Municipal Solid-State
STREET LIGHTING
CONSORTIUM

U.S. Department of Energy

Successful Selection of LED Streetlight Luminaires

Optimizing Illumination and Economic Performance

DOE Solid-State Lighting Webinar | Date: March 6, 2013

Chad Stalker
Regional Marketing Manager, Americas
Philips Lumileds Lighting

Eric Haugaard
Director of Product Technology
Cree Lighting

Moderated by: **Edward Smalley**
Director, Municipal Solid-State Street Lighting Consortium
Seattle City Light

About The Consortium - Background

- Created by the U.S. Department of Energy (DOE) in March 2010 using American Recovery and Reinvestment Act (ARRA) funding
- Supported by the DOE GATEWAY program
- Intended to be an **educational resource** on Solid-State street lighting and associated technology for those involved in lighting streets and other outdoor public areas.
  - As an independent resource, the Consortium is available to help those unfamiliar with LED technology identify important issues and how to how to begin the evaluation process
- **…and** to help **accelerate adoption** of SSL technology in the nations street lighting systems

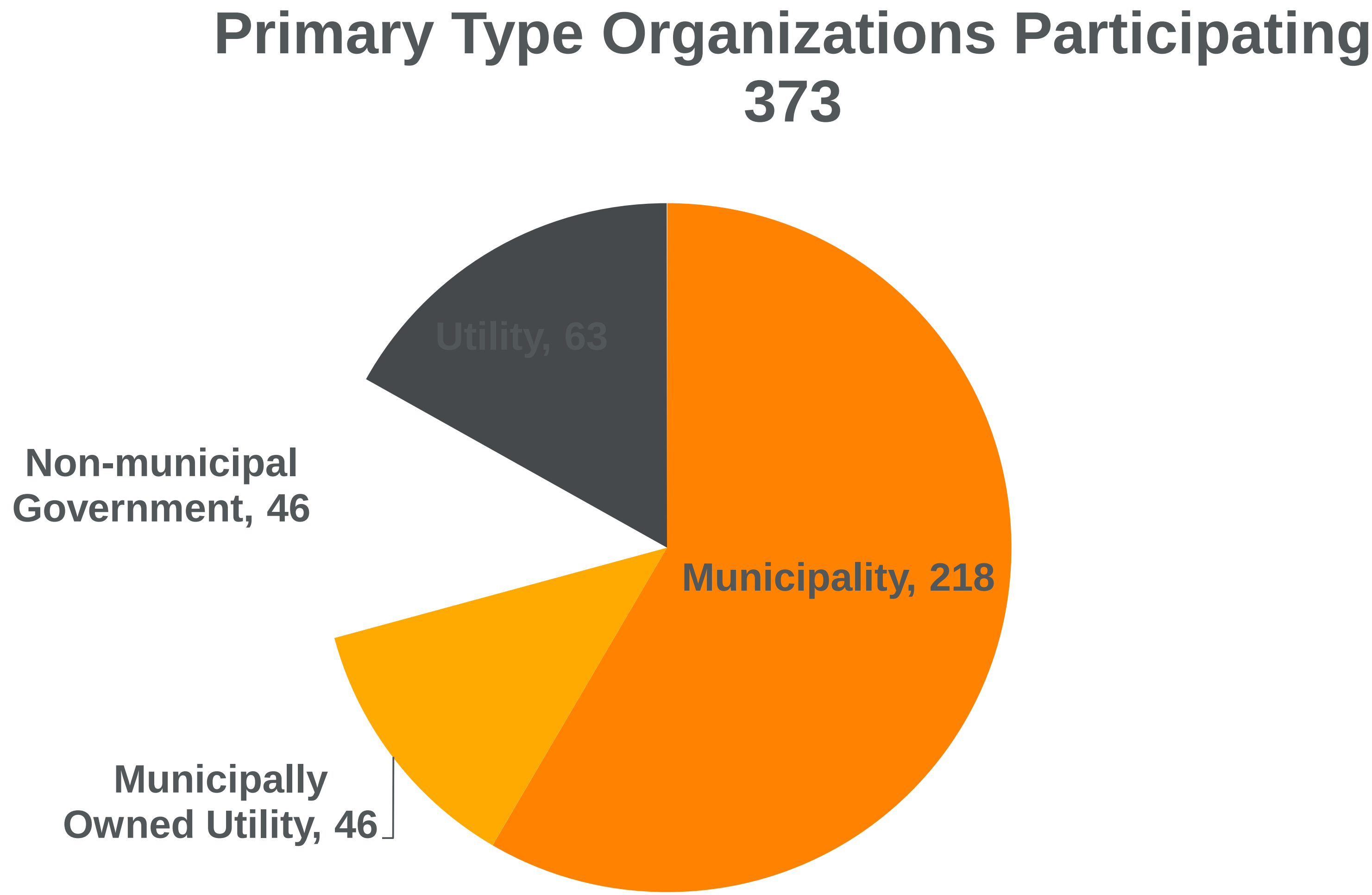
Our Vision

- Accelerate the adoption of high performance solid-state street and area lighting by leading end-user collaboration in the areas of performance, evaluation, application, and standardization.

Mission

- Increase **KNOWLEDGE** around the performance, quality, and application of SS Street Lighting.
- Develop a national **STRUCTURE** to provide oversight and guidance on the evaluation of SSL for public areas.
- Influence national **STANDARDIZATION** of benchmarks, classification, design, and performance criteria. Set standard benchmarks.

Membership


Primary Type Organizations Participating
373
Utility, 63
Non-municipal Government, 46
Municipality, 218
Municipally Owned Utility, 46

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Today's Goal…

Define a Process for Developing an LED Streetlight Specification

Enabling the Required Performance Expectations to be Met

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Evaluating the Viability of LED Solutions

Justification Based on 2 Major Criteria

- *Meeting the Illumination Performance Requirements*

- *Meeting the Economic Performance Requirements*

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Looking Back…

Example:

Outdoor HID Luminaire Technology

- *Optical Distribution Choices for a Given Luminaire Configuration*
  - *~ 1 – 5*
- *Lamp Choices 70W, 100W, 175W, 250W, 400W, Etc…*
  - *Large Increments of Luminous Intensity & Associated Energy Consumption*
- *Lumen Maintenance*
  - *Fixed Value (common rules… generally)*
    - *Hours/Start*
    - *Power Supply*
- *Rated Lamp Life → Lamp Service Requirements*

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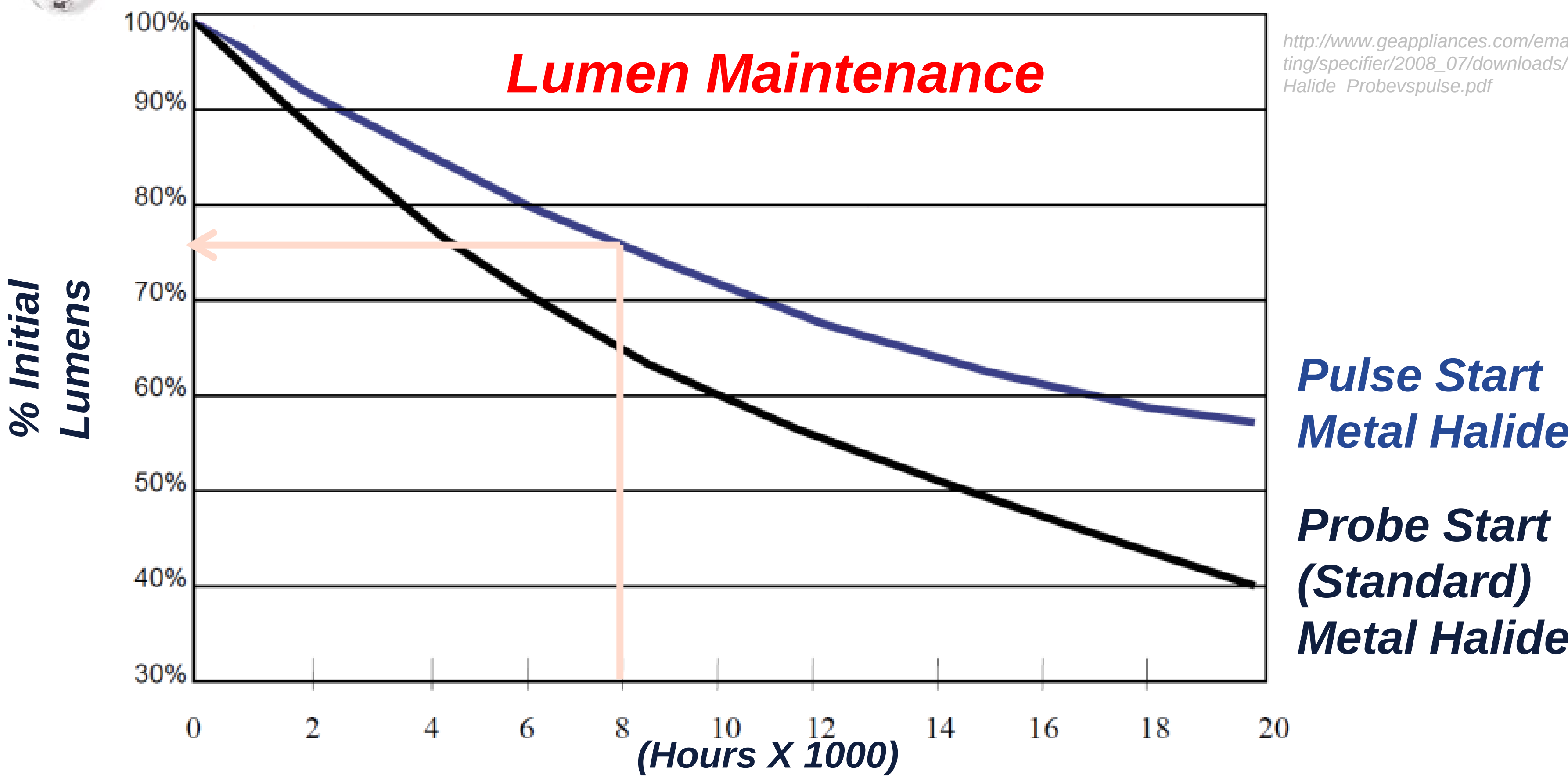
HID Lumen Maintenance Factors

Pulse Start Metal Halide (PSMH) = 0.75
Relamp at 25% Lumen Depreciation

400W PSMH Rated Life = 20,000 Hours
Requires Relamping at 40% of Rated Life = 8,000 Hours

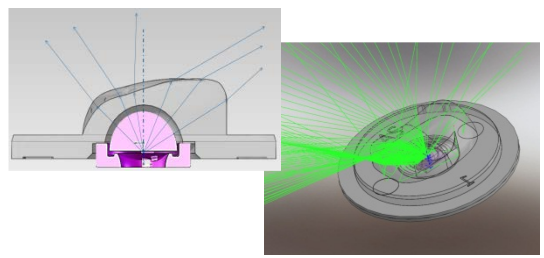


http://www.geappliances.com/email/lighting/specifier/2008_07/downloads/MetalHalide_Probevspulse.pdf

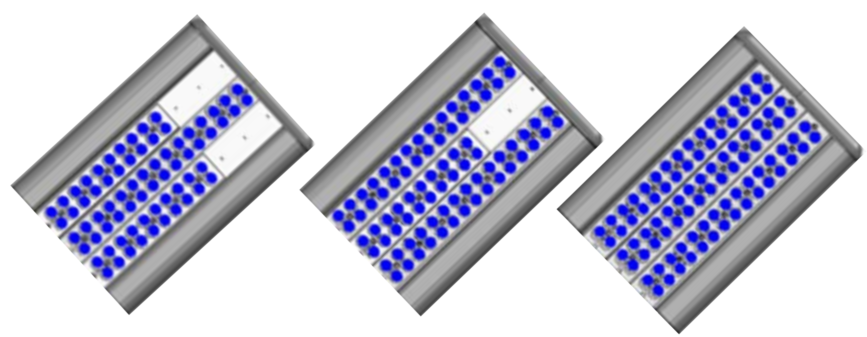
New Possibilities With LED Luminaire Technology

Application "Fine Tuning"

- *Many More Optical Distribution Choice Possibilities*



- *More/Smaller Luminous Intensity Increments*
  - *Number of LEDs*
  - *Power vs. Output Options*



