2002 State Energy Program/Rebuild

Positive Effects of White Light On **Your** *Bottom Line*

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Introduction

- Lighting practitioners have suspected for years that current lighting metrics do not accurately reflect human perceptions of full field of view visual acuity.

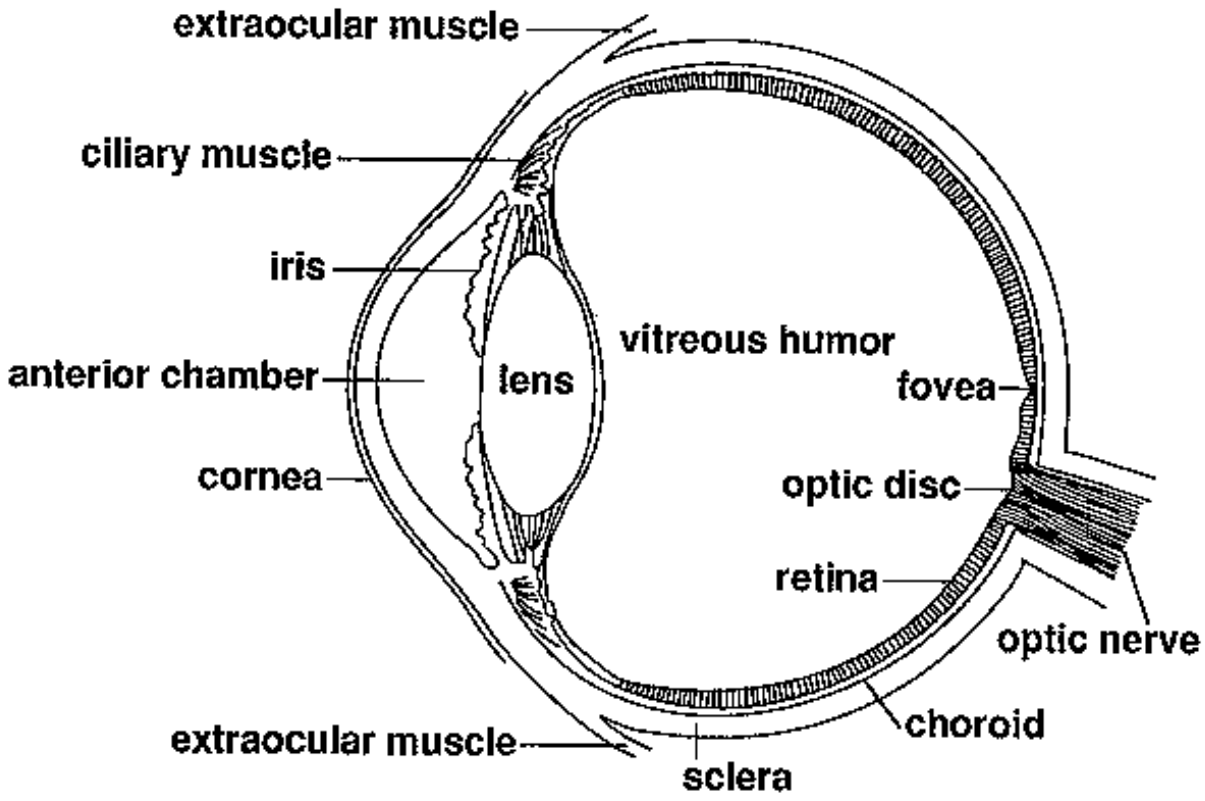
- Recent research efforts have identified physiological causes which explain nuances evident in different lighting installations. This research challenges current IESNA / CIE photometric procedures and provides alternate methods to improve reliability in design.

- Both the IESNA and the CIE acknowledge current photometric shortcomings and have been in Committee on alternatives for over 10 years.

- Developing a better understanding of the human visual response system and applying this information to outdoor and commercial/industrial indoor designs will improve visual acuity and provide substantial energy saving opportunities.

