Photopic and Scotopic lumens - 4: When the photopic lumen fails us

When should we use scotopic lumens? Never. There are *no practical situations involving lighting or lighting design* where the occupants or users of a space are sufficiently dark adapted and using only their peripheral vision so that the *scotopic* luminous efficiency function would be a useful predictor of the visual effect of radiant power. But clearly, never using the scotopic lumen *does not* mean we should always use the photopic lumen. The first important case where we really should not be using the photopic lumen is when we are adapted to twilight light levels and our visual system is functioning between scotopic and photopic modes – so called mesopic vision. Figure one shows a schematic representation of the huge range of adaptation in which we can function.

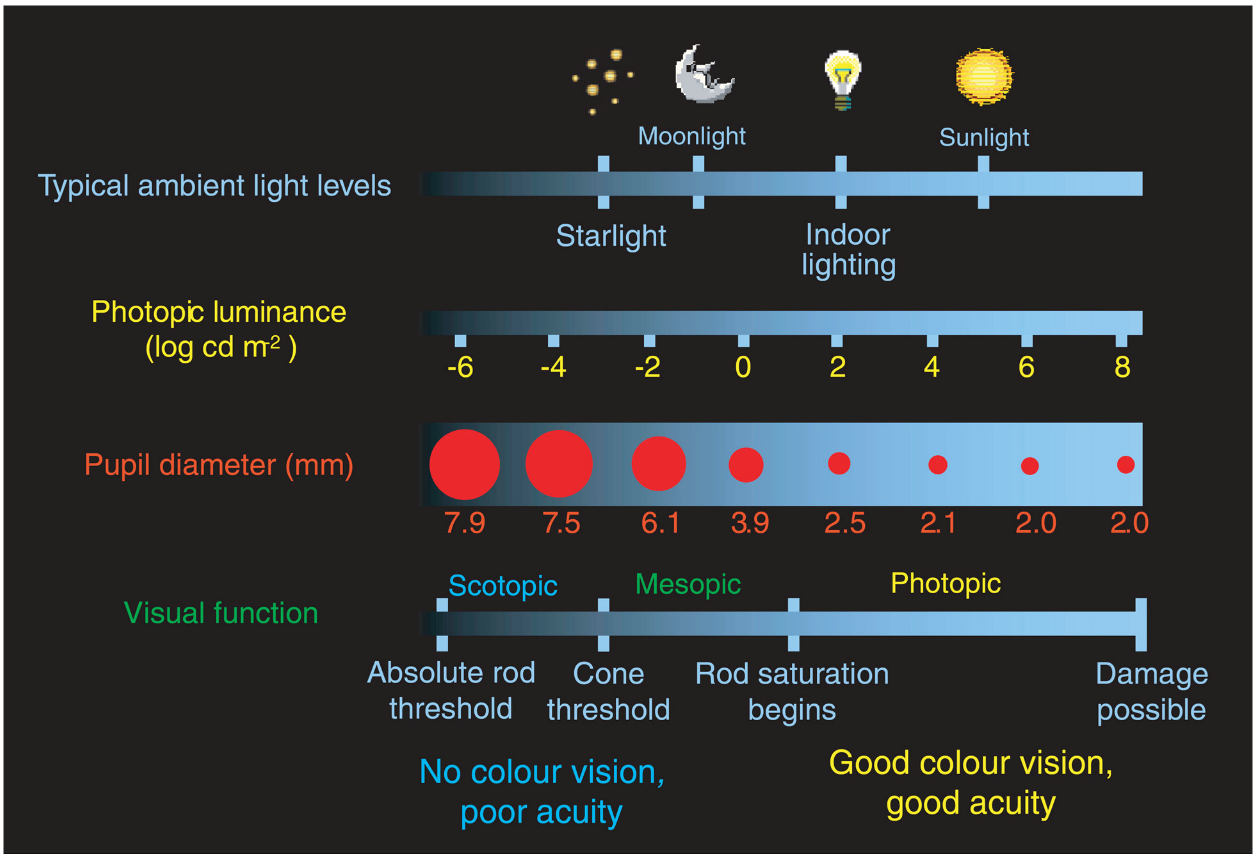

Figure 1. Schematic representation of visual adaptation.

