SPECTRALLY ENHANCED LIGHTING

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Spectrally Enhanced Lighting

Known Effects of Spectrum on Vision

There are 2 regions of lighting in which spectrum has been demonstrated to affect vision:

- Interior Lighting: Spectrum affects visual acuity
  - IES TM-24-13, upcoming publication
- Mesopic Levels: IES TM-12-12

Spectrally Enhanced Lighting

US DEPARTMENT OF ENERGY TERM:

- ***A lighting design method for interior lighting applications by which lighting with relatively higher amounts of short wavelength energy (i.e. blue) can provide equal vision under reduced illumination, thereby saving energy.***
- **Formally called "Scotopically" Enhanced Lighting; that term should not be used.**
- ***http://www1.eere.energy.gov/buildings/spectrally_enhanced.html***

Basics: Light and Vision

The color of light has inherent qualities that have not been completely understood. Recent discoveries in vision science tells us that there's more to light than what we measure.

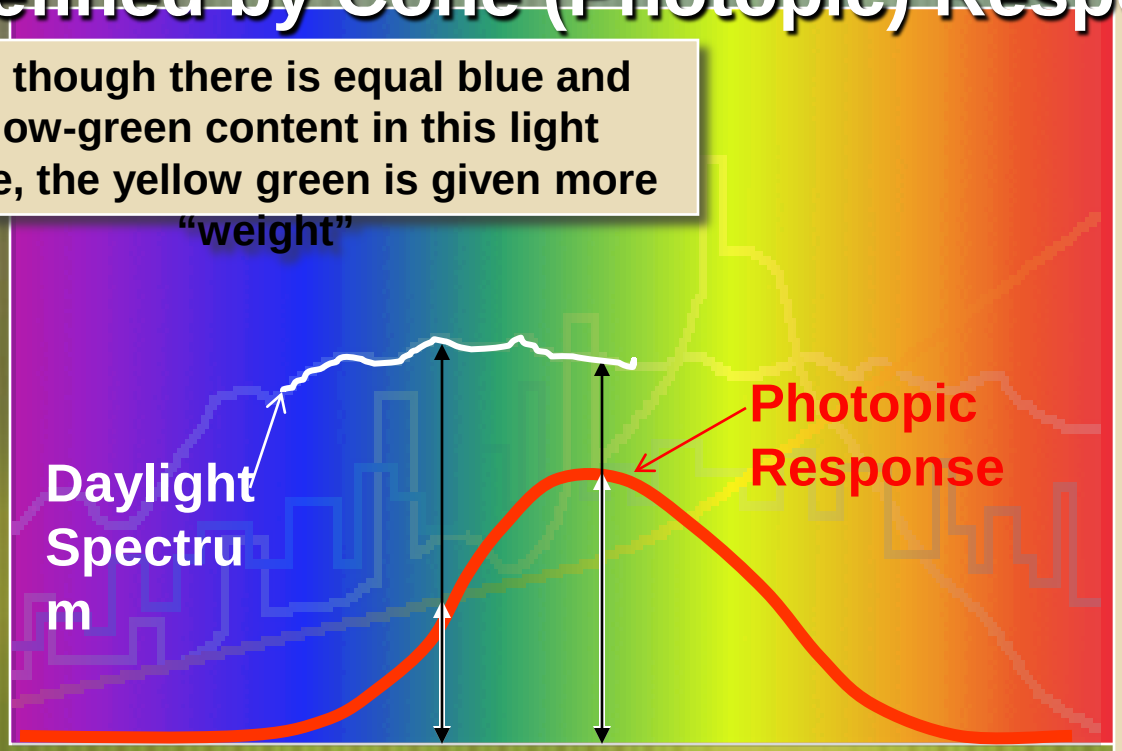
Using light sources with spectra more like daylight, but at the same light level:

- **Makes the Eye's pupil smaller**
- **Improves Visual Acuity**
- **Affects Circadian Rhythm**

Basics: Light and Vision

- **Light is the only SI unit based on Psychophysics:**
- **Defined by Cone (Photopic) Response (1924)**

Even though there is equal blue and yellow-green content in this light source, the yellow green is given more "weight"



Lighting products rely solely on the photopic response.