Enabling Dramatic Improvements in Application Level Performance Optimization

Optimizing the Process…

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Summer 2007

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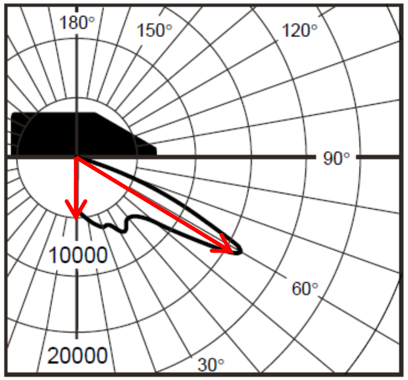
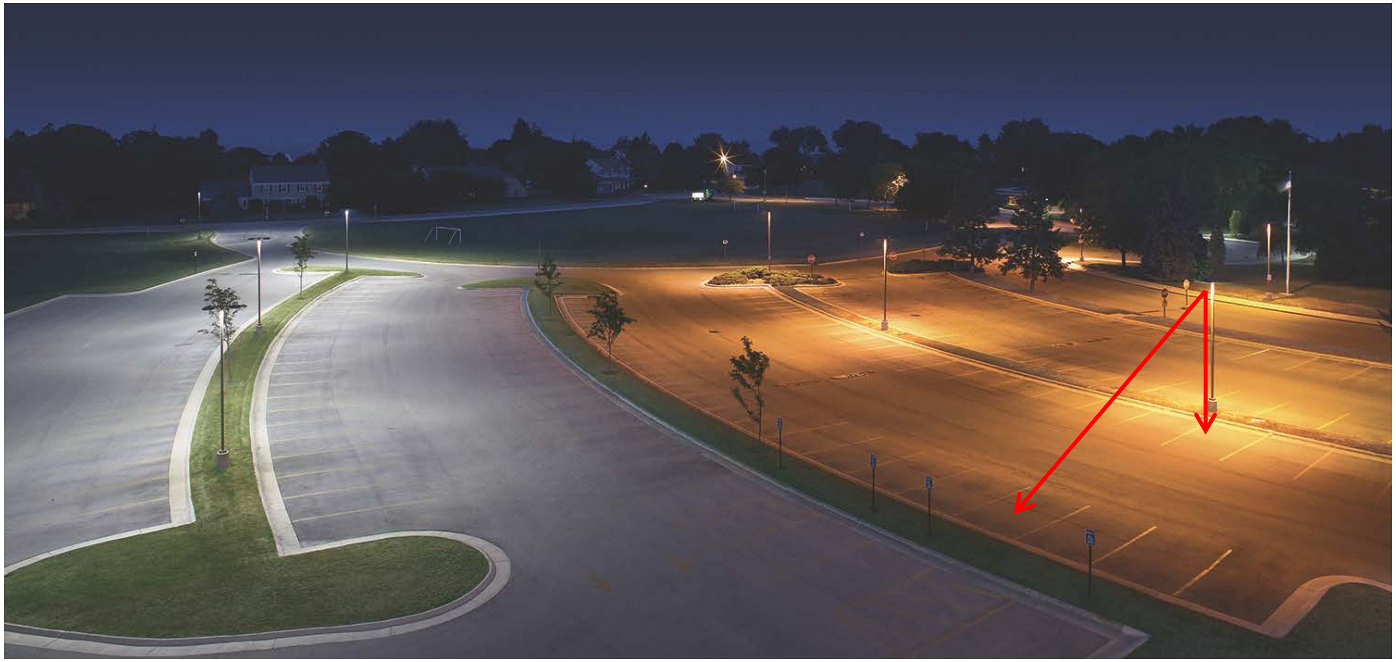
HPS Spec Sheet Info



Lighting Sciences Inc.
Certified Test Report No. LSI 10246
Candlepower distribution curve of 250W HPS
Area Cutoff Floodlight without backlight shield.

Catalog #	Lamp Type	Lamp Lumens
WAC2592-M	250W HPS	28,500



Application Performance Results

HPS		LED
300W	Total System Wattage	141W
20,520	Average Delivered Lumens	8,040(61% less Light)
68	Luminaire Efficacy (Lumens/Watt)	57
1.96fc	Maintained Average Footcandles	1.01fc
0.30fc	Maintained Minimum Footcandle	0.30fc
-	Energy Savings	53%

Essential Elements

A Specification Development Process that:

1. Defines the Required Sustainable Illumination Performance

Example:

/Illumination Performance Requirements

- **1 fc Minimum Illuminance**
- **10:1 Max/Min Uniformity**
- **50,000 Hour Application Duration**

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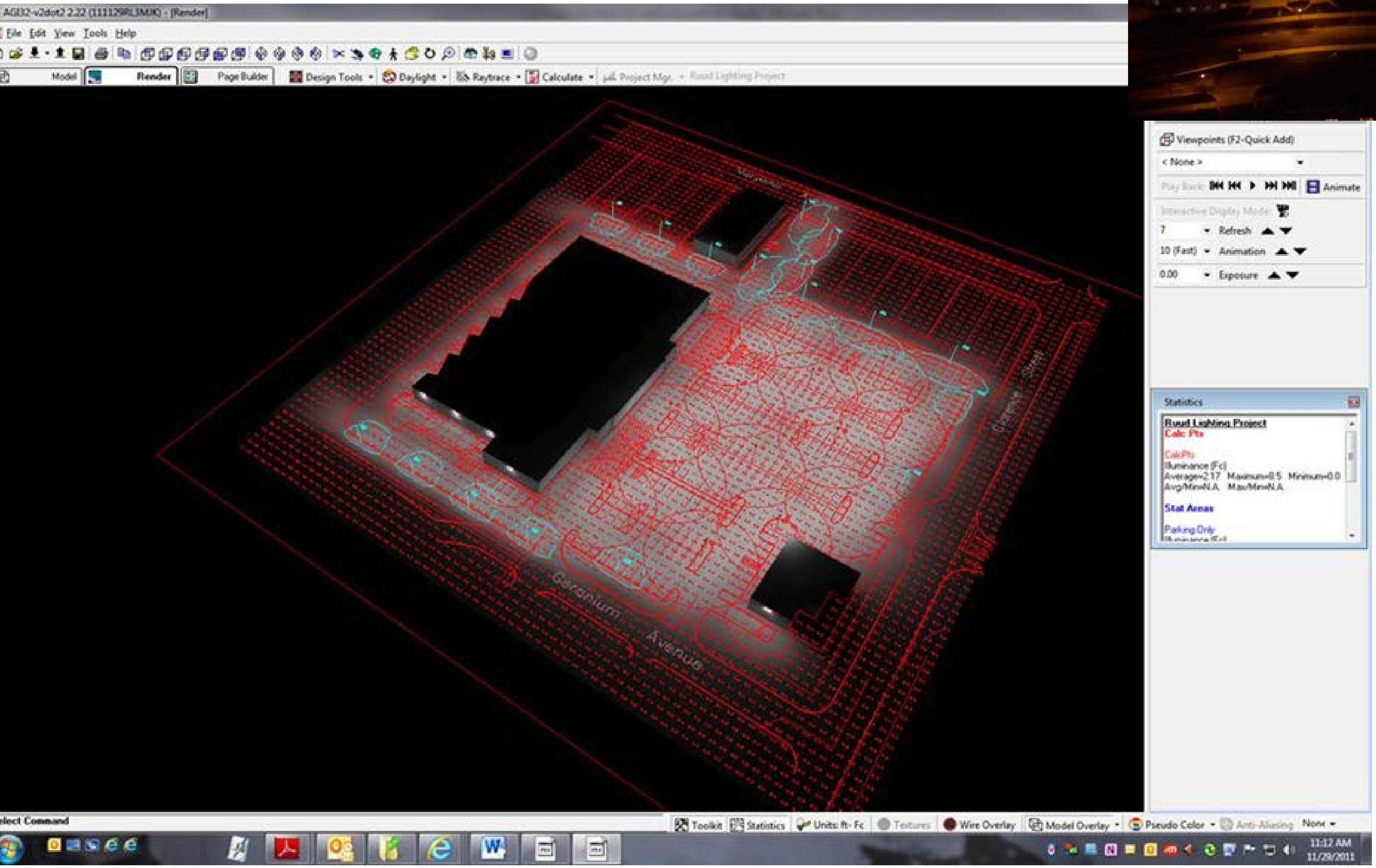
Lighting Design



System Power Comparison

LED – ~19 kW

Spec Grade HID – ~31 kW

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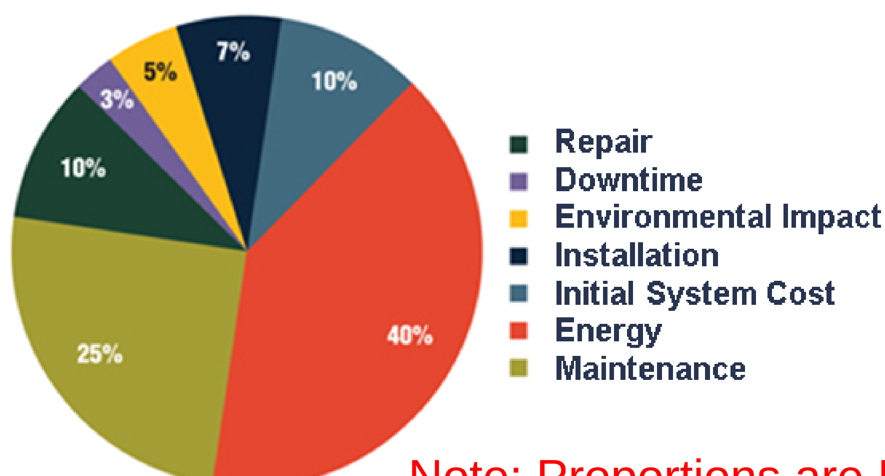
Essential Elements

A Specification Development Process that:

2. Defines the Required Sustainable (Risk Managed) Economic Performance
   - *Life Cycle Cost Analysis Elements/Variables*
     - Evaluation Timeframe /Desired Application Life
     - Product Durability Performance Requirements
     - Standards Compliance / Reliability / Warranty
     - Etc.



Note: Proportions are Relative

Step #1

Always!

Establish the Required Maintained Illumination Performance Requirements

- Lighting Performance Specification
  - Vertical and Horizontal Illumination Requirements
  - Uniformity
  - Color Quality
  - Light trespass
  - Glare Metrics...
  - Etc.

Illumination Performance

Define the Variables:

- Define the Lighting Application Geometric Target(s)
  - Boundaries
- Luminaire Position Constraints
  - New vs. Upgrade
- Service Life (i.e. Application Life)
  - Years of Expected Near Maintenance Free Operation (i.e. Hours of Operation)
  - Required Economic Assessment Period (5 -15yrs…?)

Lumen Maintenance Factors Must Be Applied!

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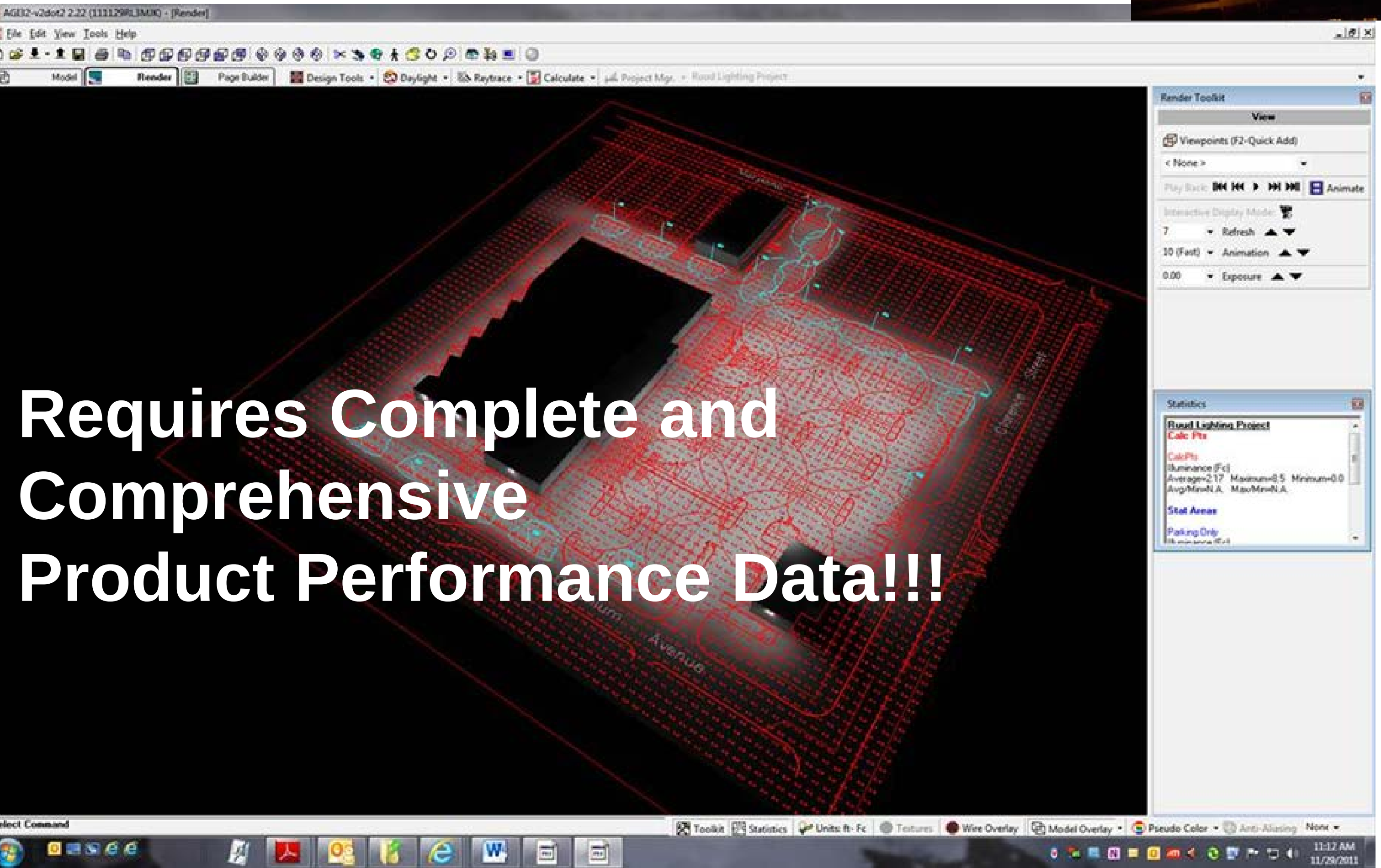
The Value of Lighting Design