Human Visual Response System

- Horizontal Cross-Section of the Human Eye

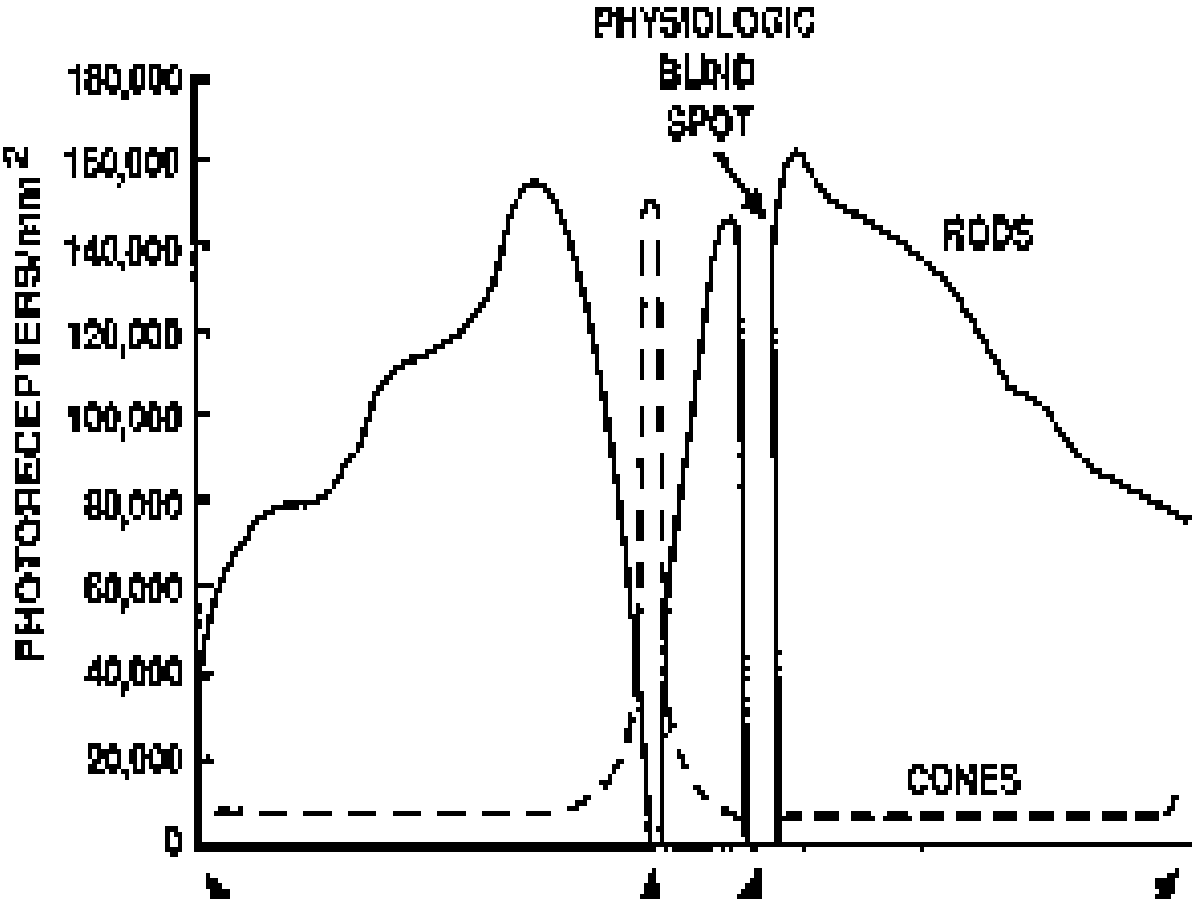


Human Visual Response System

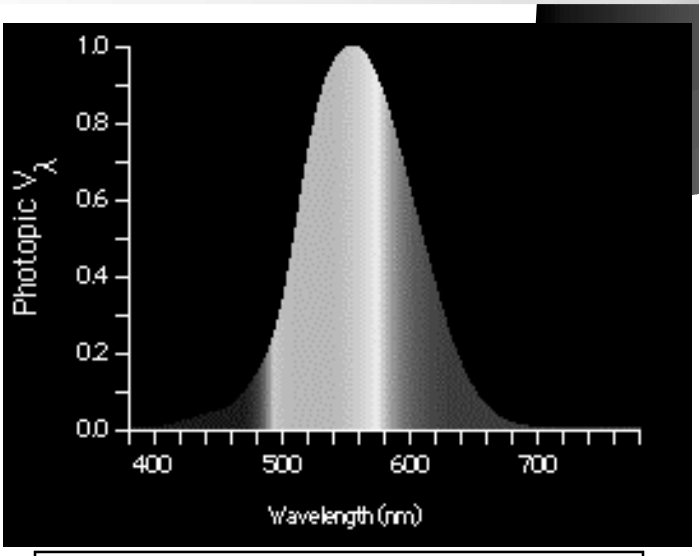
- **Optical Components**- Maintains the temporal and spatial relationships of objects in visual space. 70-85% efficient depending on age
  - Cornea, Crystalline Lens, Pupil, Intraocular Humor
- **Neurological Components**- Converts light energy into electrical impulses for processing by the brain.
  - Sclera, Choroid, Retina
  - Radiation that reaches retina is absorbed by photopigments of Rods and Cones.
  - Rods contain only one pigment, Rhodopsin and have a peak spectral sensitivity at 507nm. Neural characteristics of rods make them extremely sensitive to light. Spectral sensation known as ***Scotopic Sensitivity***.
  - Cones contain 3 photopigments and are responsible for color vision. Located in the fovea and are less sensitive to light with a peak spectral sensitivity at 555nm. Spectral sensation known as ***Photopic Sensitivity***.

