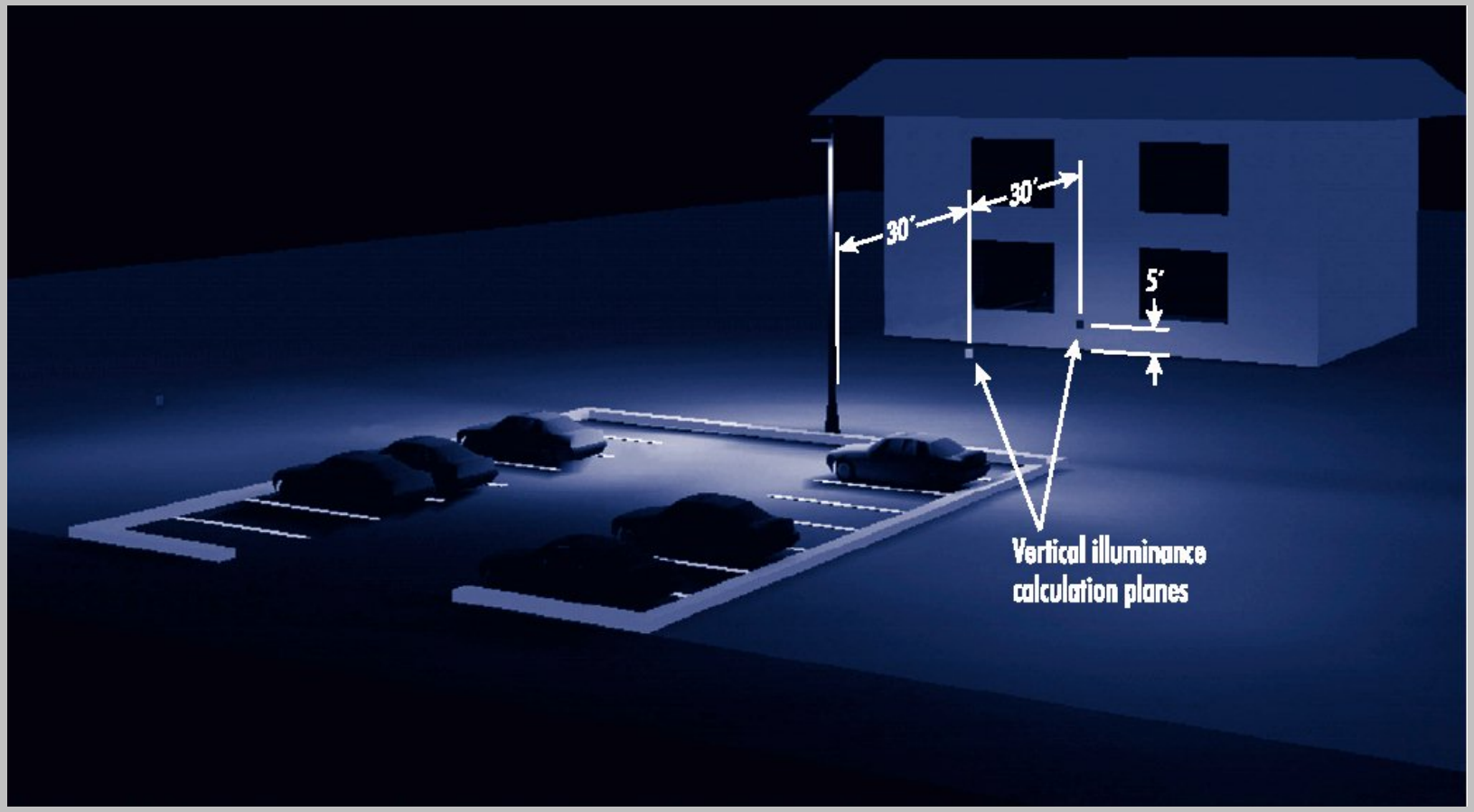
Lamp Orientation	Average Downward Efficiency (% of lamp luminous flux)	Range of Downward Efficiency (% of lamp luminous flux)
Horizontal	80	70–89
Vertical	68	55–76

Downward Efficiency

- When NLPIP compared photometric data provided by the manufacturers and the testing laboratory, close agreement between only 14 of the 23 tested luminaires.

- Manufacturer-reported data are not always a reliable source of information for comparing luminaires for downward efficiency.

Light Trespass Analysis



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Light Trespass indicated by Vertical Illuminance

- Large variation for
  - Type
  - Cutoff
  - Lamp Orientation
- Light trespass is highly dependent on factors such as mounting height, orientation, location, and site topography

Table 6. Vertical Illuminance Behind a Luminaire That May Indicate Light Trespass

Distance Behind Luminaire	Average Vertical Illuminance, 5′ above the ground (lux)	Range of Vertical Illuminance, 5′ above the ground (lux)
30′ or 1 MH	8.5	3.6–13.4
60′ or 2 MH	2.9	0.4–10.0

Glare

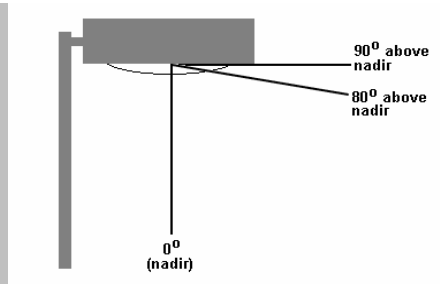

Table 5. Glare Zone Maximum Luminous Intensity

Tested Cutoff Classification	Avg. Max. Luminous Intensity, 80°-90° (% of lamp luminous flux)	Range of Max. Luminous Intensity, 80°- 90° (% of lamp luminous flux)
Semicutoff	11.6	10.1–15.0
Cutoff	4.2	2.1–6.4
Full Cutoff	3.4	1.1–9.3

Table 4. Glare Zone Luminous Flux

Tested Cutoff Classification	Avg. Glare Zone Luminous Flux, 80°-90° (% of lamp luminous flux)	Range of Glare Zone Luminous Flux, 80°- 90° (% of lamp luminous flux)
Semicutoff	1.0	0.4–2.1
Cutoff	1.5	0.4–2.7
Full Cutoff	0.3	0.0–1.3

