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
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
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
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

http://pdphoto.org/PictureDetail.php
When to Light?

There are many valid reasons to light!

**However**, 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
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
Review of Cutoff Classifications
Angles Referenced by Luminaire
Cutoff Classifications

- 90° above nadir
- 80° above nadir
- 0° (nadir)
IESNA Cutoff Classifications

<table>
<thead>
<tr>
<th>Name</th>
<th>Description of intensity distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full cutoff</td>
<td>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.</td>
</tr>
<tr>
<td>Cutoff</td>
<td>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.</td>
</tr>
<tr>
<td>Semicutoff</td>
<td>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.</td>
</tr>
<tr>
<td>Noncutoff</td>
<td>A luminaire light distribution where there is no candela limitation in the zone above maximum candela.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Classification</th>
<th>Candelas at or above</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90°</td>
</tr>
<tr>
<td>Full Cutoff</td>
<td>0</td>
</tr>
<tr>
<td>Cutoff</td>
<td>&lt;2.5%</td>
</tr>
<tr>
<td>Semicutoff</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Noncutoff</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Candelas are given as a function of lamp lumens

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)
## IESNA Cutoff Classifications

### Allowable Lamp Lumens for Given Cutoff Classifications

<table>
<thead>
<tr>
<th>Luminaire classification</th>
<th>Range of allowable lumens emitted upward</th>
<th>Range of allowable lumens emitted between $80^\circ$ and $90^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full cutoff</td>
<td>0</td>
<td>0 - 11%</td>
</tr>
<tr>
<td>Cutoff</td>
<td>0 - 16%</td>
<td>0 - 11%</td>
</tr>
<tr>
<td>Semicutoff</td>
<td>0 - 31%</td>
<td>0 - 22%</td>
</tr>
</tbody>
</table>

(McColgan, 2003)
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

(McColgan, 2004)
Light Distribution

- Lateral
  - Type I
  - Type II
  - Type III
  - Type IV
  - Type V
  - Type VS or VQ

- 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.
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
Example of Sky Glow

Institution of Lighting Engineers and the Society of Light and Lighting
Example of Light Trespass

David Fernández-Barba, Dep. d'Astronomia i Meteorologia, Universitat de Barcelona, SPAIN
Example of Light Trespass
Example of Glare
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)
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
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
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

Lighting Research Center
- **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/m²) 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)
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
- $R_{\text{asphalt}} = 7\%$
- 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°
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

<table>
<thead>
<tr>
<th>Cutoff Type</th>
<th>No. of Luminaires</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer A</strong></td>
<td></td>
</tr>
<tr>
<td>Cutoff1</td>
<td>7</td>
</tr>
<tr>
<td>Cutoff2</td>
<td>7</td>
</tr>
<tr>
<td>Semicutoff1</td>
<td>8</td>
</tr>
<tr>
<td>Semicutoff2</td>
<td>8</td>
</tr>
<tr>
<td><strong>Manufacturer B</strong></td>
<td></td>
</tr>
<tr>
<td>Full Cutoff1</td>
<td>7</td>
</tr>
<tr>
<td>Full Cutoff2</td>
<td>8</td>
</tr>
<tr>
<td>Cutoff1</td>
<td>8</td>
</tr>
<tr>
<td>Cutoff2</td>
<td>8</td>
</tr>
<tr>
<td>Semicutoff1</td>
<td>7</td>
</tr>
<tr>
<td>Semicutoff2</td>
<td>8</td>
</tr>
<tr>
<td><strong>Manufacturer C</strong></td>
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</tr>
<tr>
<td>Cutoff1</td>
<td>8</td>
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<tr>
<td>Cutoff2</td>
<td>7</td>
</tr>
<tr>
<td>Semicutoff1</td>
<td>10</td>
</tr>
<tr>
<td>Semicutoff2</td>
<td>11</td>
</tr>
<tr>
<td><strong>Manufacturer D</strong></td>
<td></td>
</tr>
<tr>
<td>Full Cutoff1</td>
<td>7</td>
</tr>
<tr>
<td>Full Cutoff2</td>
<td>7</td>
</tr>
<tr>
<td>Cutoff</td>
<td>8</td>
</tr>
<tr>
<td>Semicutoff</td>
<td>8</td>
</tr>
</tbody>
</table>
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
Light Pollution Index

LPI = Lumens on virtual planes (pollutant lumens)
Lumens on the ground (useful lumens)
LPI vs. IESNA Cutoff Classification