There are no precise boundaries between the three modes of vision (scotopic, mesopic, and photopic) but approximate adaptation luminances can be identified where one mode transitions to the next. The adaptation range is expressed in terms of *photopic* luminance (cd/m^2), but if we make the assumption that we are viewing a diffuse object with a reflectance of 0.30 then the transition points along the range can be expressed in terms of *photopic* illuminance.

Rod threshold, beginning of scotopic range:	10^{-6} fc
Cone threshold, end of scotopic beginning of mesopic range:	10^{-3} fc
End of mesopic range:	1 fc

Looking at the transition points it is clear that some outdoor lighting applications (between 0.001 and 1.0 *photopic* fc) actually have occupants in an adaptation state where mesopic is the mode of vision. Now it's easy to get confused. Notice that it is possible to use the *photopic* luminous efficiency function (and thus photopic lumens, illuminance, and luminance) over the entire adaptation range, whether that efficiency function describes our state of vision, or not. We simply treat it as a mathematical indictor. Doing this simply makes it easier to discuss wide ranges of adaptation. So then why not simply use photopic for the whole shebang? If the only effect was a linear one of scale, then you could make a photopic function work over a wide range of adaptations. But there are two problems: one easy to overcome, the other difficult. Not only does visual effectiveness as a function of wavelength change with adaptation level (the shape and placement of the curve against the wavelength axis), but the very definition of "visual effectiveness" needs to change for low adaptation states. So it seems we need a mesopic lumen.

The idea of developing a mesopic lumen rests on the same basic ideas that underpin the scotopic and photopic lumen:

1. Define "visual effectiveness" for the mesopic mode of vision,
2. Measure the function that gives the visual effectiveness at different wavelengths
3. Make assumptions about linear additivity,
4. Weight the radiant power of a source at each wavelength with this function,
5. Sum the visually-effective-weighted radiant power at all wavelengths to give the mesopic lumens produced by that source.

The difficulty is defining "visual effectiveness". For determining photopic visual effectiveness it was decided (reasonably) to use only the very center of our field of view, the fovea, and to define visual effectiveness in terms of the relative brightness produced by radiant power at different wavelengths. Similarly for scotopic visual effectiveness, except the periphery of the visual field was used. Recall that there are lots of choices for defining visual effectiveness, among these are:

Relative brightness
Threshold detection
Recognition
Conspicuity
Reaction time
Visual performance

At the time, it was thought that relative brightness was the most fundamental and useful aspect of vision that could be described, and that once a lumen was defined, other experiments would determine how much light (in terms of lumens or lumen density) would be required for things like detection, recognition, conspicuity, and various forms of visual performance. The photopic lumen has been a kind of bridge between the radiant power of light sources and the degree to which we can perform the complicated visual tasks we accomplish *at high light levels with foveal vision*. That is how the photopic lumen has been used—roughly speaking—for the illuminance level recommendations we use indoors.

But we must do something else to define this unit of light when we are adapted in the mesopic range. Once we are adapted in either the scotopic or photopic range, the data that equal brightness experiments give is relatively unchanged as the light level is changed *within that range*. But a mesopic function *cannot* be unchanged; it must somehow transition between the scotopic and photopic functions. Recall that the scotopic and photopic luminous efficiency functions appear as shown in Figure 2 when plotted together.

The differences between these curves are clear: they indicate a maximum sensitivity at different wavelengths and the scotopic curve reaches a greater maximum (since we are more sensitive to radiant power when we are dark adapted). If we want a mesopic lumen, we must seek a curve that is "between" these two. But there is no single curve between these two; there are many, and the curve to be used would depend on where in the mesopic range the observer is adapted.

