Municipal Solid-State STREET LIGHTING CONSORTIUM

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LM79 – Understanding and Evaluating

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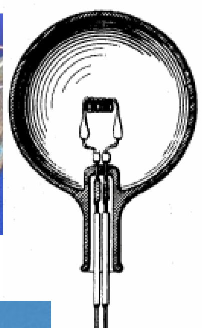


A History of Light Sources

- ~400,000 BCE - Fire is discovered.
- ~3000 BCE - Oil lamps are open bowls with a spout to hold the wick.
- ~400 - The candle is invented.
- 1809 - Sir Humphrey Davey demonstrates electrical discharge lighting to the Royal Institution in London, using an open-air arc between two carbon rods. The result is a very intense, and very pure white light. Unfortunately, as the arc runs, carbon boils off and the rods wear away: constant attention must be paid to readjusting the arc, feeding more carbon in.
- 1841 - Frederick DeMoleyns patented incandescent lamp using filaments of platinum and carbon, protected by a vacuum.
- 1880 - Thomas Edison receives U.S. patent #223,898 for the carbon filament incandescent lamp.
- 1932 - Low pressure sodium lamps are first used commercially.
- 1934 - The high-pressure mercury lamp is introduced.
- 1938 - First commercial sale of the fluorescent lamp
- 1957 - The quartz halogen lamp (A.K.A. tungsten halogen lamp) is invented. In conventional tungsten lamps, the filament metal slowly evaporates and condenses on the glass envelope, leaving a black stain. In this case, the halogen removes the deposited tungsten and puts it back on the filament.
- 1962 - First light emitting diode (LED)
- 1966 - Commercial introduction of the high pressure sodium lamp
- 1969 - A new form of metal halide lamp, the HMI lamp (mercury medium arc iodides) is introduced. The H stands for mercury (atomic symbol "Hg"), M is for Metals and the I is for halogen components (iodide, bromide). It provides a daylight type spectrum.

Nick Holonyak, Jr., an IEEE Fellow built the first LED (light-emitting diode), along with two of his former graduate students, M. George Craford and Russell Dean Dupuis in 1962.

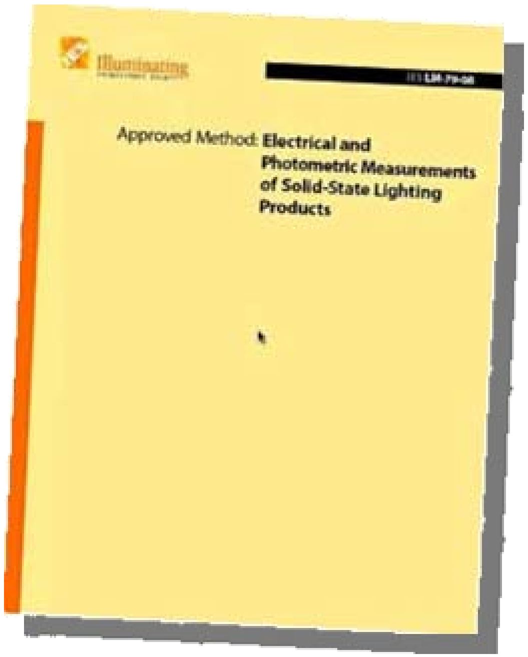
Craford, chief technology officer of LumiLeds Lighting (now Philips), made the first yellow LED in 1972.

He is one of only 13 Americans who has received both the National Medal of Technology and National Medal of Science.

Holonyak, an IEEE Medal of Honor winner has been a professor at the University of Illinois in Champaign since 1963.

IES LM-79

Electrical and Photometric Measurements of Solid-State Lighting Products



Standard LM-79-2008 includes the environmental conditions for testing, how to operate and stabilize the LED sources during testing, the methods of measurement and types of instruments to be used.

It is based on a method called *absolute photometry,* which simply means that the reported information is directly representative of the specific product tested and is not derived relative to any rated lamp standard.

The product is measured using an integrating sphere to measure gross light output and color characteristics, and a goniophotometer, a photometer that measures light intensity reflected from a surface at different angles.

The combined testing objectively captures 11 aspects of performance including total lumen output, fixture efficacy, chromaticity (from which color rendering index rating can be derived), and correlated color temperature.