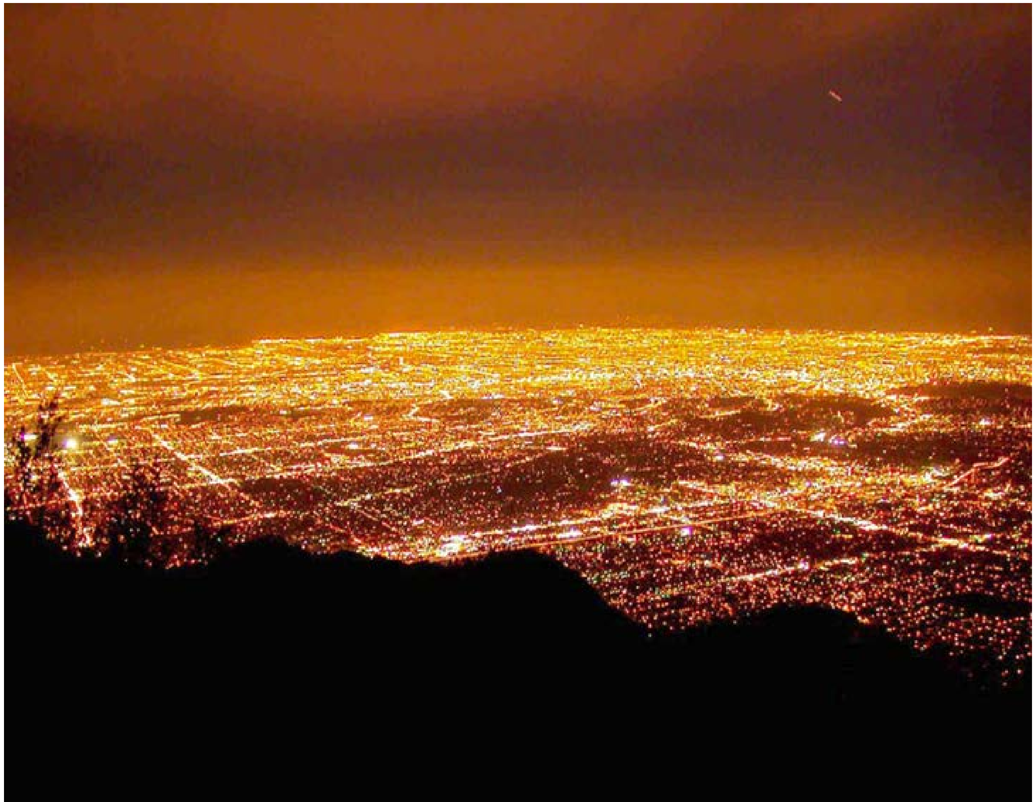


Requires Complete and Comprehensive Product Performance Data!!!

Step #1 - continued

If an Exact Application Description Can Not Be Reasonably Established

Then Create a Representative "Model" Application



Essential Data

LED Luminaire Photometric Performance Measurement

- Used for lay-out design & planning
  - Initial Photometric Performance
- IESNA LM-79-08 Testing Standard (early 2008)
  - Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products
    - Requires Absolute Photometry Methods
    - SSL products dominantly have the light source, power and optics integrated into a single system
  - Generates industry standard IES Data File

LM-79-08 Validates Many Performance Characteristics

- LM-79-08 **"Bundles"** the Effects of Many Luminaire System Variables
  - Thermal Management
    - The Effectiveness of the Heat Sink
  - Optical Control
    - Optical Precision
    - Optical Efficiency
  - Electrical Power Efficiency (Driver Efficiency)
  - Etc…


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Program
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

UNDERSTANDING LM-79 REPORTS

In 2008, the Illuminating Engineering Society of North America (IES) published LM-79-08, *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*. Why are special test procedures required for this technology, and what kind of information is gleaned from testing conducted using this new method?

LM-79 testing captures performance characteristics of products that feature solid-state lighting (SSL) technology, including light-emitting diodes (LEDs). This testing provides a snapshot of performance under specified operating conditions at some point in the life of a product, usually at the beginning of operation—these are referred to as initial measurements. It does not address lifetime ratings, changing performance over time (e.g., lumen maintenance), or LED case temperature.[1] The LM-79 method is applicable to integrated LED products, such as luminaires and replacement lamps. It is not applicable to LED packages, modules, or arrays (herein collectively referred to as LED light sources).[2]

LM-79 data enables objective product comparisons, allows for evaluation relative to performance requirements, and is required by voluntary labeling programs such as LED Lighting Facts and ENERGY STAR®.[3] Although LM-79 does not prescribe a report format or the minimum content, a substantial list of "typical items reported" is provided. Key types of measurements addressed in the document include electrical characteristics, lumen output, spatial distribution of light, and color attributes. The DOE fact sheet, "LED Color Characteristics," (which is available online at *www.ssl.energy.gov/factsheets.html*) is dedicated to a discussion of color-related metrics that may be included in LM-79 reports.

Electrical Characteristics

A variety of electrical measurements may be conducted as part of LM-79 testing, including but not limited to:

- Input voltage, expressed in volts (V). Testing is performed with the SSL product operated at its rated input voltage.
- Input current, expressed in amperes (A). Input current can be either direct current (DC) or alternating current (AC), depending on product design. Note that this metric is not equivalent to the current supplied to a given LED light source (i.e., LED drive current), which often cannot be measured directly without damaging the product.[4]
- Input power, expressed in watts (W). Input power is essential for determining energy savings.
- Power factor (PF), is a power quality metric reported as a unitless decimal value between zero and one. PF is calculated by dividing input power by the product of input voltage and input current.

A goniophotometer is used to characterize spatial distribution of light. A mirror travels around a light source and reflects light to a detector, providing intensity measurements over a range of angles. (Photo credit: ITL Boulder)

Lumen Output and Luminous Efficacy

Light output—more formally referred to as luminous flux—is expressed in lumens (lm).[5] Lumen output is a more meaningful metric than input power when establishing product equivalency because the ratio of total lumen output to input power can differ from product to product.[6] This quotient is termed luminous *efficacy* and is expressed in lumens per watt (lm/W).

Relative vs. Absolute Photometry

Non-SSL products are typically measured using *relative* photometry, for which lamps and ballasts are tested separately from luminaires. Luminaire *efficiency* is calculated by dividing the total lumen output of the luminaire by the product of the rated

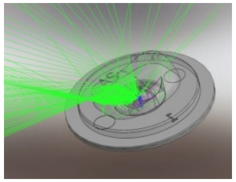
1 Long-term performance is discussed in the DOE fact sheet, "Lifetime of White LEDs," which is available at www.ssl.energy.gov/factsheets.html.
2 The term LED light source is defined in IES LM-80-08. See IES RP-16-10 for formal definitions of related terms.
3 For more information on these programs, please visit www.lightingfacts.com and www.energystar.gov.
4 LED drive current is nominal (i.e., reported by manufacturer); this metric is discussed in the DOE fact sheet, "Lifetime of White LEDs."
5 Photometric quantities are based on photopic visual adaptation. For more on this topic and the use of scotopic/photopic (S/P) ratios, see IES TM-12 and the 10th edition IES Lighting Handbook.
6 See the DOE fact sheet, "Establishing LED Equivalency," for more on this topic.

DOE Reference: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/understanding_lm79_reports.pdf

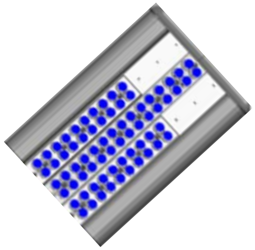
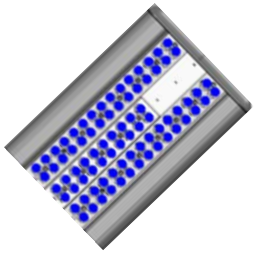
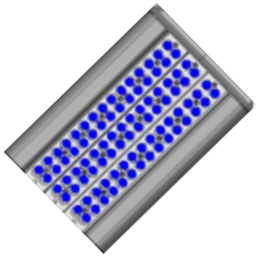
New Possibilities

Application "Fine Tuning"

- Many More Optical Distribution Choice Possibilities



- More/Smaller Luminous Intensity Increments
  - Number of LEDs
  - Power vs. Output Options

  - Thousands of Possible Luminaire Configurations (SKUs)...
- How can anyone keep up with all this???
  - MSSLC Model Specification v1.0, Appendix C
  - Product Family Testing – LM-79 and ISTMT

MSSLC Model Spec – Appendix C

Product Family Testing

- Represented by test data for another luminaire configuration having:
  - The same intensity distribution (typically only applies to LM-79)
  - The same or lower nominal CCT
  - The same or higher nominal drive currer
  - The same or greater number of LED light source(s)
  - The same or lower percentage driver loading and efficiency
  - The same or smaller size luminaire housing

Table C.1. Representative testing of a single luminaire housing size

Tests	Intensity distribution (IES Type)	CCT (K)	Drive current (mA)	# of LEDs
1, 2, 3	II, III, IV	4000	700	80
4, 5	IV	5000, 6000	700	80
6, 7	IV	4000	325, 525	80
8, 9, 10	IV	4000	700	20, 40, 60

For example, the manufacturer could detail interpolation as shown in Table C.2, applying the following multipliers to the base test #2 to model a configuration with Type III intensity distribution, 5000K CCT, 525 mA drive current, and 40 LEDs:

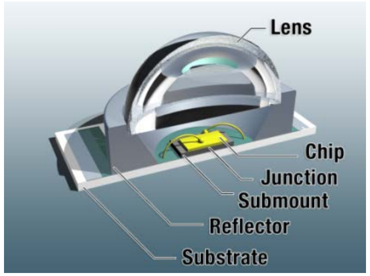
- Ratio of test #4 lumens to test #3 lumens
- Ratio of test #7 lumens to test #3 lumens
- Ratio of test #9 lumens to test #3 lumens.

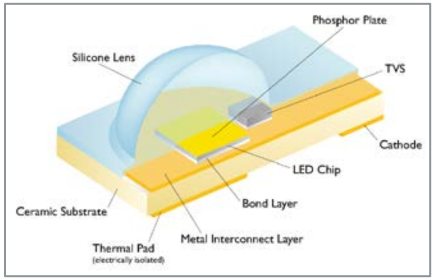
Table C.2. Multipliers for Test #2 to yield: Type III , 5000K, 525mA, 40 LEDs

Test #	Intensity distribution (IES Type)	CCT (K)	Drive current (mA)	# of LEDs	Multiplier (lumens ratio)
2	III	4000	700	80	n/a
3	IV	4000	700	80	n/a
4	IV	5000	700	80	#4 / #3
7	IV	4000	525	80	#7 / #3
9	IV	4000	700	40	#9 / #3

Accounting for
LED Luminaire
Lumen Depreciation

LED Component Lumen Depreciation





Lumen Maintenance Performance Testing Standard

- IESNA LM-80-08 (released late 2008)

  Approved Method: Measuring Lumen Maintenance of LED Light Sources

  – Covers the Measurement of Lumen Depreciation for LED Based Packages, Arrays and Modules Only
    - Not LED Luminaires

  – Does Not Provide Methods or Guidelines for Incorporating LM-80 Test Data for Luminaire Level Lumen Depreciation Extrapolation and/or Prediction.

