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

LED Street Lighting in the Greater Phoenix Metro Area

Sustainable Cities Network

Hosted by Arizona State University

August 9, 2016

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The DOE Solid-State Lighting Program (ssl.energy.gov)

- **Testing and field studies** offer unbiased analysis
- **Data and analysis** provide broad view of market trends, support standards organizations and industry consortia
- **Technology competitions** drive innovation, draw attention to well-designed products

CALiPER

GATEWAY Demonstrations

STANDARDS Support

LED lighting facts® A Program of the U.S. DOE

Next Generation LUMINAIRES

L PRIZE® U.S. Department of Energy

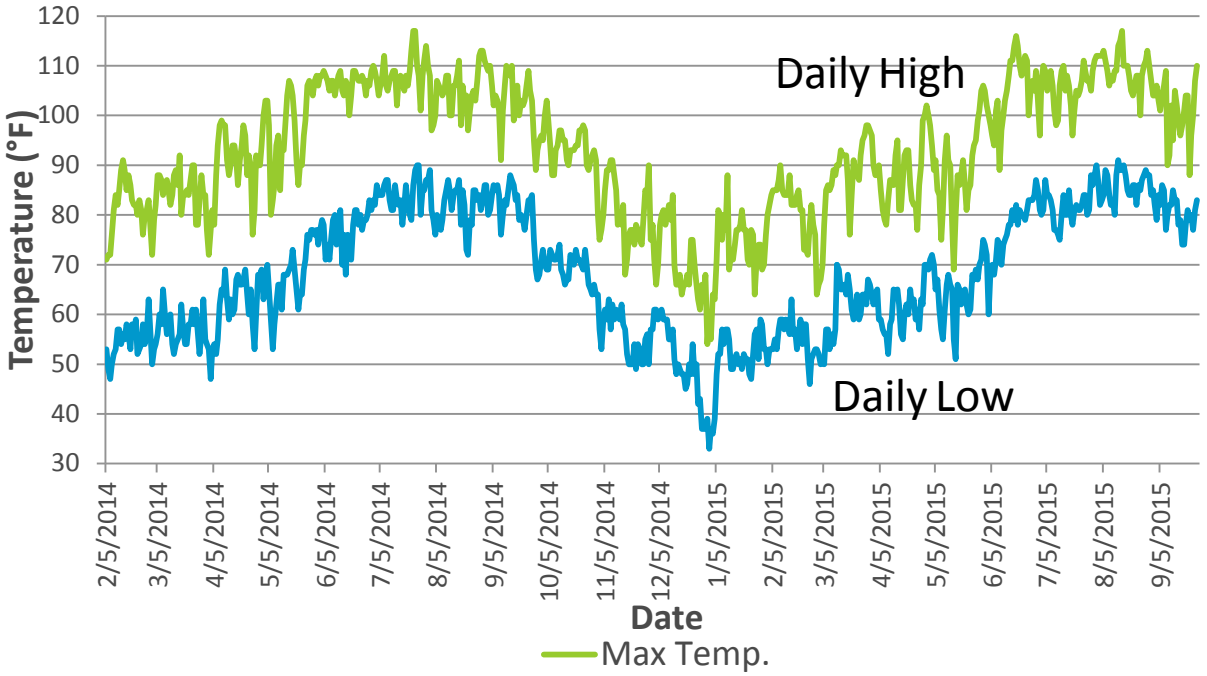
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

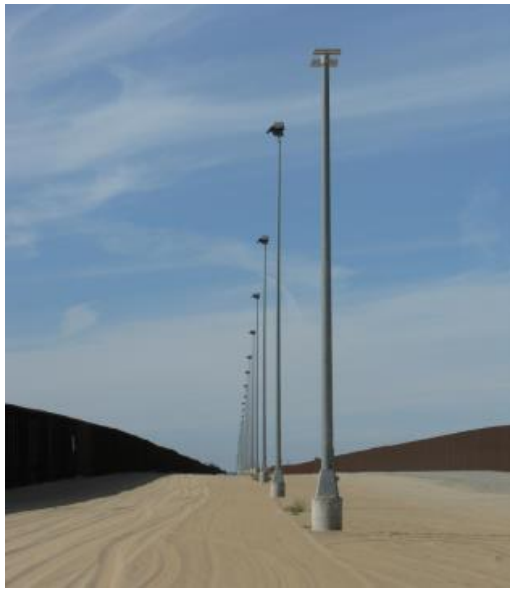
Clarity needed on a variety of street lighting issues

- Lack of field experience forces reliance on projections and assumptions
  - Still less than a single life-cycle for 50K hour products!
  - Other issues, e.g., blue light contribution to sky glow, or related health concerns, are extremely complex and not yet completely understood by the respective communities (but who sometimes fear the worst)
  - Often information presented is incomplete, inaccurate, or simply incorrect
- Owners, users, the general public understandably have questions and concerns
- Our mission: provide more complete information based on what we know, help identify remaining gaps, and help the lighting community incorporate into planning and designs

Yuma

- Results may have direct relevance to Phoenix metro area
  - Lighting system installed along U.S. border
  - Multi-year performance monitoring effort incorporating thermal measurement, lighting distribution, LDD, LLD