Table 13a. NLPIP-Tested Information

Type III Luminaires with 250-W MH Lamps

Key to Abbreviations, p. 32

	Manufacturer	Product	Lamp Pos.	Cutoff Classification: Mfr. Claim	Cutoff Classification: Mfr. IES File	Cutoff Classification: Test Report	Max. Lum. Inten. ≥ 90° (%)	GZ Max. Lum. Inten. (%)	GZ Lum. Flux (%)	IES Lat. Dist.	IES Vert. Dist.	Efficiency: Down (%)	Efficiency: Up (%)	Efficiency: Total (%)
Cobra Head	American Electric Lighting	Roadway 115	H	–	C	C	2.1	6.4	2.7	II [a]	S	83.8	3.1	86.9
	GE Lighting Systems	M-400 (cutoff opt.)	H	FC	FC	FC	0.0	1.6	0.3	III	M	88.6	0.0	88.6
	GE Lighting Systems	M-400	H	SC	SC	SC	1.6	11.6	2.1	III	S	80.2	2.0	82.2
	Streetworks	OV (F Flat Glass)	H	C	C [a]	FC	0.0	1.7	0.1	I	M	88.7	0.0	88.7
Arm Mount	Gardco Lighting	Gullwing	H	–	FC	FC	0.0	1.3	0.2	III	S	80.3	0.0	80.3
	GE Lighting Systems	Dimension	H	C	FC	SC [d]	0.0	10.5 [d]	0.4	III	M	77.9	0.0	77.9
	Kim Lighting	Archetype	H	C	FC	FC	0.0	1.1	0.2	III	S	81.4	0.0	81.4
	Kim Lighting	Curvilinear	H	C	FC	FC	0.0	1.5	0.2	III	S	83.3	0.0	83.3
	LSI Lighting Systems	Hilton	V	FC	FC [c]	FC	0.0	4.2	0.4	III	S	54.8	0.0	54.8
	Lumark	Hammer	H	–	C [c]	FC	0.0	7.8	0.6	II [f]	S	79.5	0.0	79.5
	Lumec-Schréder	Citea	V	C	C	SC [d]	0.2	10.1 [d]	1.0	III	M	72.9	0.1	73.0
	Ruud Lighting	S3V (2)	V	–	FC [b]	FC	0.0	2.8	0.4	III	S	75.6	0.0	75.6
	Spaulding Lighting	Proformer	V	FC	C [b]	FC	0.0	4.4	0.2	II	S	58.4	0.0	58.4
	Stonco Lighting	SVL	V	–	FC [b]	FC	0.0	1.1	0.2	II	S	76.2	0.0	76.2
	Visionaire Lighting	Toronto	H	–	C [b]	FC	0.0	1.7	0.0	II	S	88.6	0.0	88.6
	Wide-Lite	Effex	H	FC	C	FC	0.0	1.9	0.1	IV [g]	S	75.1	0.0	75.1
Post-top	Bieber Lighting	PCV	V	–	NC [b]	FC	0.0	3.4	0.5	II [b]	S	60.7	0.0	60.7
	Emco Lighting	Ecoround (ERP)	H	C	FC	FC	0.0	7.8	0.4	III	M	69.8	0.0	69.8
	ExceLine	VertiLyte Tenon	V	–	SC [b]	SC	1.9	10.7	1.0	III	S	67.6	0.1	67.7
	Holophane	PoleStar II	H	C	C	C	0.3	2.1	0.4	III	S	75.0	0.4	75.4
	Steiner Lighting Systems	Berkley-21	H	FC	SC	SC	0.1	15.0	0.5	III	M	71.6	0.2	71.8
	U.S. Architectural Lighting	SVLPT222	V	–	C	FC	0.0	9.3	1.3	III	S	66.7	0.0	66.7
	Wide-Lite	Effex	V	C	FC	NC	0.9	34.5	4.5	IV	M	74.3	0.1	74.4

Notes

[a] 250-W HPS

[b] 400-W MH

[c] 175-W MH

[d] May be cutoff fixtures. Measurement of the maximum intensity at or above 90° exceeds the 10% limit, but falls within the uncertainty of the measurement system.

[e] On boundary with Type III

[f] If categorized as very short, would be Type I

[g] If categorized as very short, would be Type III

[h] On boundary with Type I

- aires was
- Table)

t Uplight Luminous Flux mp luminous flux)
0.0–2.0
0.4–3.1
0.0

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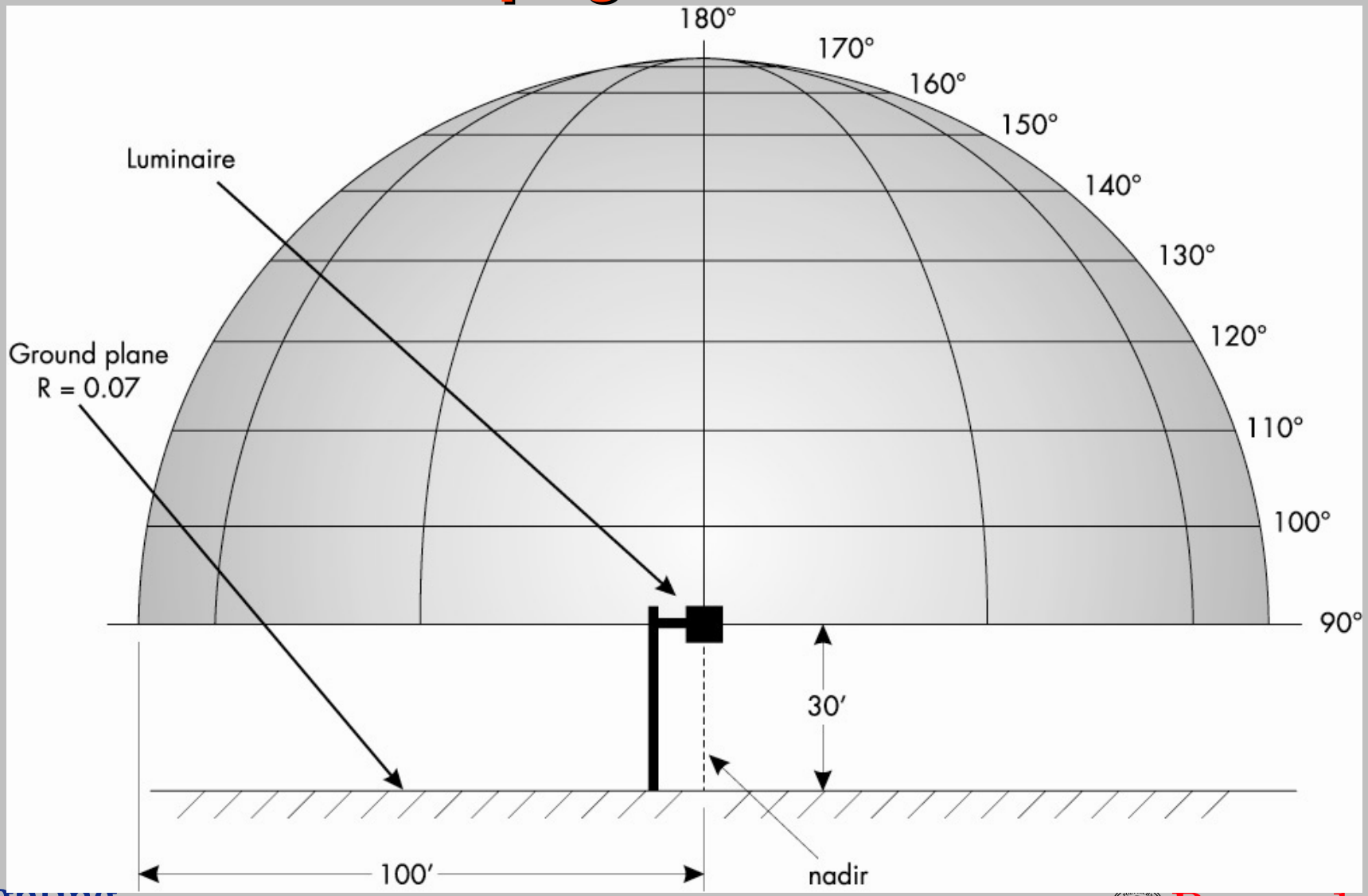
Uplight Metric