Why is LED Different

- LED lamps cannot be separated from luminaires
- LED modules cannot be measured separately because the light output in open air will be significantly different
- Thermal management plays a big role in actual performance

Relative Photometry

- Bare lamps measured separately
  - Seasoned (aged) lamps
  - Output stabilization
  - Raw output measured
- Luminaire test
  - Same lamps and ballast
  - Identical electrical and thermal characteristics
- Results scaled to initial rated lamp lumens
- Luminaire efficiency
- Ballast factor – 1.0
- Different labs get same results

- Luminaire based absolute photometry
- Total Luminous Flux
- Luminous Intensity Distribution
- Electrical Power
- Luminous Efficacy (LPW – calculated)
- Color Characteristics
- Chromaticity
- CCT
- CRI

Absolute Photometry

- LED Luminaires
- Lamps integral to luminaire
- Optical efficiency not measured
- Precise test conditions and environment
- No lamp seasoning
- System calibrated to lamp of known output
- Actual luminaire output measured

    Efficacy (lumens/watt)

Relative vs. Absolute Photometry

Electrical and Photometric Measurements of Solid-State Lighting Products

- Relative testing
  - Lamps of interest and luminaire (with reference lamp) are measured separately. Then the actual light distribution and intensity of the complete luminaire of interest is derived by normalization of the test data. Photometric tests are created with lamp lumens pro-rated as though being driven by a ballast with a ballast factor (BF) of 1.0.

- Absolute testing

The actual light distribution and intensity of the luminaire of interest is measured directly from the complete luminaire

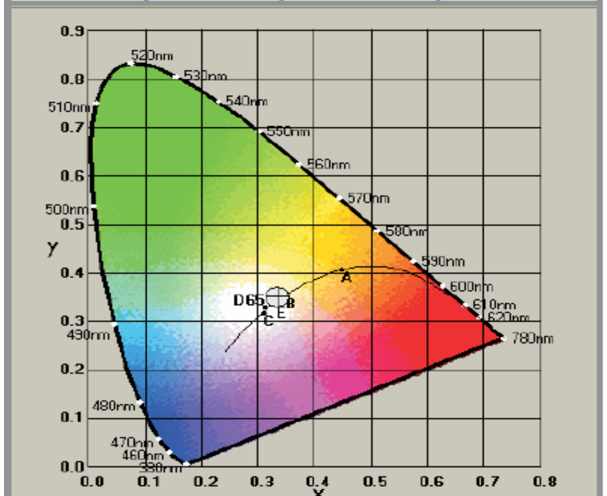
Traditional lamp luminaires are commonly measured relative to measured luminous flux of the bare lamp(s) used in the luminaire (Relative photometry), which does not work for LED luminaires.

LED lamps typically cannot be separated from their luminaire because of heat effects. The luminous efficacy (lm/W) of the whole luminaire (Luminaire efficacy) needs to be measured and evaluated (Absolute photometry).

Integrating Sphere

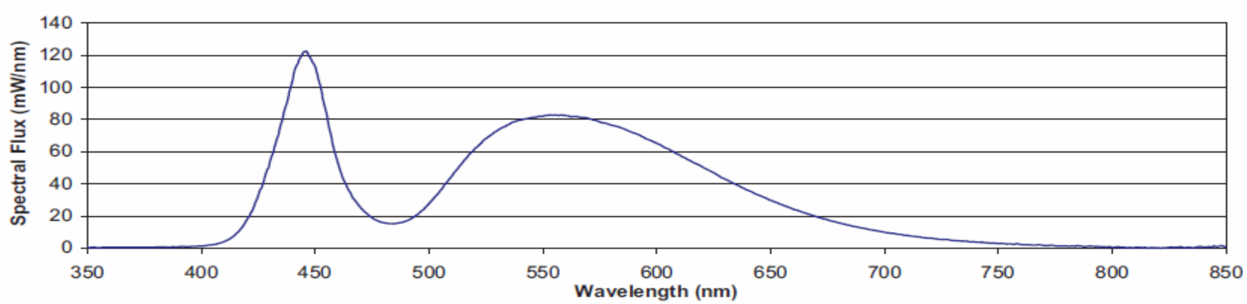
- What is it?
- Total light output measured by distribution unknown (lumens)
- Correlated Color Temperature (CCT)
- Color Rendering Index (CRI)
- CIE Chromaticity coordinates (x,y)
- Output Spectrum
- Output and Color over time

Lamp Arc Voltage	Lamp Current	Lamp Watts	Frequency
120.0VAC	0.7931A	93.58W	60Hz
Radiant Flux mW	**Luminous Flux lumen**	**Corr.Color Temperature K**	**Color Rend. Index Ra**
14877.85	4832.109	5432	70
Chroma x	**Chroma y**	**Chroma u**	**Chroma v**
0.3341	0.3509	0.2042	0.3218

