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The Nighttime Blues in Context

A "Get the Facts" Webinar Hosted by the U.S. Department of Energy Solid-State Lighting Program (ssl.energy.gov)

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Preface

- It is not this presentation's intent to single out any individual or organization for criticism or culpability, but rather to pursue an objective exchange of ideas as prompted by recent events, based on their scientific merit.
- The discussion reflects the current state of knowledge and corresponding gaps in that knowledge at the time this presentation is being provided. Our understanding can be expected to evolve over time as the science progresses.

Introduction

- Sunlight contains a large blue component in its spectrum
- Atmospheric scattering bathes the earth in blue
- Natural systems have evolved in response

- Electric lighting can provoke similar response
- Street lighting has received a lot of negative press lately from related concerns

Introduction continued

- Concerns raised about LED conversions in particular
  - Emphasize blue wavelength content
  - Underlie both sky glow and health concerns
- These topics and their various aspects are complex and not yet completely understood even by the respective scientific communities working on them
  - E.g., some disagreement on various factors of influence among both atmospheric modeling and medical research communities
  - Are the focus of much continuing research
- In the meantime, lack of clarity on these relationships forces reliance on projections and their underlying assumptions
  - E.g., "All other things remaining equal, substituting a 6000 K LED SPD for a 2100 K HPS SPD will result in…"

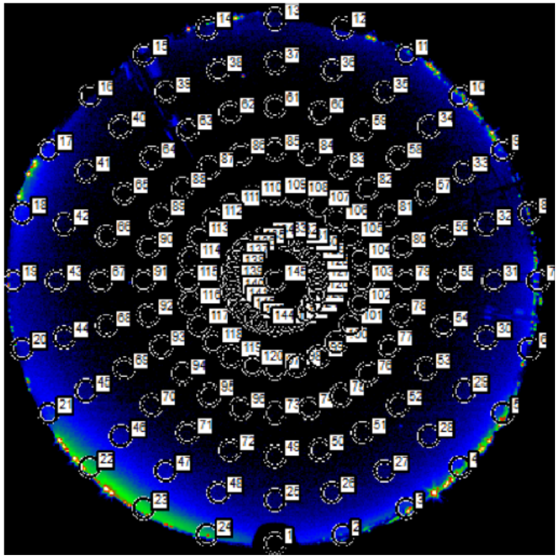
Things are never equal!

Introduction continued

- Most media reports acknowledge the importance of selecting and implementing “appropriate” luminaire characteristics
  - Avoiding overlighting (and incorporating dimming when possible)
  - Eliminating light trespass and uplight
  - Selecting appropriate correlated color temperature (CCT)
- However, in projected future scenarios and related recommendations most emphasis seems to be placed on CCT
- **Understanding the collective contribution of all key factors is essential for reasonably estimating impacts**
- DOE is supporting investigations to better quantify the influences of key factors affecting sky glow

Sky Glow

- The original plan: select an established model; run scenarios using actual luminaire characteristics; take measurements at corresponding sites to calibrate
- The reality:
  - It took a full year to launch model runs
  - One model abandoned after several months of work, insufficient support precluded use of a second
  - Abandoned the idea of taking our own measurements
- Ultimately, selected a model that is well accepted in the astronomical modeling community, carefully validated with other models and varied measurement techniques (e.g., street lights turned on and off) in Frýdek-Místek, CR (pop ~58,000). Source: Miroslav Kocifaj, "Night sky luminance under clear sky conditions: Theory vs. experiment," 2013



Positions of measured sky elements

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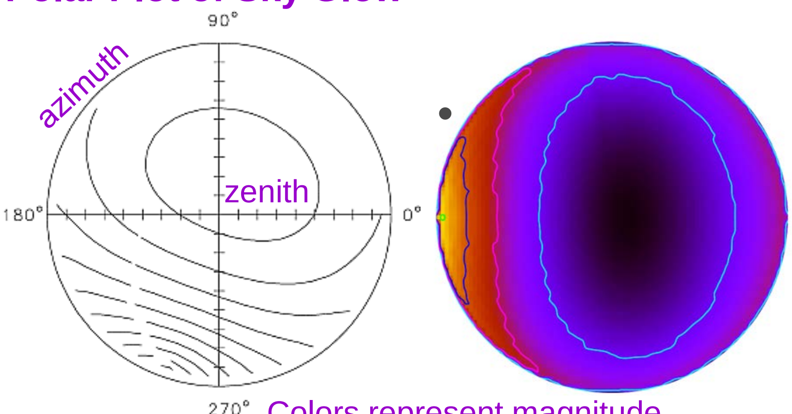
SkyGlow Simulator: Miroslav Kocifaj, PhD