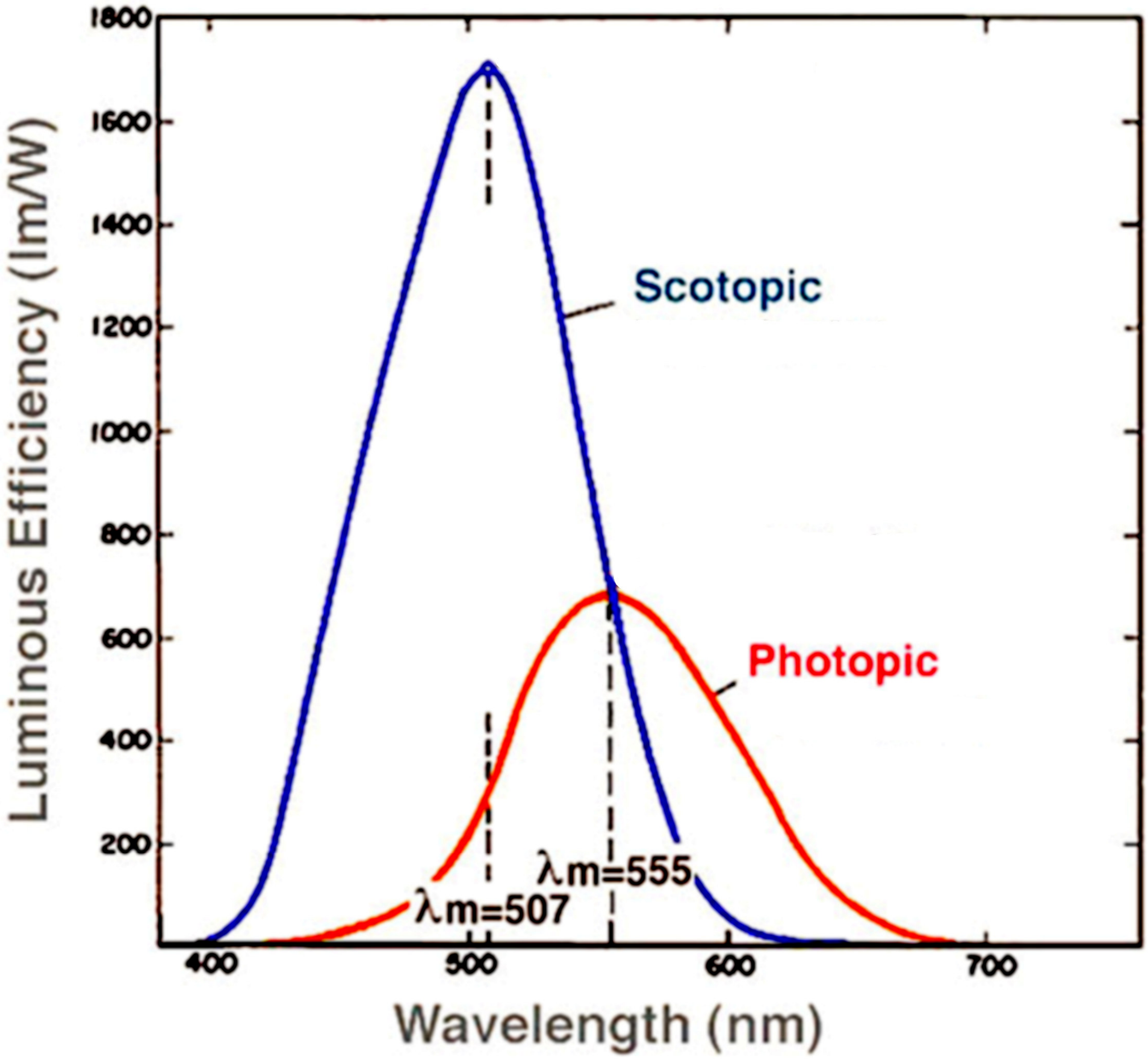

Figure 2. The photopic and scotopic luminous efficiency functions of wavelength.