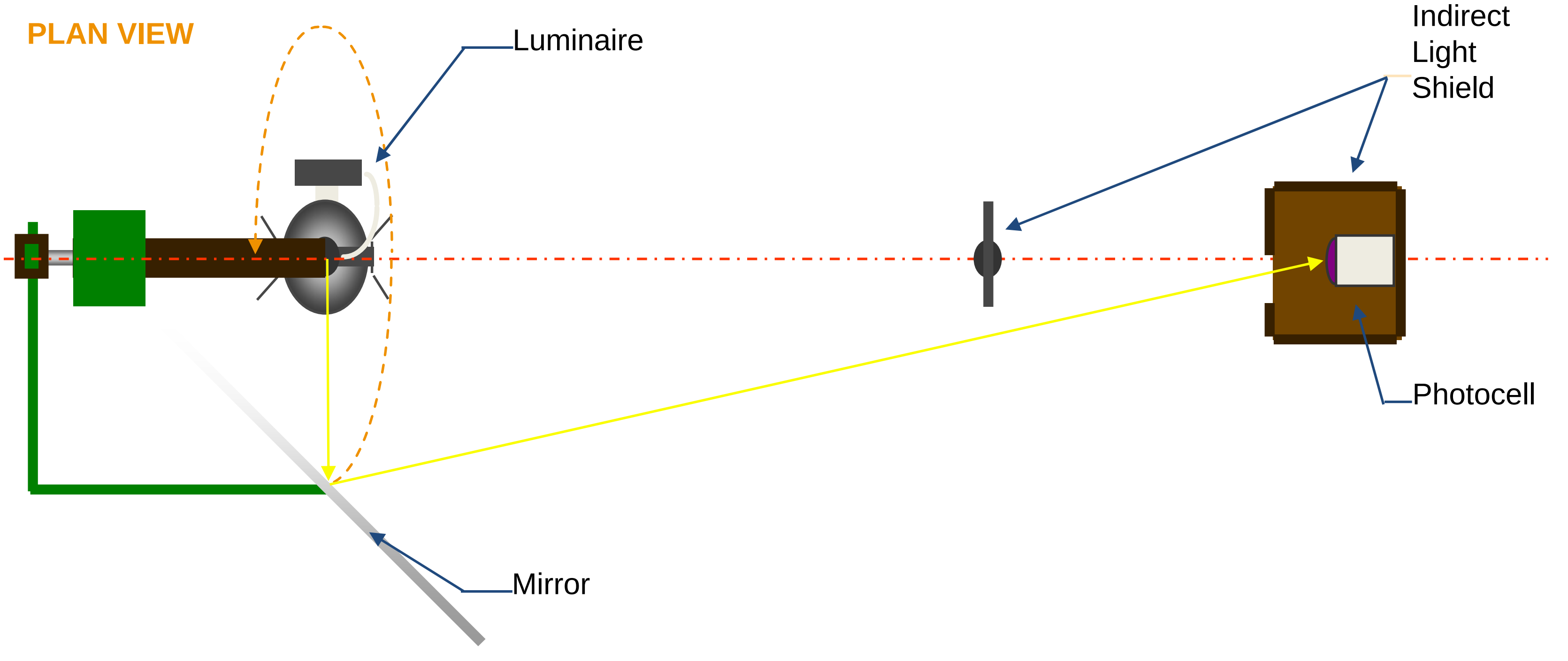


Chromaticity Diagram CIE 1931, 2 degree

Wavelength in nm	Spectral Flux in mW/nm	Wavelength in nm	Spectral Flux in mW/nm
350	0.4086	610	57.9480
360	0.6012	620	50.5390
370	0.4211	630	42.9920
380	0.7582	640	36.0230
390	0.8439	650	29.8360
400	1.3357	660	24.3050
410	4.0895	670	19.7050
420	17.7810	680	15.7180
430	53.0200	690	12.4700
440	104.4700	700	9.9248
450	112.8900	710	7.9504
460	52.9090	720	6.3056
470	25.0420	730	4.8584
480	15.8230	740	3.7486
490	16.9680	750	3.0347
500	27.7550	760	2.3077
510	45.0040	770	1.7088
520	61.6270	780	1.3245
530	73.1980	790	1.3060
540	79.6490	800	0.6952
550	82.2250	810	0.2657
560	82.5000	820	0.0408
570	80.8040	830	1.0044
580	76.5280	840	0.3915
590	71.5770	850	0.8806
600	65.2520		



