

## **LED Fundamentals**

### **Mesopic Vision**

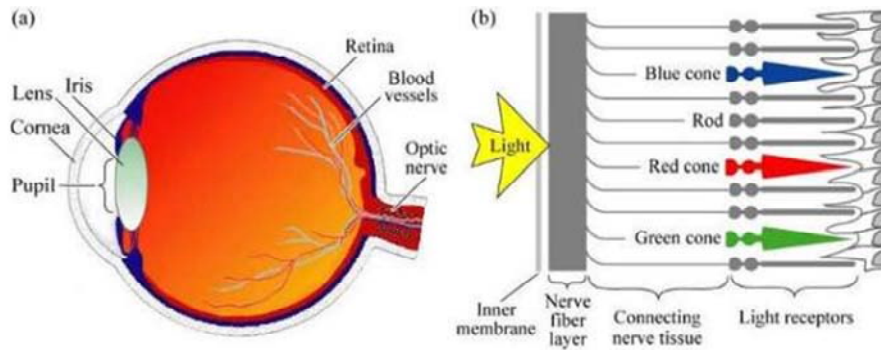
03/01/2014

**OSRAM**  
Opto Semiconductors

Welcome to this presentation on Mesopic Vision, part of OSRAM Opto Semiconductors' LED Fundamentals series.

This LED Fundamental will explain the different vision ranges and discuss the advantages of LED lighting over other light sources as it relates to human vision. The Fundamental will also comment on efforts to incorporate the mesopic vision advantages of LED lighting into standards and regulations.

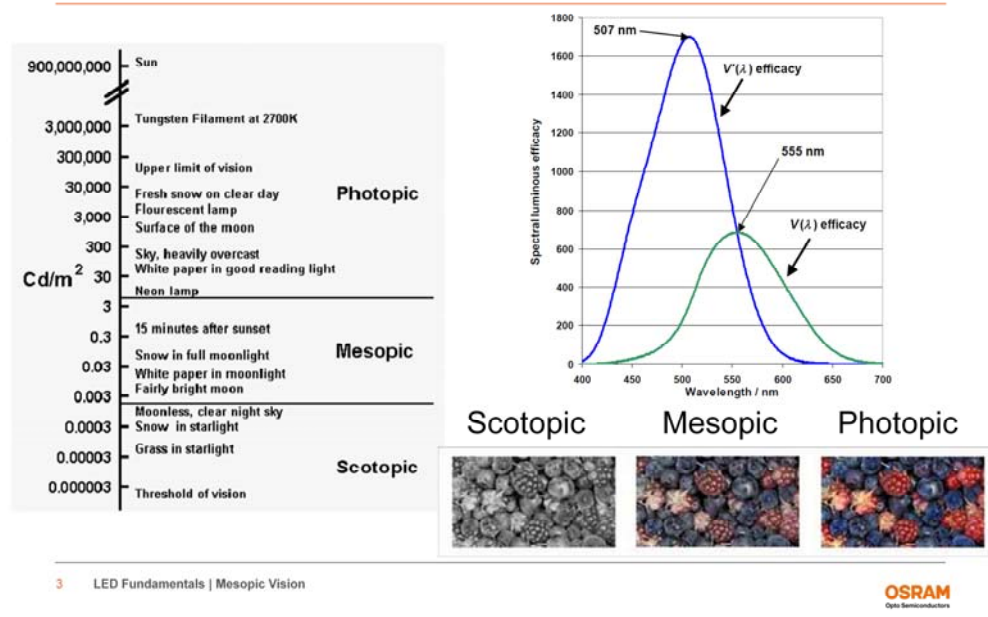
## Human Vision



Adapted from Encyclopedia Britannica, 1994

A general knowledge of how the eye works is needed to understand the idea of mesopic vision. Light is focused by the lens onto the retina. There are two types of photoreceptor cells on the retina which contribute to vision, the rods and the cones. Rods sense very low light levels and also contribute to peripheral vision. Cones detect color and come in three types. Each type senses a different wavelength range, and can roughly be thought of as red, green and blue detectors. Cones are concentrated in the center of the retina and are responsible for detailed vision.

## Human Eye Response



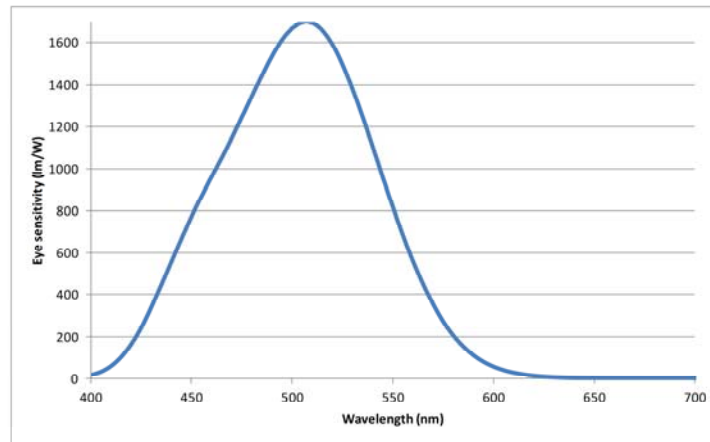
The eye has a large dynamic range; it can operate in bright light, and effectively becomes a photon counter in very dim light.