There are two current ideas and sets of experimental results for defining the transition between photopic and scotopic. One generated by a consortium of research institutions in Europe – the MOVE model – and one generated by researchers at the Lighting Research Center – the LRC model. In both models the mesopic luminous efficiency function is a blend of the photopic and scotopic functions: $v_m(\lambda) = (1\text{-}x)\ v'(\lambda) + x\ v(\lambda)$ where ranges from 0.0 to 1.0 as the adaptation state changes from scotopic to photopic. It has become customary to express the adaptation state in terms of photopic luminance; using it, as mentioned above, as a kind of mathematical placeholder. This means that the blending parameter is a function of photopic adaptation luminance: $x(L_{photopic})$. Not surprisingly, the data that gives this blending parameter varies depending on how "visual effectiveness" is defined. Different data obtains from experiments that assume visual effectiveness is, say, reaction time or whether it is some type of visual performance.

Figure 3 shows a plot of the MOVE (solid lines) and LRC, indicated here by Rea, (dashed lines) blending parameter. The blue lines plot the parameter for a source with relatively high radiant power in the short wavelengths and the yellow lines plot the parameter for a source with low short wavelength power.

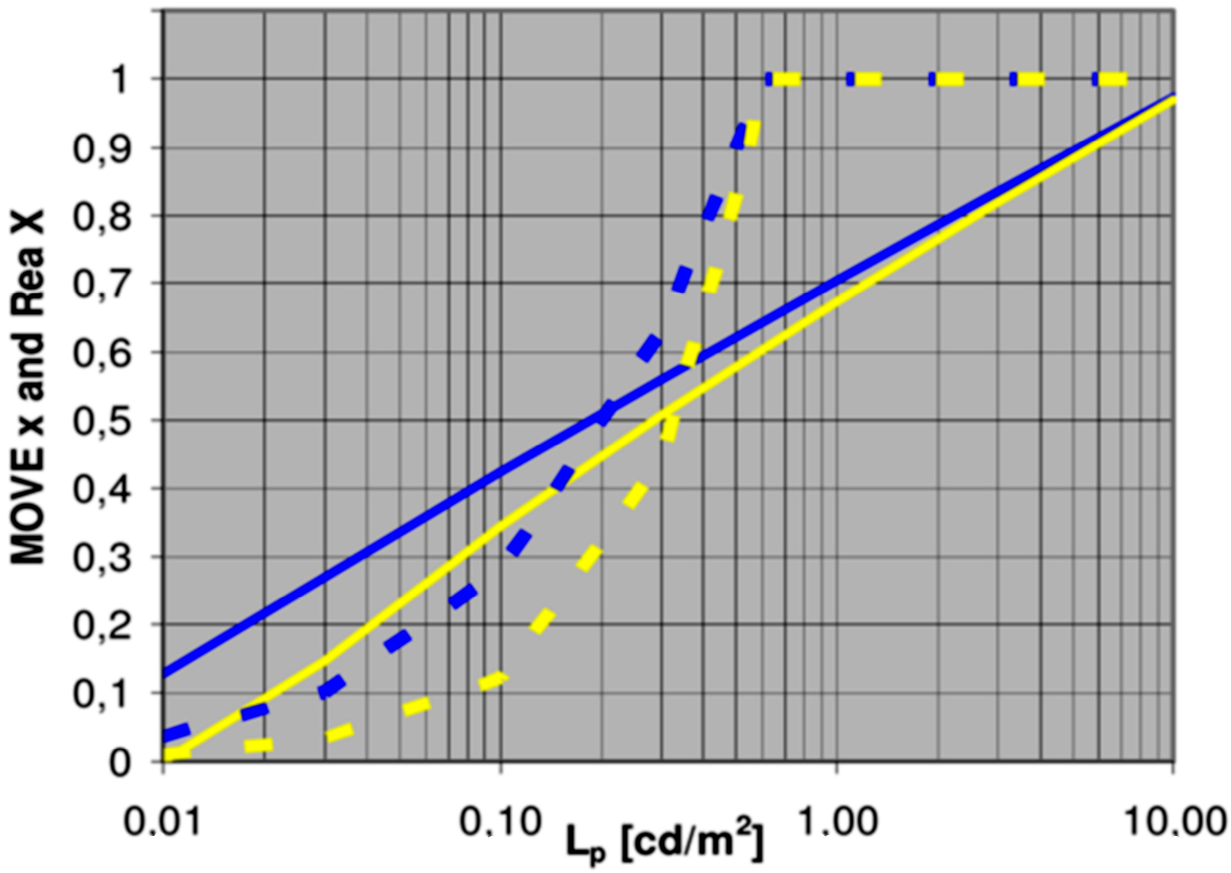

Figure 3. Two concepts and proposals for the mesopic blending parameter.

Clearly the spectral power distribution of a source affects the blending and therefore the final mesopic lumens that result. There has not yet been an international agreement on which body of experimental work to use to define mesopic vision, but the International Commission on Illumination (CIE) has an active committee working on this matter

But even if we agree on how to blend the photopic and scotopic functions to define a mesopic function, the practical business of using all this still becomes very complicated. It is clear that the very definition of light would change as our adaptation state within the mesopic region changes. There would not be *a* mesopic lumen, but rather there would be *many* mesopic lumens. There would not be *a* mesopic lumen rating for a lamp, but *many* mesopic lumen ratings. Most everyone would agree that this is not practical.