Human Visual Response System

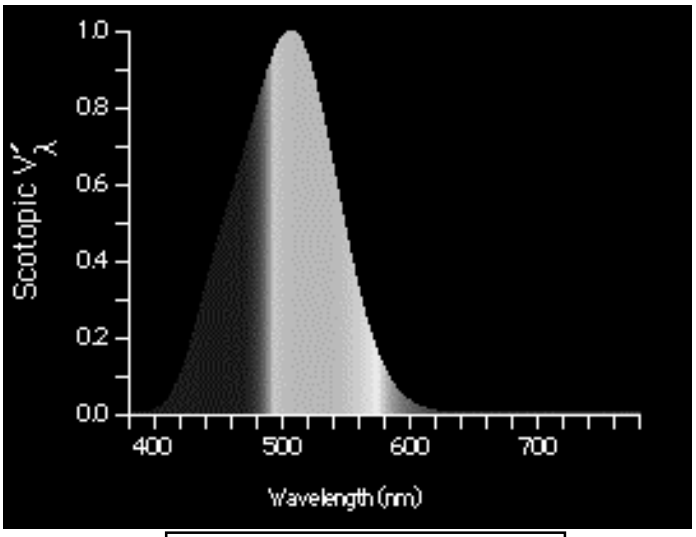
- Distribution of Rods and Cones in the Retina