  – HOWEVER luminaire manufactures can accurately correlate to "in-situ" luminaire performance from LED device manufacturers data

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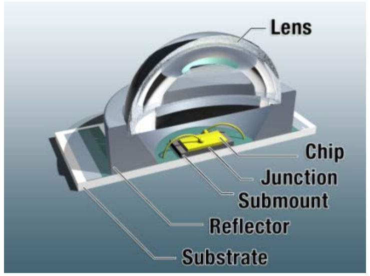
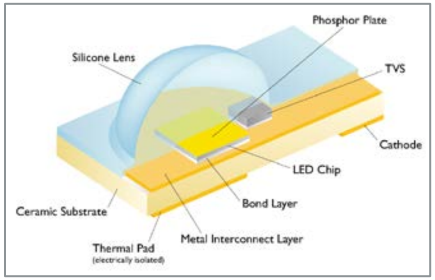
Test Details:

LM-80 for Packaged LEDs



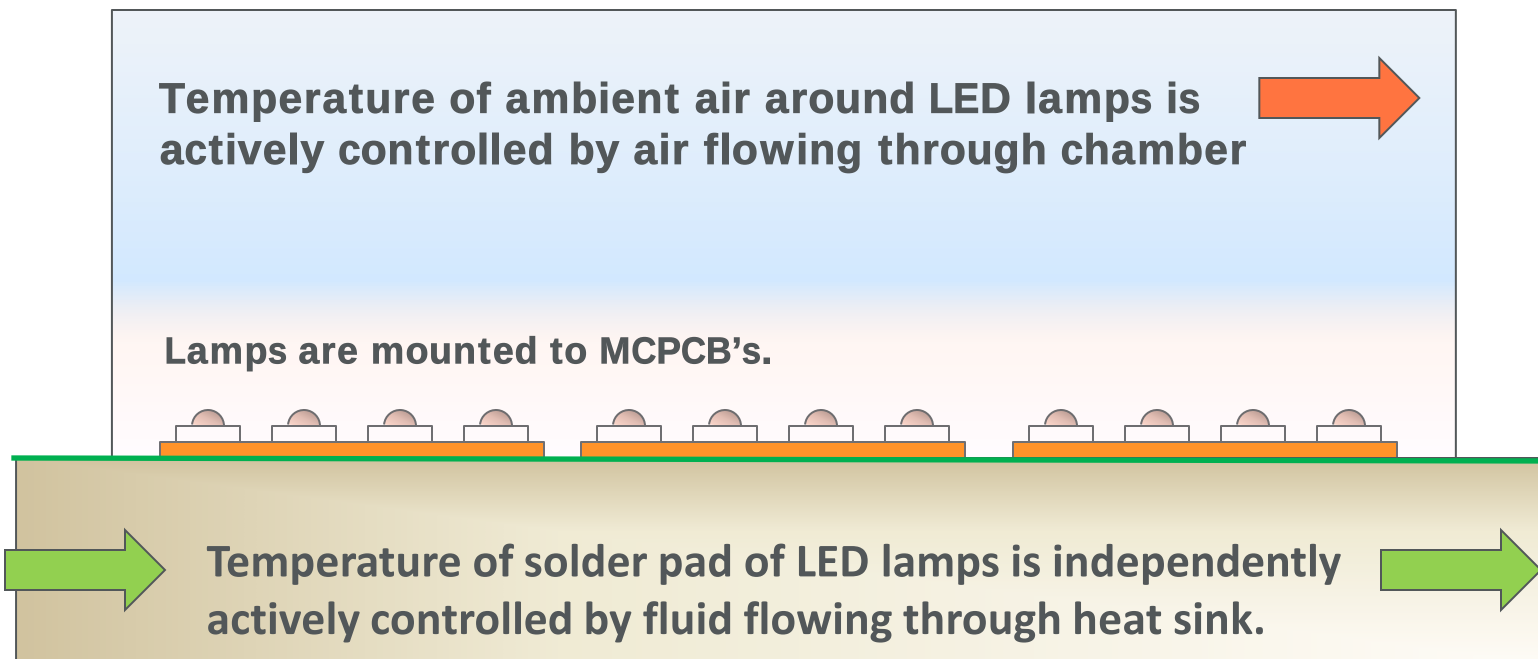


- A Specific LED Drive Current Must Be Identified and Maintained
- A Temperature Measurement Point (Case Temperature (T_S)) is Defined by the LED Chip Package Manufacturer (typically the solder pad)
- **Maintained T_S of 55^oC, 85^oC** and **One Additional Temperature** (typically higher) is Required (test environment incorporates active thermal management/control)
- Requires a Minimum 6000 Hour Test Duration
- Data is Collected Every 1000 Hours (minimum)

Additional "Interpolated" data sets are typically available from LED Chip Package manufacturers

Test Configuration Per IESNA LM-80-2008

- During test, the temperature of the solder pad of the lamps and the air around the lamps is the same
- Per LM-80,
  - For 55ºC testing, the T_{SP} of the LED lamps and air are both at 55ºC
  - For 85ºC testing, the T_{SP} of the LED lamps and air are both at 85ºC



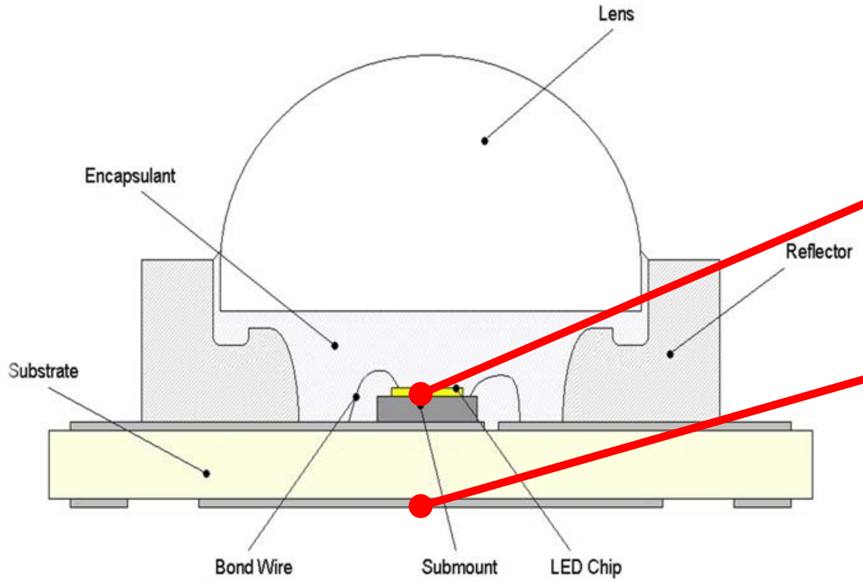
LED Device Lumen Maintenance Critical Parameters

1. Device Drive Current

2. T_{AIR}
Ambient Air Temperature

~~**T_J**~~
~~Junction Temperature~~

3. T_{SP} / T_C / T_S
Solder-Point Temperature / Case Temperature



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What An LM-80 Report Looks Like

Product	Lamp Color	Temperature	Drive Current (mA)	BoardID	Lamp Number	0	168	336	672	840	1008	1176	1512	2016	2520	3024	3528	4032	4536	5040	5544	6048	6552
XRE XLamp	Cool White	55C	350	DUR011H	1	119.56	117.79	117.89	119.25	119.35	119.29	119.66	119.12	120.01	118.40	118.91	118.75	117.61	117.87	116.63	116.18	116.77	115.09
XRE XLamp	Cool White	55C	350	DUR011H	2	120.68	117.35	118.22	119.45	119.56	119.92	120.48	119.68	120.78	119.30	119.94	120.05	118.55	119.12	117.91	117.41	118.23	116.58
XRE XLamp	Cool White	55C	350	DUR011H	3	118.83	117.36	117.99	118.98	119.15	119.34	119.88	118.90	119.95	118.34	119.01	118.97	117.64	118.17	116.96	116.70	117.28	115.70
XRE XLamp	Cool White	55C	350	DUR011H	4	120.38	118.24	118.79	119.81	119.71	119.69	120.17	119.32	120.20	118.42	119.03	118.86	117.63	118.05	116.78	116.36	116.80	115.20
XRE XLamp	Cool White	55C	350	DUR011H	5	122.92	121.63	121.95	123.00	123.05	123.21	122.55	122.90	122.84	122.21	121.52	121.65	120.26	120.74	119.56	120.45	121.06	119.20
XRE XLamp	Cool White	55C	350	DUR011H	6	122.38	120.78	121.19	122.33	122.32	122.53	122.94	122.50	123.48	121.86	122.34	122.52	121.19	121.58	120.32	120.35	120.76	119.11
XRE XLamp	Cool White	55C	350	DUR011H	7	120.91	118.77	118.52	119.81	120.69	120.85	120.66	121.06	121.21	120.52	120.11	120.33	118.88	119.21	118.08	118.62	119.25	117.21
XRE XLamp	Cool White	55C	350	DUR011H	8	119.57	118.10	119.03	120.05	119.56	119.72	119.41	119.71	119.97	118.90	118.56	118.68	117.44	117.67	117.67	117.31	117.68	116.00
XRE XLamp	Cool White	55C	350	DUR011H	9	120.19	117.72	118.51	119.43	119.01	119.02	118.70	118.75	119.11	118.07	117.88	118.00	117.14	117.32	117.17	116.76	117.48	115.41
XRE XLamp	Cool White	55C	350	DUR011H	10	121.60	120.19	119.78	120.77	121.58	121.53	121.32	121.37	121.56	120.37	120.21	120.27	119.19	119.37	118.09	118.94	119.21	117.40
XRE XLamp	Cool White	55C	350	DUR011K	1	99.24	98.26	99.18	99.96	99.81	99.93	100.58	99.93	100.96	99.46	100.04	100.07	99.09	99.21	98.00	97.74	98.24	96.64
XRE XLamp	Cool White	55C	350	DUR011K	2	100.77	99.83	100.81	101.47	101.21	101.21	101.02	101.10	101.23	100.61	100.52	100.66	99.58	99.76	98.48	99.38	99.87	98.14
XRE XLamp	Cool White	55C	350	DUR011K	3	100.35	98.17	99.08	99.81	99.55	99.60	99.38	99.31	99.42	98.81	98.56	98.51	97.56	97.63	96.30	97.27	97.82	96.01
XRE XLamp	Cool White	55C	350	DUR011K	4	102.73	102.12	101.92	103.39	103.10	103.08	102.96	102.80	102.82	102.10	101.78	101.74	100.73	100.77	99.50	100.26	100.72	98.92
XRE XLamp	Cool White	55C	350	DUR011K	5	97.67	97.87	97.83	99.40	99.27	99.27	99.18	99.33	99.46	98.99	98.90	99.06	98.17	98.29	96.88	97.92	98.56	96.82
XRE XLamp	Cool White	55C	350	DUR011K	6	101.04	100.58	100.74	102.20	102.09	102.24	102.04	101.94	102.01	101.40	101.08	101.02	99.88	100.07	98.69	99.67	100.13	98.40
XRE XLamp	Cool White	55C	350	DUR011K	7	98.79	98.89	99.08	100.51	100.43	100.53	100.41	100.28	100.56	99.90	99.72	99.79	98.50	98.81	97.63	98.61	99.08	97.35
XRE XLamp	Cool White	55C	350	DUR011K	8	101.24	101.75	101.38	103.27	103.13	102.92	102.94	102.96	103.05	102.29	102.08	101.97	101.34	101.37	100.01	100.82	101.22	99.43
XRE XLamp	Cool White	55C	350	DUR011K	9	102.19	101.46	101.58	103.02	102.82	102.88	102.67	102.59	102.56	101.92	101.52	101.51	100.11	100.41	99.22	100.27	100.78	98.99
XRE XLamp	Cool White	55C	350	DUR011K	10	99.18	97.31	98.19	98.90	98.72	98.80	98.64	98.53	98.60	98.11	97.80	97.79	96.63	96.94	95.72	96.67	97.21	95.34
XRE XLamp	Cool White	55C	350	DUR011M	1	97.48	98.37	97.86	98.88	100.06	99.95	99.34	99.90	99.39	99.17	98.16	97.85	96.90	97.03	95.27	94.95	94.70	92.33
XRE XLamp	Cool White	55C	350	DUR011M	2	97.16	95.95	95.58	96.73	97.90	97.74	97.14	97.68	97.53	97.50	96.67	96.47	95.82	96.20	94.84	94.80	94.77	92.85
XRE XLamp	Cool White	55C	350	DUR011M	3	96.73	97.69	96.73	97.86	98.14	98.62	97.99	97.73	98.05	97.70	96.80	96.71	96.16	96.15	94.79	94.59	94.48	92.50
XRE XLamp	Cool White	55C	350	DUR011M	4	96.29	94.96	95.40	95.92	96.28	96.17	96.18	95.83	96.14	95.24	94.99	94.91	93.75	93.92	92.45	92.65	92.85	91.06
XRE XLamp	Cool White	55C	350	DUR011M	5	97.11	96.56	96.16	97.05	97.36	96.96	96.77	96.75	96.81	95.72	95.40	95.02	94.03	92.96	91.41	90.94	90.65	88.58
XRE XLamp	Cool White	55C	350	DUR011M	6	97.56	97.30	96.89	97.95	98.07	97.80	97.67	97.79	97.74	96.79	96.56	96.29	95.54	94.86	93.43	92.95	92.93	90.94
XRE XLamp	Cool White	55C	350	DUR011M	7	97.11	96.35	96.47	97.24	97.62	97.40	97.45	97.17	97.31	96.51	96.03	95.92	94.93	95.81	94.40	94.21	94.24	92.00
XRE XLamp	Cool White	55C	350	DUR011M	8	95.08	94.82	94.64	95.48	95.96	95.81	95.69	95.44	95.45	94.62	94.42	94.20	93.21	94.19	92.85	92.84	92.92	90.83
XRE XLamp	Cool White	55C	350	DUR011M	9	96.43	96.11	96.06	96.76	97.10	97.18	97.14	96.79	96.93	96.08	95.62	95.41	94.54	95.41	93.85	93.98	93.96	91.31
XRE XLamp	Cool White	55C	350	DUR011M	10	96.64	96.18	96.06	96.84	97.05	96.96	96.86	96.57	96.76	95.89	95.55	95.48	94.46	95.36	94.01	94.14	94.26	91.79

