Naomi J. Miller and Anne (Lia) Irvin

M/P Ratios—A Call for Consistency Times change and so must calculations

Although they've become ubiquitous lighting metrics, the candela and the lumen are based on only one form of human spectral sensitivity, which is characterized using the weighting function known as V(λ) (called "V-lambda"). But V(λ) was derived under a very narrow set of experimental conditions way back in 1924, and today there are many alternative sensitivity curves or action spectra that can be applied to a lamp or luminaire's spectral power distribution (SPD) to yield more-relevant measures of color sensitivity, off-axis visibility at night, potential circadian stimulus, potential blue-light hazard, scene brightness or even potential for damage to artwork. Soon, practitioners may need to learn to evaluate SPDs using various weighting functions or action spectra that are most pertinent to the application, and to evaluate a lighting system's energy effectiveness using a different kind of radiant watts per electrical watt used.

In this column, we'll address the weighting functions that are applied to an SPD for calculating lumens and then discuss how that same concept is applied to calculate both melanopic (M) and photopic (P) content from the light source. Those of you who want more background, context and detail can find them in our IES FIRES article "M/P ratios – Can we agree on how to calculate them?" which also has tables listing the M/P ratios for a wide variety of familiar light sources.

You may have heard mention of M/P ratios to evaluate the appropriateness of a light spectrum for either alertness, relaxation or sleep. According to some research, the more energy in the spectrum (measured in radiant watts) emitted in the spectral range to which the intrinsically photosensitive retinal ganglion cells (ipRGCs; nonvisual photoreceptors that play a role in circadian response) are most sensitive, the more the light source's alertness potential. The M/P ratio simply compares that melanopic (ipRGC) potential to the light source's ability to produce light for daytime detail vision (photopic vision).

However, there's one catch: There are four different ways to calculate these M/P ratios! Those ways depend on how the weighting functions are determined. (Note that the authors use the term "radiant watts" to denote the resulting effective radiant energy of an SPD when it is multiplied by a melanopic or photopic weighting function.)

> "There's one catch: There are four different ways to calculate these M/P ratios

Method 1

This is based on normalizing the melanopic and photopic response functions so that they coincide at 555 nm (**Figure 1, first plot**). The maximum values of the curves are called "K-factors" and are based on the lumen being defined at 683 lumens per optical watt.

- Take the measured SPD values for a light source received from a manufacturer's laboratory test, or measure the light incident on an observer's eye using a spectrometer.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the *melanopic efficacy* function (with its maximum at 4,215 lm/W). Sum the values.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the *photopic efficacy* function (with its maximum at 683 lm/W). Sum the values; this is the number of lumens delivered by that SPD.
- Divide the summed melanopic radiant watts by the summed lumens. This gives you the *M/P* 1 ratio, which is comparable to the S/P ratio used in the past.

Method 2

The K-values from Method 1 can be very confusing, because the resulting values of melanopic lumens and photopic lumens are not in the same range. So an alternative approach is described by Sam Berman and Robert Clear in a recent IES FIRES article.

Normalize all sensitivity functions for all photoreceptors and the photopic sensitivity curve, to a maximum of 1, as shown in the **second plot of Figure 1.** Then convert the M/P to a value with units of melanopic milliwatts per lumen, as follows:

- Take the measured SPD values as described in Method 1.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the *melanopic efficiency* function, normalized so that its maximum value is 1; this occurs at 490 nm. Sum the values to a total melanopic radiant watts. Multiply the result by 1,000, which allows reporting the value in mW.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the *photopic efficiency* function, normalized so that its maximum value is 1; this occurs at 555 nm. Sum the values to a total of photopic radiant watts. Then multiply by the Km value of 683 lm/W to get the number of lumens delivered by the SPD.
- Divide the summed melanopic radiant watts by the summed lumens. This gives you the *M/P 2* ratio.

Method 3

This method is used by the WELL v2-2019 Standard and is similar to Method 2, except that instead of normalizing the sensitivity functions to a maximum of 1, the different functions are normalized to a total area under