Eye Sensitivity Curves



Photopic Curve



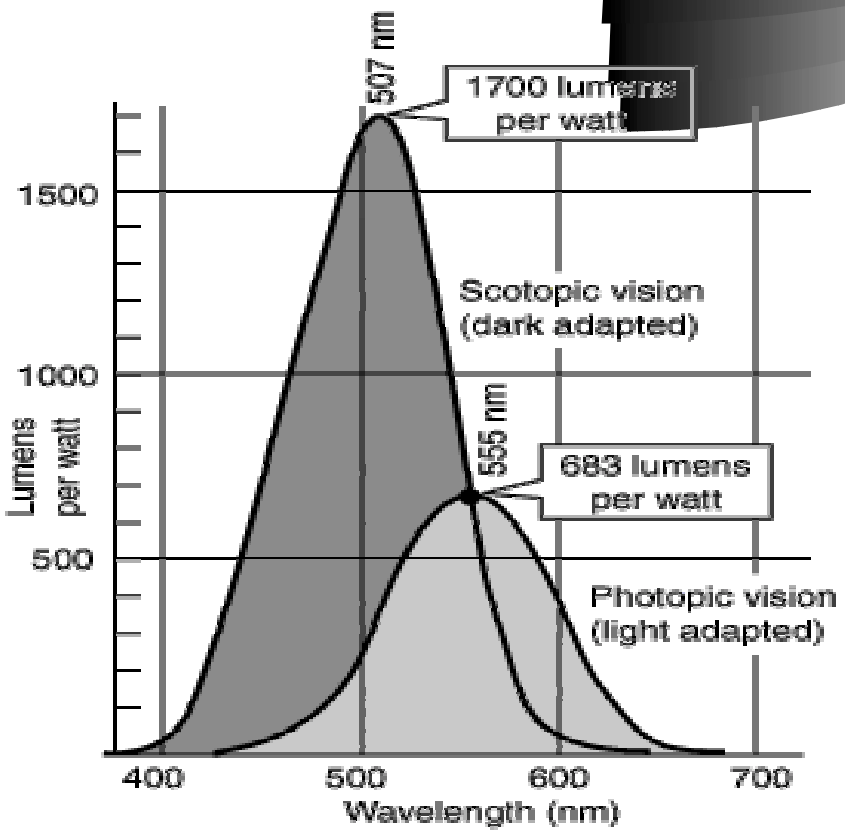
Scotopic Curve

Opinions/Research

- Background: The lighting regime of concern here ranges from starlight levels to that typical of interior spaces. Vision scientists refer to this regime as “Mesopia” because both cone and rod photoreceptors of the eye are presumed active. Although the lower luminance limit of this regime is generally agreed upon, there is no established upper limit. The following quotations from the classic text of Stiles and Wyszecki (Color Science) illustrate present knowledge defining this regime.
- *“Whereas the mesopic vision begins at luminances of approximately 10^{-3} cd/m^2, the luminance level at which it ends depends to a large extent on the spectral composition of the stimuli viewed, their sizes, and location on the retina”*
- *“The level of 3 cd/m^2 for the upper luminance level (of mesopic vision) often quoted …is at best a crude measure and applies only to certain experimental conditions”*
- *“…in some cases, luminance levels of 30,000 cd/m^2 are required to saturate the rod mechanism”**

- The Upper Limit of Mesopia depends on various conditions.

Combined Curves



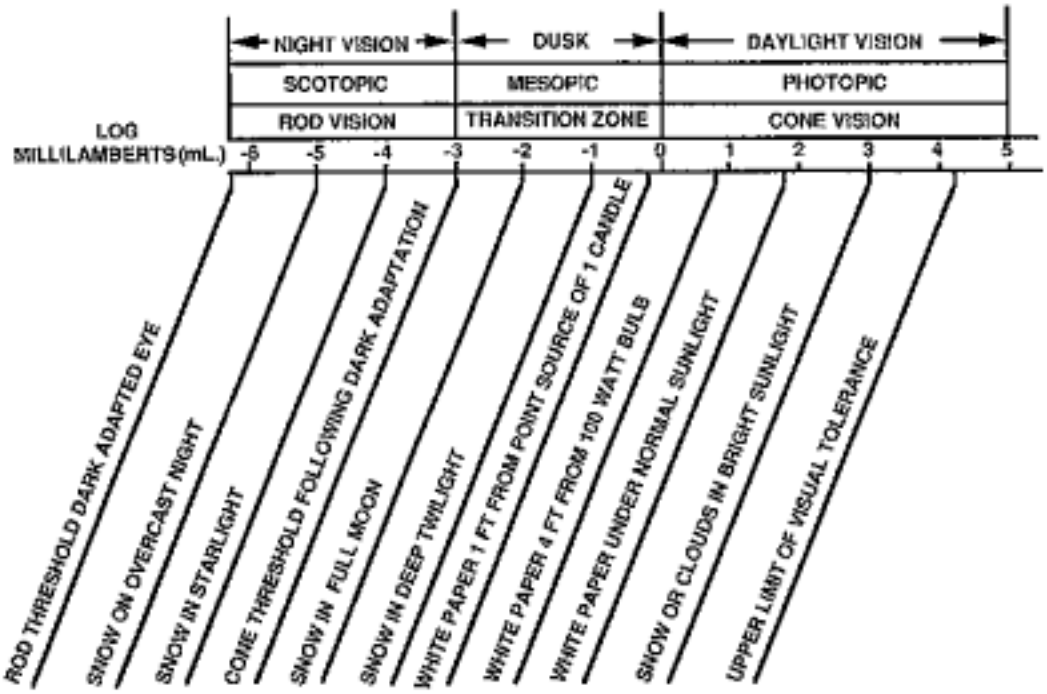
*Graphics courtesy GSU Department of Astro Physics

The Scotopic Efficacy curve was established in the same manner as the photopic curve. It's sensitivity is shifted however to peak at 507 nm, and decreases in proportionally the same manner as the photopic curve. This results in the scotopic curve reaching a relative value of zero sooner in the visible spectrum than the daylight curve. As a consequence of this fact, our nighttime vision does not see red!

The scotopic efficacy curve is assigned a value of unity at 507 nm, and is represented by the symbol Vl. To determine spectral Luminous Efficacy, the scotopic efficacy value, Vl , must be multiplied by 1700 lumens per Watt. This value was adjusted from 1754 to allow both curves to obtain the same value of 683 lumens/W at 555 nm. So, a source we see with our dark adapted vision at 507 nm produces 1700 lumens for every Watt radiated, and any other wavelength produces a fraction of that value based on the efficacy curve.