Each wavelength intensity value from the light source is multiplied by the photopic response value at the same wavelength - then they are all added up to determine the lamp lumens.

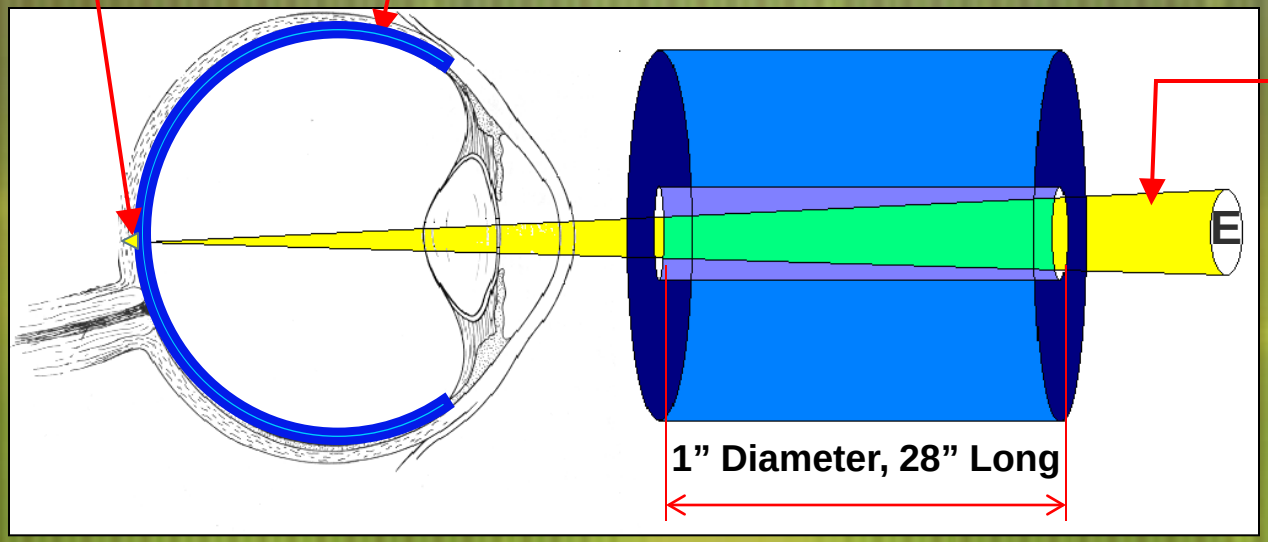
Basics: Light and Vision

LIGHTING METRICS ARE BASED ON CONES ONLY:

Determined under a very constrained field of view.

Fovea: Only Cones

This ignores the influence of peripheral photoreceptors that take in lighting from the rest of the real Field of View



2º Field of View

This is less than 1/10 of 1% of the natural Field of View!

Basics: Light and Vision

IN MOST INTERIOR LIGHTING APPLICATIONS, OUR EYES ARE EXPOSED TO A LARGE FIELD OF VIEW

Under a full field of view, the eyes have a different spectral response than what the photopic response predicts.