IESNA TM-21

- Technical Memorandum Defining Extrapolation Methods and Other Criteria for Using LM-80-08 Data for the Purpose of LED Lumen Maintenance Prediction
  - Released September 2011

IESNA TM-21 Committee included Representatives from Cree, Philips Lumileds, Nichia, OSRAM, U.S. Dept Of Energy, NIST & PNNL

Municipal Solid-State STREET LIGHTING CONSORTIUM

U.S. Department of Energy

TM-21 Reporting Criteria

Lumen Maintenance Projections Times (in hours) Limited to No More Than 6X the LM-80 Test Duration (6000 hours Min)

- “Reported Values”
  - Derived From the Three LM-80 Required Test Conditions (i.e. 55C, 85C and One Other T_S) – Lumen Maintenance times limited to 6X LM-80 test duration
    - For Example: 10,000 hour testing…allows for 60,000 hour reported lumen maintenance
- “Projected Values”
  - Derived From Other T_S Conditions Using Prescribed Interpolation Methods Outlined in TM-21
- “Calculated Values”
  - Same as Projected Values for Times Greater Than 6X LM-80 Test Duration

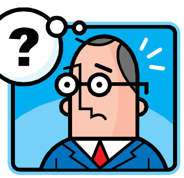
Municipal Solid-State STREET LIGHTING CONSORTIUM

U.S. Department of Energy

Why Is This Important?

Excerpt from MSSLC Model Specification…

1.6 REQUIRED SUBMITTALS FOR EACH LUMINAIRE TYPE DEFINED IN APPENDIX A



A. General submittal content shall include…

B. LM-79 luminaire photometric report(s) shall be produced by the test laboratory and include…

C. Calculations and supporting test data per Appendix B indicating a lumen maintenance life of not less than 36,000 operating hours

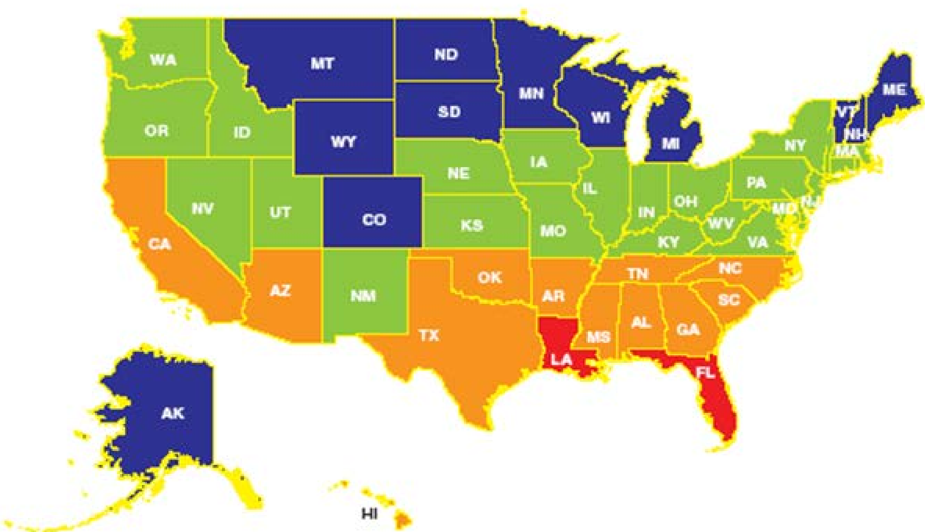
D. Computer-generated point-by-point photometric analysis of maintained photopic light levels as per Appendix A

   A. Calculations shall be for maintained values, i.e. Light Loss Factor (LLF) < 1.0, where LLF = LLD x LDD x LATF

For Luminaire Model XX.XXX…

LED Luminaire Lumen Maintenance Factors Example

Zone*	Drive Current[1] (mA)	Initial LMF	25K hr LMF (Projected[3])	50K hr LMF (Projected[3])	100K hr LMF (Calculated[4])
-20°C† (-4°F)	350mA	1.11	1.07	1.03	0.95
	525mA	1.11	1.07	1.02	0.93
	700mA	1.11	1.06	1.01	0.91
-10°C† (14°F)	350mA	1.09	1.05	1.00	0.92
	525mA	1.09	1.04	0.99	0.89
	700mA	1.09	1.03	0.98	0.87
5°C (41°F)	350mA	1.05	1.01	0.96	0.87
	525mA	1.05	1.00	0.95	0.84
	700mA	1.05	0.99	0.93	0.81
10°C (50°F)	350mA	1.04	0.99	0.95	0.86
	525mA	1.04	0.98	0.93	0.83
	700mA	1.04	0.98	0.92	0.80
15°C (59°F)	350mA	1.03	0.98	0.93	0.84
	525mA	1.03	0.97	0.92	0.81
	700mA	1.03	0.96	0.90	0.78
20°C (68°F)	350mA	1.01	0.97	0.92	0.82
	525mA	1.01	0.96	0.90	0.79
	700mA	1.01	0.95	0.88	0.76
25°C (77°F)	350mA	1.00	0.95	0.90	0.81
	525mA	1.00	0.94	0.89	0.77
	700mA	1.00	0.93	0.87	0.74
40°C (104°F)	350mA	0.96	0.91	0.86	0.76
	525mA	0.96	0.90	0.84	0.72
	700mA	0.96	0.89	0.82	0.67



MSSLC Model Spec – Appendix B

Estimating LED Lumen Maintenance

…The TM-21 methodology shall be used by the manufacturer to determine lamp lumen depreciation (LLD) at end of lumen maintenance life per section 1.6-C...The applicant may estimate lumen maintenance in one of two ways:

Option 1: Component Performance

…the applicant must submit calculations per TM-21 predicting lumen maintenance at the luminaire level using In Situ Temperature Measurement Testing (ISTMT) and LM-80 data…

BOTTOM LINE: Can/Should be provided by the manufacturer…LM-80 is avalaible from most any LED supplier…

Option 2: Luminaire Performance

…the applicant must submit TM-21 calculations based on LM-79 photometric test data for no less than three samples of the entire luminaire…

BOTTOM LINE: This compliance path poses a greater testing burden to luminaire manufacturers but incorporates long-term testing of other components in the system, such as drivers.

Essential Data:

IES Photometric File

✓LM-79 Report

✓LM-80 Report

✓(w/ TM-21 Derived Values at the Luminaire Level)

MSSLC's
Model Specification
for
LED Roadway Luminaires

Model Luminaire Spec – Timeline

- ☐ September 2010 – Concept introduced at inaugural meeting
- ☐ November 2010 – "Beta release" used by Kansas City, MO
- ☐ April 2011 – Public review of first draft
- ☐ June 2011 – Manufacturer workshop #1
- ☐ August 2011 – Manufacturer workshop #2
- ☐ September 2011 – Manufacturer meetings at IES SALC (www.ies.org/salc)
- ☐ **Released, October 2011 – Version 1.0**

Purpose

- ☐ Developed in response to demand from Consortium members and others
  - ☐ To compile experience gained by members
  - ☐ To establish a common language and framework
  - ☐ To serve as a living document, undergoing continual revision
  - ☐ To allow for customization by each adopting entity
  - ☐ To serve as a checklist to minimize errors and omissions

Risk Mitigation!

Scope

Strong Focus on Maintained Illumination Quality and Performance

- Addresses
  - Streets, roadways, and nearby pedestrian ways
  - Pole-mounted luminaires
  - Warranty details
  - Input power, electrical immunity and emission, housing finish, mechanical vibration, etc.
  - Drivers, including lighting controls interface
  - Photocontrol functionality
  - Etc.
- Doesn't address
  - Lamp/ballast retrofit products
  - Lighting control systems
  - Detailed guidance for proper usage of the model specification
    - Limited guidance is provided in hidden text

Concept

- Enabling application-specific photometric performance evaluation(s)
    - Maintained Illumination performance rather than matching lumens
- Intended to be used as a template, customized by each adopter to meet unique requirements

- Adopter to choose between two means of specification
  - Application-*dependent* **(greatly preferred!)**
    - Requires application specific details to be developed
      - Model applications can be developed to cover a range of application variables

  - Application-*independent*
    - Specific application details are not incorporated
    - Compromise in illumination quality and economic value

☐Application-*dependent – GREATLY PREFERED!*

APPENDIX A
APPLICATION-BASED SYSTEM SPECIFICATION
LUMINAIRE TYPE "A"

SITE PARAMETERS		
ROADWAY DATA:	Lane width	13.5 ft
	Number of lanes, total on both sides of median	2
	Shoulder width, drivelane to edge of pavement	4 ft
	Median width	0 ft
	IES pavement class.	☐ R1 ☐ R2 ☑ R3 ☐ R4
	Posted speed limit	☐ ≤ 25 mph ☑ > 25 mph
SIDEWALK DATA:	Sidewalk width	5 ft
	Edge of sidewalk to edge of roadway pavement	6 ft
LIGHT POLE DATA:	Luminaire mounting height	27 ft
	Arm length, horizontal	6 ft
	Luminaires per pole	1
	Pole set-back from edge of pavement	2 ft
	In-line pole spacing (one pole cycle)	150 ft
	Layout	☑ One side ☐ Opposite ☐ Staggered ☐ Median
PERFORMANCE CRITERIA: APPLICATION		
ROADWAY		

☐Application-*dependent – GREATLY PREFERED!*

Photometric Performance Requirements

	Layout	☑ One side ☐ Opposite ☐ Staggered ☐ Median
PERFORMANCE CRITERIA: APPLICATION		
ROADWAY		
PHOTOPIC ILLUMINANCE:	Maintained average horizontal at pavement	4.0 lux (0.4 fc)
	Avg:min uniformity ratio	6.0 : 1
PHOTOPIC LUMINANCE:	Maintained average luminance	n/a
	Avg:min uniformity ratio	n/a
	Max:min uniformity ratio	n/a
VEILING LUMINANCE:	Max. veiling luminance ratio	0.4
SIDEWALKS		
PHOTOPIC ILLUMINANCE:	Maintained average horizontal at pavement	2.0 lux (0.2 fc)
	Avg:min uniformity ratio (horizontal)	4.0 : 1
	Maintained min. vertical illum. at 4.9 ft, in directions of travel	1.0 lux (0.1 fc)
PERFORMANCE CRITERIA: LED LUMINAIRE		
INPUT POWER:	Max. nominal luminaire input power	103 W