In bright light ( $>3.4 \text{ cd/m}^2$ ), the eye operates in the Photopic region and has the spectral response of the green curve shown on the right. The cones are sensing full color, and the spectral response of the eye does not change if the light becomes brighter. Nearly all photometric standards and recommended practices are based on the photopic response curve, which is also known as the  $V(\lambda)$  curve.

The other end of the visual range ( $< 0.034 \text{ cd/m}^2$ ) is called the Scotopic region; light is so dim that the cones do not operate and color is not perceived. The spectral response of the eye does not change if the light becomes dimmer. Rods are much more sensitive than cones, and can be activated by only a few photons. The scotopic response curve is often denoted by  $V'(\lambda)$ .

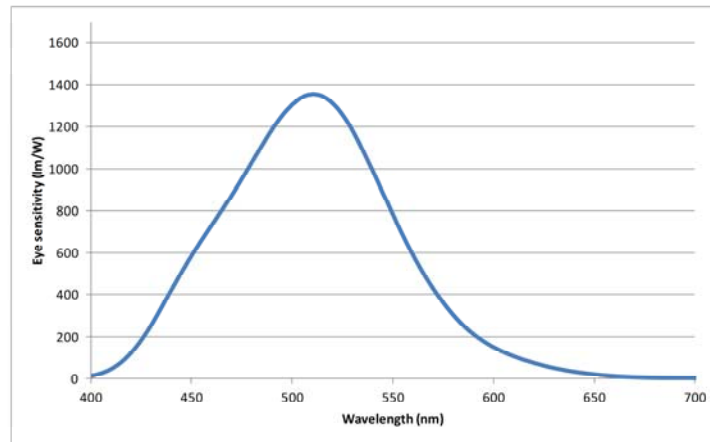
In most night time applications, including streetlighting, the eye is operating somewhere between the photopic and scotopic, in the region termed Mesopic. A combination of both rods and cones are being used to process the light, and the spectral response curve changes with brightness.

## Mesopic Eye Response



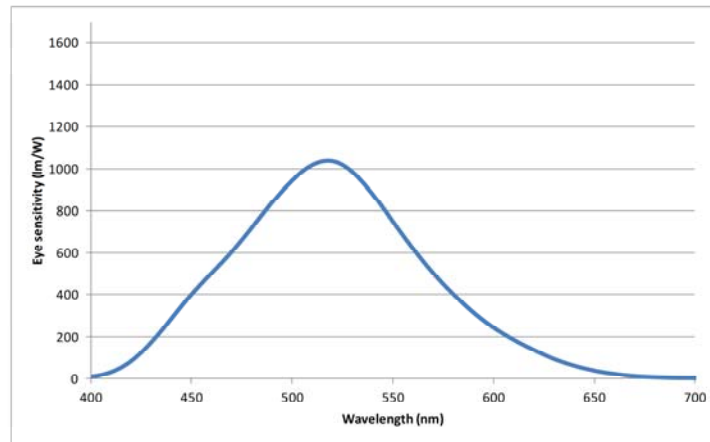
This slide illustrates the difficulty in characterizing mesopic response. Starting with scotopic response and gradually increasing the luminance (or brightness), the eye response curve changes shape and position until it ends in the photopic region. Luminance should be understood as the adaptation luminance, or the average luminance in the field of view.

## Mesopic Eye Response



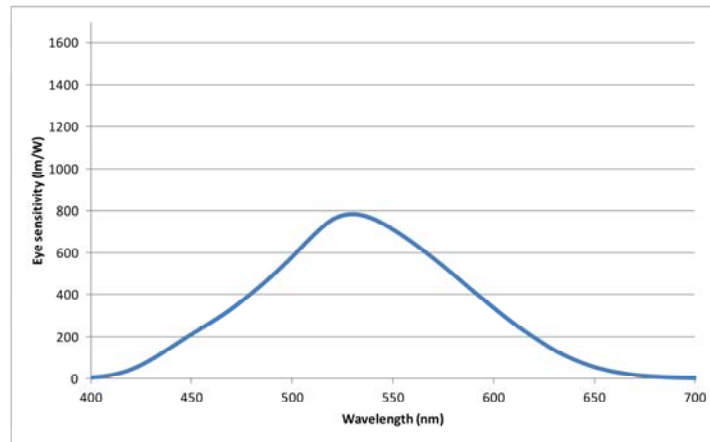
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## Mesopic Eye Response