Institute of Construction and Architecture, Slovak Academy of Sciences

Variables:

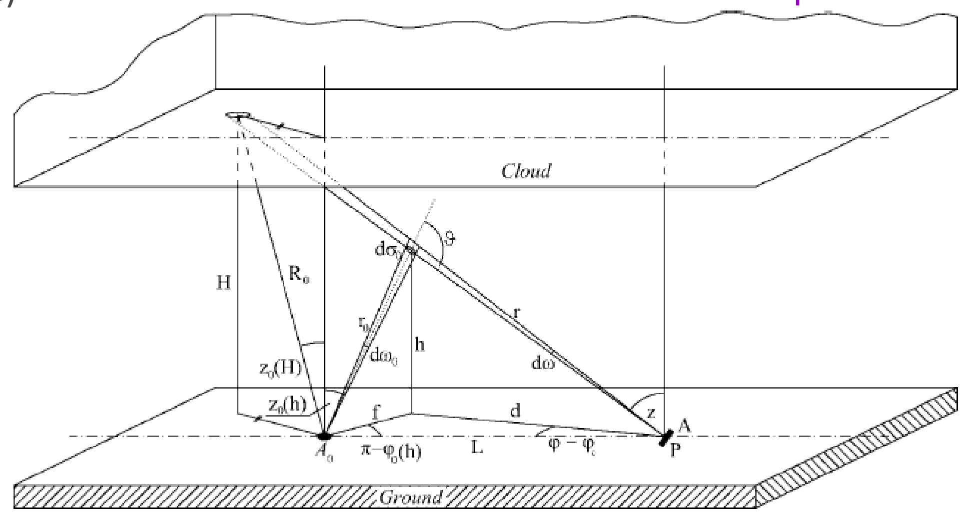
- City (size, shape, location)
- Position of observer
- Fixtures (number, output, percent uplight/ground albedo, SPD)
- City emission function (intensity as a function of zenith angle)
- Atmospheric conditions (cloudless, cloudy, overcast; aerosol content/type)
- Obstacles (horizon shielding)
- Output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

Polar Plot of Sky Glow



Colors represent magnitude
Isolines are drawn in logarithmic scale

Geometric setup of model



Source: M. Kocifaj. *Light-pollution model for cloudy and cloudless night skies with ground-based light sources*. Applied Optics 2007; 46: 3013–3022.

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:
  - 4 cities of varying population (3500 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
  - 3 uplight percentages (0%, 5%, 10%)
  - 2 observer locations
  - 2 output types (non-weighted irradiance or scotopic illuminance)
  - full SPD or 80 individual spectral increments (5 nm each)

  => ~430,000 runs, requiring several weeks on a standard desktop

"Constance"

Constance - Supermico SuperServer 6028TP-HTFR, Xeon E5-2670v3 12C 2.3GHz, Infiniband FDR

Site:	DOE/SC/Pacific Northwest National Laboratory
Manufacturer:	Atipa Technology
Cores:	7,200
Linpack Performance (Rmax)	203.238 TFlop/s
Theoretical Peak (Rpeak)	264.96 TFlop/s
Nmax	1,418,752
Power:	
Memory:	19,200 GB
Processor:	Xeon E5-2670v3 12C 2.3GHz
Interconnect:	Infiniband FDR
Operating System:	Linux
Compiler:	Intel ICC
Math Library:	Intel MKL
MPI:	Intel MPI

#297 in 2014

Source: Top500.org

Sample Result – Direct Uplight Is Significant

Replacing this / with this

5% uplight

0% uplight

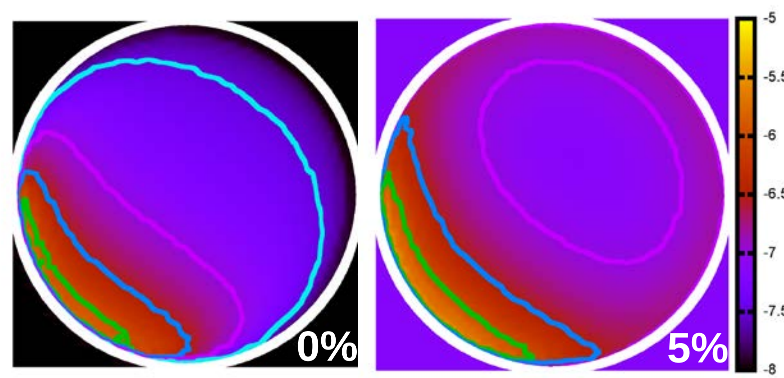
Yields reductions in sky glow in one subset of runs of:

0.87x (13%)

0.48x (52%)

0.72x (28%)

