IES Street and Area Lighting Conference 2016

Counting the Blues of Street Lighting

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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!

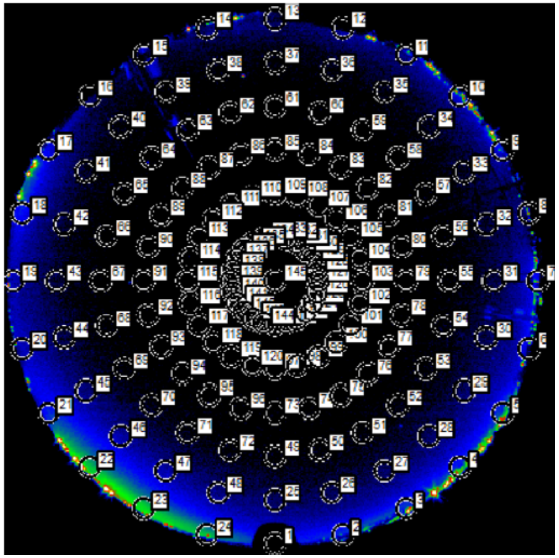
Photo: PNNL

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 factors is key to accurately estimating impacts and maximizing future potential for mitigating the issues of concern**
- DOE is supporting investigations to better quantify the blue wavelength emissions from lighting and the roles that other characteristics play

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

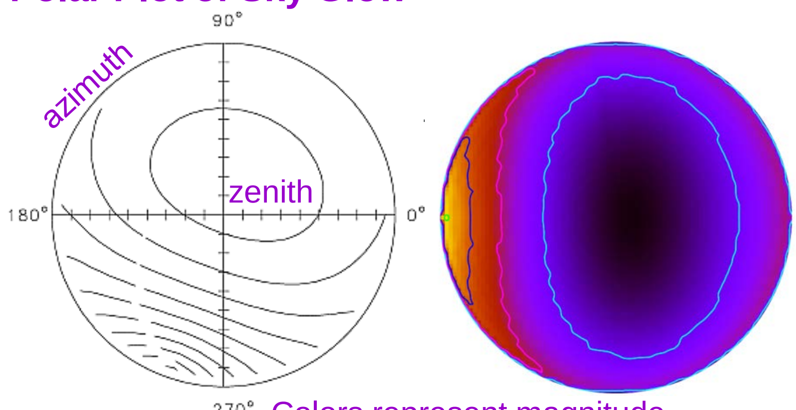
SkyGlow Simulator: Miroslav Kocifaj, PhD

Institute of Construction and Architecture, Slovak Academy of Sciences

Variables:

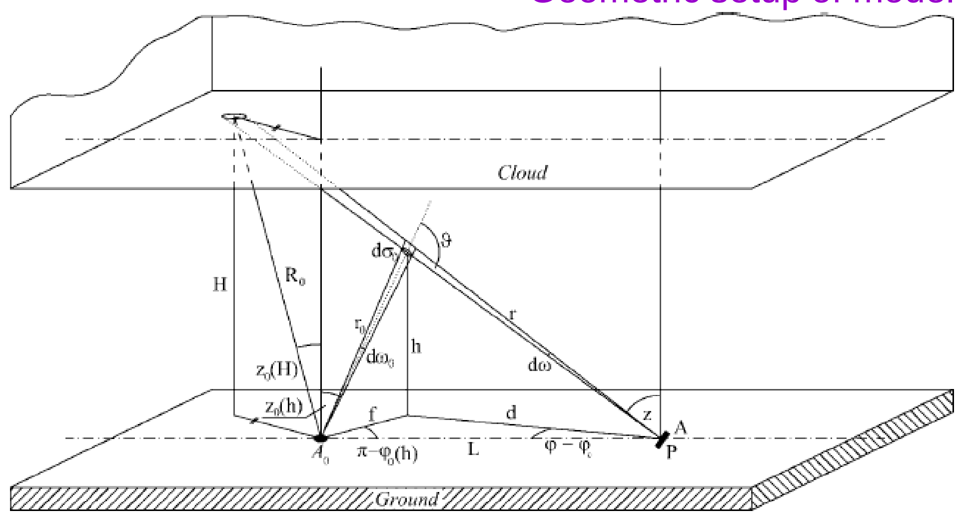
- City (size, shape, location)
- Position of observer
- Fixtures (number, output, percent uplight/ground albedo, SPD)
- City emission function (intensity as a function of zenith angle)
- Atmospheric conditions (cloudless, cloudy, overcast; aerosol content/type)
- Obstacles (horizon shielding)
- Output quantity (unweighted or weighted)
- 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, about 5-6000 hours 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