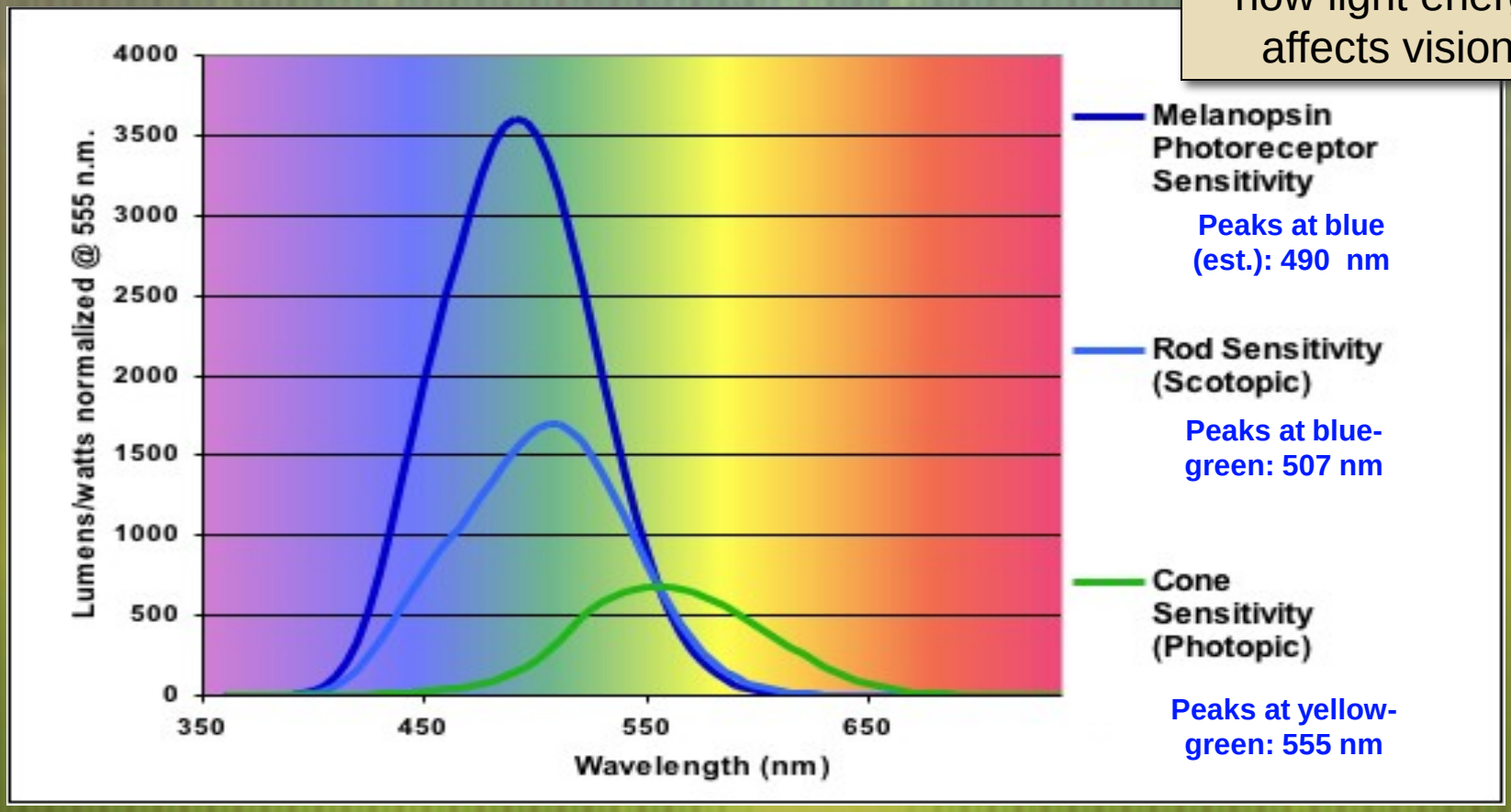
180° Horizontal

120° Vertical

Basics: Light and Vision

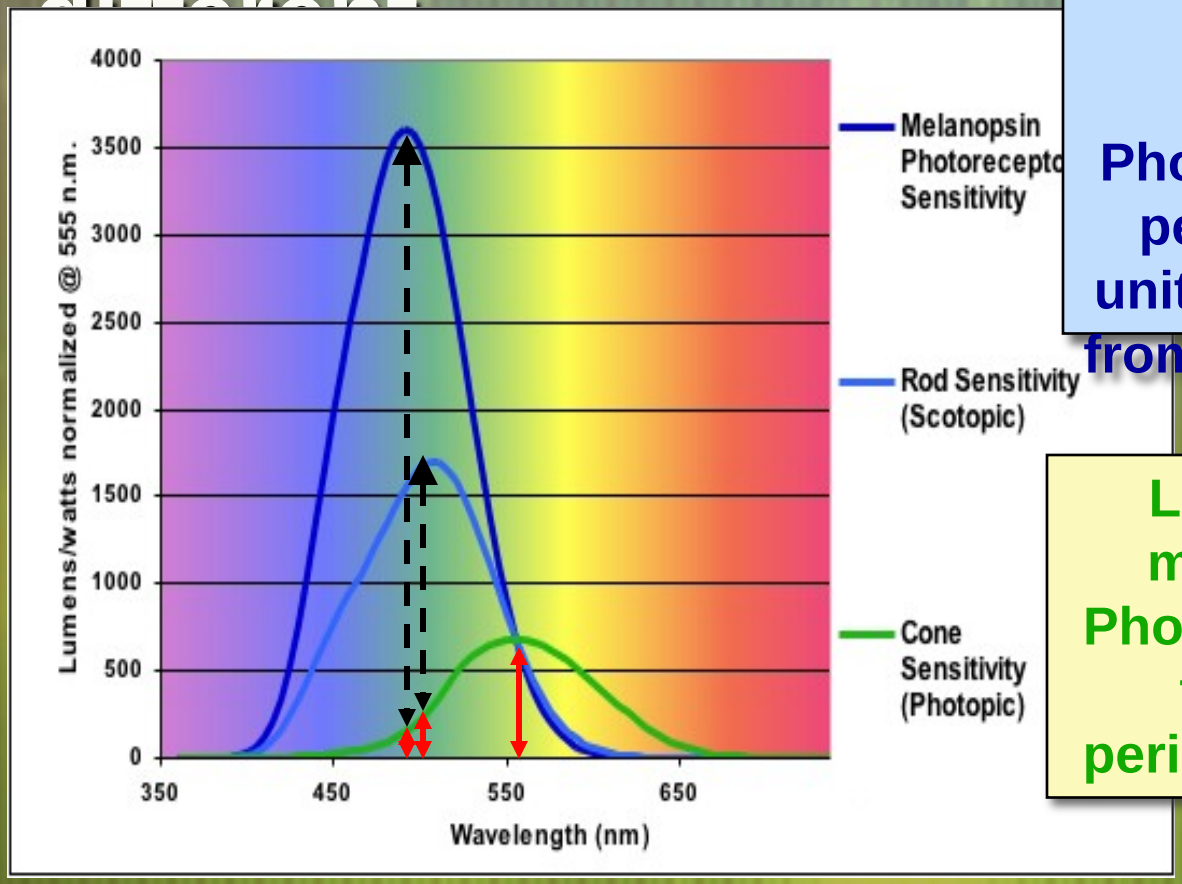
3 Photoreceptor Responses

There are 3 visual responses that can be used to evaluate how light energy affects vision.