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Unlight Demo Metric Results

Table 13a. NLPIP-Tested Information
Type III Luminaires with 250-W MH Lamps

(Key to Abbreviations, p. 32)

	Manufacturer	Product	Lamp Pos.	Cutoff Classification: Mfr. Claim	Cutoff Classification: Mfr. IES File	Cutoff Classification: Test Report	Max. Lum. Inten. ≥ 90° (%)	GZ Max. Lum. Inten. (%)	GZ Lum. Flux (%)	IES Lat. Dist.	IES Vert. Dist.	Efficiency: Down (%)	Efficiency: Up (%)	Efficiency: Total (%)
Cobra Head	American Electric Lighting	Roadway 115	H	–	C	C	2.1	6.4	2.7	II [e]	S	83.8	3.1	86.9
Cobra Head	GE Lighting Systems	M-400 (cutoff opt.)	H	FC	FC	FC	0.0	1.6	0.3	III	M	88.6	0.0	88.6
Cobra Head	GE Lighting Systems	M-400	H	SC	SC	SC	1.6	11.6	2.1	III	S	80.2	2.0	82.2
Cobra Head	Streetworks	OV (F Flat Glass)	H	C	C [a]	FC	0.0	1.7	0.1	I	M	88.7	0.0	88.7
Arm Mount	Gardco Lighting	Gullwing	H	–	FC	FC	0.0	1.3	0.2	III	S	80.3	0.0	80.3
Arm Mount	GE Lighting Systems	Dimension	H	C	FC	SC [d]	0.0	10.5 [d]	0.4	III	M	77.9	0.0	77.9
Arm Mount	Kim Lighting	Archetype	H	C	FC	FC	0.0	1.1	0.2	III	S	81.4	0.0	81.4
Arm Mount	Kim Lighting	Curvilinear	H	C	FC	FC	0.0	1.5	0.2	III	S	83.3	0.0	83.3
Arm Mount	LSI Lighting Systems	Hilton	V	FC	FC [c]	FC	0.0	4.2	0.4	III	S	54.8	0.0	54.8
Arm Mount	Lumark	Hammer	H	–	C [c]	FC	0.0	7.8	0.6	II [f]	S	79.5	0.0	79.5
Arm Mount	Lumec-Schréder	Citea	V	C	C	SC [d]	0.2	10.1 [d]	1.0	III	M	72.9	0.1	73.0
Arm Mount	Ruud Lighting	S3V (2)	V	–	FC [b]	FC	0.0	2.8	0.4	III	S	75.6	0.0	75.6
Arm Mount	Spaulding Lighting	Proformer	V	FC	C [b]	FC	0.0	4.4	0.2	II	S	58.4	0.0	58.4
Arm Mount	Stonco Lighting	SVL	V	–	FC [b]	FC	0.0	1.1	0.2	II	S	76.2	0.0	76.2
Arm Mount	Visionaire Lighting	Toronto	H	–	C [b]	FC	0.0	1.7	0.0	II	S	88.6	0.0	88.6
Arm Mount	Wide-Lite	Effex	H	FC	C	FC	0.0	1.9	0.1	IV [g]	S	75.1	0.0	75.1
Post-top	Bieber Lighting	PCV	V	–	NC [b]	FC	0.0	3.4	0.5	II [h]	S	60.7	0.0	60.7
Post-top	Emco Lighting	Ecoround (ERP)	H	C	FC	FC	0.0	7.8	0.4	III	M	69.8	0.0	69.8
Post-top	ExceLine	VertiLyte Tenon	V	–	SC [b]	SC	1.9	10.7	1.0	III	S	67.6	0.1	67.7
Post-top	Holophane	PoleStar II	H	C	C	C	0.3	2.1	0.4	III	S	75.0	0.4	75.4
Post-top	Sterner Lighting Systems	Berkley-21	H	FC	SC	SC	0.1	15.0	0.5	III	M	71.6	0.2	71.8
Post-top	U.S. Architectural Lighting	SVLPT222	V	–	C	FC	0.0	9.3	1.3	III	S	66.7	0.0	66.7
Post-top	Wide-Lite	Effex	V	C	FC	NC	0.9	34.5	4.5	IV	M	74.3	0.1	74.4

Notes

[a] 250-W HPS
[b] 400-W MH
[c] 175-W MH
[d] May be cutoff fixtures. Measurement of the maximum intensity at or above 90° exceeds the 10% limit, but falls within the uncertainty of the measurement system.
[e] On boundary with Type III
[f] If categorized as very short, would be Type I
[g] If categorized as very short, would be Type III
[h] On boundary with Type I

How would you use this in practice?