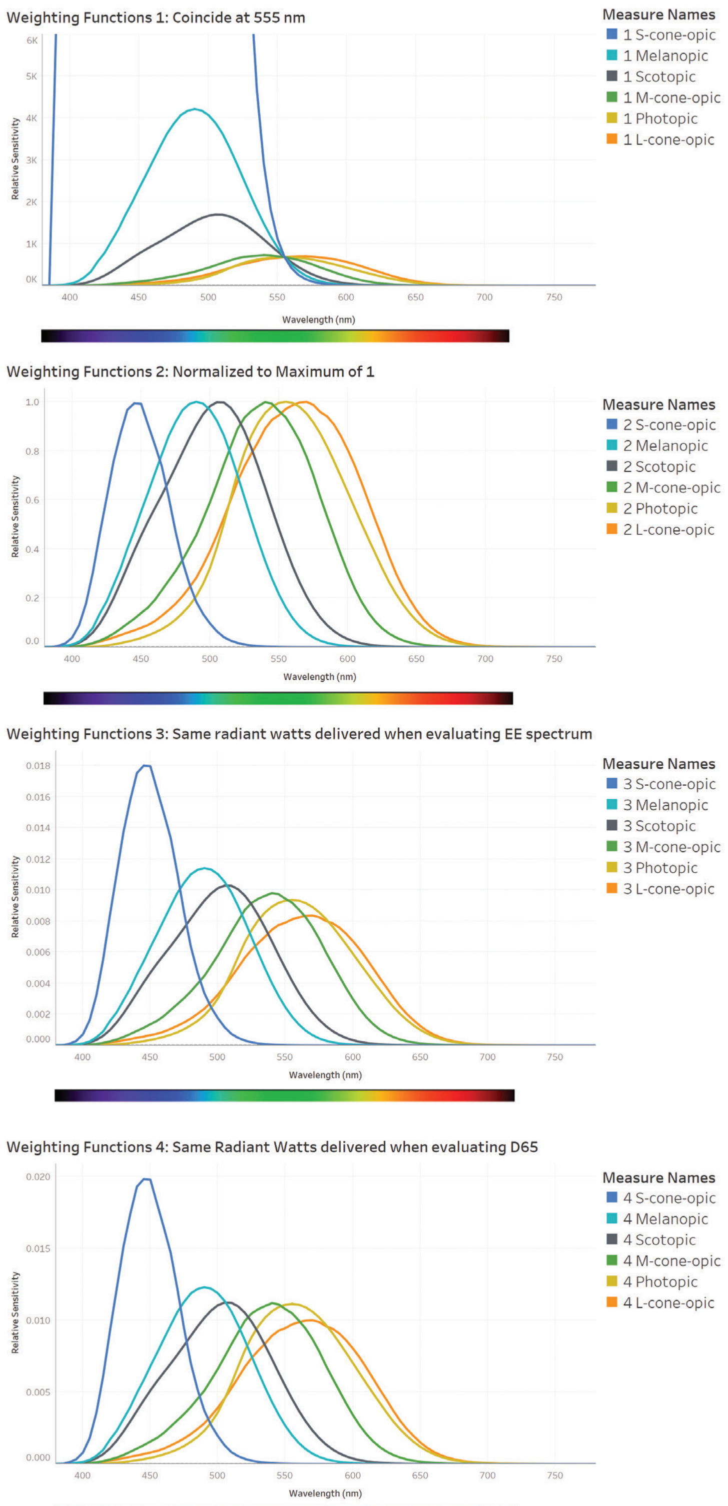

Figure 1. Spectral weighting functions for the four methods, each with different normalizations for the photoreceptor responses and the photopic function. Method 1 is at the top, Method 4 at the bottom.

each curve of 1 radiant watt when evaluating an equal-energy (that is, flat) spectrum (**third plot of Figure 1**). Because some of these sensitivity functions are broader than others, the maximum values don't all align, but the areas under each curve are the same. The steps are then:

- Take the measured SPD values as described in Method 1.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the melanopic weighting function normalized so that its area under the curve equals 1 when evaluating the equal-energy spectrum. Sum the values to get melanopic radiant watts.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the photopic weighting function normalized so that its area under the curve when evaluating an equal-energy spectrum is 1. Sum the values to get photopic radiant watts.
- Divide the summed melanopic radiant watts by the summed photopic radiant watts. This gives you the M/P 3 ratio.

Method 4

This method was recently recommended by the CIE and is covered in the CIE S026-2018 *System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light*. It is similar to Method 3, except that instead of using an equal-energy spectrum for calculating area under each sensitivity curve, it uses the standardized CIE daylight spectrum called D65 (**bottom plot of Figure 1**). The steps are then:

	To convert from /to			
	M/P 1 to 1	M/P 1 to 2	M/P 1 to 3	M/P 1 to 4
Multiply M/P 1 by	1.00	0.24	0.20	0.18
	M/P 2 to 1	*M/P 2 to 2*	*M/P 2 to 3*	*M/P 2 to 4*
Multiply M/P 2 by	4.25	1.00	0.84	0.76
	M/P 3 to 1	*M/P 3 to 2*	*M/P 3 to 3*	*M/P 3 to 4*
Multiply M/P 3 by	5.06	1.19	1.00	0.91
	M/P 4 to 1	*M/P 4 to 2*	*M/P4 to 3*	*M/P 4 to 4*
Multiply M/P 4 by	5.55	1.31	1.10	1.00

Table 1. Multiplying factors for converting from M/P methods 1-4 to all other method numbers.

- Take the measured SPD values as described in Method 1.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the melanopic weighting function normalized so that its area under the curve equals 1 when evaluating the CIE D65 SPD. Sum the values to get melanopic radiant watts.
- Multiply the value of the SPD at each wavelength by the value at the same wavelength of the photopic weighting function normalized so that its area under the curve equals 1 when evaluating the CIE D65 SPD. Sum the values to get photopic radiant watts.
- Divide the summed melanopic radiant watts by the summed photopic radiant watts. This gives you the M/P 4 ratio, also called "melanopic Daylight Equivalent Ratio," or "m-DER," by the CIE.

The calculated M/P values from each method are quite different, and we don't blame you if your head is spinning at this point. It's not possible to determine what a desirable or undesirable light source is, based on M/P value, unless you know which calculation method was used. But there's good news. As you can see by the M/P conversion columns in **Table 1**, there's a constant ratio between any two of the four methods, which means that you can easily translate from one method to another.

We suspect that few practitioners will opt for M/P 1, because the numbers for melanopic "lumens" are not comparable to photopic "lumens," plus the units are not SI-compatible. The values of Method 2 yield the highest M/P values, Method 3 the second-highest values and Method 4 the lowest values. If a designer is given a target of M/P ratios of >0.9 for daytime and <0.35 for nighttime, for example, it will be important that that advice is given with a specific calculation method cited. Alternatively, to reduce confusion, it would make sense to get the light and health community together to settle on a single approach.

Naomi J. Miller, Fellow IES, Fellow IALD, is a designer/scientist at the Pacific Northwest National Laboratory. Anne (Lia) Irvin is a post-Bachelor's research associate at PNNL.