Goniophotometer



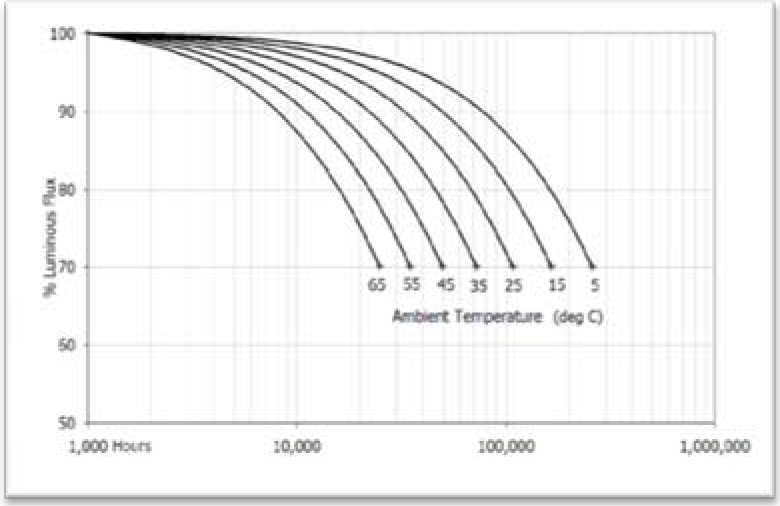
Measures light intensity reflected from a surface at different angles.

As per LM-79 testing the luminaire performance is established at an ambient of 25 degrees Celsius.

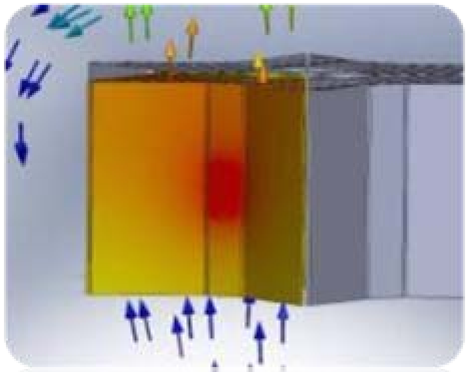
Fixture performance will vary according to the temperature of the ambient environment.

Performance can be prorated by at table of Ambient temperatures.

LED Thermals



Ambient	Lumen
Temperature	Multiplier
10°C	1.04
15°C	1.03
25°C	1.00
40°C	0.96



CHARACTERISTICS

IES Classification	Type III
Longitudinal Classification	Medium
Cutoff Classification (deprecated)	Full Cutoff
Lumens Per Lamp	14000 (1 lamp)
Total Lamp Lumens	14000
Luminaire Lumens	10370
Total Luminaire Efficiency	74 %
Downward Total Efficiency	74 %
Luminaire Efficacy Rating (LER)	56
Upward Waste Light Ratio	0.00
Maximum Candela	20672
Maximum Candela Angle	55H 70V
Maximum Candela (<90 Degrees Vertical)	20672
Maximum Candela Angle (<90 Degrees Vertical)	55H 70V
Maximum Candela At 90 Degrees Vertical	0 (0.0% Lamp Lumens)
Maximum Candela from 80 to <90 Degrees Vertical	426 (3.0% Lamp Lumens)
Total Luminaire Watts	185
Ballast Factor	1.00

CHARACTERISTICS

IES Classification	Type II
Longitudinal Classification	Short
Cutoff Classification (deprecated)	Full Cutoff
Lumens Per Lamp	N.A. (absolute)
Total Lamp Lumens	N.A. (absolute)
Luminaire Lumens	7121
Total Luminaire Efficiency	N.A.
Downward Total Efficiency	N.A.
Luminaire Efficacy Rating (LER)	69
Upward Waste Light Ratio	0.00
Maximum Candela	6848
Maximum Candela Angle	60H 65V
Maximum Candela (<90 Degrees Vertical)	6848
Maximum Candela Angle (<90 Degrees Vertical)	60H 65V
Maximum Candela At 90 Degrees Vertical	0 (0.0% Luminaire Lumens)
Maximum Candela from 80 to <90 Degrees Vertical	146.7 (2.1% Luminaire Lumens)
Total Luminaire Watts	103
Ballast Factor	1.00