- Design the installation to determine # of luminaires
- Multiply # of luminaires by the lamp lumens
- Multiply by the uplight percentage

Uplight = #luminaires X lamp lumens x uplight (%)

Direct and Reflected Light

Table 7. Direct Uplight as a Function of Tested Cutoff Classification

Tested Cutoff Classification	Average Direct Uplight Luminous Flux (% of lamp luminous flux)	Range of Direct Uplight Luminous Flux (% of lamp luminous flux)
Semicutoff	0.5	0.0–2.0
Cutoff	1.7	0.4–3.1
Full Cutoff	0.0	0.0

- ***Reflected light contributes more to uplight***

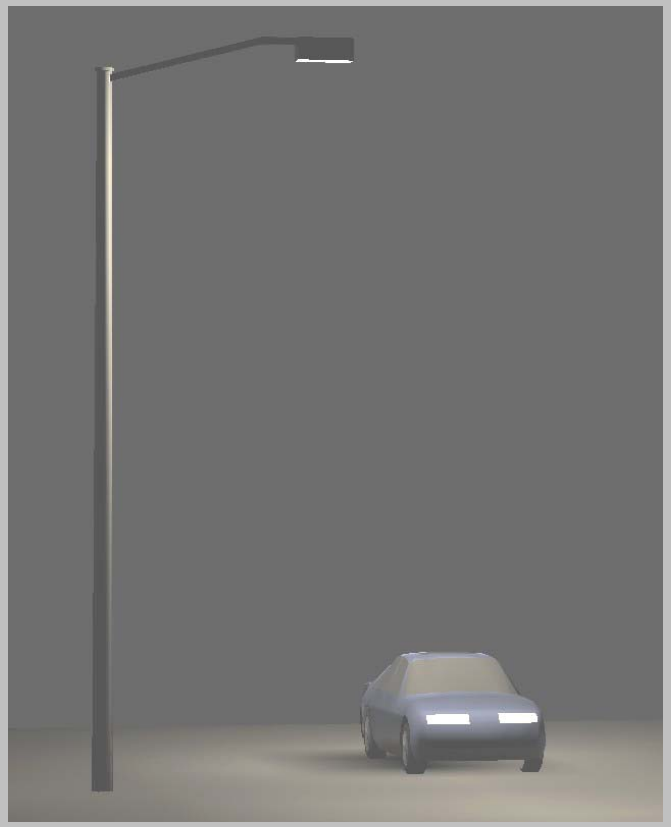
Table 10. Average Uplight Values as a Function of Tested Cutoff Classification

Tested Cutoff Classification	Total Uplight Luminous Flux (% of lamp luminous flux)	Range of Total Uplight Luminous Flux (% of lamp luminous flux)
Semicutoff	4.3	3.2–6.7
Cutoff	6.6	4.7–8.4
Full Cutoff	4.1	2.8–5.0

NLPIP Specifier Report Conclusions

- Manufacturer reported info and test info don't always agree for type, cutoff, and downward efficiency
- Reflected light contributes more to uplight than direct uplight for the luminaires tested
- Luminous intensity does not indicate amount of luminous flux

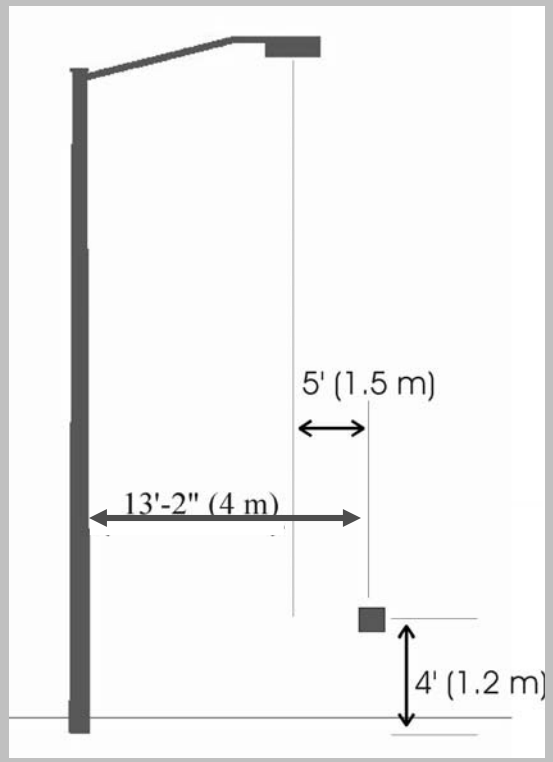
Veiling Luminance (Glare) from Roadway Lighting

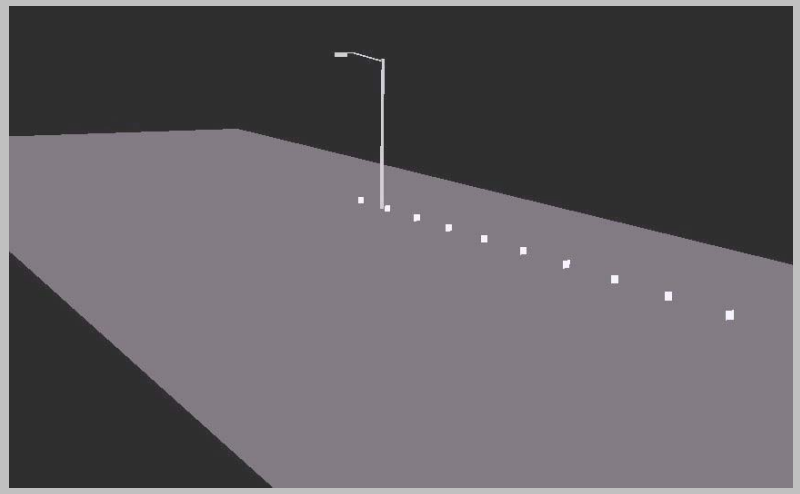


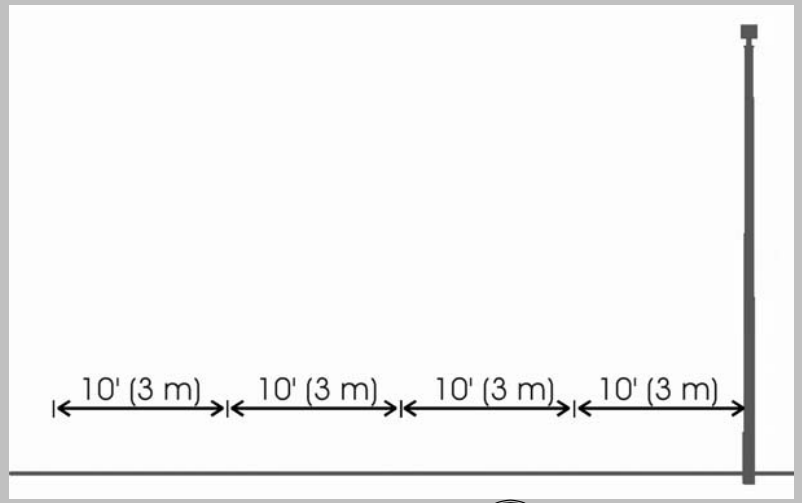
- *Are cutoff classifications predictive of the overall glare?*
- Evaluate veiling luminance as a driver approaches streetlights
  - Computer simulation using IES files of luminaires
- Veiling luminance calculated at difference distances from the luminaire
- 18 fixtures compared
  - 4 full cutoff, 7 cutoff, 7 semicutoff
  - 250 W, 27' mounting height