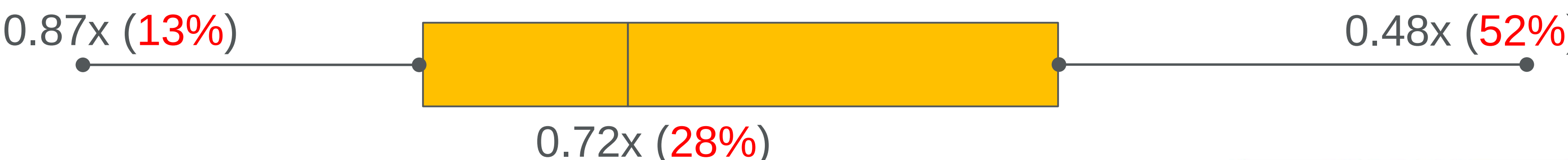
Source: Top500.org

Sample Result – Direct Uplight Is Significant

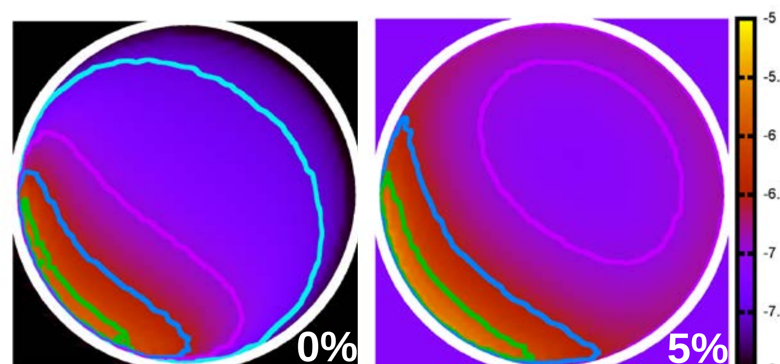
Replacing this | with this

5% uplight | 0% uplight

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



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)

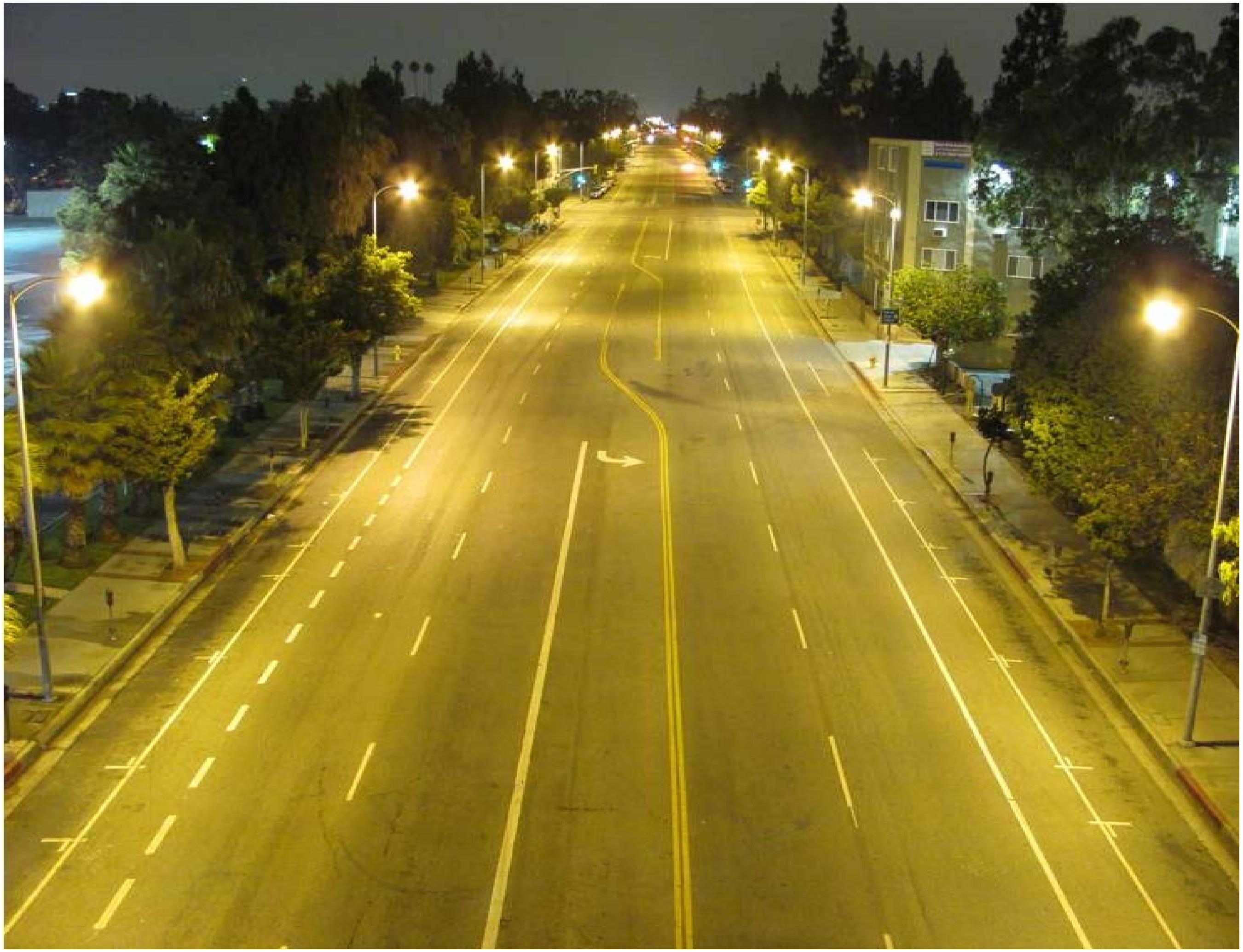


Photo Courtesy: LABSL

Real-World Example (after)

Photo Courtesy: LABSL

Blue-Light Characteristics of Outdoor Sources

Row	Light source	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 (and *footnotes): MSSLC Light Post (http://energy.gov/eere/ssl/downloads/light-post-july-2016)

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 warmer and dimmer than the moon from my porch

Street Lighting in Context – Buildings

From this perspective, everything you see is uncontrolled uplight

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

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

Contact

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