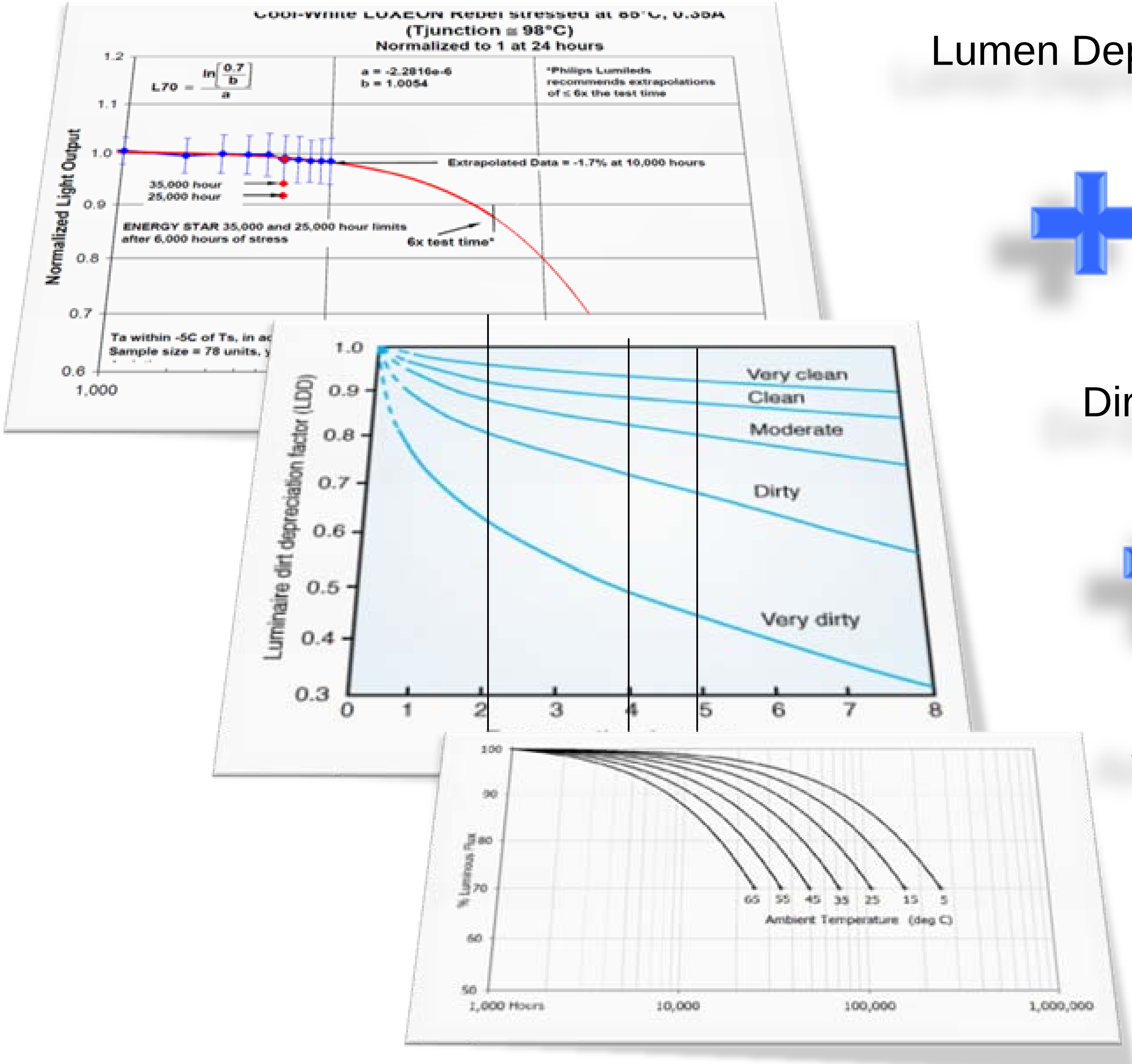
	Lumens	% Lamp	% Luminaire
FL - Front-Low (0-30)	840.5	6.0	8.1
FM - Front-Medium (30-60)	4097.5	29.3	39.5
FH - Front-High (60-80)	2560.3	18.3	24.7
FVH - Front-Very High (80-90)	15.1	0.1	0.1
BL - Back-Low (0-30)	623.9	4.5	6.0
BM - Back-Medium (30-60)	1564.5	11.2	15.1
BH - Back-High (60-80)	658.4	4.7	6.3
BVH - Back-Very High (80-90)	9.4	0.1	0.1
UL - Uplight-Low (90-100)	0.0	0.0	0.0
UH - Uplight-High (100-180)	0.0	0.0	0.0
Total	10369.6	74.2	100.0
BUG Rating	B2-U0-G2		