Night Vision Characteristics

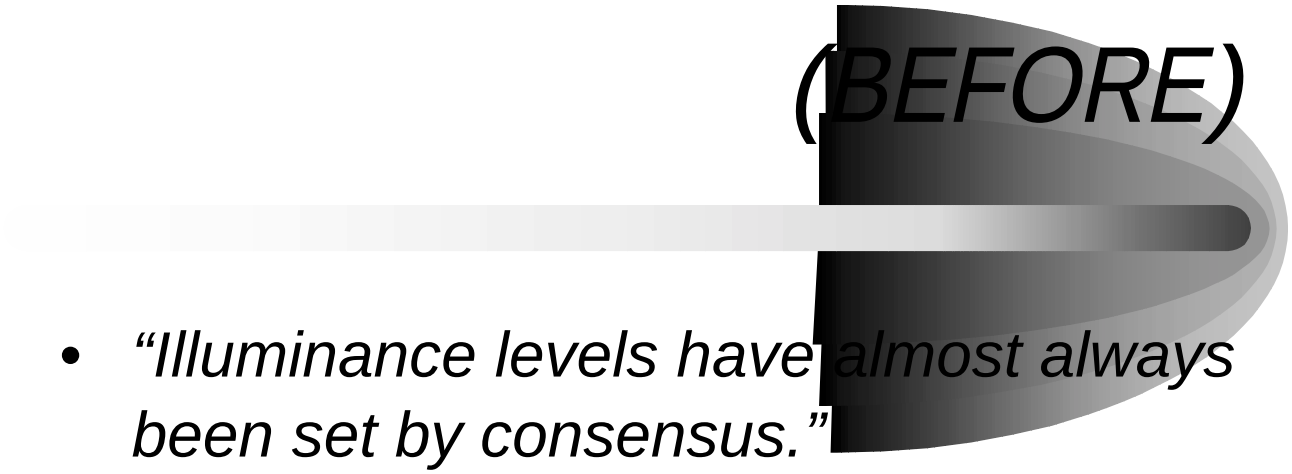
- Past vision theories suggested that rods were used only at night and that cones were used during the daytime.
- Rods and cones function simultaneously at most levels. ***Mesopic vision describes the transition sensation between Photopic and Scotopic.***
- Mesopic vision takes into account almost all



Night Vision Characteristics

- Visual Acuity-
  - Objective Factors-
    - Size- Size of object affects size of image on Retina.
    - Luminance- The amount of light striking an object and being reflected back to the eye.
    - Contrast- Measure of the luminance between two adjacent areas.
    - Time- Time lag in electrochemical processing causes exposure differentials of image.
  - Subjective Factors-
    - **Disability Glare-** Stray light produced by imperfections of the eye which reduces the contrast of the primary image.
    - **Discomfort Glare-** High or non-uniform brightness within the visual field which causes pain, discomfort or inadvertent changes to dark adaptation.
    - **Dark(Bleaching) Adaptation[1]-** A process during which the eye adapts from high luminance to low luminance settings. Full dark adaptation can take hours or days. Momentary high luminances can cause reduced or lost adaptation. Under these conditions the rods behave as though they are

Exterior Lighting Design & Illuminance Selection (BEFORE)



- *"Illuminance levels have almost always been set by consensus."*
- *"…the conceptual "model" of visual performance used has often been imprecise and undeclared."*
- Illuminance recommendations and selection procedures do not incorporate or allow for spectral or quality features of luminaire design or layout.
- Computer modeling relies on IESNA photometric testing. All testing is accomplished with photodetectors calibrated for the photopic sensitivity curve only.

