U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

The Impact of LED Street Lighting on Sky Glow

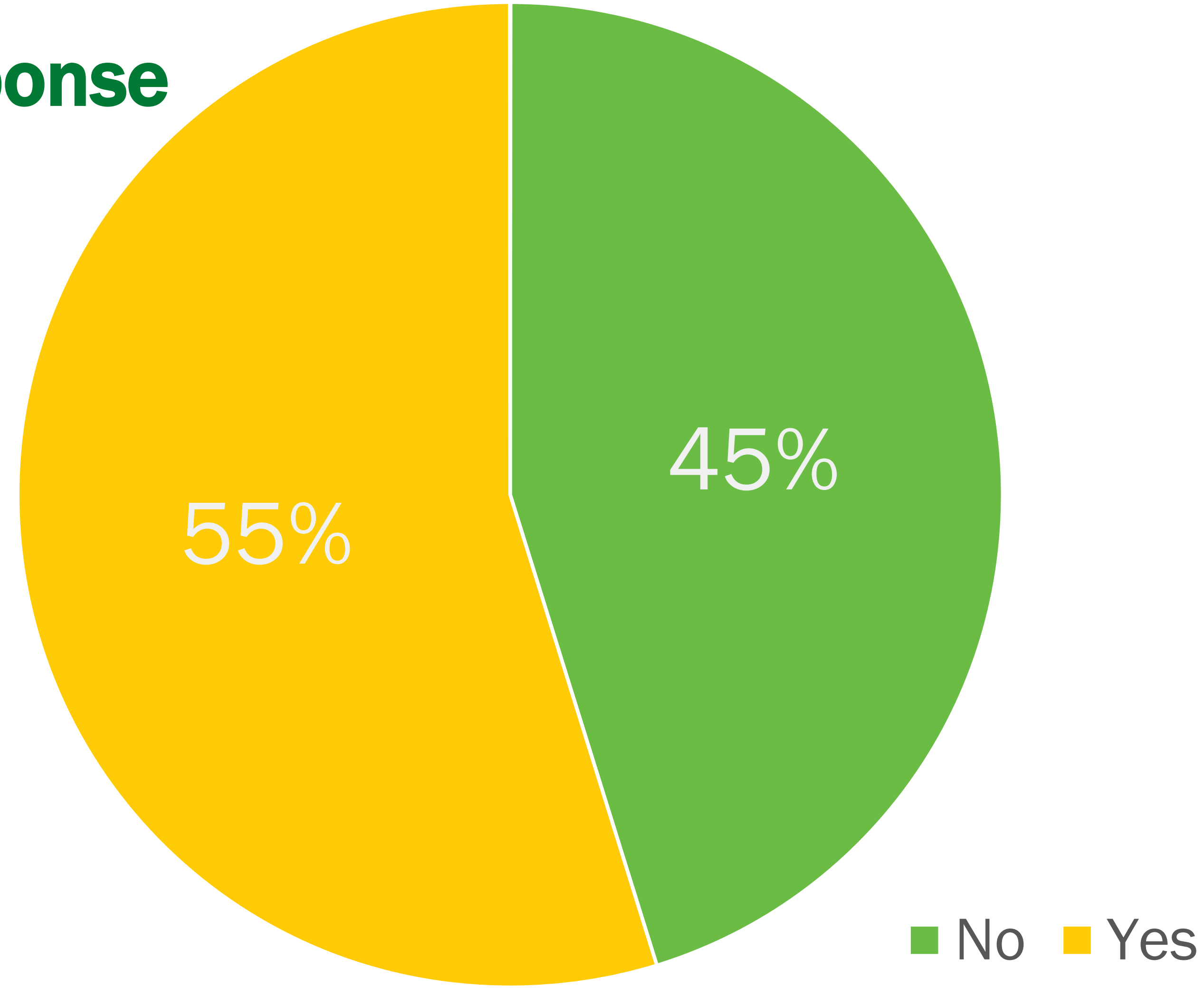
Bruce Kinzey, Pacific Northwest National Laboratory

Solid-State Lighting Program Webinar July 27, 2017

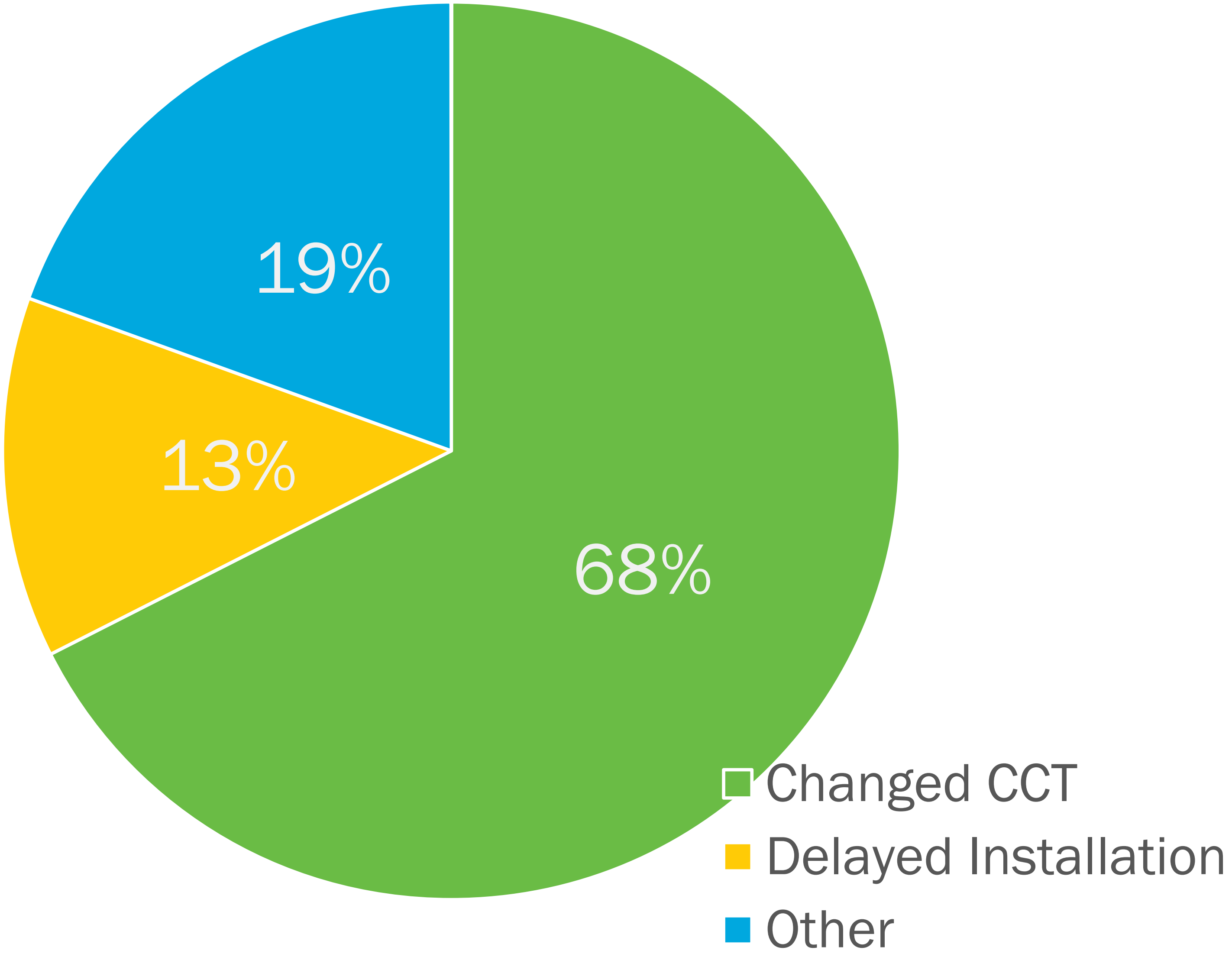
Photo Credit: Wendy Graves

Have These Concerns Impacted Your Local System Design?