Basics: Light and Vision

Peripheral photoreceptors are different

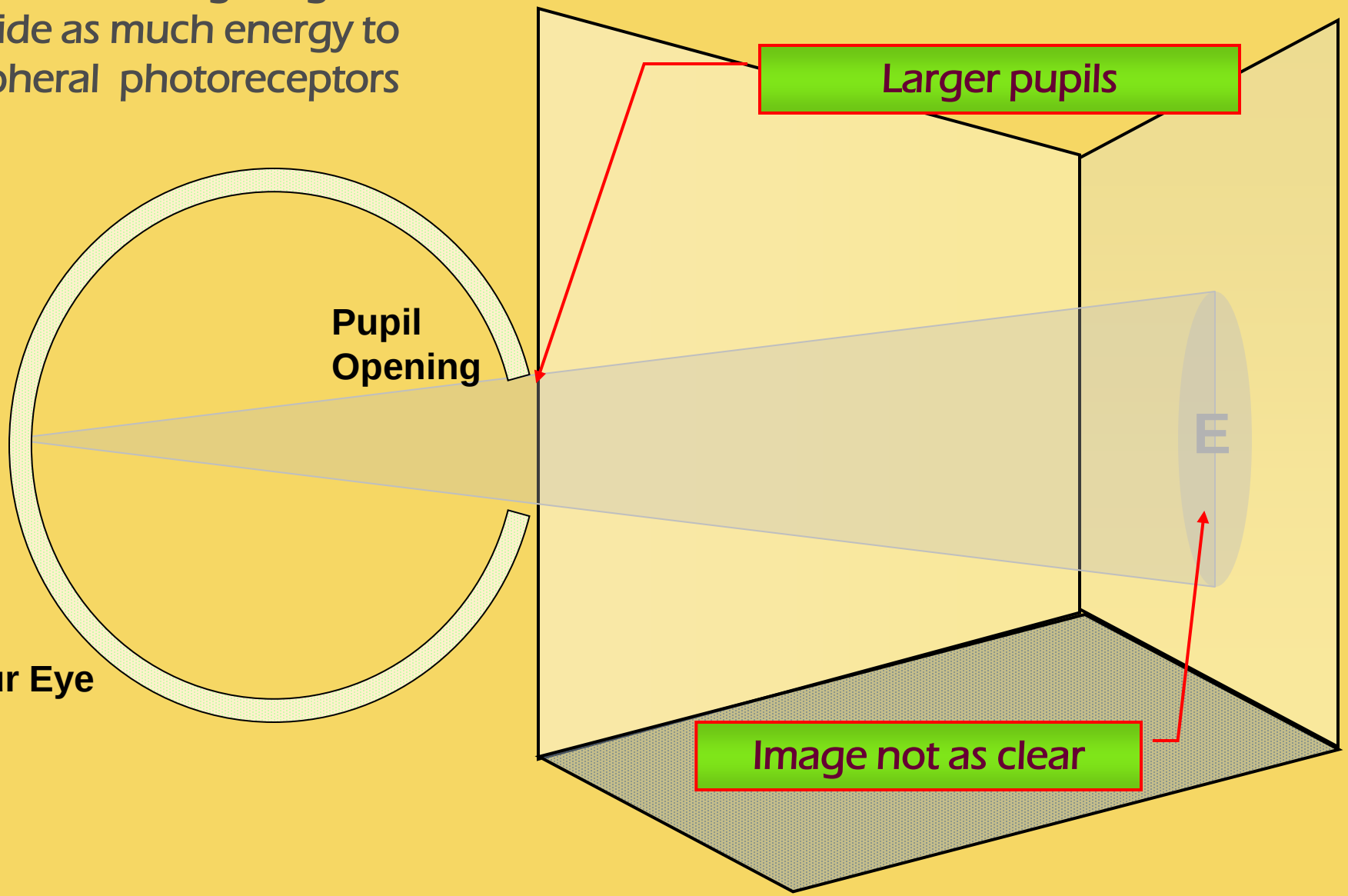


Rod and ipRGC (Melanopsin) Photoreceptor responses peak in blue: Photopic units ignore visual effects from these photoreceptors

Limiting our Lighting measurements to the Photopic Function misses the contribution of peripheral photoreceptors