LUMINAIRE CLASSIFICATION SYSTEM (LCS)

	Lumens	% Lamp	% Luminaire
FL - Front-Low (0-30)	782.8	N.A.	11.0
FM - Front-Medium (30-60)	3306.6	N.A.	46.4
FH - Front-High (60-80)	1788.1	N.A.	25.1
FVH - Front-Very High (80-90)	32.6	N.A.	0.5
BL - Back-Low (0-30)	468.0	N.A.	6.6
BM - Back-Medium (30-60)	506.2	N.A.	7.1
BH - Back-High (60-80)	223.3	N.A.	3.1
BVH - Back-Very High (80-90)	13.6	N.A.	0.2
UL - Uplight-Low (90-100)	0.0	N.A.	0.0
UH - Uplight-High (100-180)	0.0	N.A.	0.0
Total	7121.3	N.A.	100.0
BUG Rating	B1-U0-G1		

IES Classification	Type III	Type II
Longitudinal Classification	Medium	Short
Cutoff Classification (deprecated)	Full Cutoff	Full Cutoff
Lumens Per Lamp	14000 (1 lamp)	N.A. (absolute)
Total Lamp Lumens	14000	N.A. (absolute)
Luminaire Lumens	10370	7121
Downward Total Efficiency	74 %	N.A.
Luminaire Efficacy Rating (LER)	56	69
Upward Waste Light Ratio	0.00	0.00
Maximum Candela	20672	6848
Maximum Candela Angle	55 H x 70 V	60 H x 65 V
Max. Candela (<90 Vert.)	20672	6848
Max. Candela Angle (<90 Vert.)	55 H x 70 V	60 H x 65 V
Max. Candela At 90 Degrees Vert.	0 (0% Lamp Lms.)	0 (0% Lum. Lms.)
Max. Candela 80 to < 90 Vert.	426 (3.04% Lamp Lms.)	146.7 (2.06% Lum. Lms.)
Total Luminaire Watts	185	103
Ballast Factor	1.00	1.00
Total Downward Lumens Street Side	7513.32	5910.10
Total Upward Lumens Street Side	0	0
Total Downward Lumens House Side	2856.24	1211.11
Total Upward Lumens House Side	0	0
Avg. Glare Zone Flux 80-90	0.18 %Lamp Luminous Flux	0.65 %Lum. Luminous Flux
Avg. Glare Zone Max. Luminous Intensity 80-90	3.04 %Lamp Luminous Flux	2.06 %Lum. Luminous Flux

Predicting System Performance



Lumen Depreciation

Dirt Depreciation

Ambient Thermal Effect

Resources

- **NEMA**
- SSL-3 High Power White LED Binning for General Illumination
- SSL-1 Electronic Drivers for LED Devices, Arrays, or Systems
- SSL-6 Replacements for Incandescent lamps
- White Papers – LSD 44, 45, 49
- www.nema.org

Resources

- **ANSI – American National Standards Institute**
- C136.15 Wattage Source Labels
- C136.37   Standard for Solid State Lighting

- www.nema.org

CHALLENGES

- LED products are directly affected by the output of the source itself which can vary
- Not sufficient to test a single sample
- Appropriate sampling and averaging of results are required

CHALLENGES

- Absolute photometry can sometimes hide differences in optical efficiency.
- Much more difficult to sort our the variations- you may not know if the chip is not performaning as stated or if the optic is inefficient.
- Takes much more time and more test to determine variations.

CONCLUSIONS

- SOLID STATE LIGHTING IS THE FUTURE OF WHITE LIGHT SOURCES
- EFFICIENCIES WILL CONTINUE IN A UPWARD TREND
- THE SYSTEM WILL BECOME MORE COST EFFECTIVE
- STANDARDS WILL CONTINUE TO EVOLVE AS WE LEARN MORE

CONCLUSIONS

- FEDERAL LEGISLATION WILL CONTINUE TO PROMOTE MORE ENERGY EFFICIENT PRODUCTS
- CONTROLS WILL BECOME PART OF THE SYSTEM IN AN EFFORT TO REDUCE ENERGY CONSUMPTION
- SOLID STATE LIGHTING IS NOT THE ANSWER TO ALL LIGHTING APPLICATIONS