50% response

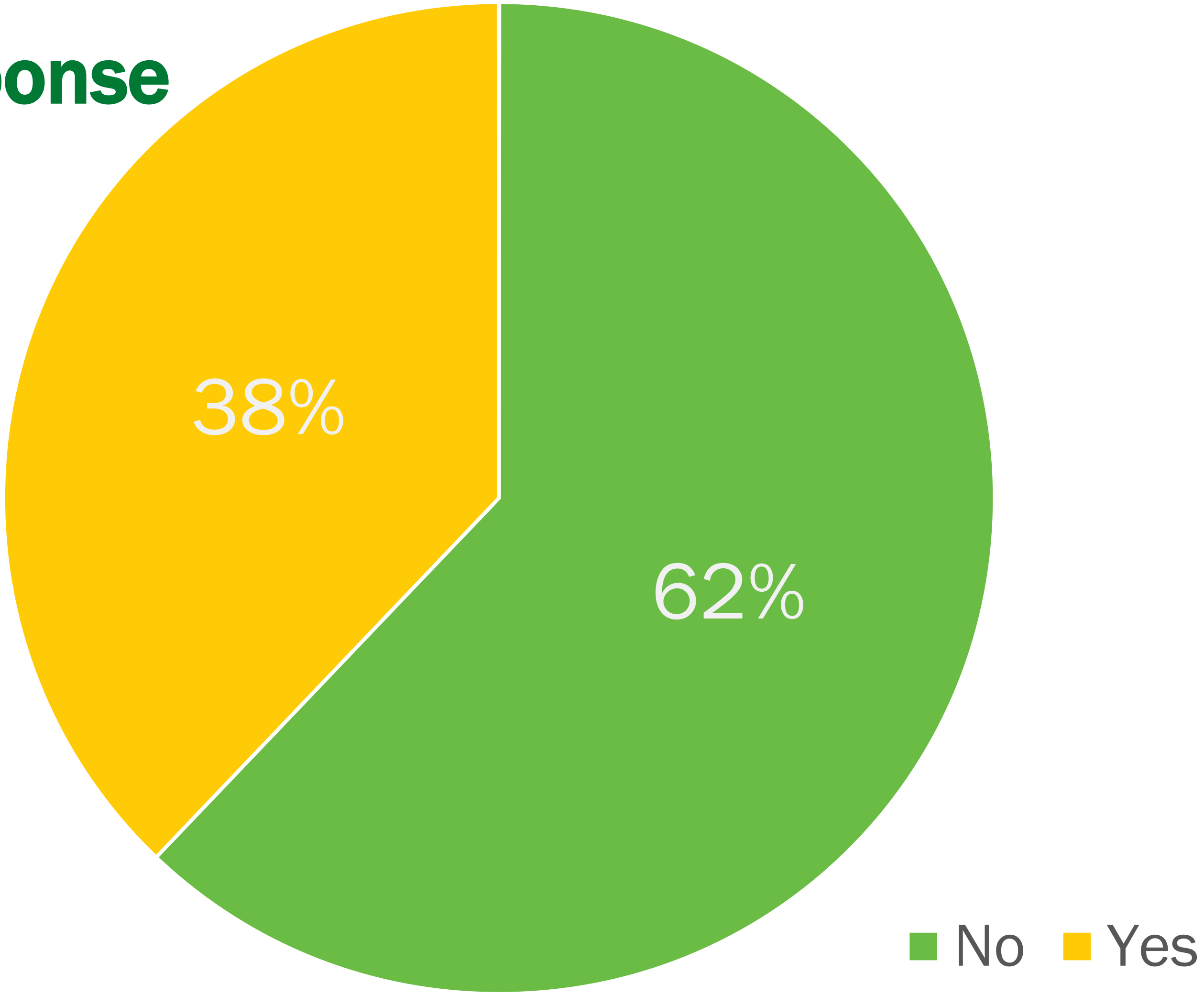


If Yes, How?



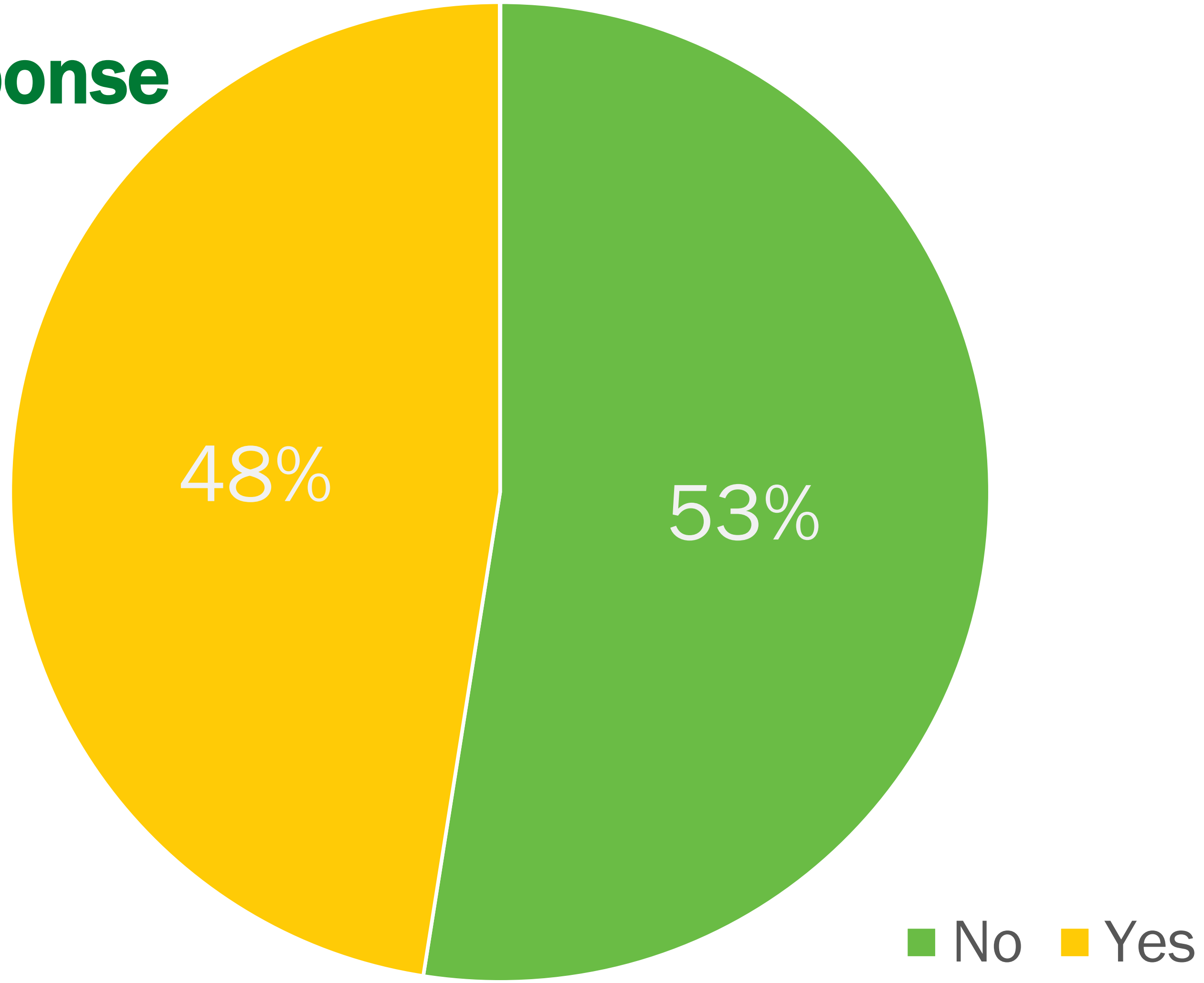
Are Any Wireless Controls Installed on Your Local System?

63% response



Are Wireless Controls Being Considered?

44% response



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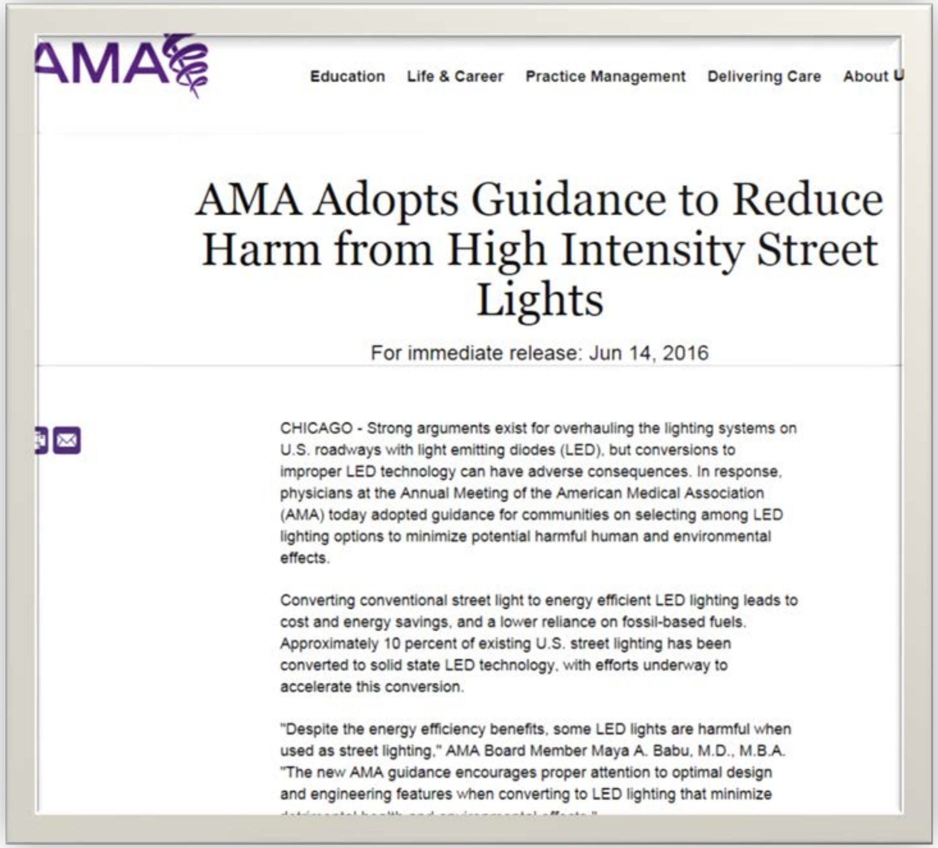
Street lighting, blue light and CCT are all the talk these days

- Potential issues have fired the public's imagination
- Ongoing discussion contains many misperceptions and mischaracterizations
- The SSL Program's position has always been to provide accurate, objective information to assist in decision-making
- Sky glow and health issues overlap, both related to light at night


AMA

Education Life & Career Practice Management Delivering Care About U

AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights

For immediate release: Jun 14, 2016

CHICAGO - Strong arguments exist for overhauling the lighting systems on U.S. roadways with light emitting diodes (LED), but conversions to improper LED technology can have adverse consequences. In response, physicians at the Annual Meeting of the American Medical Association (AMA) today adopted guidance for communities on selecting among LED lighting options to minimize potential harmful human and environmental effects.

Converting conventional street light to energy efficient LED lighting leads to cost and energy savings, and a lower reliance on fossil-based fuels. Approximately 10 percent of existing U.S. street lighting has been converted to solid state LED technology, with efforts underway to accelerate this conversion.