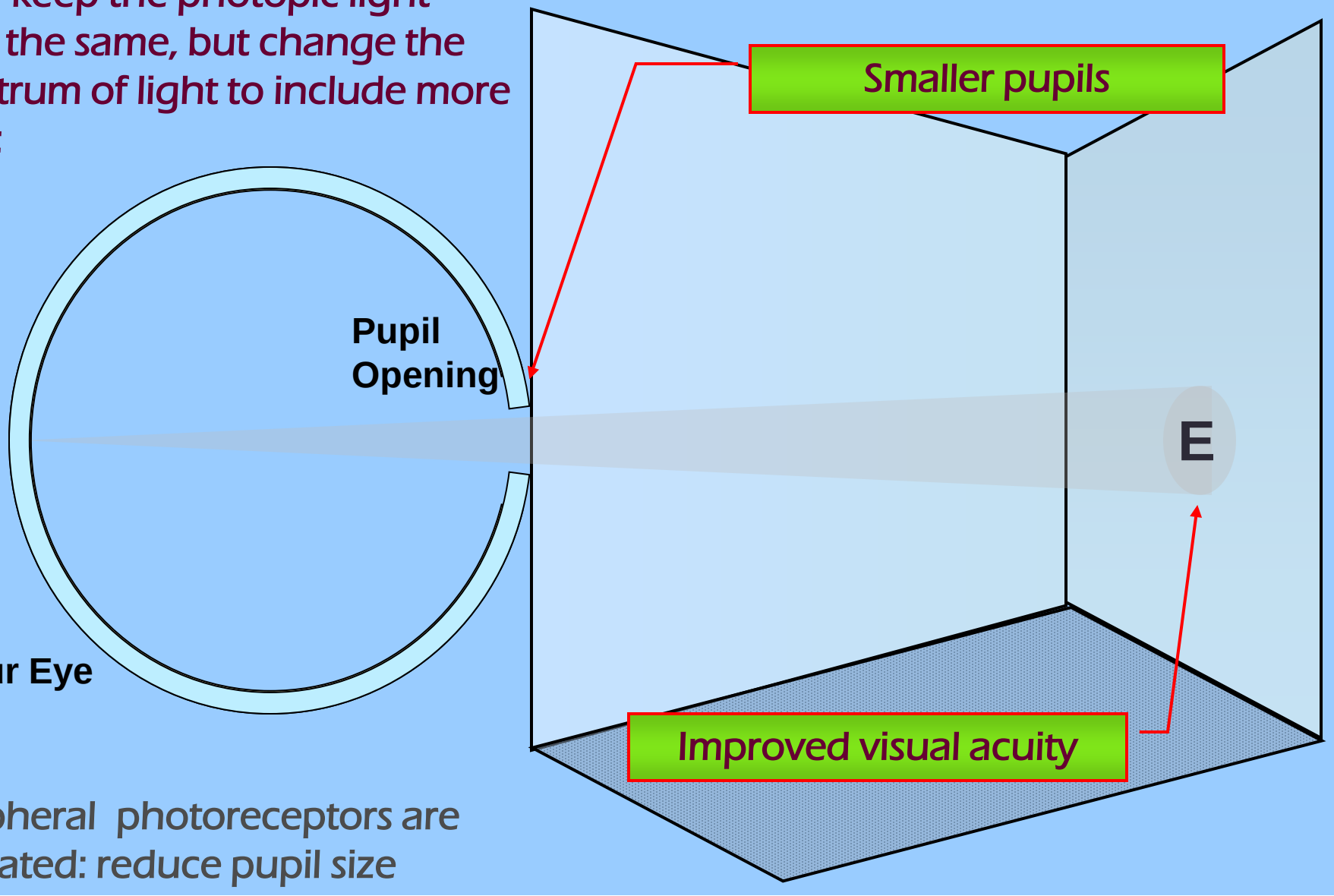
Basics: Light and Vision

Warm Colored lighting does not provide as much energy to peripheral photoreceptors



Basics: Light and Vision

If we keep the photopic light level the same, but change the spectrum of light to include more blue:



Peripheral photoreceptors are activated: reduce pupil size

Light Source

Shift Spectrum to Include More Blue

Peripheral Photoreceptors

Smaller Pupils

Increased Visual Acuity

Reduce Light Level → **Save Energy**

Equal Visual Acuity

LIMITATIONS

THIS METHOD IS LIMITED TO:

1. IES CATEGORIES P – Y, for tasks in which Visual Acuity is important;
2. TASK BACKGROUND LUMINANCE $\geq$ 50 cd/m^2
3. GENERAL POPULATION, i.e. not a space where people have poor ocular health;
4. Tasks performed in FULL FIELD OF VIEW