Number of underlying data runs: 176
Unweighted, Cloudless Conditions
Held Constant: emission function, lumen output per fixture, observer location, full SPD



Real-World Example (before)

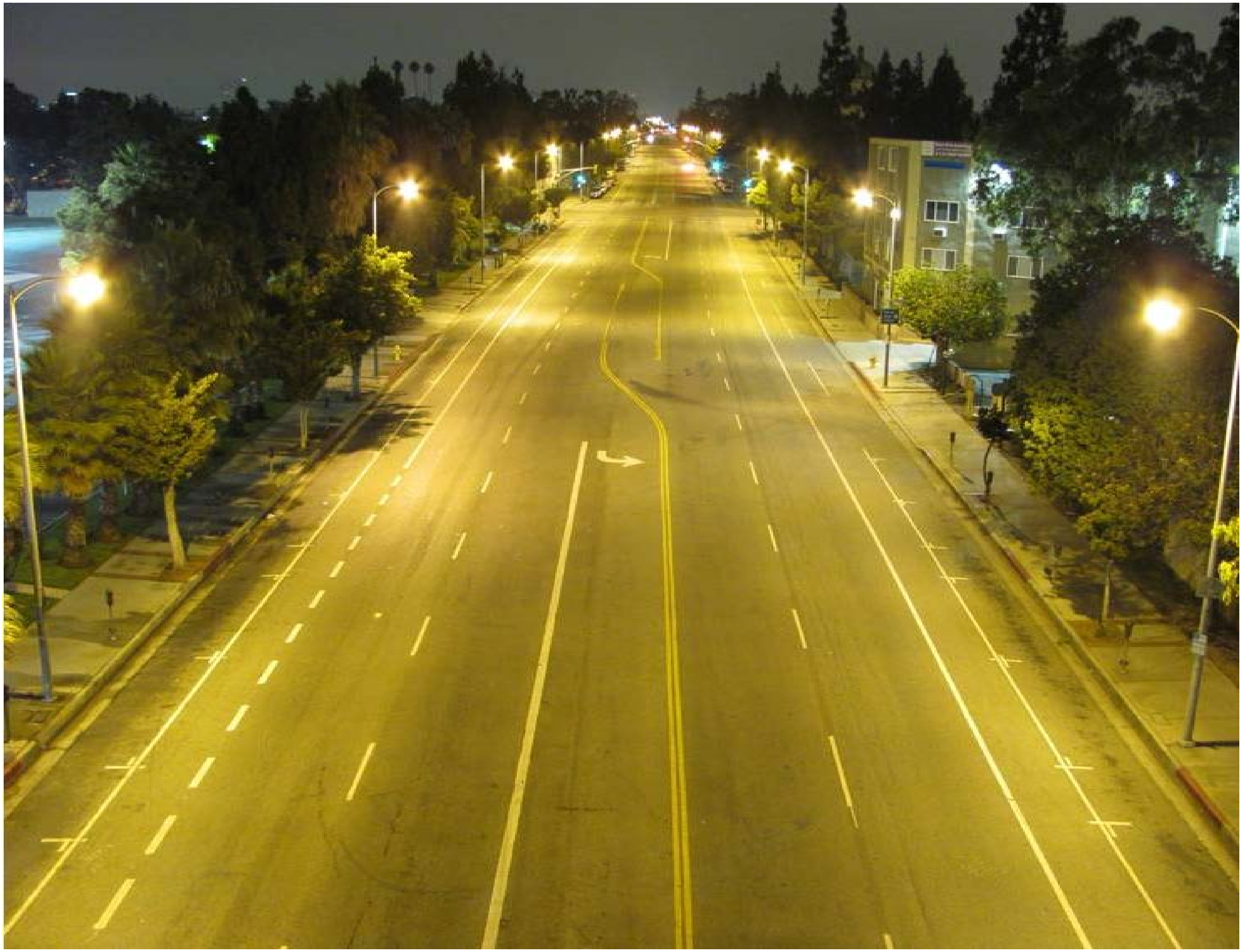


Photo Courtesy: LABSL

Real-World Example (after)

Photo Courtesy: LABSL

Blue-Light Characteristics of Outdoor Sources

Row	Light source	Luminous Flux (lm)	CCT (K)	% Blue*	Relative Scotopic Content	Relative Melanopic Content**
A	PC White LED	1000	2700	17% - 20%	1.77 - 2.20	1.90 - 2.68
B	PC White LED	1000	3000	18% - 25%	1.89 - 2.39	2.10 - 2.99
C	PC White LED	1000	3500	22% - 27%	2.04 - 2.73	2.34 - 3.57
D	PC White LED	1000	4000	27% - 32%	2.10 - 2.65	2.35 - 3.40
E	PC White LED	1000	4500	31% - 35%	2.35 - 2.85	2.75 - 3.81
F	PC White LED	1000	5000	34% - 39%	2.60 - 2.89	3.18 - 3.74
G	PC White LED	1000	5700	39% - 43%	2.77 - 3.31	3.44 - 4.52
H	PC White LED	1000	6500	43% - 48%	3.27 - 3.96	4.38 - 5.84
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	3725	25%	1.82	1.95
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	2836	12%	2.23	2.73
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