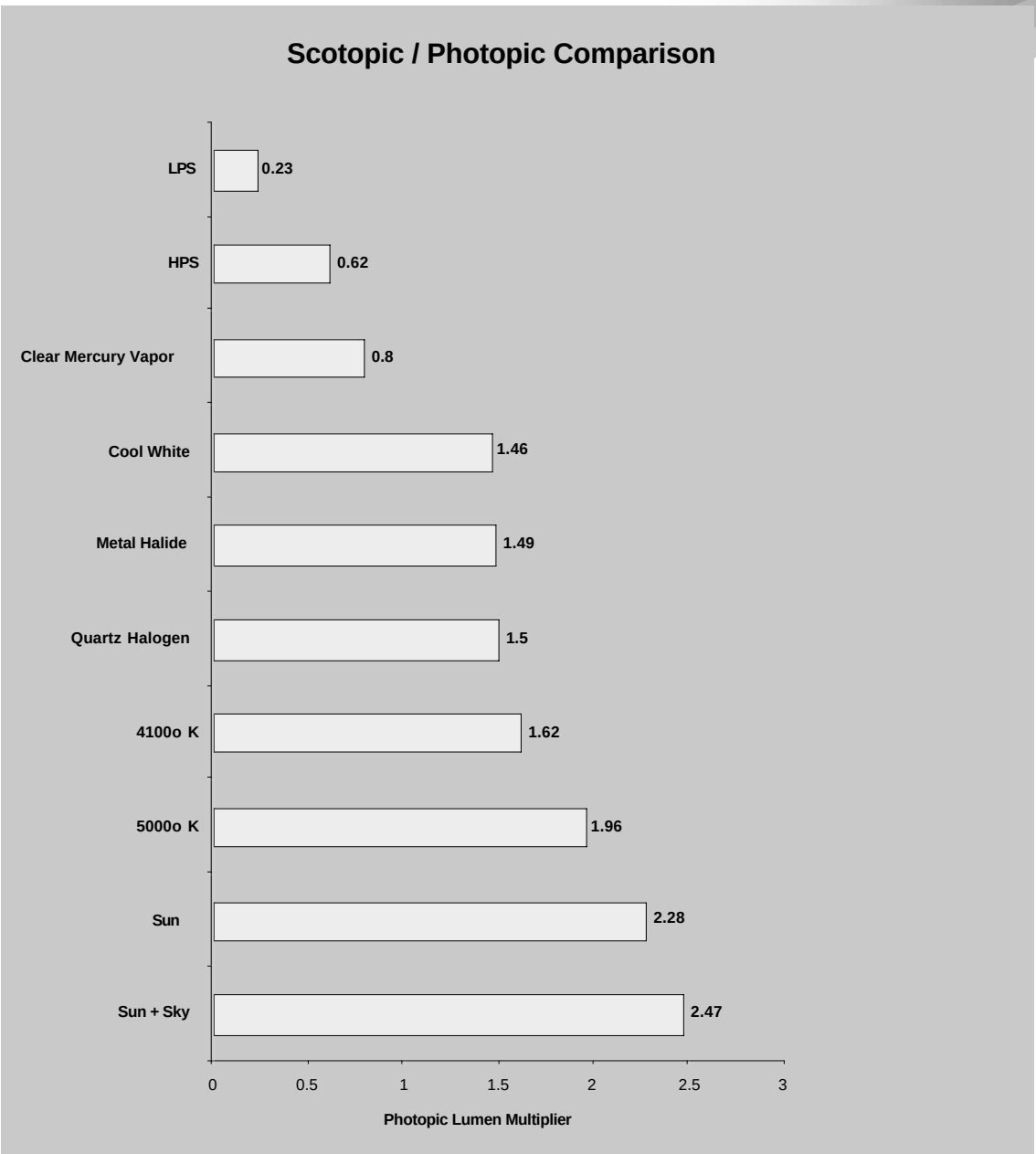
Italics indicate excerpts from IES Lighting Handbook