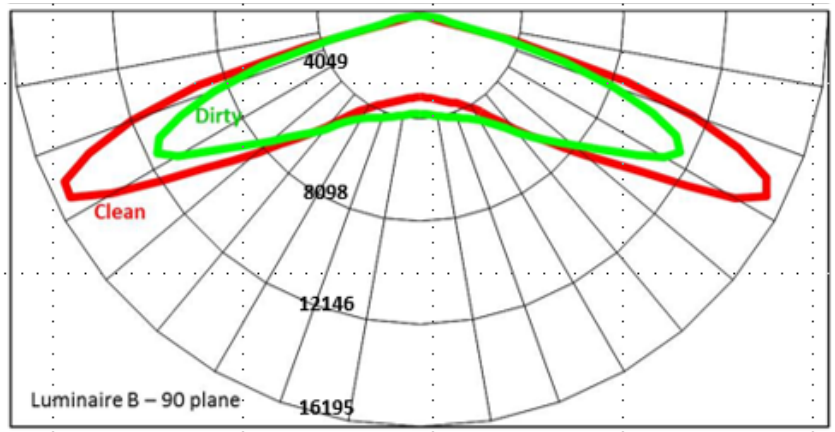


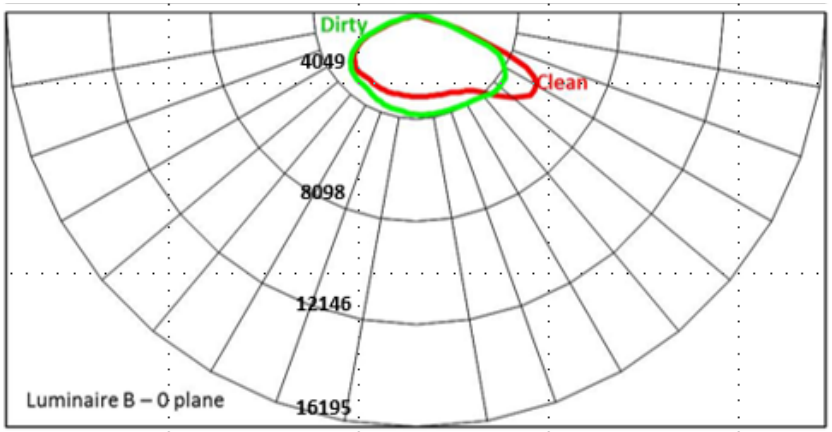


Available at: http://energy.gov/eere/ssl/gateway-demonstration-outdoor-projects

Yuma

- Significant dirt depreciation and resulting change in distribution



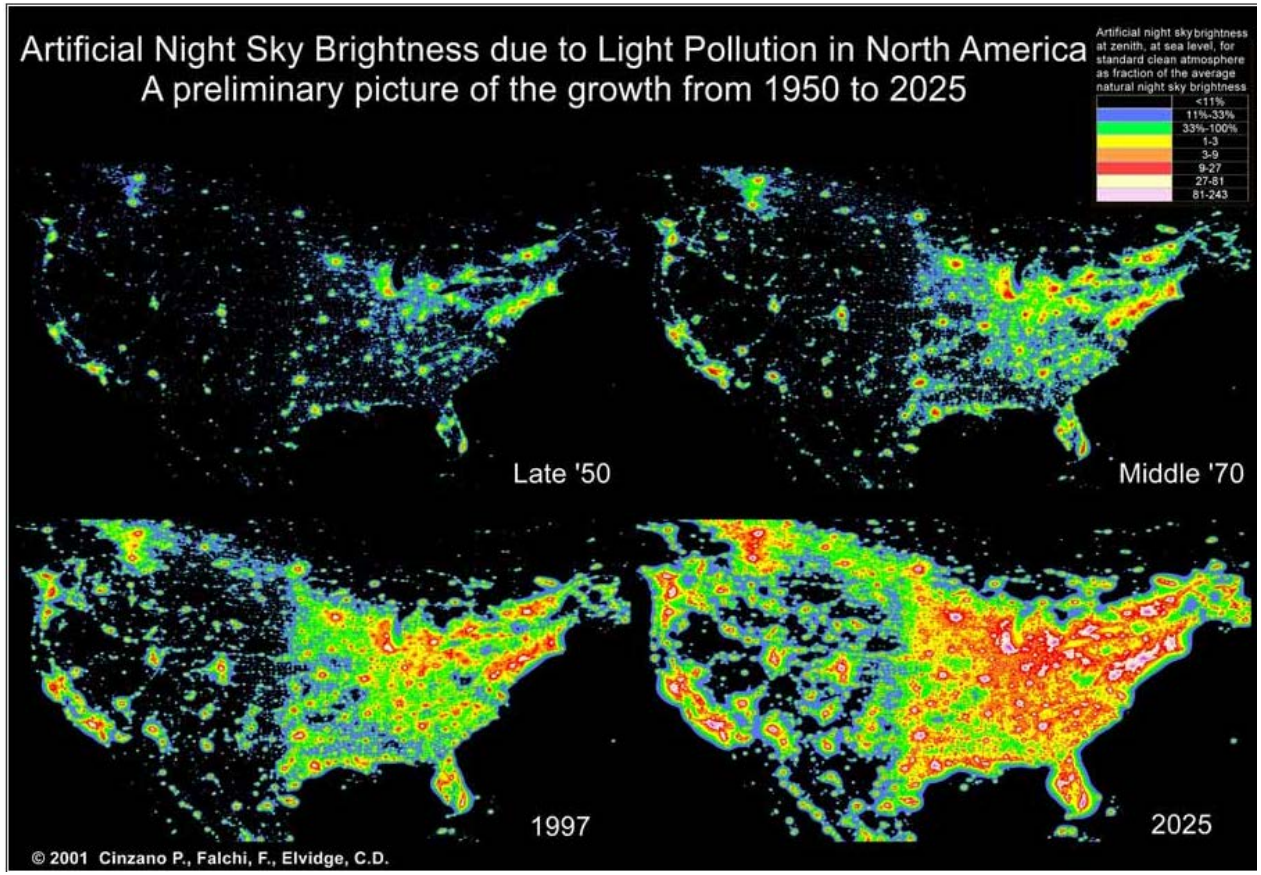


Test	Total Output (lumens)	Peak Intensity at 90° Horizontal Angle (candela)[b]	Peak Intensity at 0° Horizontal Angle (candela)[c]	Intensity at Nadir (candela)