McColgan and Van Derlofske, 2004

Geometry







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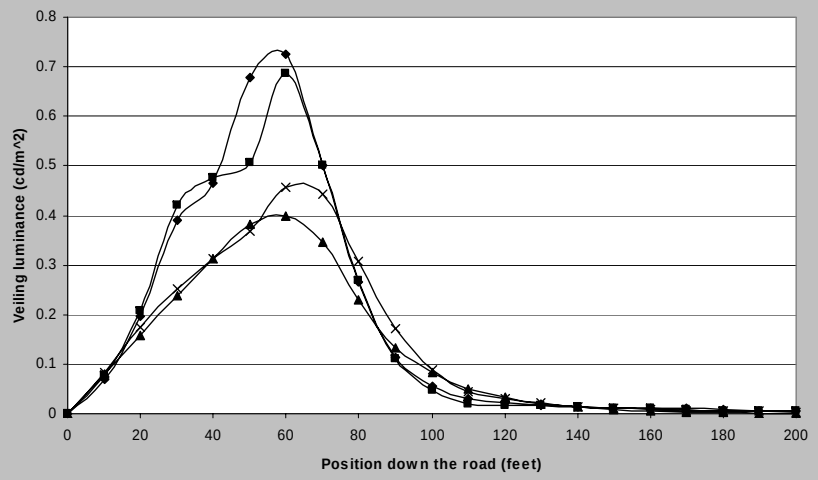
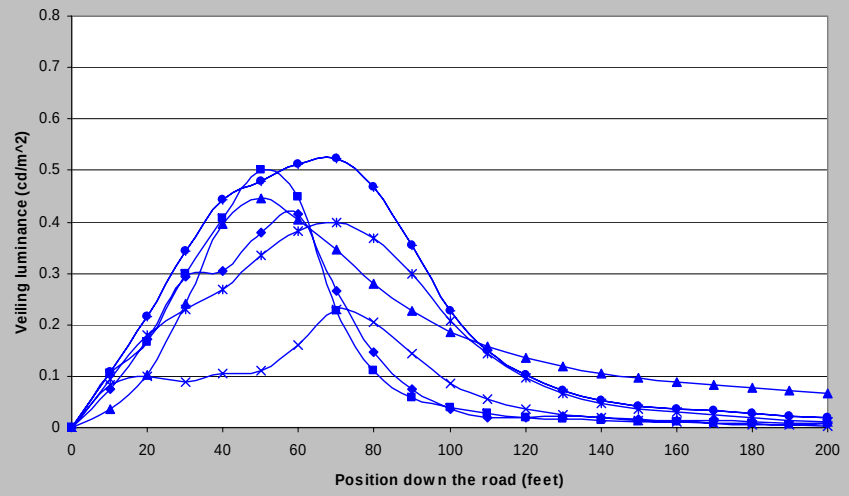
Calculations

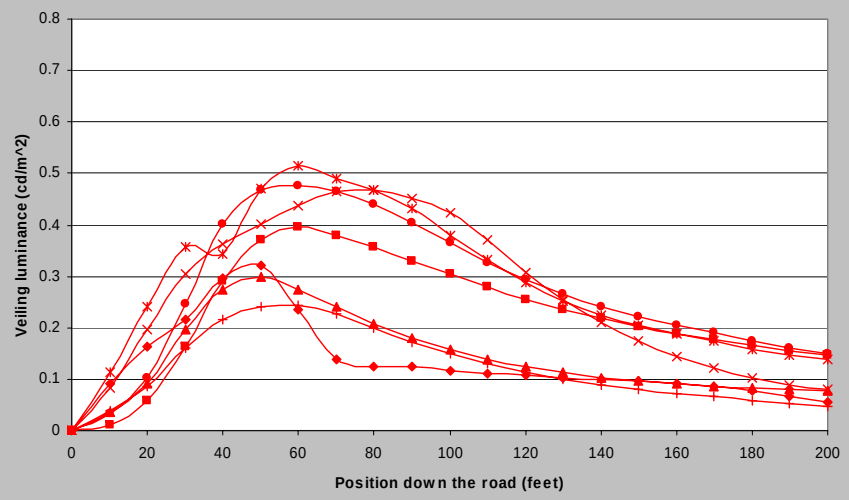
$$L_{veil} = \frac{E_{glare} \cdot 10}{\theta^2}$$