Lamp Spectrum & Brightness Perception

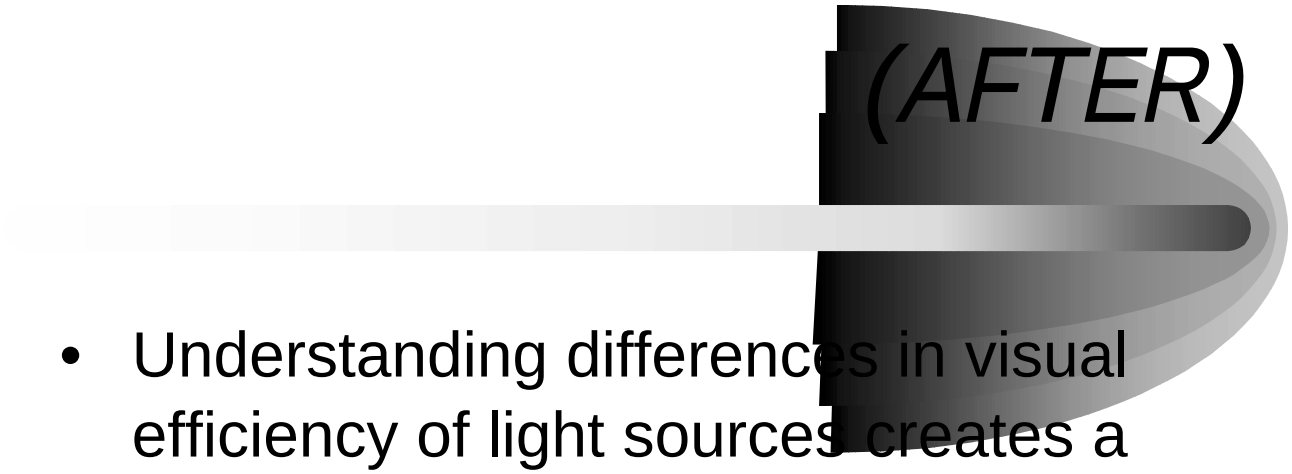
- *"Brightness is the perceptual counterpart of the photometric quantity luminance."*
- *"Under some viewing conditions, the brightness perception of photopically equated fields with different spectral power distributions can paradoxically be opposite to their relative photopic luminance."*
- *"Apparently, Scotopic luminance is the predominant factor in brightness judgements…"*
- Research efforts[3] have concluded that under normal field of view conditions, rod vision is dominant in determining visual acuity and brightness perception..
- This benefit is a direct result of smaller pupil size created by the eyes increased sensitivity to light sources with a spectral output closely matching the Scotopic Sensitivity Curve[4]. The exact limits of these benefits are not fully understood at this time.
- Testing of various lamp types have concluded Scotopic/ Photopic Ratios which can be used as correction guidelines in the design process.

***Italics indicate excerpts from IES Lighting Handbook**

Lamp Comparison and S/P Ratio Chart



Exterior Lighting Design & Illuminance Selection (AFTER)



- Understanding differences in visual efficiency of light sources creates a higher level of confidence in outdoor illumination.
- Use of S/P Ratios allows modeling based on modern test methods which more accurately depict real world performance of the human visual response system.
- Optimum lighting designs will ensure levels of dark adaptation are maintained.
- Using visually efficient practices will enhance energy savings and reduce emissions of radiant energy into the atmosphere.

Visually Efficient Economics

- The relevance of Scotopic performance in any Lighting System is significant and may offer substantial opportunities for energy savings.
- By way of application of the S/P Ratio one may expect significant economic advantages while maintaining or improving the visual effectiveness of Outdoor, and many Interior Environments.
- Lighting systems which utilize those sources which are S/P efficient may expect upwards of 50% reduction in energy consumption from traditional design strategies.
- Adding the use lighting controls can increase savings to 96%!

Lighting Efficiency Strategies

- Any lighting design should be approached with sound design effort and thorough consideration of all elements pertaining to an effectively lit environment.
- A comprehensive design initiative will sometimes identify applications which would preclude the use of luminaires which maximize the benefits of scotopically rich light sources.
- It may be necessary to balance the utilization of available luminaires to provide photopic performance in areas which will receive scrutiny from building officials and the like, while promoting the use of efficient designs where appropriate.

Examples

• 2 Lamp F32T8 in 4’ reflectorized units
15’ Mounting Height - 30’ Spacing

• Building is 200’ at furthermost point
and 4 Stories High, with luminaires angled at 45º angle of declination

• Very low sky glow; note cut-off at base of fence.

• 2-Lamp PL40 in 4’ reflectorized housing, at 4th floor roof line for easy maintenance.

• 325’ long building illuminsated with 4-84 watt units, which replaced 18-90 watt LPS units.

• Need for Security Guard ceased to exist after change out.

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- 2- Leibrock, C.S.; Reuter, T.; & Lamb, D., Molecular basis of dark adaptation in rod photoreceptors, Department of Physiology, University of Cambridge, Eye (1998) 12, 511-520, 1998.

- 3- Berman, S.M., Energy Efficiency Consequences of scotopic sensitivity. J.IES Vol. 21, No. 1, Winter 1992.

- 4- Berman, S.M., Spectral Determinants of steady-state pupil size with full field of view., J.IES Vol. 21, No. 2, Summer 1992.