Dirty B Eaton	24,956	11,643	4,226	3,883
Clean B Eaton	27,472	15,471	5,565	3,218
Percent Change Due to Dirt	**-9.2%**	**-24.7%**	**-24.1%**	**+20.7%**
Dirty A Eaton[a]	27,782	12,970	5,208	3,990
Clean A Eaton[a]	29,881	17,558	6,138	3,436
Percent Change Due to Dirt	**-7.0%**	**-26.1%**	**-15.2%**	**+16.1%**

Yuma

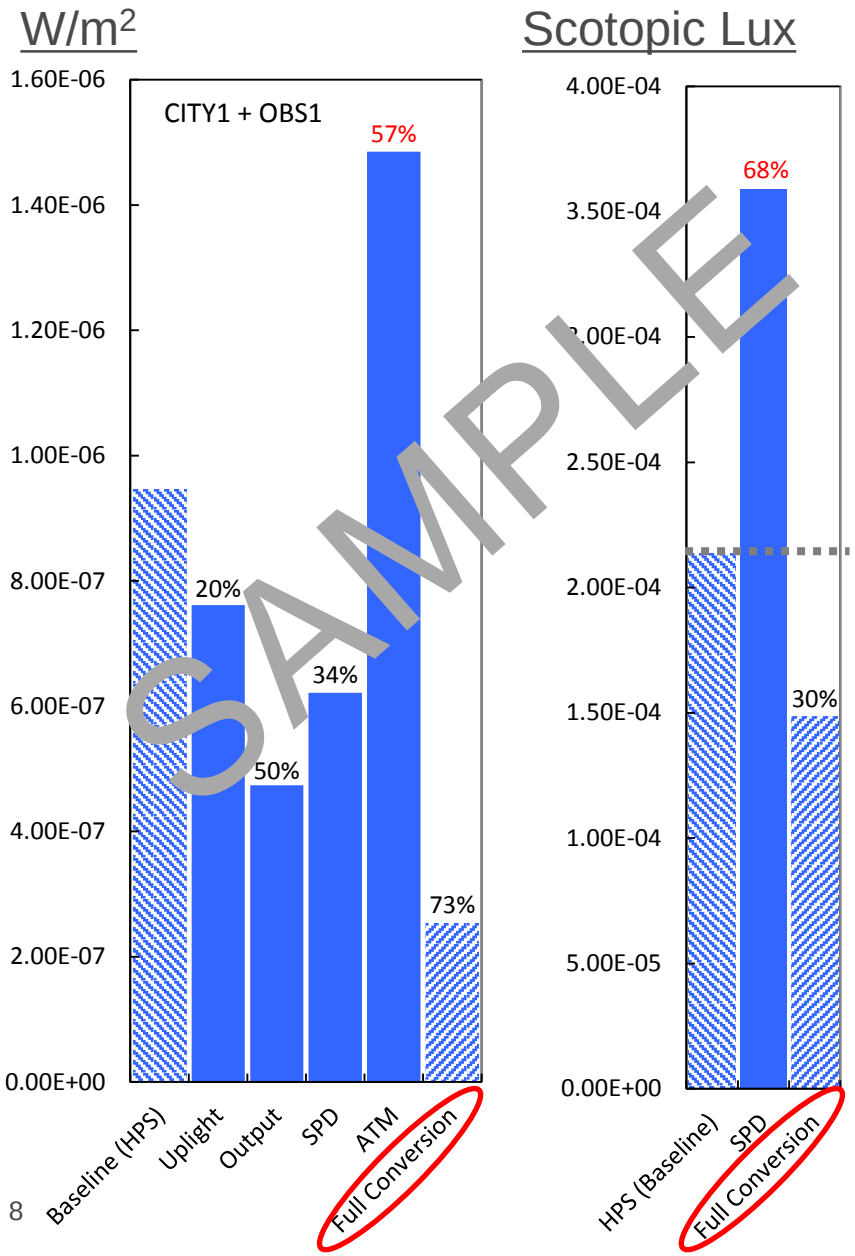
- LED lighting is still an improvement relative to the incumbent!

Sky glow



Things are never equal!