"Despite the energy efficiency benefits, some LED lights are harmful when used as street lighting," AMA Board Member Maya A. Babu, M.D., M.B.A. "The new AMA guidance encourages proper attention to optimal design and engineering features when converting to LED lighting that minimize

What is anthropogenic sky glow?

This

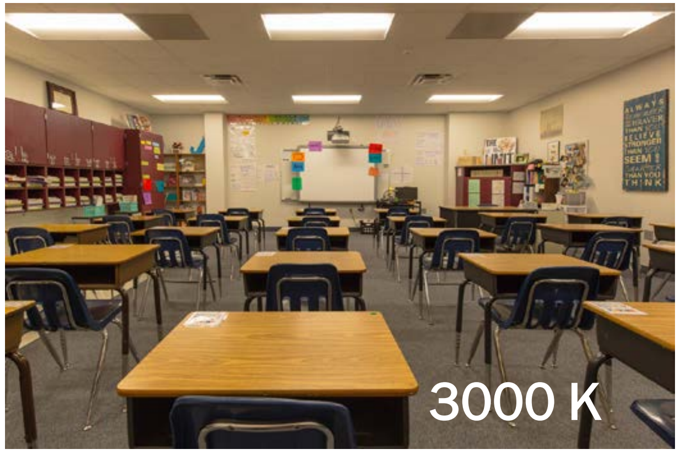
Photo: Dan Duriscoe, NPS

Not this (glare)

“An increase in human-induced night brightness resulting from use of supplemental illumination for any purpose.”

CCT is insufficient as both a measure and solution

- Color temperature describes only the appearance of a light source…
- and is only a rough gauge of its spectral content or associated influences



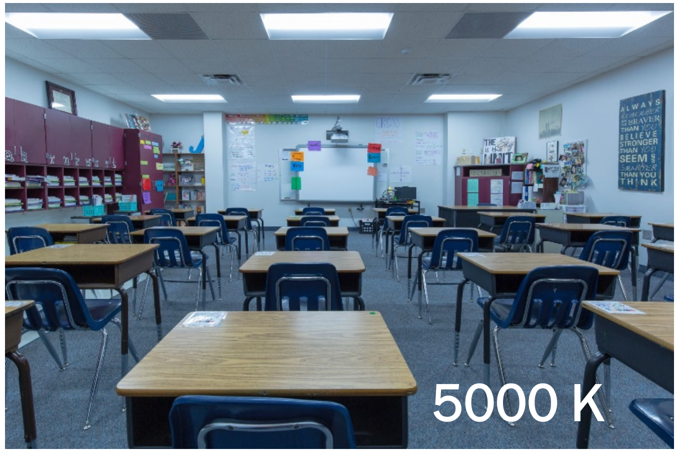
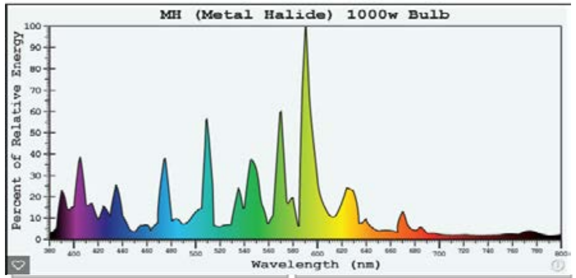
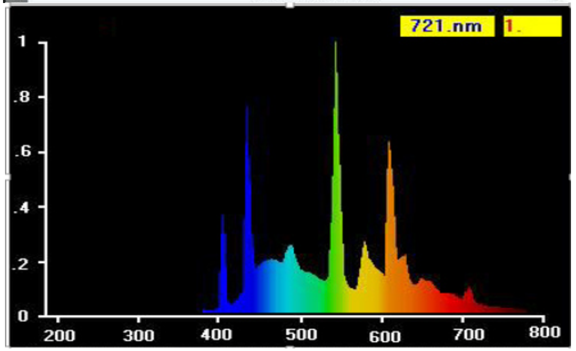
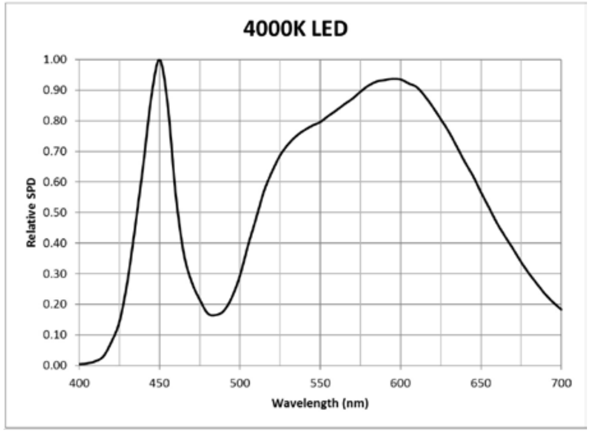


Photo Credit: Acuity

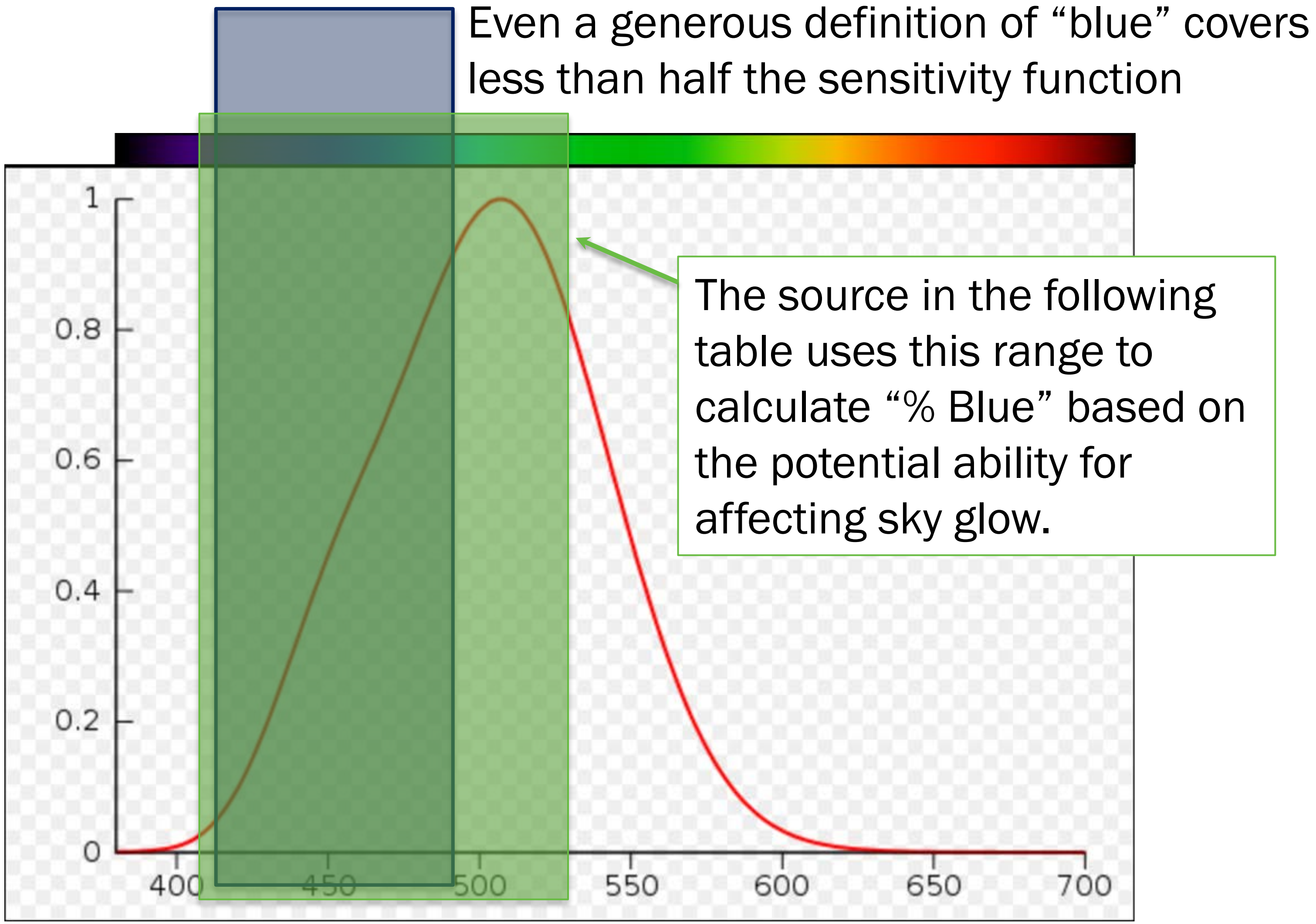






An exclusive focus on “blue” is also misdirected

- The scotopic function accounts for the particular sensitivity of the human eye in low light conditions
- Indicates, for example, which wavelengths present in the night sky have greater ability to obscure visibility of stars to a naked eye