Full cutoff fixtures



Cutoff fixtures



Semicutoff fixtures

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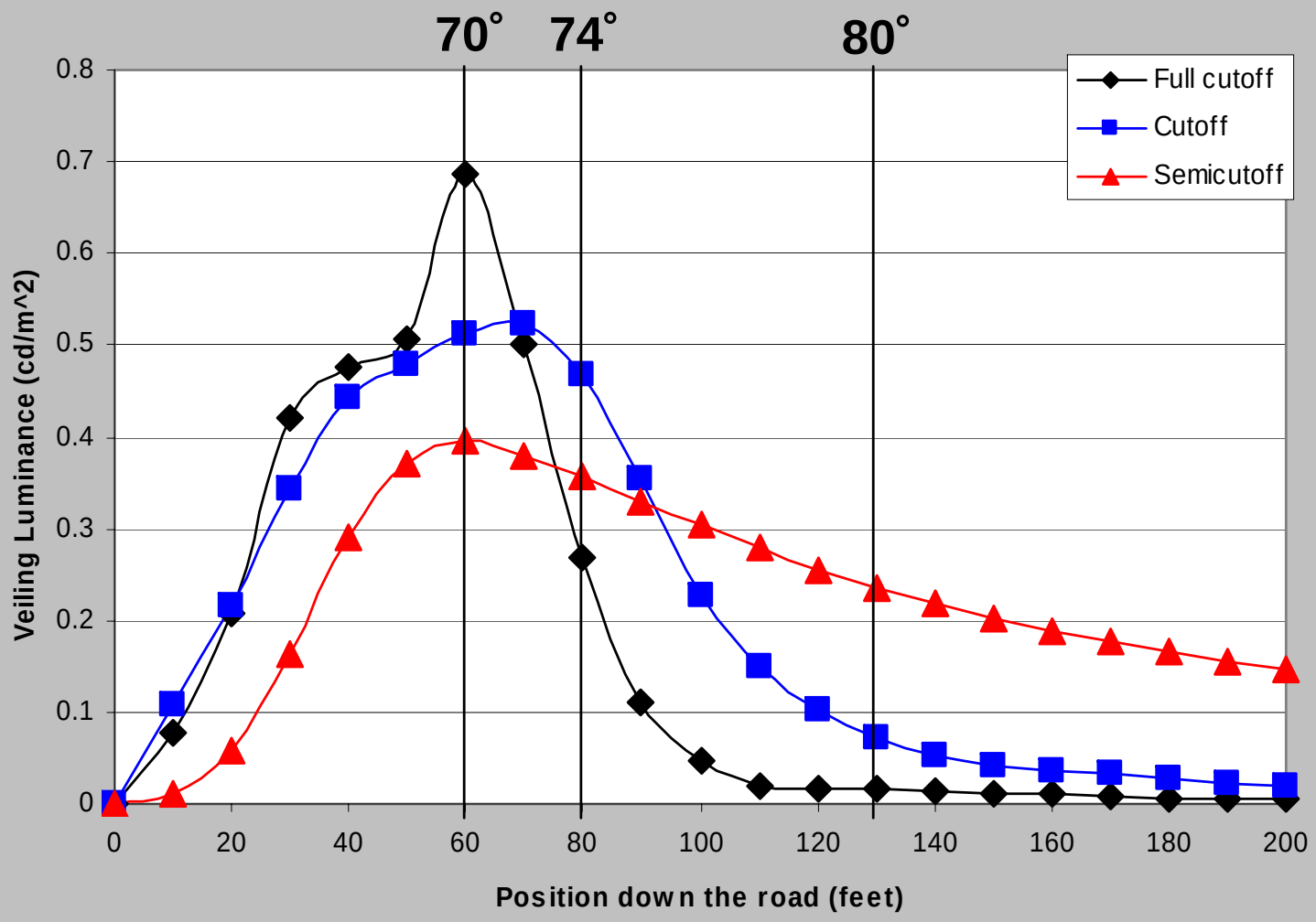
Cutoff Classifications



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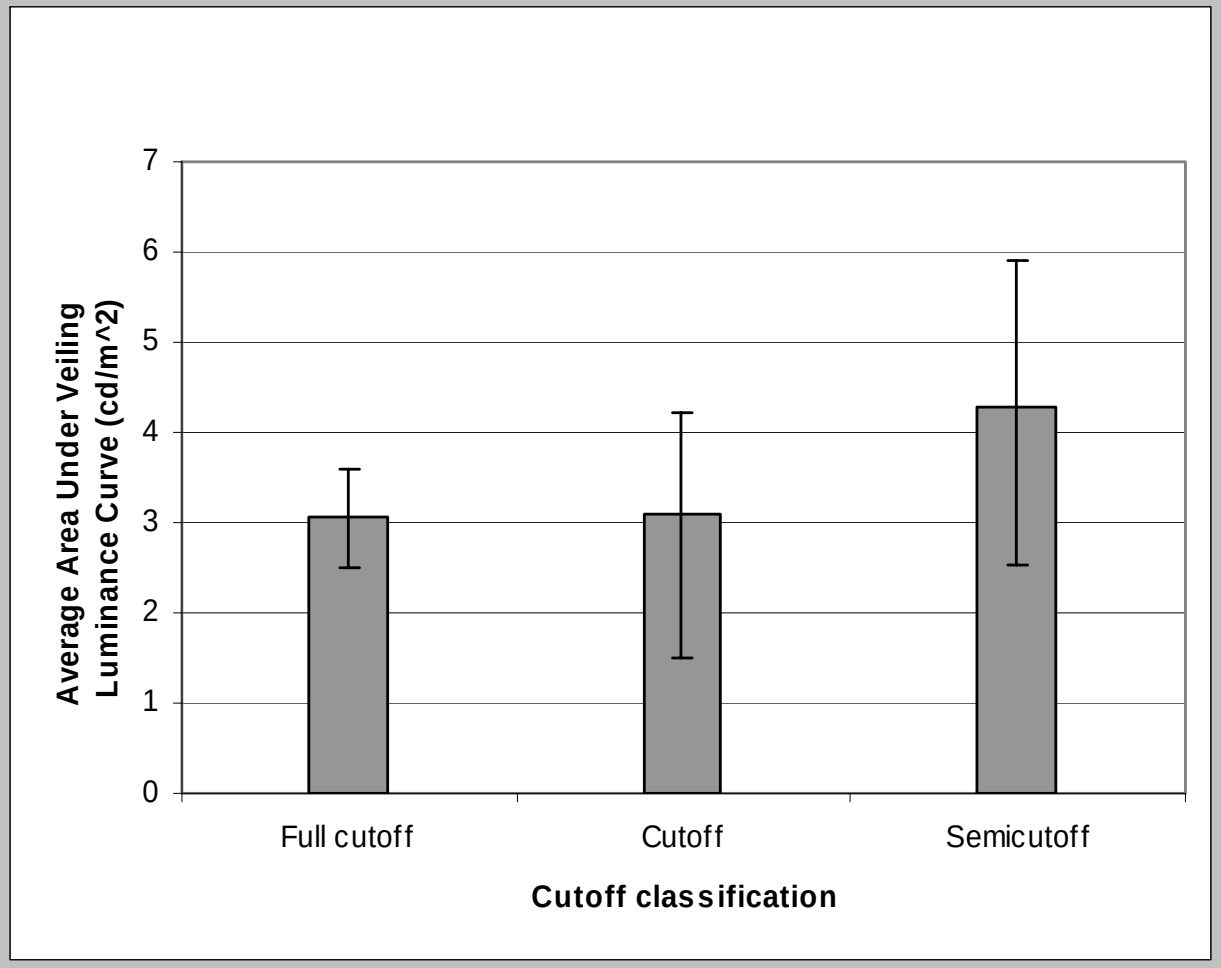
Overall Glare "Dosage"