- Luminaire cutoff classification is not predictive of installation uplight
LPI vs. Optical System

- Optical type is also not predictive of installation upright
Luminaire efficiency is also not predictive of installation uplight.
Direct and Reflected Uplight Metric

- Luminaire cutoff classification is not predictive of luminaire uplight
Uplight Metric

Luminaire (30’ high)

Ground Plane
R = 0.2

Zone 3
140° – 180°

Zone 2
85° – 140°
The LPI metric can lead to a new luminaire classifications that is predictive of uplight.
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/SR Parking.pdf](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

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Lamp</th>
<th>Wattage</th>
<th>Lamp Pos.</th>
<th>IES Cat.</th>
<th>Cutoff Class.</th>
<th>Reflector Type</th>
<th>Retractable Optics</th>
<th>Gasket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithonia Lighting</td>
<td>OML600</td>
<td>HPS</td>
<td>300–400</td>
<td>H, W, V</td>
<td>H, W, V</td>
<td>—</td>
<td>poly</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

### Arm-Mount Luminaires

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product</th>
<th>Lamp</th>
<th>Wattage</th>
<th>Lamp Pos.</th>
<th>IES Cat.</th>
<th>Cutoff Class.</th>
<th>Reflector Type</th>
<th>Retractable Optics</th>
<th>Gasket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural Acrylic Lighting</td>
<td>AL-01</td>
<td>HPS, MH</td>
<td>100–400</td>
<td>H, W, V</td>
<td>H, W, V</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Architectural Acrylic Lighting</td>
<td>AL-10</td>
<td>HPS, MH</td>
<td>100–400</td>
<td>H, W, V</td>
<td>H, W, V</td>
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<td>—</td>
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<tr>
<td>Architectural Acrylic Lighting</td>
<td>AL-12</td>
<td>HPS, MH</td>
<td>100–400</td>
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<td>H, W, V</td>
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<td>—</td>
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</tr>
<tr>
<td>Bega</td>
<td>BAG</td>
<td>HPS</td>
<td>100–600</td>
<td>H, W, V</td>
<td>H, W, V</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>50–400</td>
<td>H, W, V</td>
<td>H, W, V</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>100–400</td>
<td>H, W, V</td>
<td>H, W, V</td>
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<tr>
<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>150–600</td>
<td>H, W, V</td>
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<tr>
<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>200–600</td>
<td>H, W, V</td>
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<tr>
<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>250–600</td>
<td>H, W, V</td>
<td>H, W, V</td>
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<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>300–600</td>
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<td>H, W, V</td>
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<tr>
<td>Bega</td>
<td>BS150, BS150</td>
<td>HPS, MH</td>
<td>350–600</td>
<td>H, W, V</td>
<td>H, W, V</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Specifier Reports: Parking Lot and Area Luminaires
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
NLPI P 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
Independent Testing

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

Very short
Type III Medium

ISOFOOTCANDLE LINES OF HORIZONTAL ILLUMINATION
VALUES BASED ON 30 FOOT MOUNTING HEIGHT
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)

<table>
<thead>
<tr>
<th>Luminaire Type</th>
<th>Average Downward Efficiency (% of lamp luminous flux)</th>
<th>Range of Downward Efficiency (% of lamp luminous flux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobra Head</td>
<td>85</td>
<td>80–89</td>
</tr>
<tr>
<td>Arm Mount</td>
<td>75</td>
<td>55–89</td>
</tr>
<tr>
<td>Post-top</td>
<td>71</td>
<td>61–83</td>
</tr>
</tbody>
</table>

### Table 3. Average Downward Efficiency (by lamp orientation)

<table>
<thead>
<tr>
<th>Lamp Orientation</th>
<th>Average Downward Efficiency (% of lamp luminous flux)</th>
<th>Range of Downward Efficiency (% of lamp luminous flux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>80</td>
<td>70–89</td>
</tr>
<tr>
<td>Vertical</td>
<td>68</td>
<td>55–76</td>
</tr>
</tbody>
</table>
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

Vertical illuminance calculation planes

30° 30° 5°
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>
<thead>
<tr>
<th>Distance Behind Luminaire</th>
<th>Average Vertical Illuminance, 5’ above the ground (lux)</th>
<th>Range of Vertical Illuminance, 5’ above the ground (lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30’ or 1 MH</td>
<td>8.5</td>
<td>3.6–13.4</td>
</tr>
<tr>
<td>60’ or 2 MH</td>
<td>2.9</td>
<td>0.4–10.0</td>
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</table>
### Table 5. Glare Zone Maximum Luminous Intensity