The 1951 CIE Scotopic Luminosity Function

Issues raised (re: SPD) are common to white light sources

Count
59
162
53
51
36
44
20
32

Row	Light source	Luminous Flux (lm)	CCT (K)	% Blue*	Relative Scotopic Potential	Relative Melanopic Potential**
A	PC White LED	1000	2700	15% - 21%	1.74 - 2.33	1.90 - 2.82
B	PC White LED	1000	3000	18% - 25%	1.88 - 2.46	2.09 - 3.06
C	PC White LED	1000	3500	22% - 28%	2.04 - 2.54	2.34 - 3.25
D	PC White LED	1000	4000	26% - 33%	2.11 - 2.77	2.36 - 3.64
E	PC White LED	1000	4500	32% - 35%	2.39 - 2.94	2.83 - 3.95
F	PC White LED	1000	5000	35% - 40%	2.61 - 3.43	3.22 - 4.69
G	PC White LED	1000	5700	39% - 45%	2.75 - 3.39	3.42 - 4.62
H	PC White LED	1000	6500	43% - 48%	3.12 - 3.97	4.10 - 5.87
I	Narrowband Amber LED	1000	1606	0%	0.36	0.12
J	Low Pressure Sodium	1000	1718	0%	0.34	0.10
K	PC Amber LED	1000	1872	1%	0.70	0.42
L	High Pressure Sodium	1000	1959	9%	0.89	0.86
M	**High Pressure Sodium**	**1000**	**2041**	**10%**	**1.00**	**1.00**
N	Mercury Vapor	1000	6924	36%	2.33	2.47
O	Mercury Vapor	1000	4037	35%	2.13	2.51
P	Metal Halide	1000	3145	24%	2.16	2.56
Q	Metal Halide	1000	4002	33%	2.53	3.16
R	Metal Halide	1000	4041	35%	2.84	3.75
S	Moonlight †	1000	4681	29%	3.33	4.56
T	Incandescent	1000	2812	11%	2.21	2.72
U	Halogen	1000	2934	13%	2.28	2.81
V	F32T8/830 Fluorescent	1000	2940	20%	2.02	2.29
W	F32T8/835 Fluorescent	1000	3480	26%	2.37	2.87
X	F32T8/841 Fluorescent	1000	3969	30%	2.58	3.18

*Percent blue calculated according to LSPDD: Light Spectral Power Distribution Database, http://galileo.graphycs.cegepsherbrooke.qc.CA/app/en/home

**Melanopic content calculated according to CIE Irradiance Toolbox, http://files.cie.co.at/784_TN003_Toolbox.xls, 2015

† Moonlight CCT provided by Telelumen, LLC.

1.74 – 2.33

2.11 – 2.77

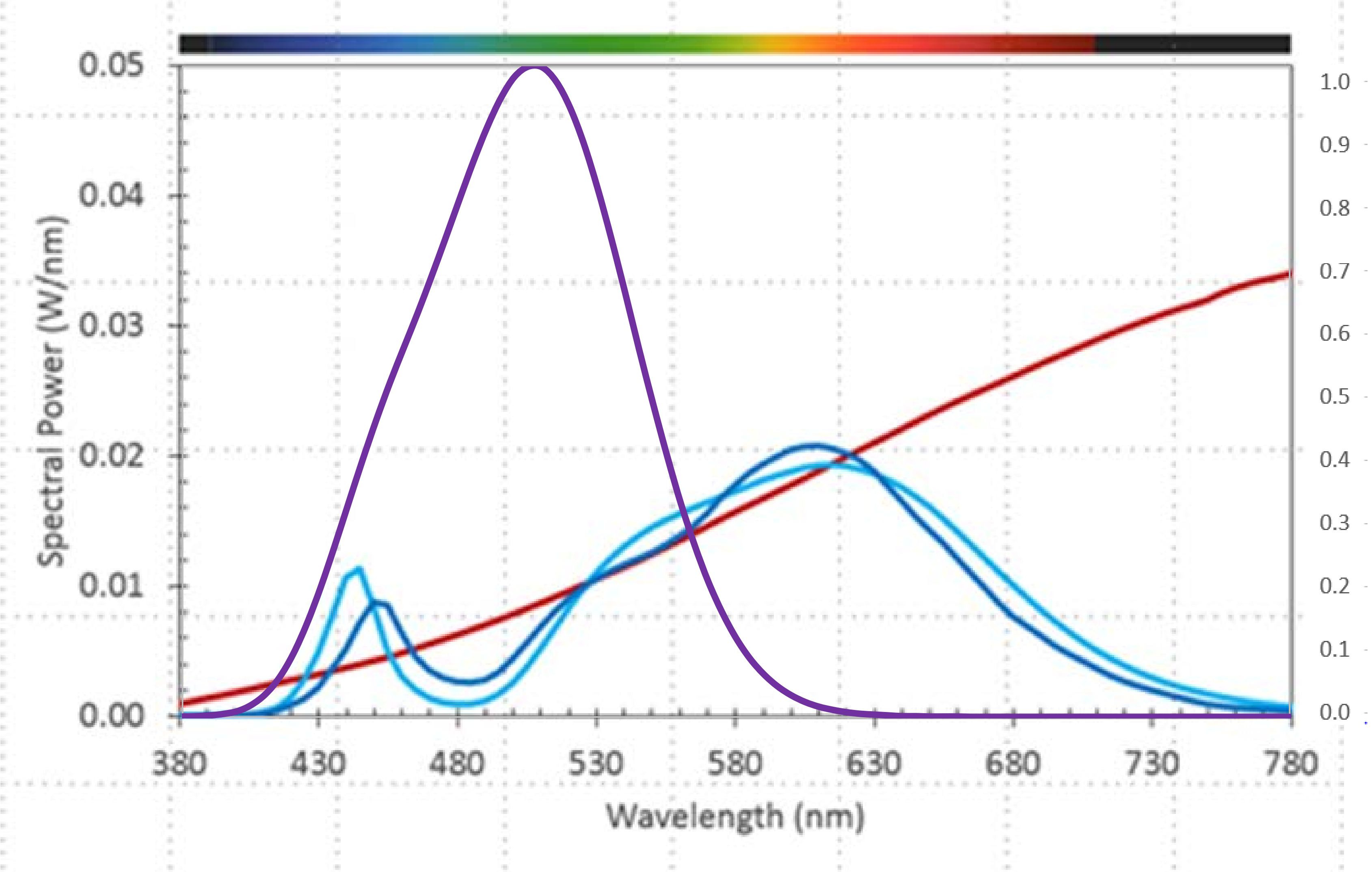
2.21

LED property ranges shown are based on a total of more than 450 real product SPDs

Sources: IES and CIE Product Databases (Table updated June 2017)

Scotopic potential extends across much of SPD

- Two LEDs, one incandescent, all at 2800 K CCT
- Graphic shows the radiant power emitted in each wavelength
- Scotopic potential of each product is the sum of the weighted area under the curve



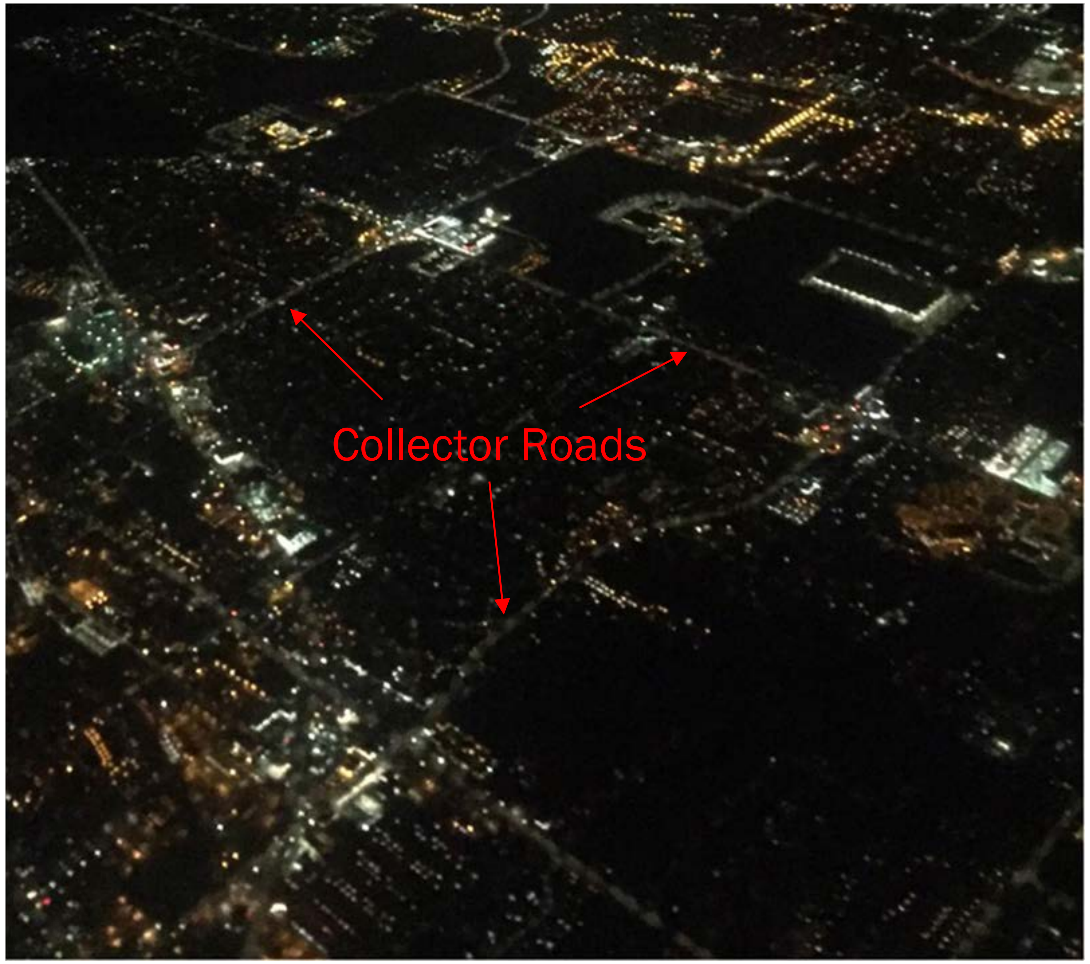
Beyond spectrum: the impact of distribution - Los Angeles

Photos Courtesy: LABSL

Collectively, the improved distribution, elimination of hot spots and uplight, etc., enabled a >50% reduction in fixture output.