Pupil Size Variation Calculation

PUPIL SIZE CHANGE CAN BE CALCULATED USING BOTH LIGHT LEVEL AND SPECTRUM

P = Photopic Measurement

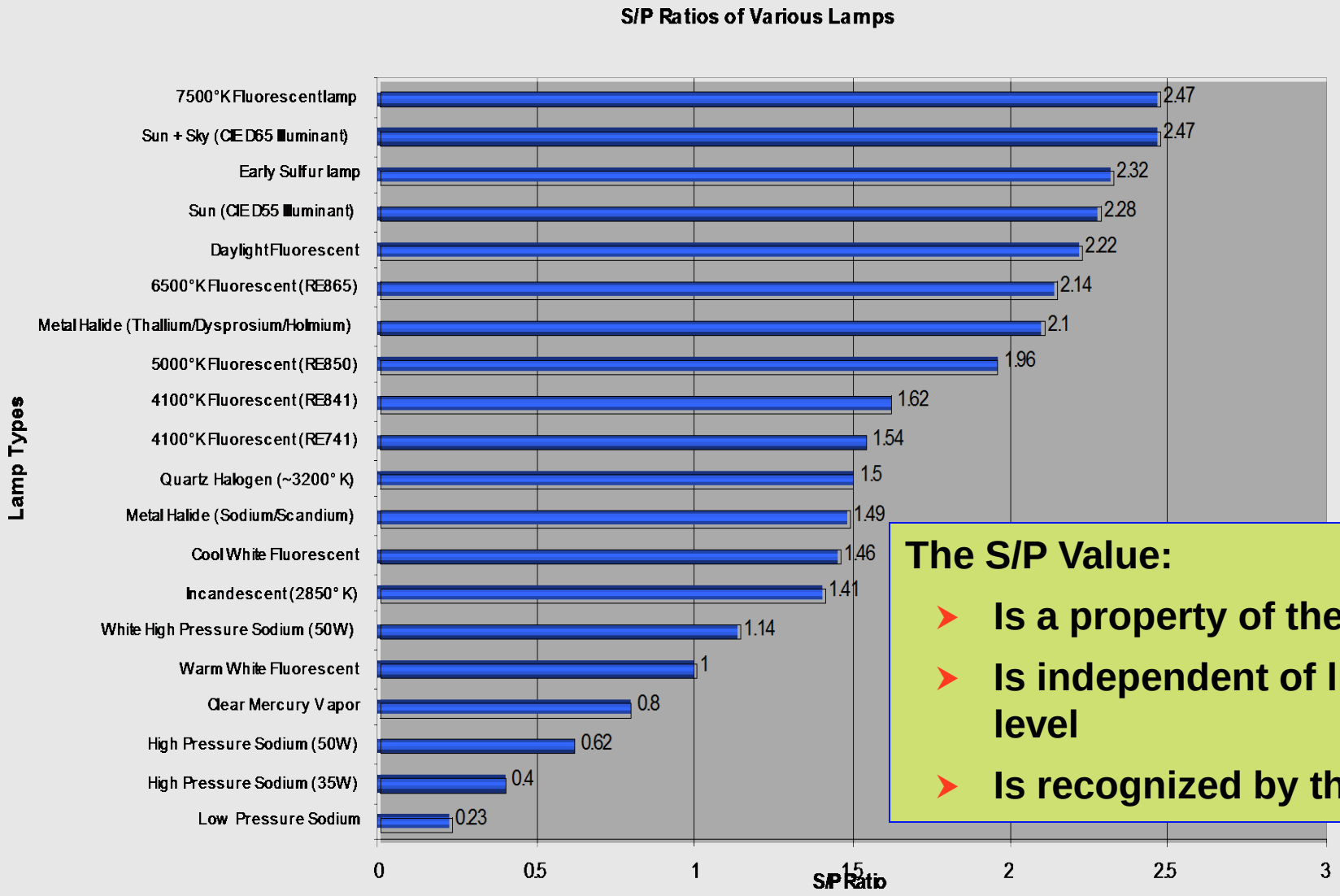
$$P(S/P)^{0.80}$$

S/P Ratio
(Scotopic/Photopic)

The S/P Ratio is a constant value for a light source whose spectral distribution does not vary with intensity

(There is no ratified ipRGC spectral response function)

Examples of S/P Ratios



The S/P Value:

- **Is a property of the lamp**
- **Is independent of light level**
- **Is recognized by the IES**

Equivalent Visual Efficiency (EVE) Equation

THE EVE CALCULATION ASSURES EQUIVALENT VISUAL ACUITY

(Light Level) x (Spectrum)

(Light Level) x (Spectrum)

$$P_1(S/P_1)^{0.8} = P_2(S/P_2)^{0.8}$$

$$P_2 = P_1\{(S/P_1)/(S/P_2)\}^{0.8}$$

(Light Level)

(Light Level x (Ratio of Spectrums)

APPLIES TO IES CATEGORIES P-Y ONLY!