<table>
<thead>
<tr>
<th>Tested Cutoff Classification</th>
<th>Avg. Max. Luminous Intensity, 80°-90° (% of lamp luminous flux)</th>
<th>Range of Max. Luminous Intensity, 80°-90° (% of lamp luminous flux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semicutoff</td>
<td>11.6</td>
<td>10.1–15.0</td>
</tr>
<tr>
<td>Cutoff</td>
<td>4.2</td>
<td>2.1–6.4</td>
</tr>
<tr>
<td>Full Cutoff</td>
<td>3.4</td>
<td>1.1–9.3</td>
</tr>
</tbody>
</table>

### Table 4. Glare Zone Luminous Flux

<table>
<thead>
<tr>
<th>Tested Cutoff Classification</th>
<th>Avg. Glare Zone Luminous Flux, 80°-90° (% of lamp luminous flux)</th>
<th>Range of Glare Zone Luminous Flux, 80°-90° (% of lamp luminous flux)</th>
</tr>
</thead>
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<tr>
<td>Semicutoff</td>
<td>1.0</td>
<td>0.4–2.1</td>
</tr>
<tr>
<td>Cutoff</td>
<td>1.5</td>
<td>0.4–2.7</td>
</tr>
<tr>
<td>Full Cutoff</td>
<td>0.3</td>
<td>0.0–1.3</td>
</tr>
</tbody>
</table>
Maximum luminous intensity for all luminaires was 2.1% of lamp lumens. All luminaires met the cutoff classification (Table).
<table>
<thead>
<tr>
<th></th>
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<tr>
<td>American Electric Lighting</td>
<td>Trobyay 115</td>
<td>H</td>
<td>C</td>
<td>C</td>
<td>2.1</td>
<td>6.4</td>
<td>2.7</td>
<td>I 1 S</td>
<td>60.1 S</td>
<td>81.0 S</td>
<td>65.9</td>
<td>81.0 S</td>
<td>60.1 S</td>
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</tr>
<tr>
<td>GE Lighting Systems</td>
<td>A-4000 (cast opt.)</td>
<td>H</td>
<td>C</td>
<td>C</td>
<td>0.0</td>
<td>1.6</td>
<td>0.3</td>
<td>III N</td>
<td>80.4 S</td>
<td>80.4 S</td>
<td>80.6</td>
<td>80.6 S</td>
<td>80.4 S</td>
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<td>GE Lighting Systems</td>
<td>A-400</td>
<td>H</td>
<td>C</td>
<td>SC</td>
<td>1.6</td>
<td>11.6</td>
<td>2.1</td>
<td>III S</td>
<td>80.2 S</td>
<td>80.2 S</td>
<td>80.2</td>
<td>80.2 S</td>
<td>80.2 S</td>
<td>80.2 S</td>
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<tr>
<td>Streetlights</td>
<td>200 (175W Glass)</td>
<td>H</td>
<td>C</td>
<td>C</td>
<td>0.0</td>
<td>1.7</td>
<td>0.1</td>
<td>I N</td>
<td>80.7 S</td>
<td>80.7 S</td>
<td>80.7</td>
<td>80.7 S</td>
<td>80.7 S</td>
<td>80.7 S</td>
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<tr>
<td>Genie Lighting</td>
<td>Guiding</td>
<td>H</td>
<td>C</td>
<td>SC</td>
<td>0.0</td>
<td>1.5</td>
<td>0.2</td>
<td>III S</td>
<td>80.3 S</td>
<td>80.3 S</td>
<td>80.3</td>
<td>80.3 S</td>
<td>80.3 S</td>
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<tr>
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<td>Dimension</td>
<td>H</td>
<td>C</td>
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<td>0.2</td>
<td>III S</td>
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<td>80.4 S</td>
<td>80.4</td>
<td>80.4 S</td>
<td>80.4 S</td>
<td>80.4 S</td>
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<tr>
<td>Ken Lighting</td>
<td>Jachten</td>
<td>H</td>
<td>C</td>
<td>FC</td>
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<td>1.2</td>
<td>0.2</td>
<td>III S</td>
<td>81.0 S</td>
<td>81.0 S</td>
<td>81.0</td>
<td>81.0 S</td>
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<tr>
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<td>Lovelair</td>
<td>H</td>
<td>C</td>
<td>FC</td>
<td>0.2</td>
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<td>1.0</td>
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<td>72.9 S</td>
<td>72.9 S</td>
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<td>LSI Lighting Systems</td>
<td>Hades</td>
<td>V</td>
<td>FC</td>
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<td>0.4</td>
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<td>54.8 S</td>
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<td>H</td>
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<td>79.5 S</td>
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<td>V</td>
<td>C</td>
<td>SC</td>
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<td>1.0</td>
<td>0.2</td>
<td>III S</td>
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<td>75.6 S</td>
<td>75.6</td>
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<td>Rust Lighting</td>
<td>SVP (2)</td>
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<td>FC</td>
<td>FC</td>
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<td>55.2 S</td>
<td>55.2 S</td>
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<td>55.2 S</td>
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<td>V</td>
<td>FC</td>
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<td>1.5</td>
<td>0.2</td>
<td>II S</td>
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<td>76.2</td>
<td>76.2 S</td>
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<td>Vezet materials</td>
<td>Topaz</td>
<td>H</td>
<td>C</td>
<td>C</td>
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<td>80.6 S</td>
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<tr>
<td>Wals Lighting</td>
<td>Eiffel</td>
<td>H</td>
<td>C</td>
<td>FC</td>
<td>0.0</td>
<td>1.0</td>
<td>0.1</td>
<td>II S</td>
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<td>Learcor (CHF)</td>
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<td>7.0</td>
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<td>III S</td>
<td>67.4 S</td>
<td>67.4 S</td>
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<td>67.4 S</td>
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<tr>
<td>Ecolux Lighting</td>
<td>Heptagon</td>
<td>V</td>
<td>SC</td>
<td>SC</td>
<td>1.9</td>
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<td>III S</td>
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<td>C</td>
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<td>III S</td>
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<td>Beckley-Pi</td>
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<td>SC</td>
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<td>71.6 S</td>
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<td>U.S. Architectural Lighting</td>
<td>SY Pl2</td>
<td>V</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Wals Lighting</td>
<td>Eiffel</td>
<td>V</td>
<td>C</td>
<td>FC</td>
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<td>54.5</td>
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<td>IV N</td>
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<td>74.3 S</td>
<td>74.3 S</td>
<td>74.3 S</td>
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</tr>
</tbody>
</table>