Beyond spectrum: the importance of 0% uplight - Portland, OR

- Photo taken above Portland, OR January, 2017
- Darkened areas in foreground are residential converted to 4000 K LED
- Compare these areas to others with previous incumbent products
- Are these areas still a concern? How much additional attention, e.g., to spectrum, should they warrant?

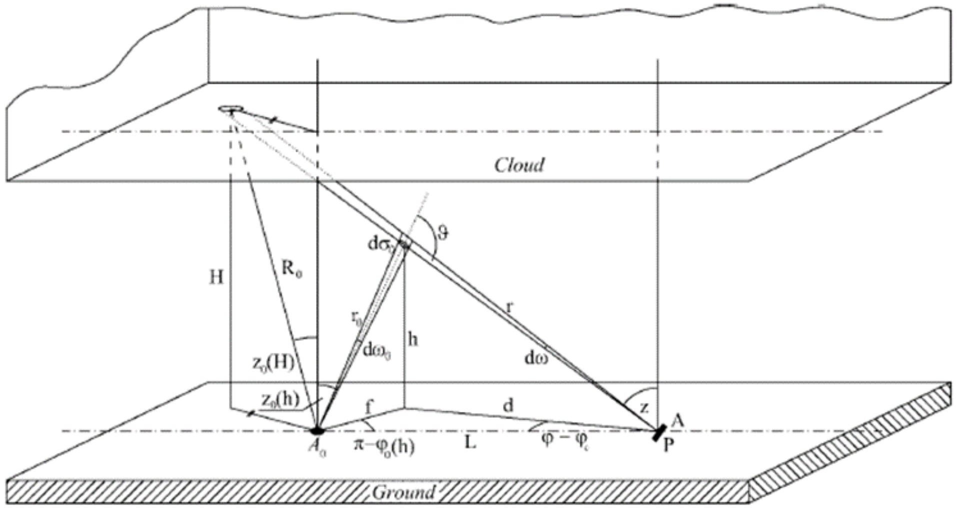


SkyGlow Simulator: Miroslav Kocifaj, PhD

Institute of Construction and Architecture, Slovak Academy of Sciences

Variables:

- City (size, shape, location)
- Position of observer
- Fixtures (number, output, percent uplight, SPD)
- City emission function (intensity as a function of zenith angle)
- Atmospheric conditions (cloudless, cloudy, overcast; aerosol content/type)
- Obstacles (horizon shielding)
- Output quantity (unweighted or weighted)
- Option to write input files



The scenarios

- Each run of the model increments a single parameter to determine its individual influence with all other parameters fixed (i.e., results generated for every single combination of input parameters)
- Input parameters include:
  - 3 cities of varying population (3,500 to 500,000)
  - 2 lumen output levels
  - 2 emission functions (Garstang or cosine)
  - 5 atmospheric conditions (4 clear with increased loading, 1 cloudy)
  - 11 SPDs
  - 4 uplight percentages (0%, 2%, 5%, 10%)
  - 2 observer locations
  - 2 output types (non-weighted irradiance or scotopic illuminance)
  - full SPD or 80 individual spectral increments (5 nm each)
  - => ~215,000 runs

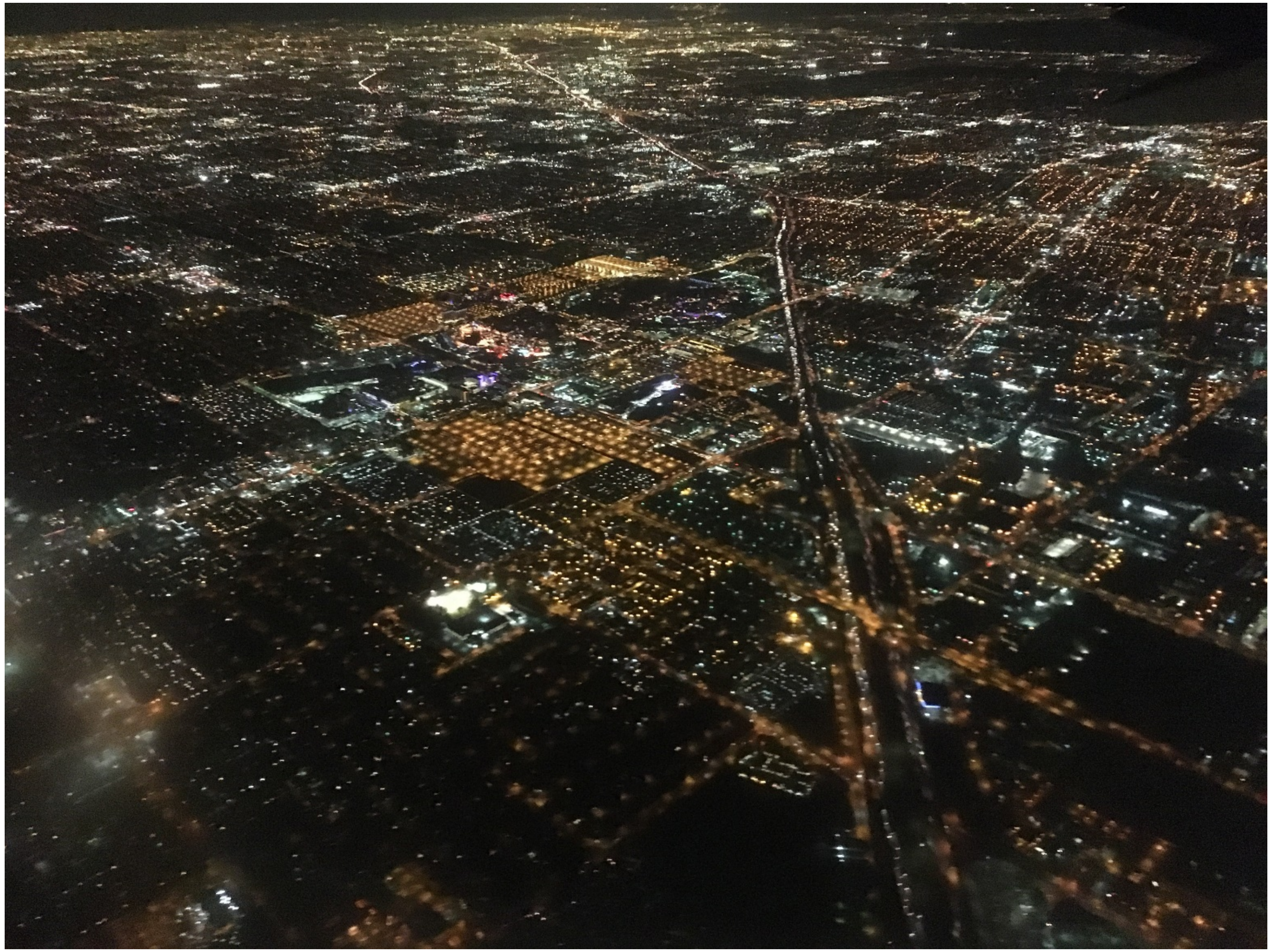
A few words about modeling

- Results are only as accurate as their underlying assumptions
- All atmospheric models incorporate many assumptions/simplifications
- Our approach was to investigate what happens in a typical conversion in the U.S., but Your Mileage May Vary!
- E.g., a couple of comments to the published report stated that many 0% uplight HPS cobra heads have already been installed, but…
- We contend this is a more representative scenario across the U.S.:

Chicago area, 2012
Photo credit: Nathan Rupert via Flickr, no alterations

The visible difference of conversion

- Los Angeles –2017

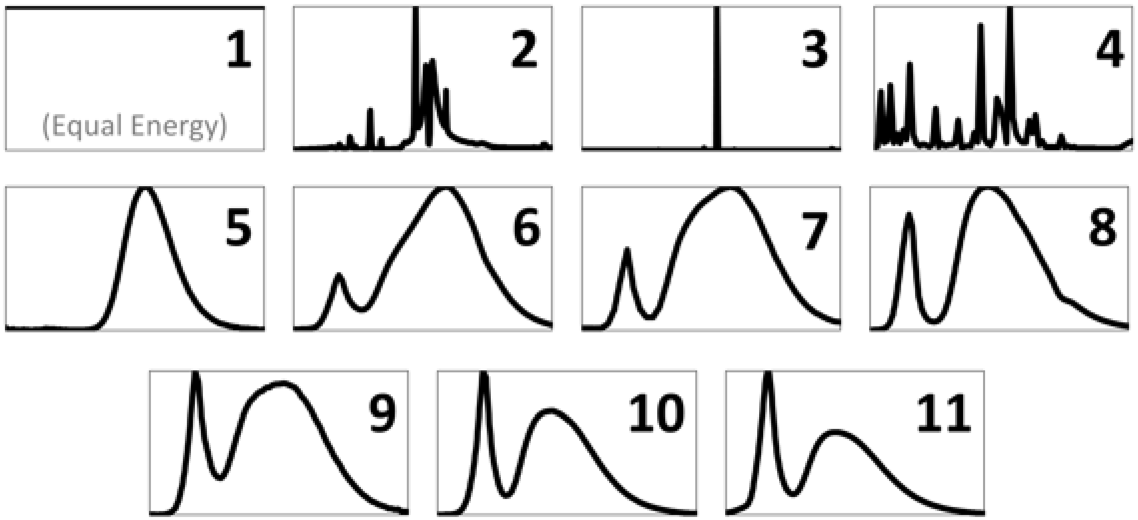


DOE sky glow investigation results

- Each variable tested separately, then combined for overall comparison with HPS baseline
- The following show impacts of changing SPD, light output, and uplight for near and distant (40 km) observers, across 5 different atmospheric conditions (4 clear with increasing turbidity, 1 cloudy)
- Impacts are displayed in both unweighted and scotopically-weighted values (all sky irradiance and illuminance on a horizontal surface at the observer's location)