☐ Application-*dependent – GREATLY PREFERED!*

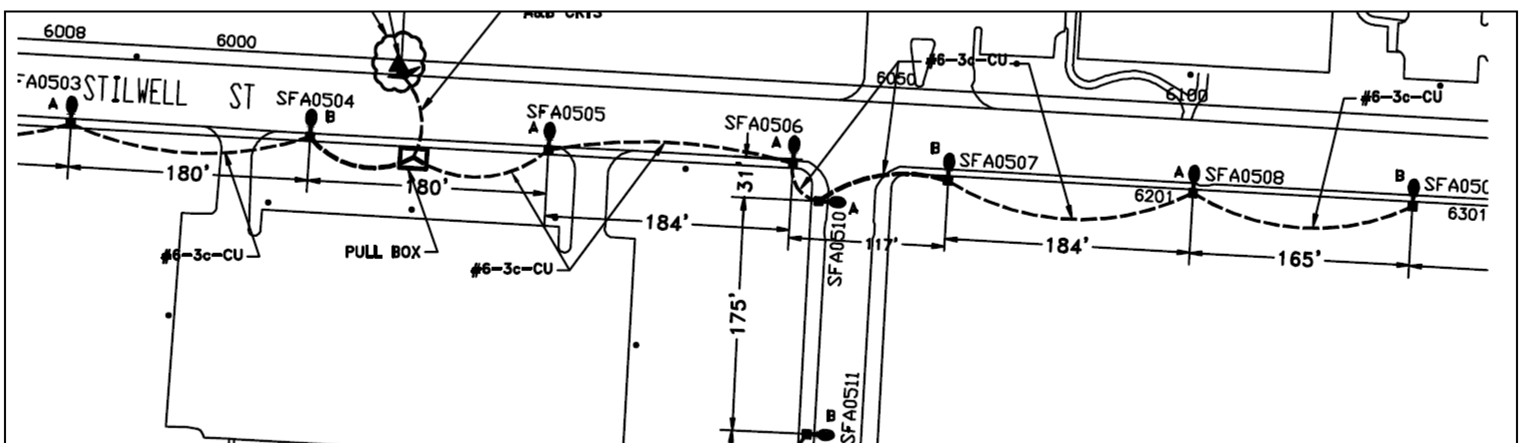
Luminaire Functionality Requirements

	Maintained min. vertical illum. at 4.5 ft, in directions of travel	1.0 lux (0.1 fc)
PERFORMANCE CRITERIA: LED LUMINAIRE		
INPUT POWER:	Max. nominal luminaire input power	103 W
NOMINAL CCT:	Rated correlated color temperature	4000 K
BUG[1] RATING:	Max. nominal backlight-uplight-glare ratings	B1-U2-G1
VOLTAGE:	Nominal luminaire input voltage	120 V
FINISH:	Luminaire housing finish color	Gray
WEIGHT:	Maximum luminaire weight	30 lb
EPA:	Maximum effective projected area	0.7 ft^2
MOUNTING:	Mtg. method	☐ Post-top ☑ Side-arm ☐ Trunnion/yoke ☐ Swivel-tenon
	Tenon nominal pipe size (NPS)	2 inches
VIBRATION:	ANSI test level	☑ Level 1 (normal) ☐ Level 2 (bridge/overpass)
DRIVER:	Control signal interface	☑ Not required ☐ Required

[1] The deprecated "cutoff" classification system cannot be accurately applied to LED luminaires.

- Addressing application variability?
  - In practice, pole spacing varies along any given street
  - Defining representative “typical” scenario(s) for each type is critical

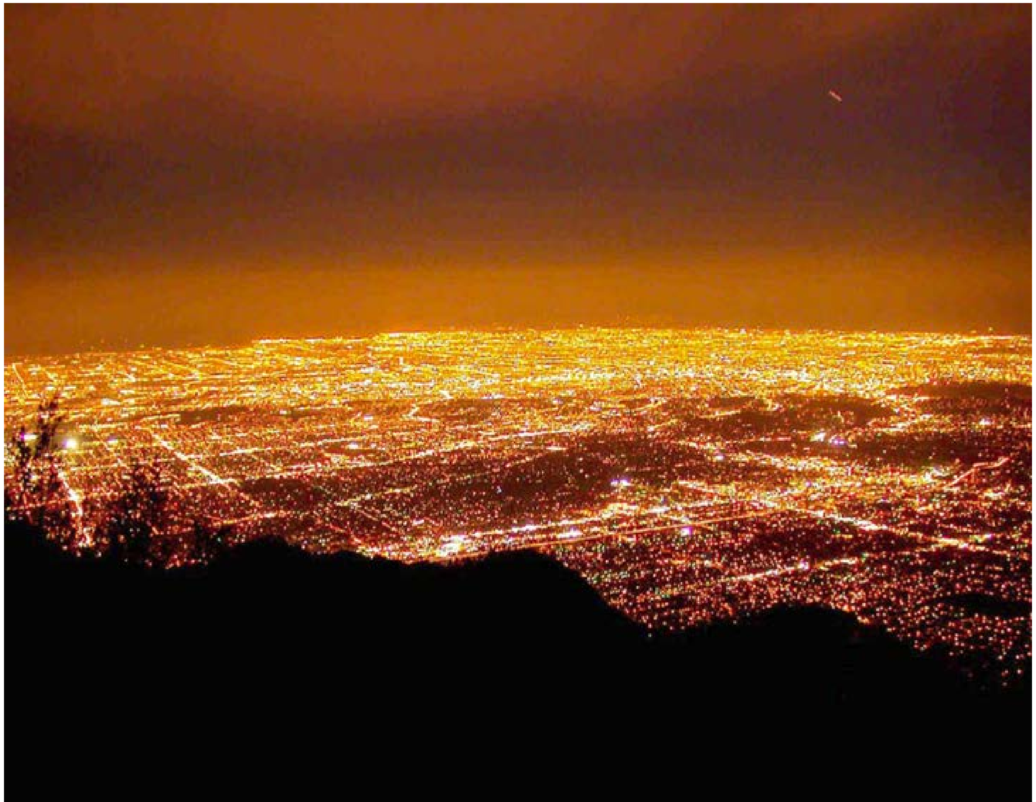
- Create model applications to define and solidify application variables
  - Vital for fair evaluation of various solutions being evaluated
  - Be aware of the resulting range of application performance variation



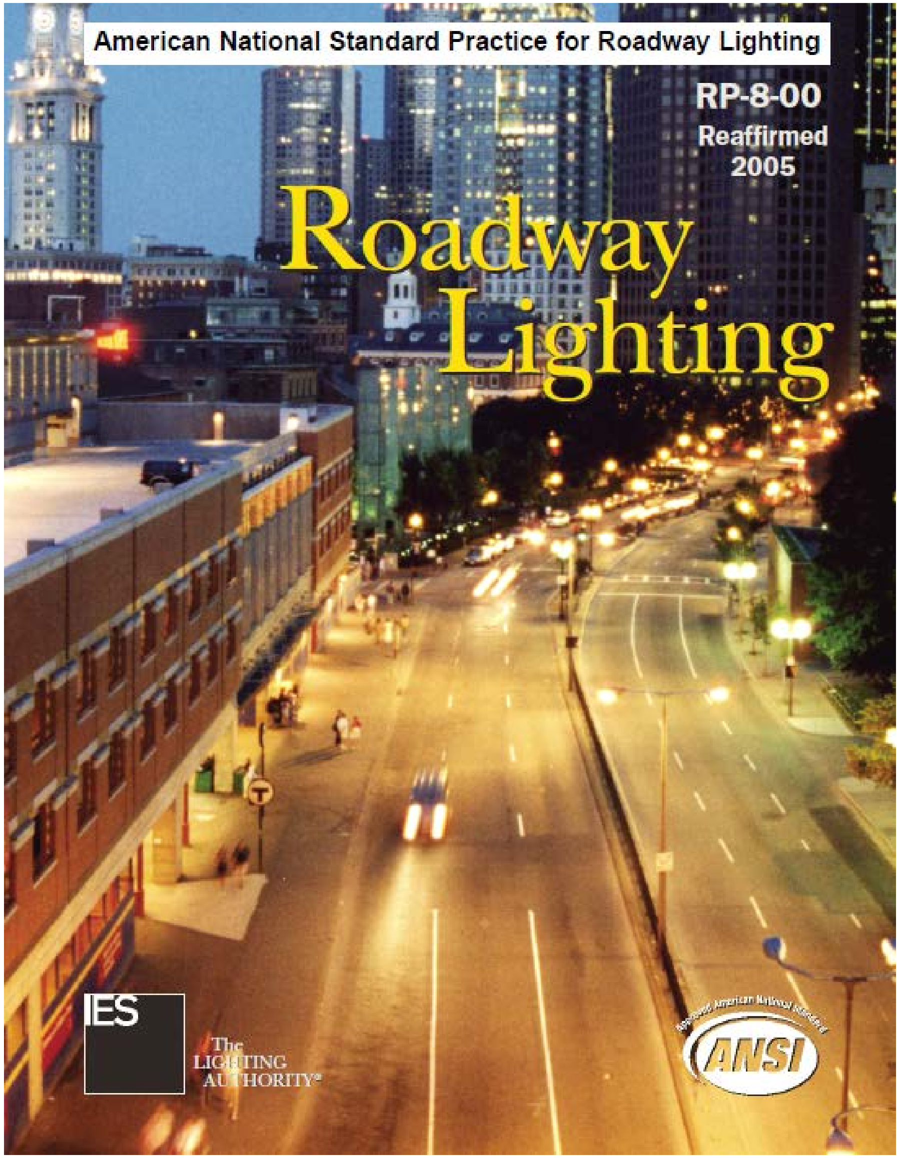
Step #1 - continued

If an Exact Application Description Can Not Be Reasonably Established

Then Create a Representative "Model" Application



Examples


American National Standard Practice for Roadway Lighting
RP-8-00
Reaffirmed
2005
Roadway
Lighting
IES
The
LIGHTING
AUTHORITY
Approved American National Standard
ANSI

Model Application Example - Roadway

Defined Illumination Performance: IESNA RP-8-00

Collector - Medium Pedestrian Conflict Area

Application		Pavement Classification			Uniformity Illuminance	Veiling Luminance Ratio
Roadway Type	Pedestrian Conflict Area	R1	R2/R3	R4	E avg /E min	L_V max /L avg
Collector	High	8.0 (0.8)	12.0 (1.2)	10.0 (1.0)	4.0	0.4
	Medium	6.0 (0.6)	9.0 (0.9)	8.0 (0.8)	4.0	0.4
	Low	4.0 (0.4)	6.0 (0.6)	5.0 (0.5)	4.0	0.4

Table per IESNA RP-8-00

0.9 fc Average

4 to 1 avg./min. (or less…)

Defined Application Geometric Target and Constraints

Luminaire Mounting Height, Spacing and Positioning:

30.5’ AFG, 152.5’ single spacing (non-staggered), 2’ set back, 8’ arm

Roadway: 4 lanes (44’ width)

Ambient Environment: 10° C (Average Nighttime Temperature)

Required Hours of Operation: 50,000 Hours (approximately 12 years)

Required CCT (Correlated Color Temperature): 4000K

Defined Illumination Performance: IESNA RP-8-00

Optimized Luminaire Selection

LED PERFORMANCE SPECS																		
# of LEDs	Initial Delivered Lumens – Type II Short @ 6000K	B	U	G	Initial Delivered Lumens – Type II Short @ 4300K	B	U	G	System Watts 120–277V	Total Current @ 120V	Total Current @ 240V	Total Current @ 277V	System Watts 347–480V*	Total Current @ 347V	Total Current @ 480V	L_{70} Hours** @ 25° C (77° F)	50K Hours Lumen Maintenance** @ 15° C (59° F)
		Rating***				Rating***											
700mA (Standard) Fixture Operating at 25° C (77° F)																	
40	7,294 (04)	2	1	2	6,722 (04)	2	1	2	92	0.78	0.40	0.35	100	0.29	0.23	> 150,000	93%
50	9,013 (05)	2	1	2	8,307 (05)	2	1	2	120	1.00	0.52	0.44	128	0.37	0.29	> 150,000	89%
60	10,752 (06)	3	1	3	9,909 (06)	2	1	2	139	1.17	0.60	0.51	148	0.43	0.32	149,000	89%

Model Application Example - Roadway

Defined Illumination Performance: IESNA RP-8-00

Results

Calculation Summary							
Label	CalcType	Units	Avg	Max	Min	Avg/Min	Max/Min
Road_Illum	Illuminance	Fc	0.91	2.07	0.30	3.03	6.90
Road_Luminance	Luminance	Cd/SqM	0.66	1.35	0.23	2.87	5.87