Example Sensitivity Test of the Model



- City 1 (pop 3500)
- Observer Position 1 is near the city radius
- Percentages are changes from baseline, each parameter considered in isolation except the final "Full Conversion"
  - 10% to 0% uplight
  - 100% to 50% lumen output
  - HPS to LED (4000K) SPD
  - Atmosphere 1 to 4
- "Full Conversion" represents the resulting combined effect
  - Atmosphere held constant
- Results shown are not actual, for illustration purposes only

Blue light characteristics of light sources

- Blue light characteristics of light sources at equivalent lumen output

Row	Light source	CCT (K)	% Blue*	Luminous Flux (lm)	Scotopic content relative to HPS	Melanopic content relative to HPS**
A	PC white LED	2700	17% - 20%	1000	1.77 - 1.82	1.90 - 2.06
B	PC white LED	3000	18% - 25%	1000	1.89 - 2.13	2.10 - 2.51
C	PC white LED	3500	22% - 27%	1000	2.04 - 2.37	2.34 - 2.97
D	PC white LED	4000	27% - 32%	1000	2.10 - 2.65	2.35 - 3.40
E	PC white LED	4500	31% - 35%	1000	2.35 - 2.85	2.75 - 3.81
F	PC white LED	5000	34% - 39%	1000	2.60 - 2.89	3.18 - 3.74
G	PC white LED	5700	39% - 43%	1000	2.77 - 3.31	3.44 - 4.52
H	PC white LED	6500	43% - 48%	1000	3.27 - 3.96	4.38 - 5.84
I	Narrowband amber LED	1606	0%	1000	0.36	0.12
J	Low pressure sodium	1719	0%	1000	0.35	0.10
K	PC amber LED	1872	1%	1000	0.70	0.42
L	High pressure sodium	1959	9%	1000	0.89	0.86
M	**High pressure sodium**	**2041**	**10%**	**1000**	**1.00**	**1.00**
N	Incandescent	2851	12%	1000	2.26	2.79
O	Halogen	2934	13%	1000	2.28	2.81
P	F32T8/830 fluorescent	2940	20%	1000	2.02	2.29
Q	Metal halide	3145	24%	1000	2.16	2.56
R	F32T8/835 fluorescent	3480	26%	1000	2.37	2.87
S	F32T8/841 fluorescent	3969	30%	1000	2.58	3.18
T	Metal halide	4002	33%	1000	2.53	3.16
U	Metal halide	4041	35%	1000	2.84	3.75

Source: DOE

Blue light is nothing new to our lighted environment, nor is it a characteristic exclusive to LEDs.

Controlling blue wavelengths – Cambridge example

- Lumen values derived from 2013 inventory
- Blue content calculated by PNNL
- System operates at 70% output at startup; dimmed by 50% (i.e., to 35% of full) after midnight

Cambridge, MA	Initial Output (million lumens)				"Blue" Lumens (millions)		
Blue Light Impacts from LED Conversion	**Full system as installed**	**At dusk startup**	**After midnight**	**Blue percent of radiant power**	**at full power**	**at dusk**	**after midnight**
Pre-Conversion HPS	54	54	54	10%	5.4	5.4	5.4
Post-Conversion 4000K LED	32	22.4	11.2	32%	10.2	7.2	3.6
Percent Change	-41%	-59%	-79%	N/A	90%	33%	-34%

*includes 405 to 530 nm

MSSLC Model Specification for LED Roadway Luminaires

- Intended
  - To serve as a template (common language/framework)
  - To be customized by each adopting entity
  - For specification of luminaires
  - For specification of control system interface
- ***Not*** intended
  - To provide detailed guidance on lighting system design
  - To be adopted without modification
  - For specification of lamp/ballast retrofit kits
  - For specification of control system

MSSLC Model Specification for LED Roadway Luminaires

- Sections
  - Normative References, Related Documents, Definitions
  - Product Requirements
  - Required Submittals
  - Quality Assurance
  - Warranty
  - Manufacturer Services, Eligible Manufacturers
  - Appendix A – Pole Layout Illustrations
  - Appendix B – Product Submittal Form

MSSLC Model Specification for LED Roadway Luminaires

- Sections
  - Normative References, Related Documents, Definitions
  - Product Requirements
    - General requirements
    - Requirements by luminaire designation, using application-dependent “system” (e.g., footcandles) or application-independent “material” (e.g., lumens) method
  - Required Submittals
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  - Manufacturer Services, Eligible Manufacturers
  - Appendix A – Pole Layout Illustrations
  - Appendix B – Product Submittal Form

MSSLC Model Specification for LED Roadway Luminaires

Luminaire Designation: "70H"
System Specification Method

SITE PARAMETERS (*See drawings in Appendix A*)				
ROADWAY DATA	Median width (including curbs, gutters, and shoulders)			0 ft
	Number of vehicular lanes (total on both sides of median)			2
	Width of one vehicular lane			11 ft
	Shoulder width (including gutter and curb)			7 ft
	IES pavement class.	☐ R1 ☐ R2 ☑ R3 ☐ R4		
SIDEWALK DATA	Berm width (from curb to sidewalk)			5 ft
	Sidewalk width			5 ft
	Sidewalk on	☑ Both sides of street	☐ Pole side	☐ Other side
LIGHT POLE DATA	Luminaire mounting height			27 ft
	Arm length (horizontal)			6 ft
	Luminaires per pole			1
	Pole set-back from curb			2 ft
	Pole spacing (one pole cycle, parallel to path of travel)			150 ft
	Pole layout	☑ One side ☐ Opposite ☐ Staggered		☐ Median
PERFORMANCE CRITERIA				
MAINTAINED ROADWAY ILLUMINATION				
PHOTOPIC ILLUMINANCE	Average horizontal illuminance at pavement			4.0 lux (0.4 fc)
	Avg:min uniformity ratio			6.0
	Max:min uniformity ratio			n/a
DISABILITY GLARE	Max. veiling luminance ratio			0.4
MAINTAINED SIDEWALK ILLUMINATION				
PHOTOPIC	Average horizontal at pavement			2.0 lux (0.2 fc)