SPDs tested in this study

Input SPDs (normalized to maximum output of 1)



Specifications and Calculated Metrics/Values

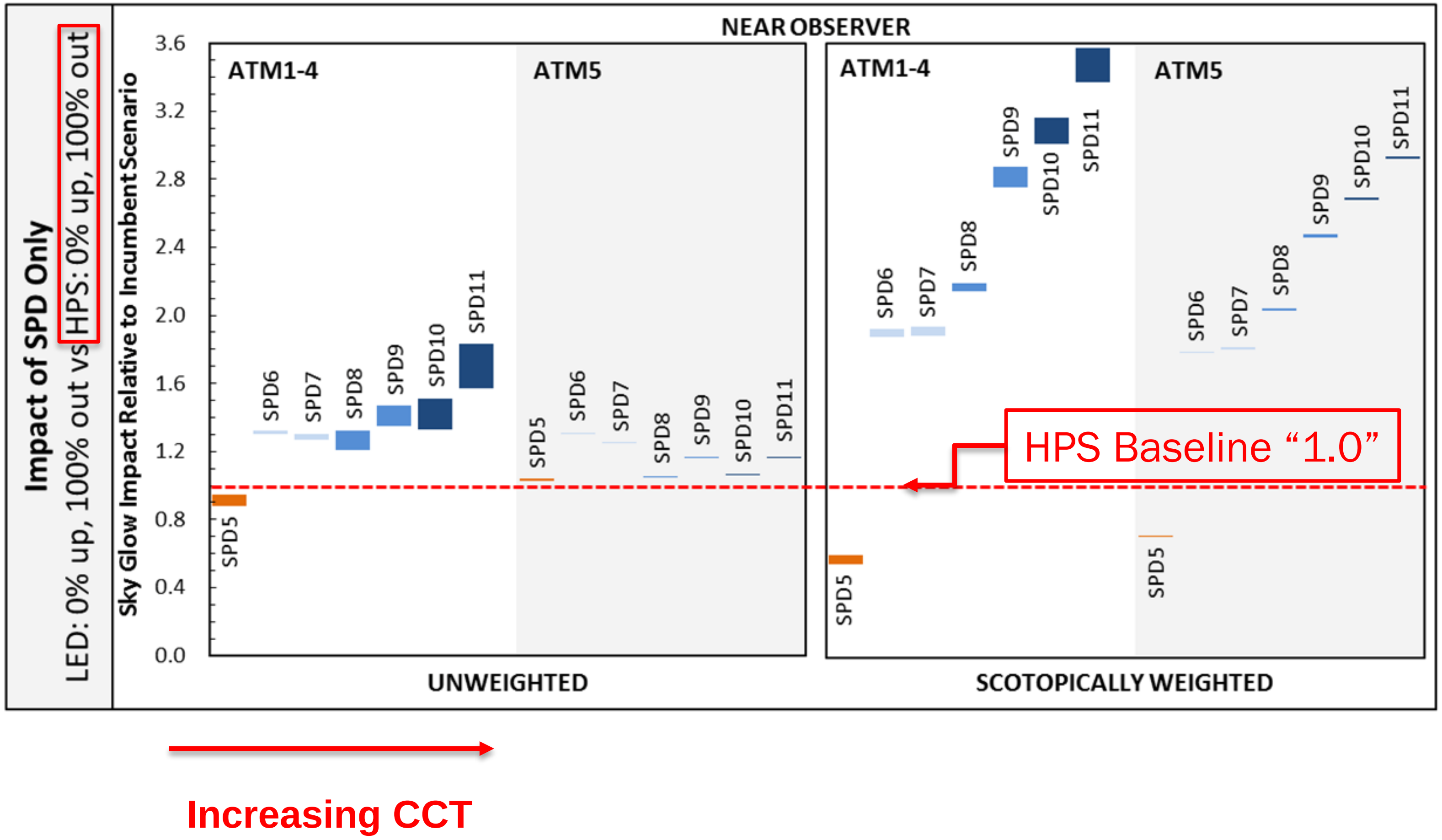
	SPD1	SPD2	SPD3	SPD4	SPD5	SPD6	SPD7	SPD8	SPD9	SPD10	SPD11
Source type	N/A[A]	HPS	LPS	MH[B]	LED[C]	LED	LED	LED	LED	LED	LED
CCT (K)	5455	2041	1778	3924	1872	2704	2981	3940	4101	5197	6101
photopic lux	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
scotopic lux	2265	629	218	1381	445	1173	1188	1345	1650	1797	1970
S/P ratio (relative to HPS)	3.60	1.00	0.35	2.19	0.71	1.86	1.89	2.14	2.62	2.85	3.13

[A] Equal energy
[B] Metal halide
[C] Phosphor-converted (PC) Amber LED

DOE sky glow investigation results – Near Observer

- Short wavelength content does contribute towards increased sky glow…
- …but CCT is not always a reliable predictor of that impact

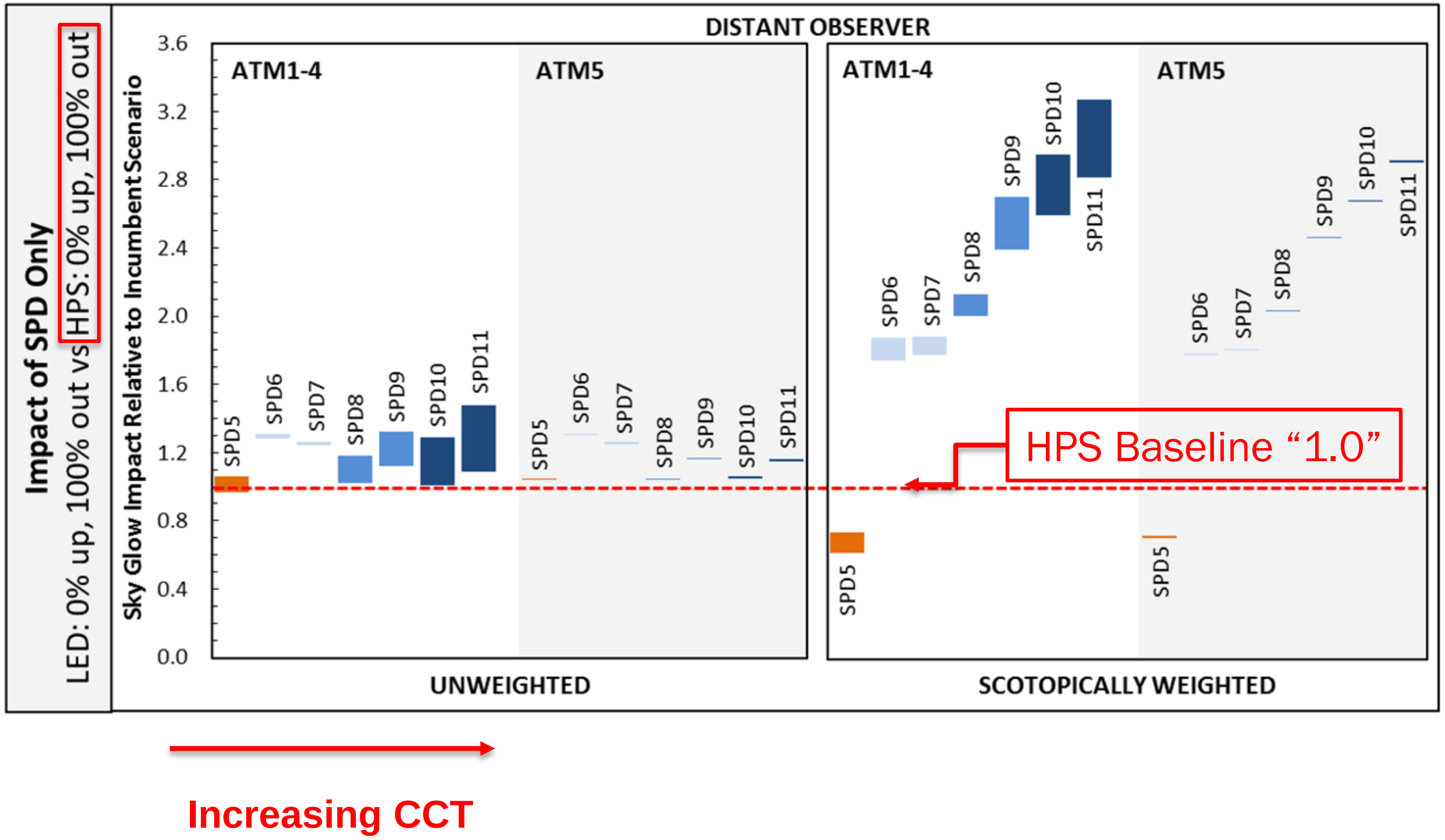
Impact of SPD in isolation of other variables



DOE sky glow investigation results – Distant Observer

- Greater variability for the distant observer occurs due to different atmospheric effects
- Much of the current public discussion reflects this comparison (in isolation of other factors)

