The Light Post

Official MSSLC e-Newsletter

July 2016

Hello MSSLC Members:

I imagine most everyone is familiar with the recent position statement issued by the American Medical Association (AMA) on "high-intensity street lighting," due to the extensive media coverage following its release. We continue to field inquiries that include many passed along from our member municipalities and utilities, originating from their citizens and customers. The messages contained in the release have caused a stir.

DOE's Solid-State Lighting Program issued an SSL Postings within a few days of the AMA's release. This notes the importance of matching the characteristics of the product with the specific application, underscoring the AMA's call for the use of appropriate products. Since then a number of other organizations have also weighed in with very useful perspectives. You might want to check these out if you haven't already:

- Glenn Heinmiller of LAM Partners in Cambridge, MA, responded to a number of the AMA points and subsequent misinterpretations in the media coverage that immediately followed the release; Glenn was directly involved with the street lighting conversion in Cambridge that was referenced in the AMA's statement.
- The Lighting Research Center at RPI responded with a mix of technical discussion and concise topic-by-topic summaries to clarify some central points. They note that two key contributors to the influence of blue wavelengths on health include intensity and the amount of exposure time of the retina, both of which were left out of the AMA statement.
- The National Electrical Manufacturer's Association has also weighed in, reiterating the potential for controlling light distribution from LED products and noting that one color temperature (3000K) will not be appropriate for all applications.

In addition to the above I thought I might also provide some numbers for your use should you continue to get inquiries from your respective agencies and citizens. Probably most people do not have access to the actual spectral contents of the different types of lighting in common use or know how they compare with one another, even if they understand that virtually all lighting sources produce *some* amount of melanopic content. Melanopic content is of interest here because it is regarded as a primary indicator of the relative potential for the listed light sources to stimulate the human biological responses that are the subject of much of the AMA's statement. Note, however, that influences from other photoreceptors like the rods and cones are also known to contribute to biological responses such as circadian and neurophysiological regulation, but in ways that are not fully clear to the medical research community.

Table 1 lists various sources used in street and area lighting and selected performance characteristics related to their spectral content. Data for each source includes a measured Correlated Color Temperature (CCT), the calculated percentage of radiant power contained in "blue wavelengths" (defined here from the literature related to sky glow as wavelengths between 405 and 530 nanometers [nm]), and the corresponding scotopic and melanopic multipliers relative to a high-pressure sodium (HPS) baseline, normalized for equivalent lumen output. Note that research on the contributions of different types of photoreceptors to visual and non-visual responses continues (e.g., see Amundadottir, 2016; Schlangen, 2016; Lucas et al., 2014) and may warrant updates to this table in the future.

Table 1. Selected blue light characteristics of various outdoor lighting 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

* Percent blue calculated according to LSPDD: Light Spectral Power Distribution Database, http://galileo.graphycs.cegepsherbrooke.qc.CA/app/en/home. The specific calculation, developed for evaluating the potential for affecting sky glow, divides the radiant power contained in the wavelengths between 405 and 530 nm by the total radiant power contained from 380 to 780 nm, for each light source.

** Melanopic content calculated according to CIE Irradiance Toolbox, http://files.cie.co.at/784_TN003_Toolbox.xls, 2015 as derived from Lucas et al., 2014.

Key: PC -- Phosphor Converted; LED -- Light Emitting Diode

As most products differ slightly from one another, the scotopic and melanopic values presented should be taken as being typical for the associated light source type, rather than exact. We have included ranges, for which we have data, to indicate the upper and lower limits that might be found in a representative set of LED product samples. The number of product samples underlying each CCT ranges from 2 (for 2700 K) to 19 (for 3000 K), with others falling in between (76 samples in all). Conventional light sources are all listed with single values rather than a range because DOE has performed less testing on those, but they would likewise be most accurately characterized by a range (albeit narrower than LED).

It is important to understand that performing a calculation with these values only provides an idea of the relative *potential* to cause human health impacts, rather than the actual (if any) impact of the melanopic content. These values do not yet take into account several critically-contributing factors noted in the LRC paper linked above, such as the intensity one might expect to find inside a bedroom from a streetlight outside. Furthermore, the melanopic content itself directly scales with light output for a given source, so reducing output by dimming dynamically reduces the corresponding content.

Finally, note that the scotopic and melanopic contents reported are listed relative to HPS, which was selected as the baseline for comparison due to its predominance in the existing outdoor lighting market.

The influence of blue wavelengths is immediately evident in all "white light" sources containing them. In addition, as demonstrated by the relative melanopic contents of conventional lighting sources in the table, the blue light issues being raised by the AMA are clearly nothing new to our lighted environment. What *is* new is our increased understanding of their *potential* influence regarding human and environmental health issues, as the related research progresses.