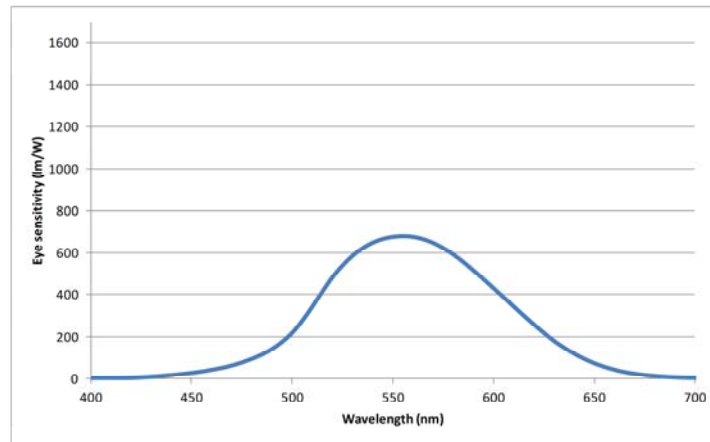
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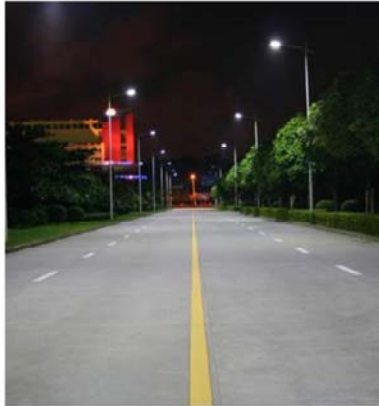


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## Why is Mesopic Vision Important? An Example

Street lighting with  
LED lamps

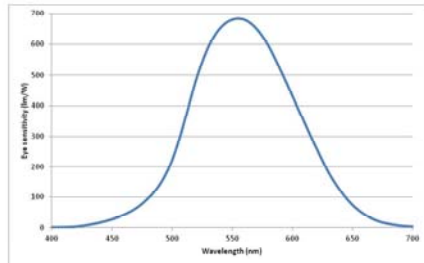


Street lighting with  
HPS lamps



Why is mesopic vision important for SSL lighting? Consider these two photographs. The photo on the right shows a street lit by high pressure sodium streetlights. The photo on the left shows a street lit by LED streetlights. Under mesopic conditions, light sources with more bluish-white content will appear brighter than sources with more yellow content, even though they have the same lumen output. This “mesopic effect” has implications for the way LED lighting is evaluated.

## Why is Mesopic Vision Important?

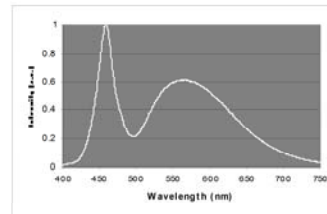


Photopic Response



**Adaptation Luminance**  
(the average luminance in  
the field of view)

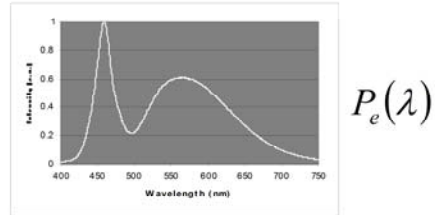
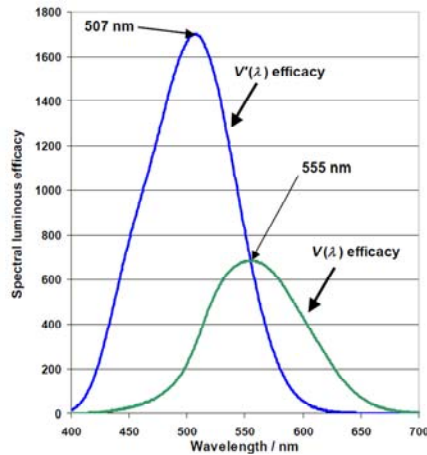
+



Spectral Power Distribution

In other words, if one luminaire has a higher photopic lumen output than another luminaire, it does not necessarily mean the visual performance will be better. It has long been known that accounting for mesopic vision, which depends upon the luminance and spectral power distribution, is a better predictor of performance. The question is how best to quantify the mesopic effect?