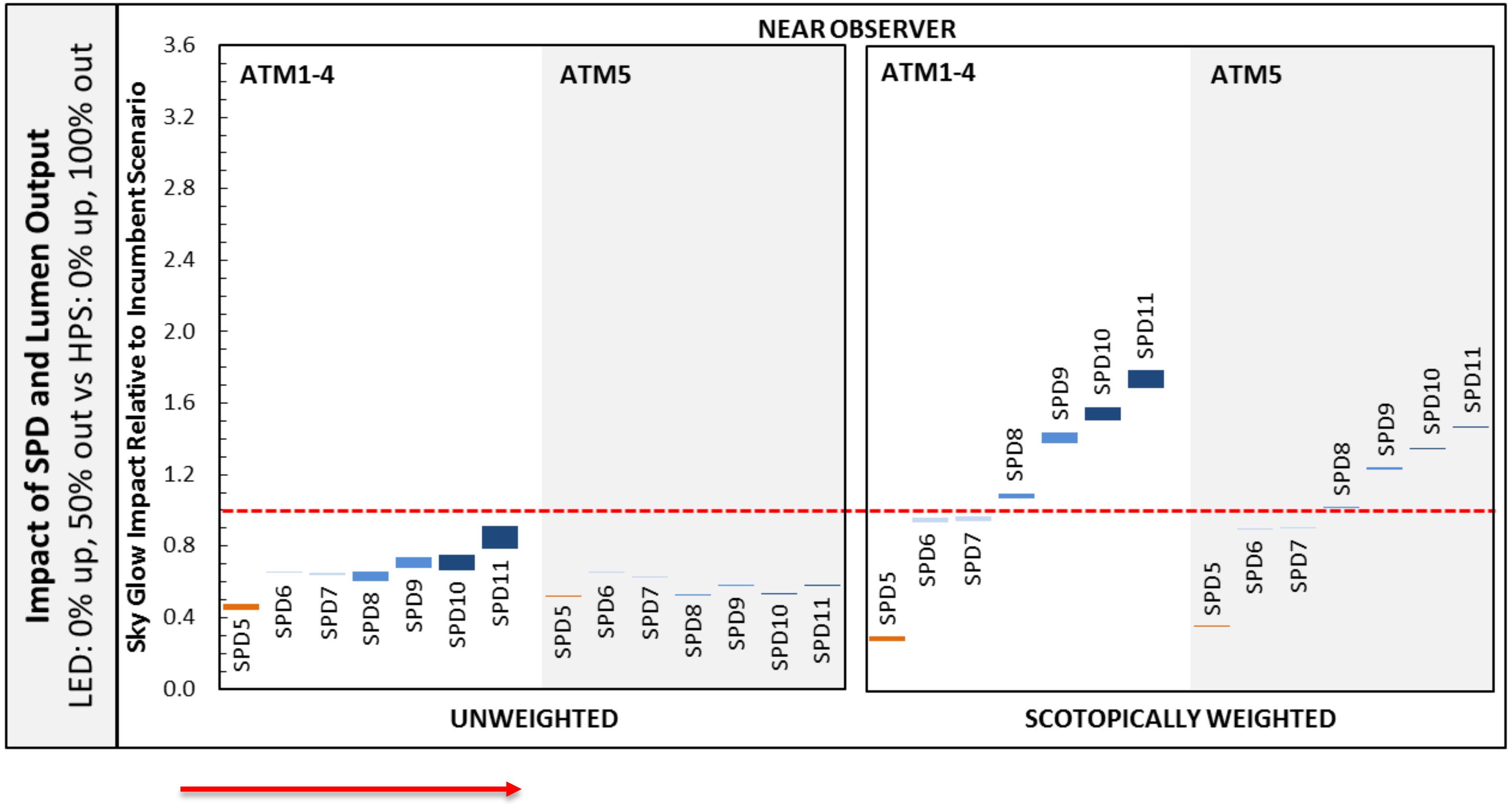
Impact of SPD in isolation of other variables



DOE sky glow investigation results – Near Observer

- All unweighted results now show reduced sky glow for all SPDs
- With scotopic weighting, some SPDs reduce sky glow relative to HPS baseline and others increase it

Impact of SPD plus 50% reduction in output

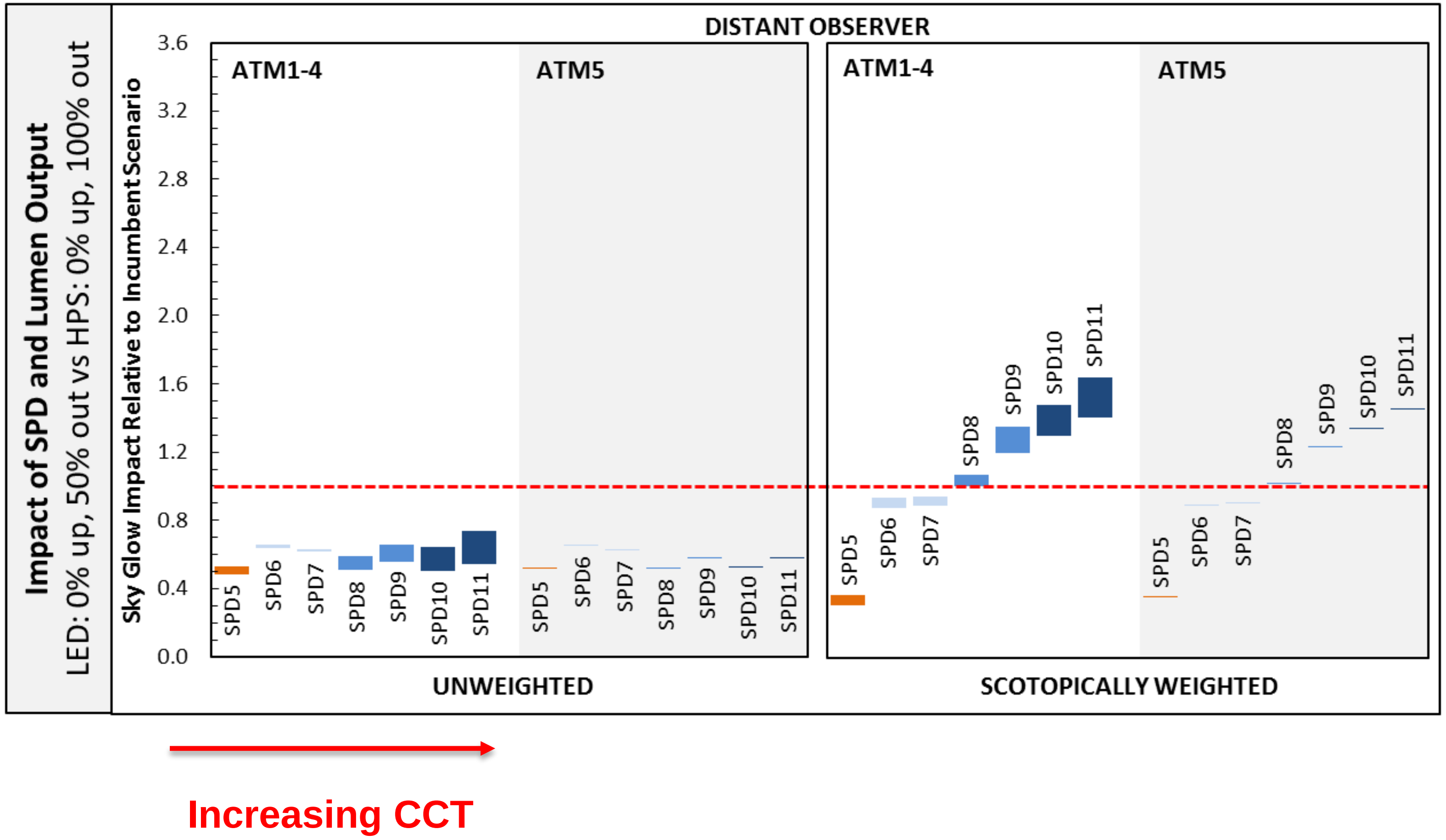


Increasing CCT

DOE sky glow investigation results – Distant Observer

- Again the greater travel distance through the atmosphere enables greater variation in the results