1.32	1.27	1.09	0.78	0.52	0.39	0.34	0.30	0.30	0.33	0.38	0.48	0.71	1.02	1.24	1.31
1.71	1.69	1.55	1.10	0.72	0.52	0.44	0.37	0.36	0.42	0.49	0.65	0.98	1.44	1.69	1.70
2.01	1.93	1.54	1.23	0.86	0.63	0.49	0.42	0.41	0.47	0.60	0.78	1.13	1.46	1.86	1.99
1.96	2.00	1.51	1.15	0.91	0.63	0.49	0.45	0.44	0.48	0.58	0.83	1.11	1.36	1.93	1.96
1.78	2.04	1.49	1.07	0.89	0.59	0.47	0.43	0.42	0.46	0.54	0.81	1.06	1.31	2.00	1.81
1.59	2.07	1.45	0.96	0.82	0.56	0.44	0.40	0.39	0.43	0.52	0.76	0.96	1.25	2.04	1.64
1.65	2.04	1.46	0.87	0.73	0.53	0.42	0.38	0.37	0.42	0.49	0.68	0.84	1.26	1.97	1.69
1.51	1.86	1.45	0.84	0.66	0.51	0.41	0.37	0.36	0.40	0.48	0.63	0.77	1.27	1.84	1.57

44Ft

152.5Ft

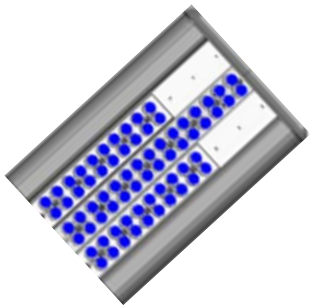
Model Application Example - Roadway

Alternate Evaluation

Proposed

IES Type II Short, 4000K

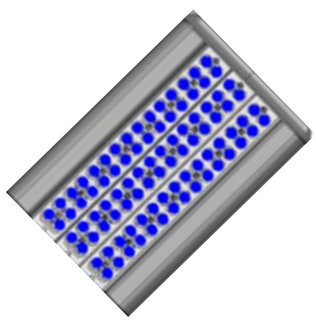
9116 Lumens @ 50,000 Hours and 139 watts



Approx. equivalent

IES Type II Short, 4000K

9053 Lumens @ 50,000 Hours and 119 watts

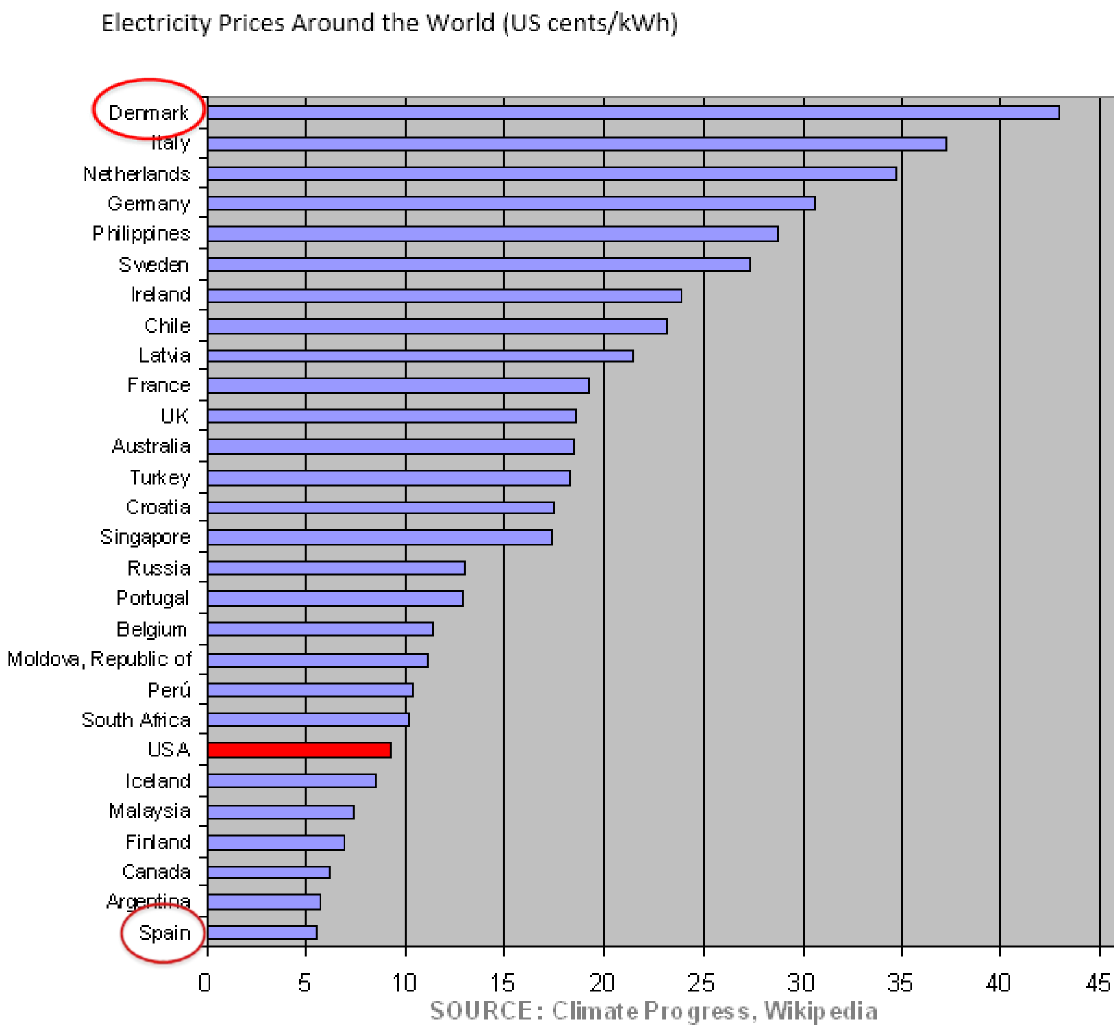


Additional 20 Watt Energy Savings…

What's Product Provides the Best Value?

Municipal Solid-State
STREET LIGHTING
CONSORTIUM

U.S. Department of Energy



<u>Assuming the More Energy Efficient Product Costs $100.00 More:</u>

50,000 Hour (~12 Year) Expected Service Life

$60.00 Savings
At $0.06/kwh

$430.00 Savings
At $0.43/kwh

Step #2

Define the Required Product Functionality and Durability Requirements and/or Limits

- Electrical
  - Input Voltage Range...
  - Maximum Power Consumption...?
    - Infrastructure, Rebate Requirements, etc...
  - Power Factor...
  - THD...
- Mechanical
  - Vibration Resistance...
  - Corrosion Resistance...
- Warranty
- Etc.

Step #2 - continued

Examples

Define the Required Product Functionality and Durability Requirements and/or Limits

Municipal Solid-State STREET LIGHTING CONSORTIUM

U.S. Department of Energy

Step #2 - continued

Required Product Characteristics
Possible "Must Haves"

- Designed to mount on 1.25" IP (1.66" O.D.) and/or 2" IP (2.375" O.D.) horizontal tenon
- Adjustable Horizontal tenon mounting capable of (+/- 5 Degrees) in 2.5° vertical increments
- Finish Color shall be silver
- Luminaire EPA shall not exceed 0.90 / maximum weight not to exceed 30 LBS
- UL Listed for Wet Locations
- RoHS Compliant
- ANSI C136.31-2001 Normal Applications Vibration Standards
- ANSI C136.31-2001 Bridge & Overpass Vibration Standards

Step #2 - continued

Required Product Characteristics
Possible "Must Haves"

- Driver: UL Listed, Power Factor > 90% and THD < 20% at full load; Complies with FCC rules and regulations, Title 47 CFR Part 15 Non-Consumer (Class A), 100,000 hours expected life (≤ 0.5% failure at 100,000 hours of operation in 25° C ambient).
- Integral 10kV Surge Protection
  - Tested in Accordance With IEEE/ANSI C62.41
  - Refer to MSSLC Model Specification Appendix D
- Serviceable and upgradable light engine
- Passive thermal management (heat sink)

Step #2 - continued

Required Product Characteristics
Possible "Must Haves"

- International Dark-Sky Association (IDA) approved
- Suitable to operate in -40° C to +40° C ambient environments
- XX year Luminaire Warranty
- Minimum XX year Finish Warranty
- Etc.

Step #2 - continued

Optional Product Characteristics

Possible "*Nice Haves*"

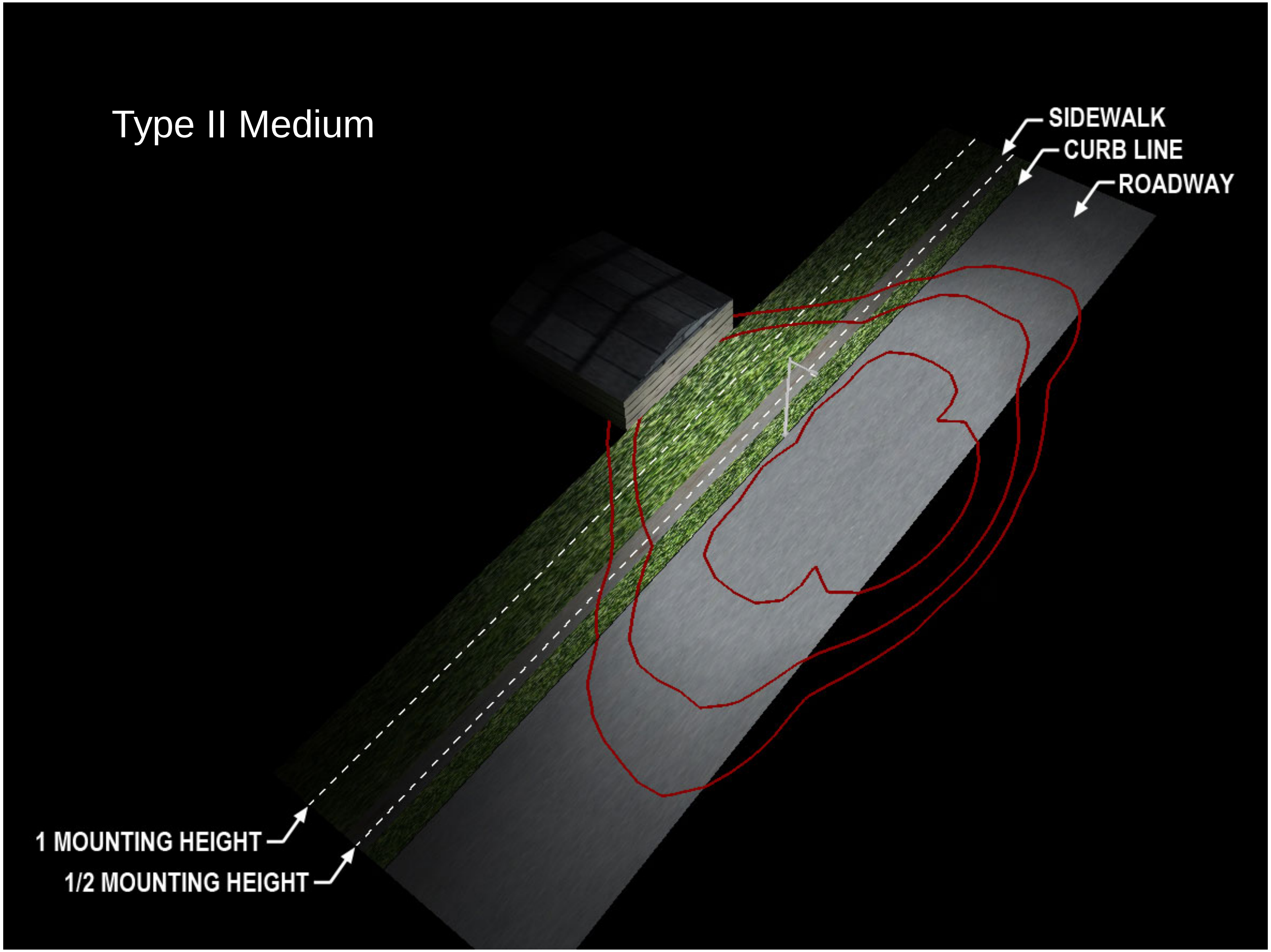
- Manufactured in an ISO9001 facility
- Tool-less Entry
- Minimum 70% recyclable content (by weight)
- Adjustable output power
- Leveling Indicator
- Power supply quick disconnect harness(s) suitable for mate-and-break under load on power feed
- Minimum XX years LED luminaire manufacturing experience and XX installed LED projects (XX References Required)
- Etc.