Source: MSSLC Light Post (http://energy.gov/eere/ssl/downloads/light-post-july-2016)

† Moonlight CCT measured and provided by Telelumen, LLC.

Controlling Blue Wavelengths – Cambridge, MA

- Lumen values derived from city's 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

Street Lighting in Context – Interior Comparisons

Combined subset* of readings taken by Naomi Miller, Bruce Kinzey, Rita Koltai, Terry McGowan, Derry Berrigan (*note: not all participants provided readings in every category; not all categories listed)	Reading (Lux)
Vert illuminance from window facing street light, if avail., interior lights off	
-- blinds open	≤0.1
-- blinds closed	0
Vert illuminance from window not facing street light	0-1
Kitchen	30-340
TV from 10 feet away, room light off	0-10
TV from 10 feet away, room light on	2-30
Phone/tablet at reading distance, other room lighting off	0-5
Phone/tablet at reading distance, room lighting on	15-45
Bedside lamp(s) reflecting on magazine/book page	35-350
Max horizontal illuminance at street light nadir - no vegetation interference	5-10
Max horizontal illuminance at street light nadir - some interference	0-5

Street Lighting in Context - Moonlight

- Full moon is ~ 0.1 lx
- 4000 K LED is dimmer and warmer than the moon from my porch, as allegedly depicted in this photo

Street Lighting in Context – Buildings

From this perspective, everything you see is uncontrolled uplight

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Street Lighting in Context – Billboards / Signage

Note the street lighting in this photo

(Note: there is street lighting in this photo)

Street Lighting in Context - Vehicular

Transitory, but often persistent

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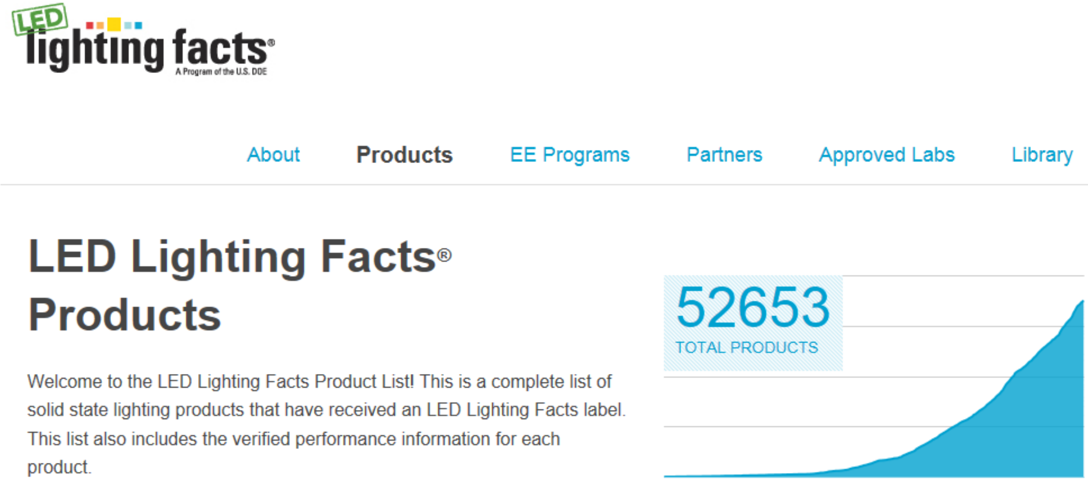
What Do We Do With this Information?

- Provide to lighting owners concerned about potential adverse impacts of their planned or completed conversions, improving decision-making ability
- Provide related tools to the lighting community to help refine designs
- Increase effectiveness of efforts undertaken to address the concerns
- Reduce the association in the public mind that these issues are unique characteristics of LED technology
- Hopefully, identify larger areas of common ground between stakeholder and public guardian groups

Related DOE Resources

- "SSL Posting" issued in response to the AMA release
- Municipal Solid-State Lighting Consortium response to the AMA release
- "SSL Posting" on LED Outdoor Area Lighting
- "True Colors" Fact Sheet
- GATEWAY Demonstration Outdoor Projects
- LightingFacts® Database



Q&A

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