MSSLC Model Specification for LED Roadway Luminaires

Luminaire Designation: "70H"
Material Specification Method

EXISTING LUMINAIRE TO BE REPLACED (*FOR REFERENCE ONLY*)		
LAMP	Lamp wattage and type	70 W HPS
DOWNWARD OUTPUT	*Initial* downward luminaire output (lumens below horizontal)	4284 lm
LLF	Light Loss Factor	0.76
LENS	☐ Flat ("cutoff" style) ☑ Sag/drop	
IES FORWARD TYPE*	☐ I ☐ II ☑ III ☐ IV ☐ V ☐ VS	
IES LATERAL TYPE*	☐ Very Short ☐ Short ☑ Medium ☐ Long ☐ Very Long	
PERFORMANCE CRITERIA LED LUMINAIRE		
INPUT POWER	Max. nominal luminaire input power	103 W
VOLTAGE	Nominal luminaire input voltage (or range as applicable)	120 V
LUMEN MAINT.	Min. % of initial output at 36,000 hours operation	90%
WARRANTY	Min. luminaire warranty	5 years
NOMINAL CCT	Rated correlated color temperature	4100 ± 200 K
BUG RATING	Max. nominal backlight-uplight-glare ratings	B1-U2-G1
DOWNWARD OUTPUT	Min. *maintained* luminaire output below horizontal	3256 lm
FINISH	Luminaire housing finish color	Gray

MSSLC Model Specification for LED Roadway Luminaires

- Key considerations
  - Efficient application of light
  - Adaptive control
  - Color characteristics (CCT, CRI, Duv)
  - Thermal environment
  - Light Loss Factor (LLF)
    - Luminaire Ambient Temperature (LAT)
    - Lamp Lumen Depreciation (LLD)
    - Luminaire Dirt Depreciation (LDD)
  - Electrical immunity
  - Lifetime and warranty

MSSLC Model Specification for LED Roadway Luminaires

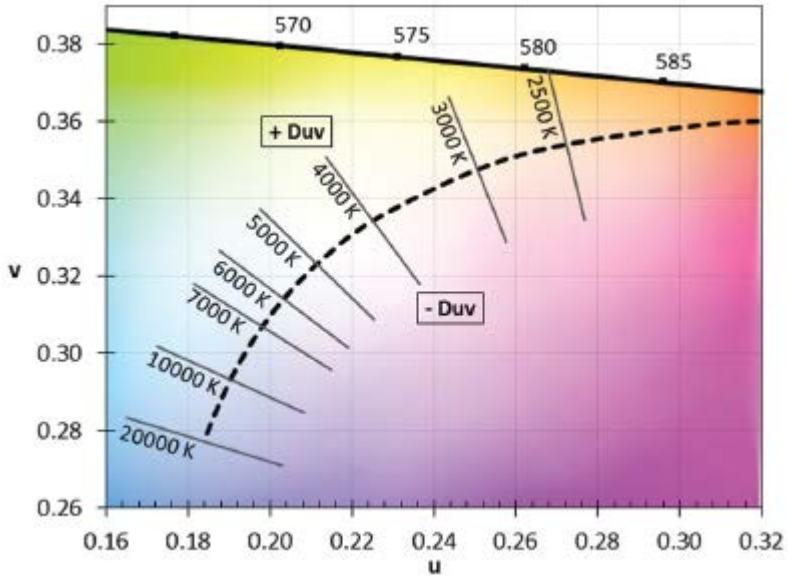
- Efficient application of light
  - Specify maximum luminaire input power (watts)
    - The value specified should be realistic and aligned with economic analysis
    - Consider giving preference to submitted luminaires with lowest input power
  - Specify required illumination for vehicular ways, pedestrian ways, etc.
    - This can include evaluation of disability glare (max Lv ratio) for drivers
  - Obtrusive light is penalized when systems are optimized for minimal input power and “just enough” illumination
    - Excess illumination requires more input power ($) and more LEDs ($)
    - Errant light requires more input power ($)
  - Consider supplemental restrictions on light trespass
    - Best to specify maximum vertical illuminance at or just beyond the property line, keeping in mind that facial identification on sidewalks is desirable
    - Backlight Uplight Glare (BUG) ratings do not consider pole spacing or mounting height or distance to property line, and can effectively disallow proper illumination

MSSLC Model Specification for LED Roadway Luminaires

- Adaptive control
  - Dimming (0-10 V or DALI)
    - Further minimize energy use and obtrusive light by dynamically reducing illumination as vehicular/pedestrian activity diminishes over the course of the night, in accordance with section 5.4 of IES RP-8-14 (www.ies.org)
    - Specify required dimming range of LED driver (e.g., to 10% of full output)
    - Limit flicker by specifying IEEE Std 1789-2015 Low Risk Level
  - Color tuning (DALI)
    - Consider cost/availability, as this is not commonly implemented
    - More flexible if dimming signal is separate from color tuning signal
  - ANSI C136.41-2013, American National Standard for Roadway and Area Lighting Equipment–Dimming Control Between an External Locking Type Photocontrol and Ballast or Driver (www.nema.org)
  - MSSLC Model Specification for Networked Outdoor Lighting Control Systems (http://energy.gov/eere/ssl/outdoor-lighting-resources)