Estimating the potential impacts

A commonly cited advantage of LED lighting is the superior control available over its light distribution. This advantage arises because a luminaire needs to fit its output to a target area, for example a rectangular stretch of roadway extending 100+ feet out from under each side of a streetlight. To satisfy the application, fixtures employing omni-directional emitters like glass lamps require significant reshaping of the lamp's output through reflectors and lenses, and despite great skill in this regard, the results remain far from perfect with large components of the light continuing to exit the fixture in unwanted directions. The latter often results in light trespass, glare, uplight (in older installations especially) and non-uniform illumination on the ground, all of which amount to wasted light and energy. In contrast, because LEDs emit in only one hemispherical direction, the optics' job of shaping their light output into the pattern wanted is much easier from the start, and thereby enables the elimination of much of this waste.

One direct benefit resulting from the improved distribution is that lamp-based fixtures are now routinely being replaced with LED products that emit only half (or less) of the light output of the replaced conventional light source. This is a key concept for estimating the potential for impact from a lighting conversion program. For example, if product X has a melanopic content twice that of product Y, but can be run at one-third the output, then converting to product X might actually reduce melanopic output. As previously noted, dimming a given product similarly reduces its emitted melanopic content, in direct proportion to the reduced light output.

Numerous real-world examples exist of such reductions being achieved in actual street lighting conversion programs around the U.S. As a salient example, the city where I live, Portland, OR, has replaced its previous 100 W HPS fixtures emitting about 9,000 lumens (initial) with 4000 K LED products that are set to an initial output of 3,000 lumens, achieving a two-thirds reduction. As a result, in absolute terms, the LED products in Portland have likely had little impact on the melanopic output compared to the previous (and notably non-white) HPS fixtures they replaced, because the reduced light output offsets the LED's higher melanopic multiplier.

A second example is Cambridge, MA, which installed a dimming control system when it converted its street lighting to LED in 2013. According to a complete inventory of its lighting system at the time, the city replaced a total of about 54 million lumens (initial) of HPS lighting with about 32 million lumens (initial) of 4000 K LED lighting. The city's "maintained" setting of the controls system is at 70% output, meaning it actually only uses about 22.4 million lumens to light its streets at dusk when the lights first come on. Moreover, at midnight the dimmer setting is further reduced by another 50% (i.e., to 35% of full output), where it remains until early morning. Assuming even a high melanopic content factor relative to the original HPS of 3.4, during the initial evening hours its relative melanopic content emissions would amount to 3.4 x (22.4/54) = **1.41x** those of the original HPS system. From midnight to the early morning hours, this value is reduced again by 0.5, yielding a factor of about **0.71x**. In other words, the Cambridge system has offset the increase in melanopic content of converting to 4000 K lights, at least during the middle of the night, by reducing their output while still gaining the benefits of improved visibility, reduced energy and maintenance, and increased lifetime and reliability.

To summarize a few key takeaways:

- The spectral content of a light source determines its melanopic content and can thereby be used to help in selecting the associated level of melanopic content of a system. In contrast, while CCT is acceptable as a first approximation of spectral content, it is a less accurate measure of relative melanopic content than SPD. The significant overlap between melanopic contents of PC White LEDs at 3000 K and 4000 K in the table, for example, shows that simply substituting a 3000 K product for a 4000 K product may not necessarily accomplish the intended result.
- The "raw" melanopic content produced by a light source is only one contributor to any ensuing environmental or health impacts actually realized. Focusing exclusively on that measure (or any single measure, such as CCT) ignores the various means of controlling or offsetting the increased melanopic content of white light sources, and particularly those noted (e.g., greatly improved distribution, dimming capability) that are enabled by LED technology.
- The ranges in melanopic content available among LED products suggest that LEDs offer substantial flexibility towards tailoring them to the specific application.
- For a given light source, output from the luminaire is directly related to its emitted level of melanopic content, so reducing initial output (as in the Portland example) or dimming the system (as Cambridge does after midnight) offer direct, easily realized reductions in this regard.

The real value in LEDs, as has been stressed all along, comes from the combination of these elements. The wide-ranging capabilities and characteristics of LEDs are greater than any other lighting source that has come before them, and thus they offer unparalleled potential for addressing the issues raised by the AMA. As noted in the SSL Postings, LEDs are a critical part of the solution provided that these functionalities are applied. This is the message that should be shared.

I hope this information is helpful in planning and understanding the potential impacts of your own conversion efforts. I would like to extend my sincere thanks to George Brainard, Ph.D., and Robert Lucas, Ph.D., who reviewed and commented on this issue of *The Light Post* for accuracy. Their assistance is greatly appreciated.

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