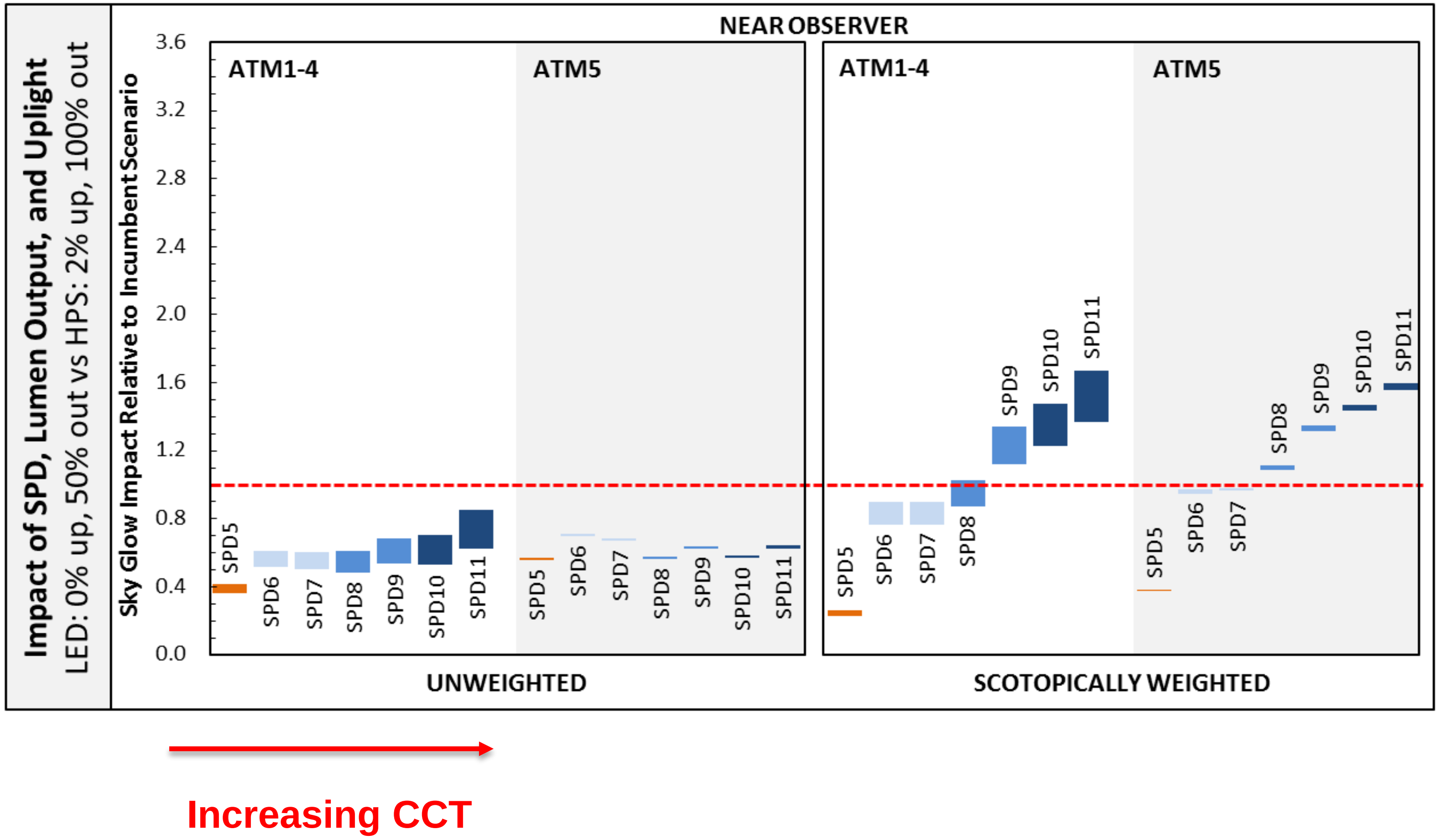
Impact of SPD plus 50% reduction in output



DOE sky glow investigation results – Near Observer

- Reduction in uplight from 2% (primarily emitted at low elevation angles) to 0% increases the range of impacts for the near observer…

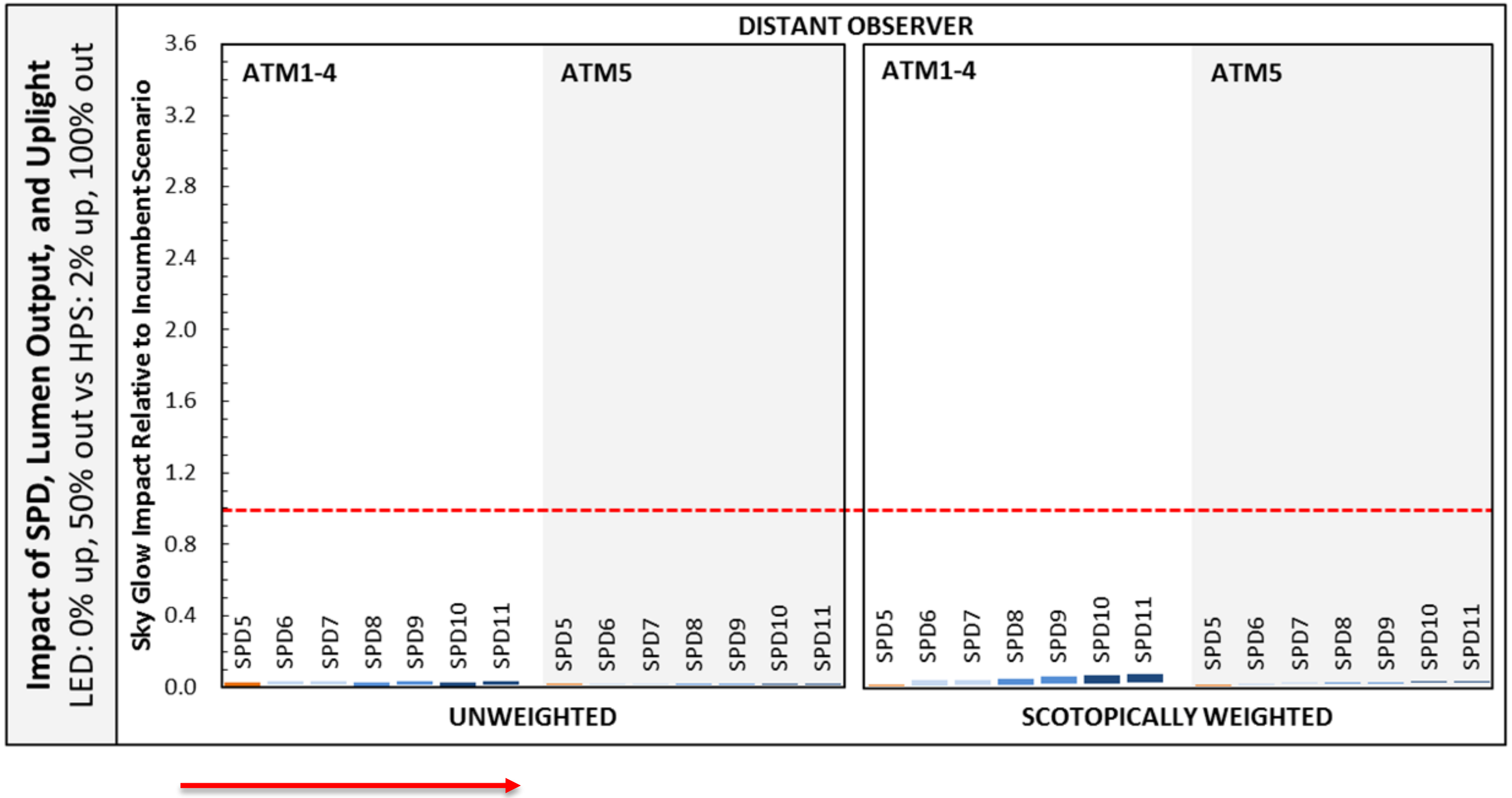
Impact of SPD, 50% reduction in output, and 0% uplight



DOE sky glow investigation results – Distant Observer

- And almost eliminates sky glow (by 95+%) for the distant (40 km) observer, from the street lighting system

Impact of SPD, 50% reduction in output, and 0% uplight



Increasing CCT

Remember: street lighting is only one component of sky glow

- And not necessarily the primary source!
- Significant reductions in sky glow are likely to require concerted efforts across a range of applications.

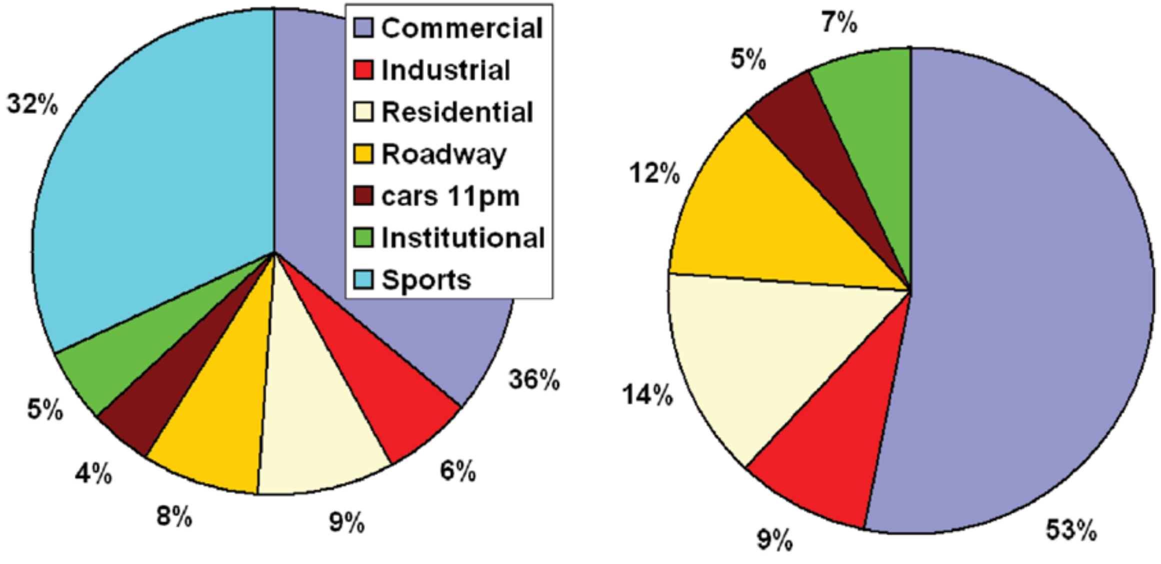


FIG. 5—Adjusted Total Uplight by Category (excluding post-1989 lighting). (*a*) Sports on; (*b*) Sports off.

Source: Luginbuhl, et al., 2009, "From the Ground Up I: Light Pollution Sources in Flagstaff, Arizona," Publications of the Astronomical Society of the Pacific, 121:185.

There is much work ahead

Chicago, 2007

Credit: Premshree Pillai via Flickr, no alterations

Thank you and Q&A

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August 3: “A Technical Discussion of DOE’s Sky Glow Study, Modeling Methods, and Key Variables”
Register on the DOE SSL Website

Related resources: *https://energy.gov/eere/ssl/street-lighting-and-blue-light*

Includes, among others:

- Sky Glow Investigation Report
- Frequently Asked Questions: Street Lighting and Blue Light
- Webinar: Get the Facts on LED Street Lighting
- SSL Posting: Getting the Facts Straight About LED Street Lighting