MSSLC Model Specification for LED Roadway Luminaires

- Color characteristics
  - Color Rendition
  - Correlated Color Temperature (CCT) and Duv
    - ANSI C78.377-2015, American National Standard for Electric Lamps—Specifications for the Chromaticity of Solid State Lighting (SSL) Products



LED Color Characteristics
(http://energy.gov/eere/ssl/technology-fact-sheets)

MSSLC Model Specification for LED Roadway Luminaires

- Thermal environment
  - Need to specify typical minimum and maximum ambient temperatures anticipated during operation
    - Ambient temperature affects LED heat dissipation and performance
    - Manufacturer must understand the application and certify luminaire suitability
    - Solar radiation can also boost luminaire surface temperature
  - Specified ambient temperatures should be “just right”
    - Poor luminaire performance if too lenient
    - Excessive luminaire price if too extreme
  - Typical Meteorological Year (TMY) data
    - http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

MSSLC Model Specification for LED Roadway Luminaires

- Thermal environment
  - Yuma Sector Border Patrol Area
    - According to TMY2 data, “the maximum temperature at sunset in this area is approximately 38 to 44 °C and the minimum is approximately 2 to 6 °C.” (http://energy.gov/eere/ssl/gateway-demonstration-outdoor-projects)

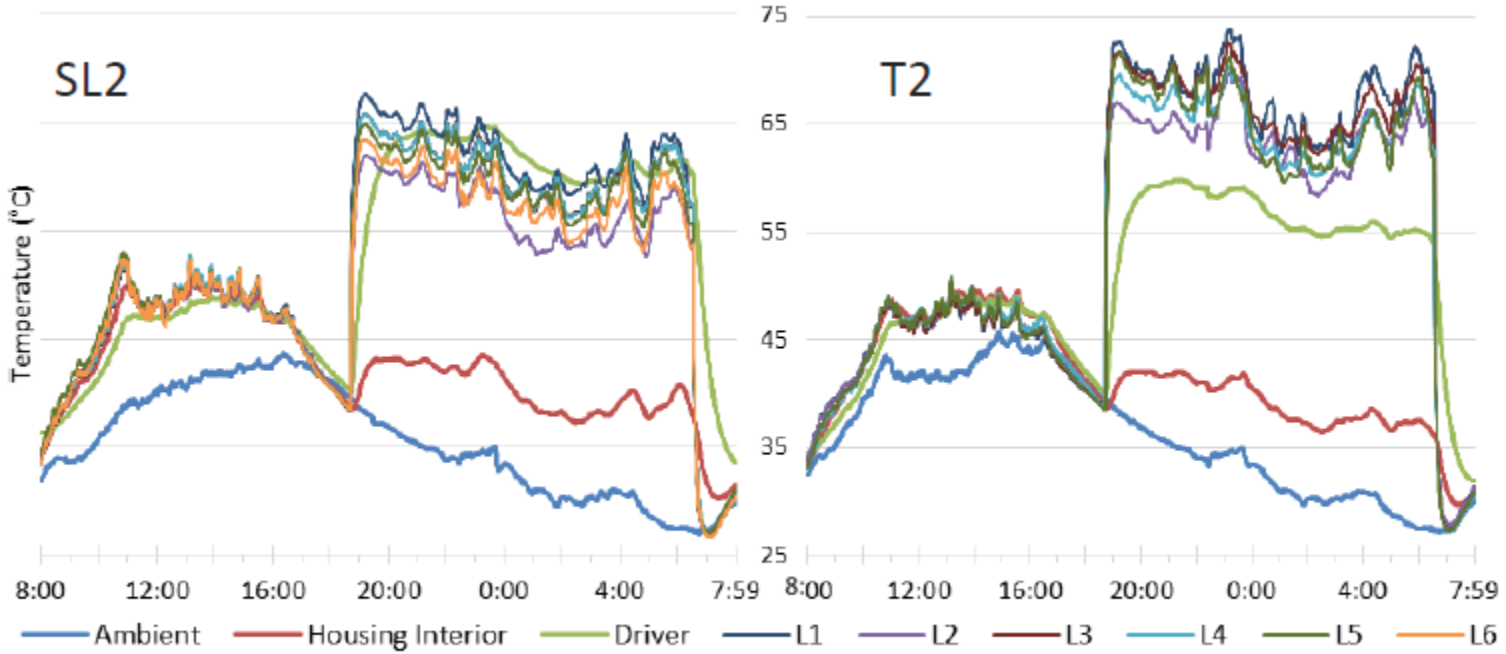
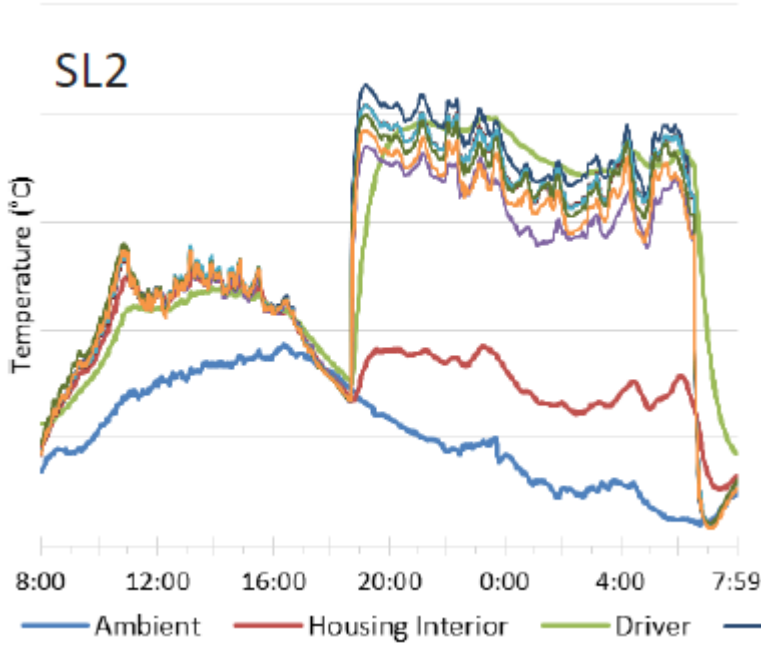