Do **NOT** Specify Product Performance Variables That Directly or Indirectly Affect Illumination Performance

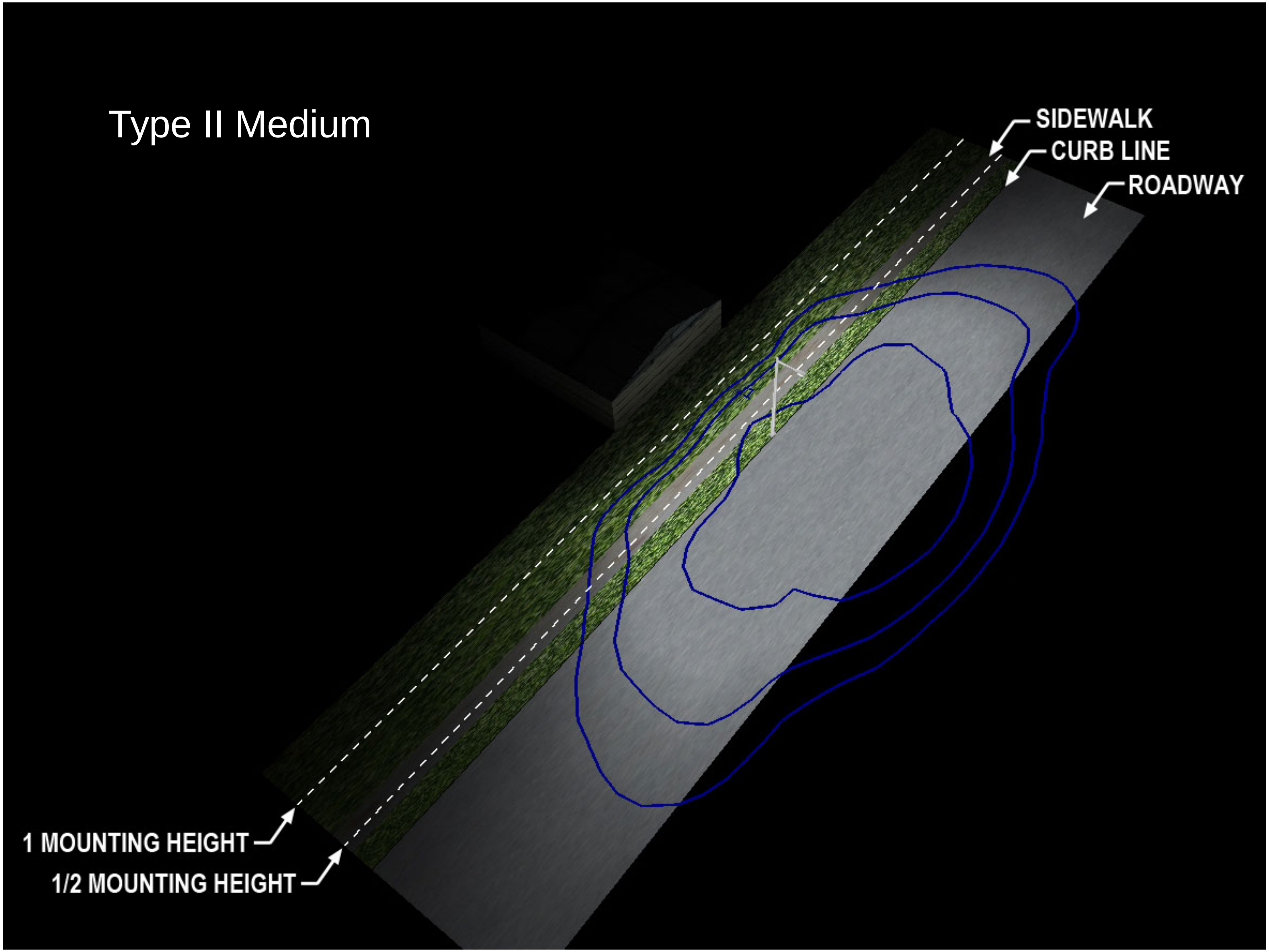
For Example:

- Total Luminaire Efficacy (lumens per watt)
    - Optical Efficiency
    - Thermal Efficiency
    - Electrical Efficiency
- Specific IES Types (Type I, II, III, IV, V)
- Etc.

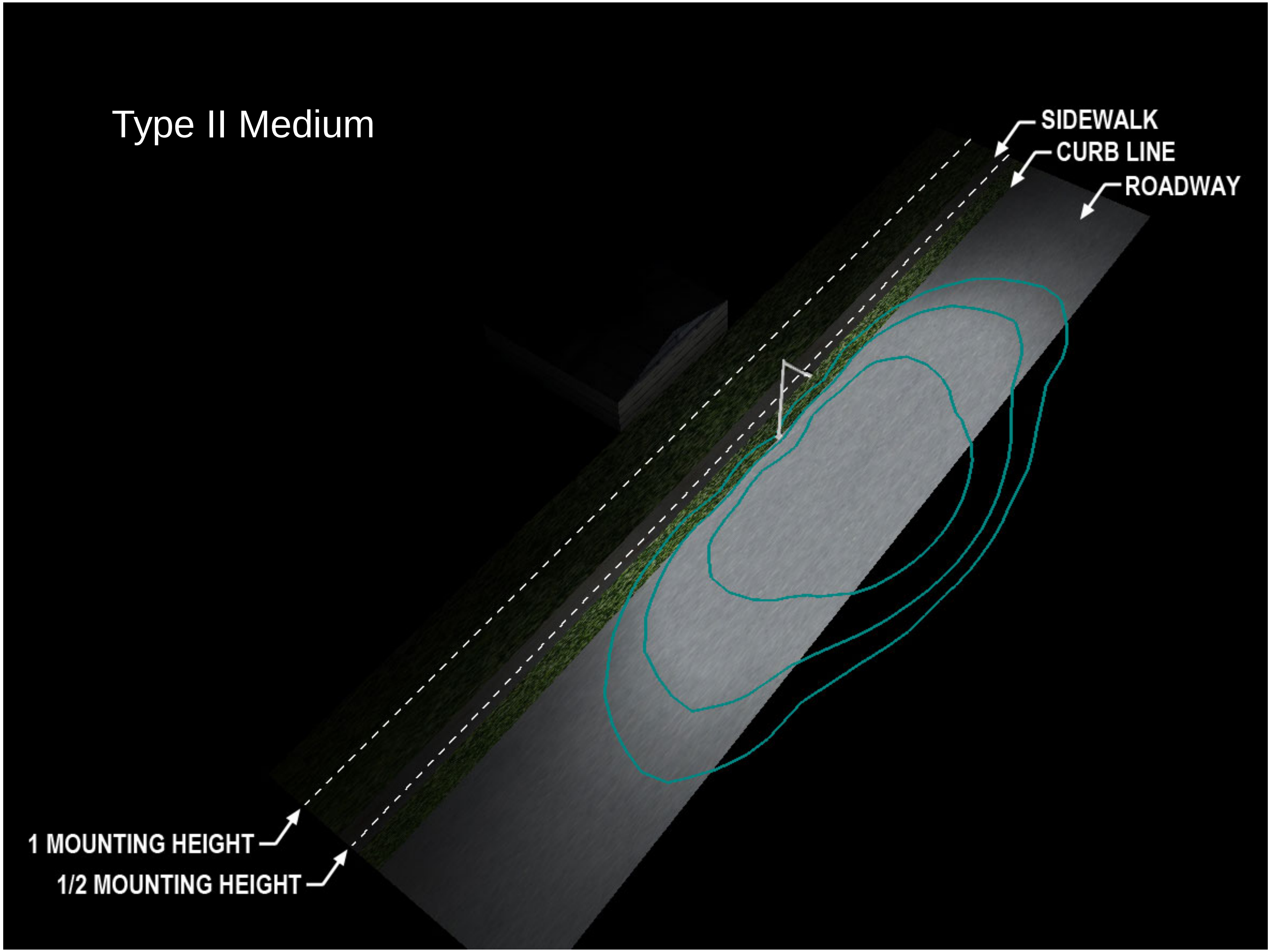
Optical Choices



Optical Choices



Optical Choices



Other Economic Variables Outside the Scope of the Spec

- Energy Costs
- Maintenance Costs
- System Operation Options

    Financing

    Public / Private Partnerships

    Etc.

MSSLC’s Retrofit Financial Analysis Tool

http://www1.eere.energy.gov/buildings/ssl/financial-tool.html

- Detailed Analysis Provides Numerous Outputs, Including:
  - Annual Energy and Energy-Cost Savings
  - Annual Maintenance Savings
  - Annual Greenhouse Gas Reductions
  - Simple Payback, IRR
  - Net Present Value

Important Take-Aways for All Applications

- Application based performance evaluations provide the best opportunity for optimizing maintained illumination performance and economic performance
  - Requires complete and comprehensive product performance data
    - Disqualify solutions that have incomplete data
- Always use a Lifecycle-Cost-Analysis (LCA) approach when evaluating LED luminaire solutions
- THE GOAL…
  - **Sustainable illumination performance**
    - Establish the appropriate illumination performance requirements
    - Time based
    - Predictable and risk managed (data!)
  - **Sustainable economic performance**
    - Time based
    - Lowest Total-Cost-of-Ownership objective

Brief Review

How to get the right luminaire…

Supplement or Revise Existing Lighting Specs?

1. Determine which of the following approaches will be more efficient
   - ☐ Revise existing specifications (usually based on HID and/or induction) to seamlessly incorporate the various elements of the Model Spec
   - ☐ Simply customize the Model Spec as needed to serve as a stand-alone specification for LED luminaires (separate from existing specs)

Customize the Body Text for Your Locality

2. Either customize or incorporate the body text of the Model Spec
   - Some municipalities or utilities may find very little editing is required (default values are generally appropriate for the locality) but ALL users should review the text before adopting
   - For example, more stringent salt-spray criteria would likely be appropriate (cost-effective) in coastal regions

(insert owner/utility/esco name here)
Specification for LED Roadway Luminaires

PART 1 – GENERAL

1.1. REFERENCES

The publications listed below form a part of this specification to the extent referenced. Publications are referenced within the text by their basic designation only. Versions listed shall be superseded by updated versions as they become available.

A. American National Standards Institute (ANSI)
   1. C136.2-2004 (or latest), American National Standard for Roadway and Area Lighting

Specifying Photometric Performance

3. Establish “typical” or representative *applications* for each luminaire *type* being installed/replaced
   - For example, if three different HPS luminaires are being replaced, there should be three different luminaire types
   - More than one application may be defined for each product type since the same luminaire is often used in different situations
4. For each application, establish site geometries and corresponding photometric criteria based on
5. Customize Appendix A of the Model Specification accordingly

Issuing an RFP for Product Evaluation

6. Use the customized specification to issue an RFP, or distribute among manufacturers and their sales reps
   - Manufacturers and/or their sales reps will save you a substantial amount of work by identifying their best product(s) for the job
   - Low-quality or ill-suited products are effectively excluded

Submittal Review

7. Review product submittals to ensure conformance with the specification
   - ☐ Labor-intensive but worth the effort
   - ☐ Some less-reputable manufacturers may be counting on inadequate review of incomplete or non-conforming submittals

Luminaire Type[1]		
Manufacturer		
Model number		
Housing finish color		
Tenon nominal pipe size (inches)		
Nominal luminaire weight (lb)		
Nominal luminaire EPA (ft^2)		
Nominal input voltage (V)		
ANSI vibration test level	☑ Level 1 (Normal)	☐ Level 2 (bridge/overpass)
Nominal BUG Ratings		
Make/model of LED light source(s)		
Make/model of LED driver(s)		
Dimmability	☐ Dimmable	☑ Not dimmable
Control signal interface		
Upon electrical immunity system failure	☐ Possible disconnect	☐ No possible disconnect
Thermal management	☐ Moving parts	☑ No moving parts
Lumen maintenance testing duration (hr)		
Reported lumen maintenance life (hr)[2]		
Warranty period (yr)		
Parameter	Nominal value	Tolerance (%)
Initial photopic output (lm)		

Small-Scale Mock-ups

8. Acquire at least four product samples of each qualifying luminaire for evaluation of
   - ☐ Lead time for production and shipment
   - ☐ General quality of construction, fit, and finish
   - ☐ Ease of installation and maintenance
   - ☐ Quantity and quality of illumination when installed in the field

Larger-Scale Demonstrations

9. Continue evaluation of "finalists" on a larger scale
   - ☐ Survey residents before/after installation
   - ☐ Survey design should avoid biasing of results – sample surveys can be found at www.ssl.energy.gov/gatewaydemos_results.html

2. Compared to the standard street lighting on Gertz Road, how would you characterize the lighting on Lija Loop?

Responses	Number	Percentage
extremely different	8	72.7%
somewhat different	2	18.2%
not different	0	
no opinion	1	9.1%

3. The quality of street lighting on Lija Loop _________ my ability to see the street and objects that are on it.

Responses	Number	Percentage
greatly enhances	7	63.6%
enhances	2	18.2%
has no effect on	1	9.1%

Finalizing Specifications

10. Update standard specifications
    - ☐ Identify pre-approved luminaires (if appropriate)
    - ☐ Revise customized Model Specification (if needed) and merge with standard specifications (if appropriate)

Q&A