## S/P Ratio



$$\Phi_P = 683 \int_{380}^{780} P_e(\lambda) V(\lambda) d\lambda$$

$$\Phi_S = 1700 \int_{380}^{780} P_e(\lambda) V'(\lambda) d\lambda$$

$$\text{S/P ratio} = \frac{\Phi_S}{\Phi_P}$$

How can the effective lumens or effective luminance produced by an LED light source be quantified? One metric is the S/P ratio. The S/P ratio is the scotopic lumens divided by photopic lumens. The same light source will have different values for photopic and scotopic lumens because the response curves are different. For example, a spectral power distribution  $P_e$  for an LED with more blue content will have a higher S/P ratio than a high pressure sodium source. The LED source with higher ratio would appear brighter than a low S/P ratio source with the same lumens under mesopic conditions.

## Some Typical S/P Ratios

Lamp Type	Typical S/P Ratio
Low-pressure sodium	0.25
High-pressure sodium	0.66
Halogen headlamp	1.43
Linear fluorescent	1.3 to 2.3
Metal halide	1.26 to 2.1
Warm white LED	1.21
Cool white LED	2.04

More detailed tables are available (e.g., IES TM-12-12)

This table shows some typical S/P ratios for different lamp types. Lamps with more blue content have higher ratios. A more extensive list can be found in IES TM-12-12.

## Effective Luminance Factor (ELF)

$$ELF = \frac{L_{mesopic}}{L_{photopic}}$$

$$L_{mesopic} = \frac{mL_{photopic} + (1-m)(S/P)(K)}{m + (1-m)(K)},$$

where

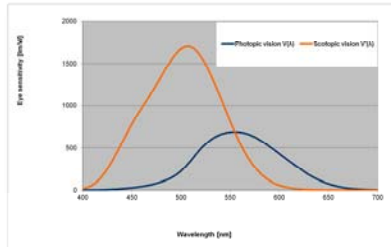
$$K = \frac{683}{1699}$$

S/P = S/P ratio

Comprehensive ELF tables are presented in IES TM-12-12 and CIE 191:2010

A more developed method for evaluating lighting in the mesopic response region has been proposed by CIE and is summarized in IES TM-12-12. An effective luminance is calculated and used in place of photopic luminance by lighting designers and end users to determine if specifications have been met. Finding the multiplier, or effective luminance factor, is central to this calculation. The Effective Luminance Factor (ELF) is determined using an iterative process which uses S/P ratio and adapted luminance as inputs.

## Mesopic Vision Practical Examples



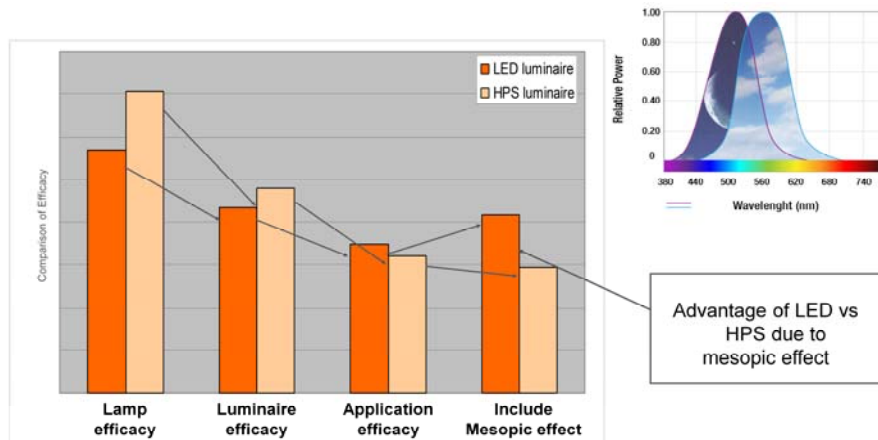
### Effective Luminance Factor (ELF)

The ELF describes the perceived brightness at a given surrounding luminance. For street lighting conditions we assume an adapted (photopic) luminance of 0.3 cd/m<sup>2</sup>.

Lamp	CCT (°K)	S/P	Efficacy	Effective Efficacy	Δ%
HPS	2100	0.51	140 lm/W	124 lm/W	-12%
HCI	3000	1.30	105 lm/W	112 lm/W	+6%
Warm white LED	3000	1.20	101 lm/W	105 lm/W	+4%
White LED	5000	1.73	117 lm/W	134 lm/W	+14%
Cool White LED	6000	1.87	126 lm/W	148 lm/W	+16%

This table shows how applying the effective luminance factor affects the efficacy, or lm/W, of the lamp. Since the effective lumens increase without consuming more power, the efficacy will increase for S/P ratios greater than one.

## Consequences for Streetlighting Energy Saving



Applying an effective luminance factor would allow a reduction of electrical power of the system while maintaining desired light levels, resulting in an energy saving. When compared on this basis, LED streetlighting shows a clear advantage over traditional high pressure sodium streetlighting.

**Many Thanks.**

Thank you for viewing this presentation by OSRAM Opto Semiconductors.