Area under Each Veiling Luminance Curve



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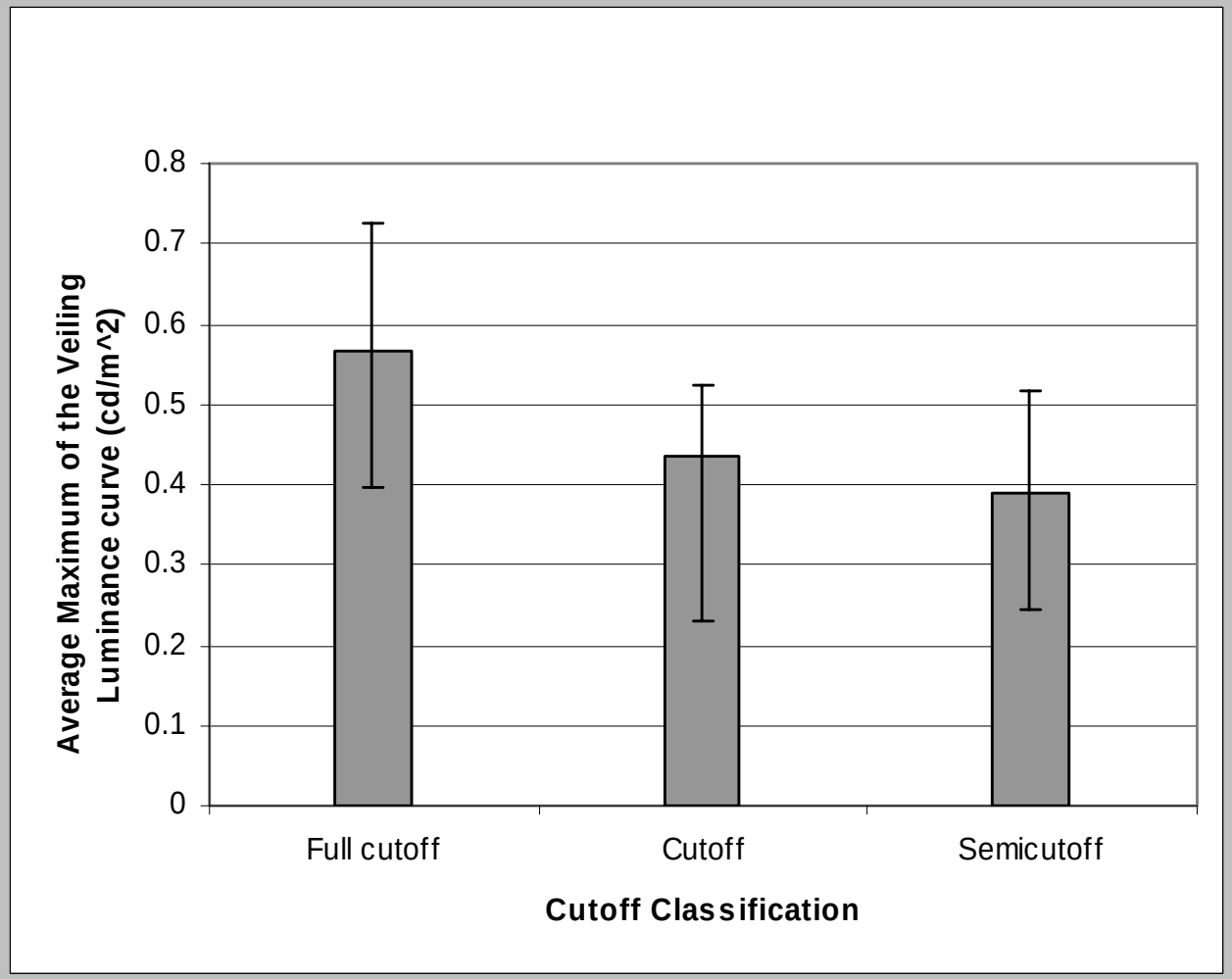
Maximum Value of Glare



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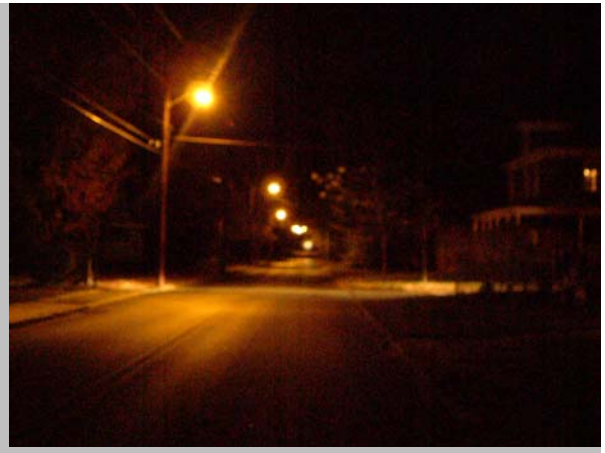
Veiling Luminance (Glare) from Roadway Lighting

- A new luminaire classification is needed to describe glare
  - Cutoff classification is predictive of the amount of glare far from the fixture
  - Cutoff classifications are *not* predictive of the relative amount of glare produced near the fixture
  - Cutoff classifications are *not* predictive of the total glare dosage
- This has impacts on disability glare and re-adaptation time
  - Both can adversely impact visual performance

How to Strike the Right Balance



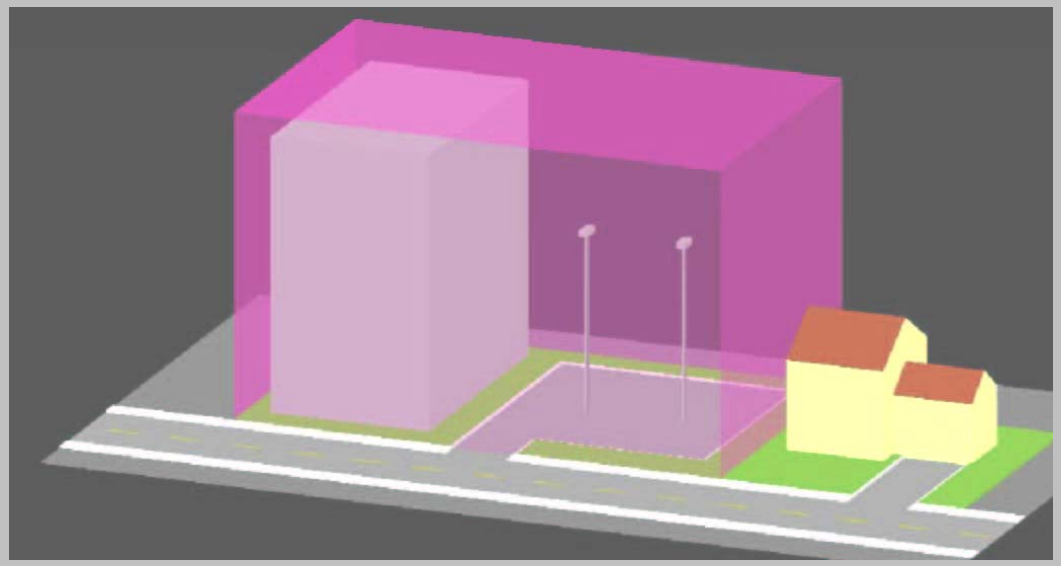
- Increased nighttime lighting and awareness of light pollution issues has led to calls for a reduction in outdoor lighting
- Conflicting opinion exists on actions necessary to reduce light pollution
  - Inadequate metrics and measurement methods are a main cause of this problem
- A new accepted industry metric is needed