**Notes**

1. 250W HPS
2. 400W HPS
3. 175W HPS
4. May be cutoffness. Measurement of the maximum intensity at or above 90° exceeds the 10% limit, but falls within the uncertainty of the measurement system.
5. On boundary with Type III
6. If reclassified as any other, would be Type I
7. On boundary with Type III
8. 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

Reflected light contributes more to uplight

<table>
<thead>
<tr>
<th>Table 7. Direct Uplight as a Function of Tested Cutoff Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tested Cutoff Classification</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>Semicutoff</td>
</tr>
<tr>
<td>Cutoff</td>
</tr>
<tr>
<td>Full Cutoff</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Table 10. Average Uplight Values as a Function of Tested Cutoff Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tested Cutoff Classification</td>
</tr>
<tr>
<td>------------------------------</td>
</tr>
<tr>
<td>Semicutoff</td>
</tr>
<tr>
<td>Cutoff</td>
</tr>
<tr>
<td>Full Cutoff</td>
</tr>
</tbody>
</table>
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

5' (1.5 m)

13' 2" (4 m)

4' (1.2 m)

10' (3 m)  10' (3 m)  10' (3 m)  10' (3 m)
Calculations

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

Full cutoff fixtures

Cutoff fixtures

Semicutoff fixtures
Overall Glare “Dosage”
Area under Each Veiling Luminance Curve

![Graph showing average area under veiling luminance curve for different cutoff classifications.](image)
Maximum Value of Glare

Average Maximum of the Veiling Luminance curve (cd/m²)

Cutoff Classification

- Full cutoff
- Cutoff
- Semicutoff
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
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
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.
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

<table>
<thead>
<tr>
<th>Category</th>
<th>Country</th>
<th>SIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blind women</td>
<td>USA (Hahn, 1991)</td>
<td>0.5</td>
</tr>
<tr>
<td>Flight attendants</td>
<td>Finland (Pukkala et al., 1995)</td>
<td>1.9</td>
</tr>
<tr>
<td>Shift workers</td>
<td>(Hansen, 2001)</td>
<td></td>
</tr>
<tr>
<td>Daytime work</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Nighttime, II trades</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>combined (Manufacturing,</td>
<td></td>
<td></td>
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<tr>
<td>transportation, catering</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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
References and Further Reading