What is likely to result is that in practical applications there will be no mesopic lumen lamp ratings. The complicated process of determining the adaptation state, assessment of a lamp's spectral power distribution, subsequent blending of v(λ) and v'(λ), and the final mesopic result will be handled by computer calculations. Even with this aid, it will be unlike what we do now. If we change the amount of radiant power involved by changing lamp size, luminaire distribution, or pole spacing in a parking lot, the resulting change in say, mesopic illuminance, will not be linear function of the power we put on the pavement, but a complicated result of the changed adaptation state.

We should be careful about wishing for mesopic lumens; we may get them! Next we will consider the other important occasion when the photopic lumen fails us: general, wide-field brightness assessment.

Learn More. Here are some references related to mesopic vision and mesopic photometry.

The entire May 2006 (Vol 26, No 3) issue of Ophthalmic and Physiological Optics is devoted to the experimental and practical issues of mesopic vision and photometric systems. Of particular interest are the following articles.

Andrew Stockman and Lindsay T. Sharpe:
Into the twilight zone: the complexities of mesopic vision and luminous efficiency
Ophthalmic and Physiological Optics, May 2006, Vol 26, No 3, pp 225-239.

Ken Sagawa:
Toward a CIE supplementary system of photometry: brightness at any level including mesopic vision
Ophthalmic and Physiological Optics, May 2006, Vol 26, No 3, pp 240-245.

Géza Várady and Peter Bodrogi:
Mesopic spectral sensitivity functions based on visibility and recognition contrast thresholds
Ophthalmic and Physiological Optics, May 2006, Vol 26, No 3, pp 246—253.

A complete description of the MOVE mesopic photometry proposal is found in:
M Elohoma and L Halonen:
New Model of Mesopic Photometry and its Application to Road Lighting
Leukos, April 2006, Vol 2, No 4, pp

On-line. There are many things on-line related to mesopic photometry. These are among the most complete and accessible.

http://lrt.sagepub.com/cgi/reprint/36/2/85

http://www.lightinglab.fi/CIETC1-58/mphotometry.html

http://www.balkanlight.eu/abstracts_pdf/i11.pdf

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V23-4FSCV5M-1&_user=918210&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000047944&_version=1&_urlVersion=0&_userid=918210&md5=4f44e117c62107901306b7fd9b6813f7

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T0W-4M1D9XC-2&_user=918210&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000047944&_version=1&_urlVersion=0&_userid=918210&md5=96fe428050b2c73d36a5257a6a29eb82