The Shoebox Metric

- A comprehensive framework for quantifying light pollution is needed that:
  - Acts to reduce glare and light trespass and sky glow
  - Is general enough to be applied to large areas, such as a city, yet specific enough to be applied to a particular lighting installation
  - Is flexible enough to allow for different preferences in different localities
  - Allows compliance with regulations to be predicted at the design stage of an installation
  - Is simple to understand and easy to apply
  - Is outcome-based not equipment-based

How to Use the Shoebox

- Set up the virtual “shoebox” around the property
- The virtual “shoebox” has vertical sides at the property boundary and a flat “ceiling” at a fixed distance above the highest mounted luminaire
- For each Environmental Zone, specify the maximum illuminances to different parts of the “shoebox” by the proposed lighting installation



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Justification

- The environmental zone chosen is an indication of the priority given to limiting light pollution
  - Should be up to the local authorities
- Simple way to deal with sky glow, light trespass, and glare produced by an individual installation
- Flexible enough to handle specifics of each site
- Compliance can be determined by calculation prior to construction
- Curfews easily applied by adjusting the allowed maximum illuminances

Spectrum – Light Levels

- The spectral (color) content of a light source affects visibility at night.
- At daytime levels, only the cone photoreceptors in the eye contribute directly to seeing (known as *photopic* vision).
- At very low levels close to complete darkness, only rods contribute to seeing (*scotopic* vision).
- At light levels typically selected for outdoor area and street lighting, both rods and cones contribute to seeing (*mesopic* vision).
- The rods are more sensitive to shorter ("blue-green") wavelengths of light than the combined response of the cones, so as light levels decrease, the visual system's spectral sensitivity shifts toward the shorter wavelengths.

Spectrum –Off-Axis Vision

MH

HPS

- Light measurements based on the photopic (cone) spectral response do not accurately characterize light at low, mesopic light levels.
- At these levels, lamps with a greater proportion of output in the "blue-green" region of the spectrum result in increased peripheral (off-axis) visibility (e.g., object detection) compared to lamps with little output in this spectral region.
  - This is true even when they produce equal photopic light levels.
- This applies only to off-axis vision, because there are no rods located in the central part of the retina, which provides on-axis vision.
- For on-axis visual tasks such as steering a vehicle into a parking space or reading a sign, photopic light quantities are an accurate specification of objects in the lighted environment.

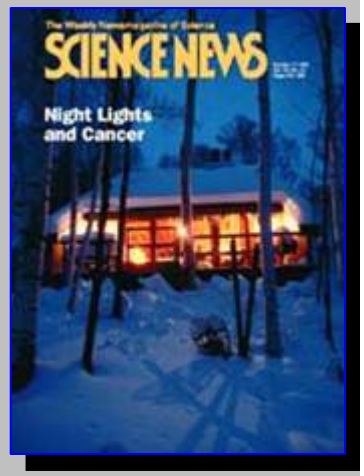
Spectrum
Visibility and Energy Efficiency

- With respect to HPS and MH lamps, for two installations providing equal (photopic) light levels at night,
  - peripheral (off-axis) detection of objects is better under the MH lamp,
  - foveal (on-axis – reading a sign) detection would be equal under each lamp.
- HPS lamps are rated slightly more energy efficient than MH lamps
  - MH lamps might be more energy efficient at providing off-axis visibility.
  - HPS lamps will always be more energy efficient than MH lamps for providing on-axis visibility.

Breast Cancer

Standardized Incidence Ratios

	SIR
▪ Blind women	
– USA (Hahn, 1991)	0.5
▪ Flight attendants	
– Finland (Pukkala et al., 1995)	1.9
▪ Shift workers (Hansen, 2001)	
– Daytime work	1.0
– Nightime, ll trades combined	1.5
(Manufacturing, transportation, catering)	



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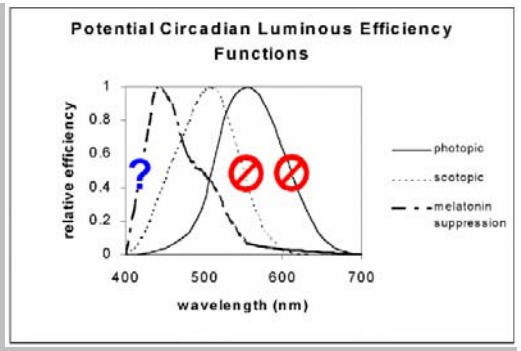
Breast Cancer



- Melatonin retards growth rate of certain types of cancer (Blask et al., 1991)
- Very low light levels of white light will suppress melatonin in rats (Reiter, 1985)
  - Rodents are generally several orders of magnitude more sensitive to light than humans
- 0.7 lux at the eye of monochromatic 460 nm light suppressed 20% melatonin in humans, but:
  - Pupils were dilated (resulting in at least 4 times more light reaching the retina)
  - Duration of exposure was 90 minutes
  - Full field exposure (Brainard et al., 2001)
- 240 lx of LPS at the eye for 1 hour suppressed virtually no melatonin (LRC, unpublished data)
- 200 lx of white light (Vitalite) at the eye for 1 hour suppressed melatonin by 16% (McIntyre et.al., 1989)

Breast Cancer

- Light suppresses melatonin at night and, hypothetically, may be linked to higher incidence of breast cancer in nightshift workers (Stevens and Rea, 2001)
  - Need to characterize how much light nightshift workers are being exposed to at night and how it relates to melatonin levels
  - Need to account for other factors that may be associated with cancer risks (e.g., stress, food, sleep deprivation)
- Good practice for general population
  - Keep regular sleep/wake schedules
  - Go outdoors during the day
    - Sensitivity to light at night is related to amount of light exposure during the day (Lynch et al., 1985)
  - Dim light at night for safety (avoid trips and falls) (Figueiro, 2001)

Conclusions

- Outdoor lighting can be designed that is efficient and responsive to light pollution issues and also meets the particular application objectives
  - Good lighting practice must be followed
    - Including asking why are we lighting?
  - New metrics and ways of measuring outdoor lighting are being developed to better specify and predict light pollution issues

Acknowledgments

- LRC
  - John Van Derlofske
  - John Bullough
  - Marianna Figuero
  - Yukio Akashi
  - Peter Boyce
  - Sandra Vasconez
  - Swapna Sundaram

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