(Subscripts 1 & 2 represent 2 different light sources with different S/P values)

Equivalent Visual Efficiency (EVE) Equation

Example:

Base Case is 400 lux, S/P=1.4

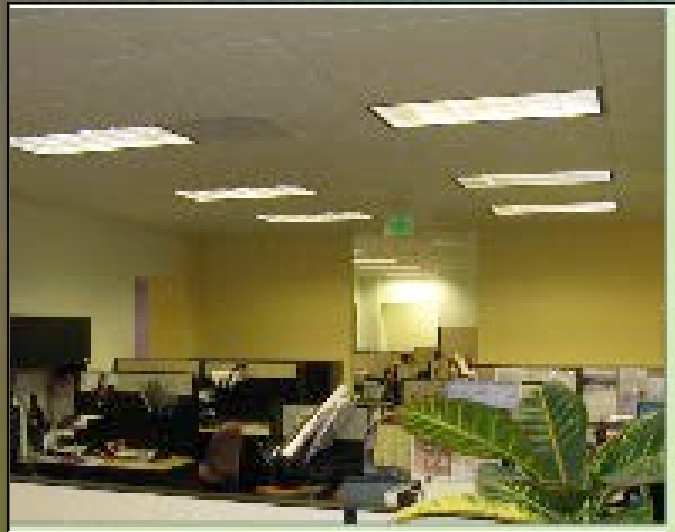
Proposed new illuminant S/P=2.0

$$P_2 = 400\{1.4/2.0\}^{0.8}$$

$$P_2 = 300 \text{ lux}$$

25% illuminance reduction, same visual acuity

Applications – Building Retrofits



Before

After

Comparison

Occupant Reaction to High CCT Lighting

Studies Demonstrate Acceptance up to 6500K

- 2004 DOE/PG&E/UCOP Study: Occupant acceptance of 850, under lower light level than 835.
- 2006 DOE Field Study: 3 Buildings completely retrofit with 850 lamps and standard ballasts
- 2006: LRC STUDY: 3500K @ 500 lx compared to 6500K @ 340 lx - No Difference in Occupant Ranking of 10 subjective feelings

Designer Reaction to High CCT Lighting

- Designers have been trained to believe that people prefer warm CCTs: “Kruithof Effect” (1941)
- More recent research suggests otherwise; provided that occupants are fully adapted to the lighting, the CCT of the lamps has little effect on people’s impressions of the lighting in the room.
- Designers that have used Spectrally Enhanced Lighting tend to stick with it.

Businesses That Have Standardized

Companies/Institutions using 850 lamps:

- Pacific Gas & Electric Company
  - PG&E now calls SEL one of the top 5 strategies for lighting energy efficiency.
- San Diego Unified School District
- Cities of San Diego and Oakland
- Counties of Napa and San Mateo
- State of Wisconsin

All these have adopted 5000K lighting as their standard for retrofits and new construction.

Status in IES

- A Technical Memorandum (TM-24-13) has been approved by the IES Board of Directors
- TM-24-13 Allows the EVE Method for use under certain restrictions; it is optional, not mandatory
- TM-24-13 Includes a Position Statement; it should not be used by energy regulators as a justification for lowering Lighting Power Densities (LPDs) in energy Standards or legislation

Optimized Light Source

- An ideal light source will have:
  - High S/P ratio for visual clarity;
  - High color rendering properties to render objects and spaces realistically
  - High efficacy, to minimize energy consumption.
- The CCT of the lighting will be dependent on the designer, the owner/occupant, the compatibility with the finishes, and compatibility with other light sources in the space, etc.

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DOE Website:
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