Figure 14. Thermocouple Measurements: September 25 8:00 a.m. to September 26 7:59 a.m., 2015. The one-minute interval thermocouple measurements for the hottest ambient temperature day recorded for luminaires SL2 and T2.

MSSLC Model Specification for LED Roadway Luminaires

- LAT factor
  - Accounts for reduced lumen output when ambient temperature exceeds the standard 25 °C used in IES LM-79-08 photometric testing
    - Some manufacturers publish nominal multipliers



LUMINAIRE AMBIENT TEMPERATURE FACTOR (LATF)

AMBIENT DATA		
TEMP		LUMEN MULT.
0°C	32°F	1.02
10°C	50°F	1.01
20°C	68°F	1.00
25°C	77°F	1.00
30°C	86°F	1.00
40°C	104°F	0.98
50°C	122°F	0.98

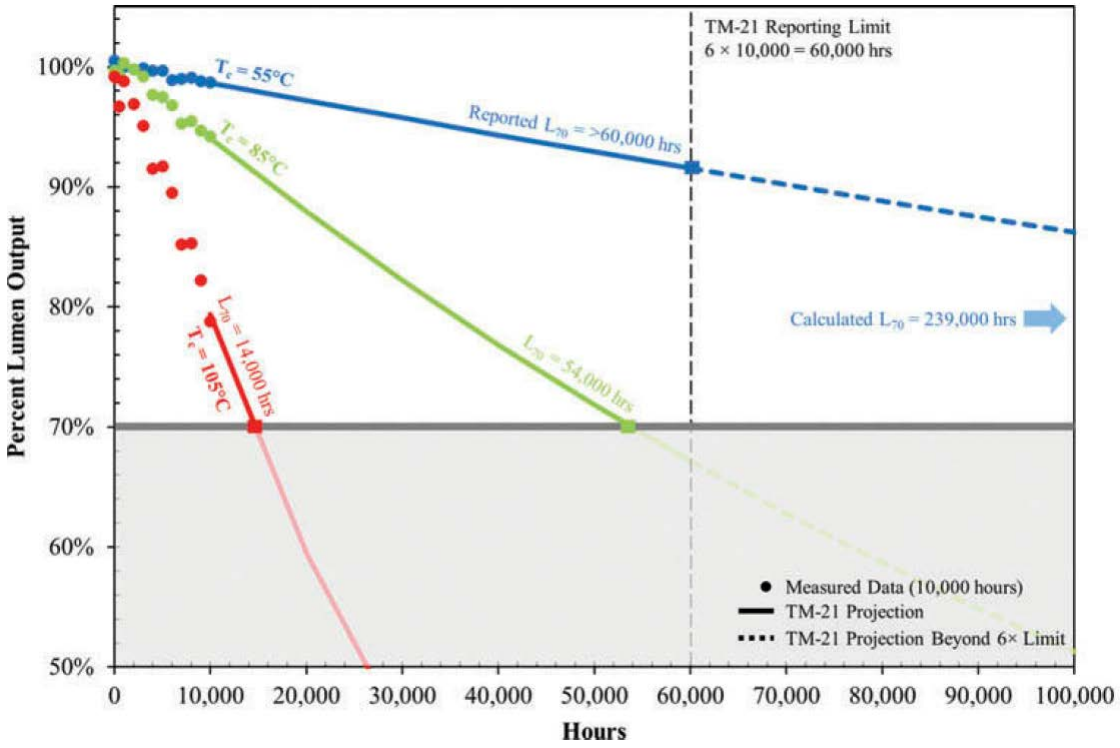
Credit: Spaulding Lighting

MSSLC Model Specification for LED Roadway Luminaires

- LLD factor (i.e., LED lumen maintenance)
  - Pertains to LED light source (not an LED lamp) for integrated LED luminaires
  - Inputs for calculations as per IES TM-21-11 with addenda
    - IES LM-80-15 test data for the LED light source(s)
    - LED case temperature from In-situ Temperature Measurement Testing (ISTMT) data for the hottest LED light source in the luminaire
    - Nominal LED drive current
  - LED Lighting Facts (www.lightingfacts.com) and the DesignLights Consortium (www.designlights.org) publish guidance for laboratory accreditation, etc.
    - Both programs reference ENERGY STAR for ISTMT methodology
  - TM-21 Calculator maintained by ENERGY STAR (www.energystar.gov) streamlines the submittal/review process
    - Value used should be “Reported” (limited extrapolation), rather than “Calculated” or “Projected” (unlimited extrapolation), as defined by TM-21

MSSLC Model Specification for LED Roadway Luminaires

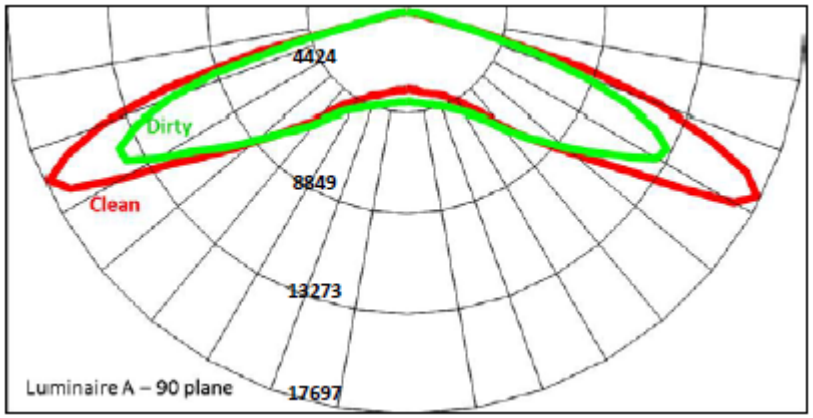
- LLD factor (i.e., LED lumen maintenance)

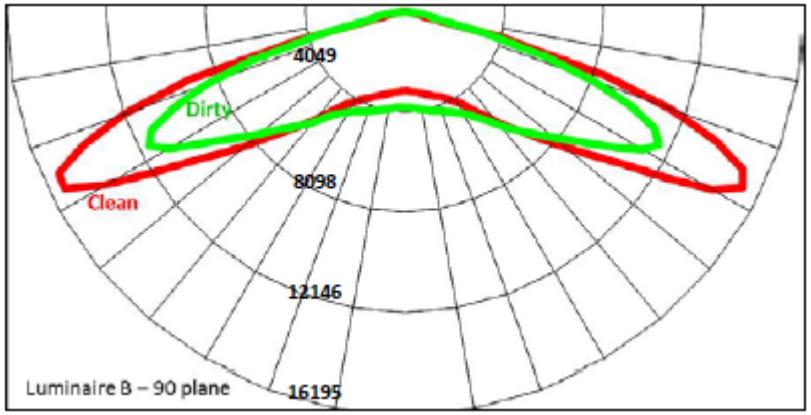


Lumen Maintenance and Light Loss Factors: Consequences of Current Design Practices for LEDs (http://dx.doi.org/10.1080/15502724.2013.855613)

MSSLC Model Specification for LED Roadway Luminaires

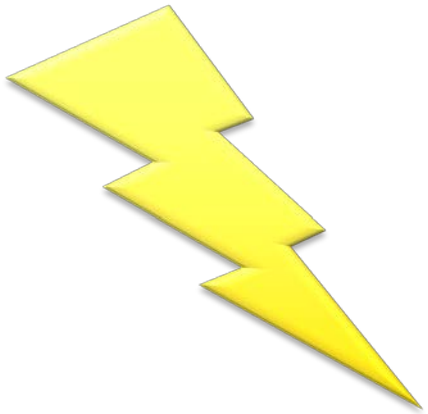
- LDD factor
  - Depends on maintenance cycle IF luminaires will be cleaned; otherwise depends on luminaire service life (same period as LLD)
    - Beware of luminaire “self-cleaning” claims by manufacturers
    - Figure 5 in IES RP-20-14 gives LDD curves as a function of airborne particulate level and cleaning cycle
  - Simple factor cannot capture redirection of light due to dirt
    - http://energy.gov/sites/prod/files/2016/04/f30/gateway-yuma_1-2.pdf





MSSLC Model Specification for LED Roadway Luminaires

- Electrical immunity
  - Criteria developed by MSSLC informed ANSI C136.2-2015, American National Standard for Roadway and Area Lighting Equipment—Dielectric Withstand and Electrical Transient Immunity Requirements
    - C136.2-2015 was preceded by the current version of the MSSLC model specification, but we can help to ensure the standard is properly referenced



MSSLC Model Specification for LED Roadway Luminaires

- Lifetime and warranty
  - Failure mechanisms (http://energy.gov/eere/ssl/product-performance-guides)
    - LLD
    - LED driver failure
    - Non-parametric (catastrophic) LED light source failure
    - Broken electrical connections
    - Optical component degradation
  - How are failures defined and detected?
    - Percent of LED light sources in luminaire that are no longer functioning
    - Percent of initial or nominal luminaire lumen output, as measured in laboratory (field measurements are less reliable), for a random sample of sufficient size
  - How many failures are acceptable prior to end of warranty period?
    - Percent of luminaires (of same model and vintage) that have failed
    - Many standard warranties do not cover lumen maintenance

MSSLC Model Specification for LED Roadway Luminaires

- Common specification pitfalls
  - Proprietary
    - e.g., “technology X optics”
  - Vague/incomplete
    - e.g., “must meet LM-79” or “volumetric lighting”
  - Not demonstrable
    - e.g., “useful life > 500,000 hours”
  - Unrealistic
    - e.g., “input power < 1 W” or “BUG rating of B0-U0-G0”
  - Ineffective
    - e.g., “IES Type III”
  - Not applicable
    - e.g., “Full Cutoff” or “luminaire efficiency > 90%”
  - Conflicting
    - e.g., luminaire efficacy is specified in addition to illuminance and wattage

Q&A

- Speaker contact information
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