OMNI-RAY LIGHTING™

Oconto, Wisconsin USA

Better Vision with LED lights

Scotopic and Photopic Lumens

Executive Summary

Scotopic lumens are a recent development in our understanding of the response of the human eye to light. Scotopic lumen output depends not only on the absolute light output from a lamp but also on the wavelengths comprising light from a light source. Human eye has two kinds of light sensing cells – Rods and Cones. Both these cells have different spectral sensitivities. Line of sight vision is due largely to cone cells. Peripheral vision on the other hand is affected by rod cells. This, plus the fact that feedback inputs from rod cells control pupil size mean that factoring in the response of rod cells to lighting needs to be figured into the design of artificial lights.

An understanding of the concept of Scotopic lumens can deeply influence cost and performance equations of lighting solutions. This white paper explores the science behind the concept of scotopic lumens and how it can influence your choice of lighting products

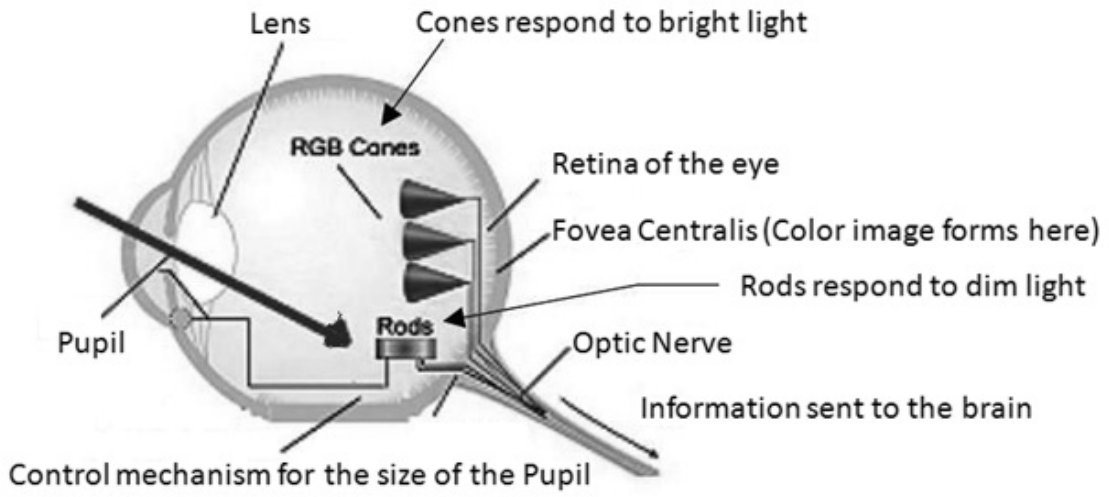
The Evidence

LED parking area lights (8040 Lumens) appear to be brighter than HPS light (19,000 Lumens) due to scotopic advantage, better Color Rendering Index and more uniform light spread

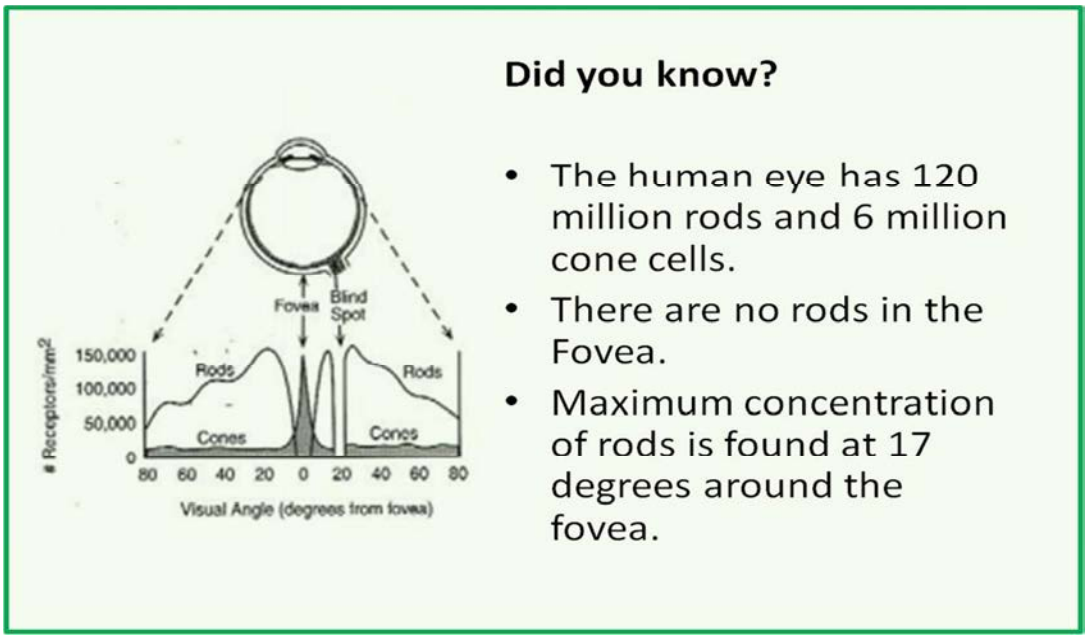
The road on the right is illuminated with LED lights and that on the left with High pressure Sodium (HPS) lamps. LED lights produce on 8040 lumens each as compared to 19,000 lumens for the HPS lamp. Yet visibility is better under LED lights. Better Color Rendering Index, Light uniformity and scotopic efficiency are the secret behind this paradox. LED lamps have a far better distribution of light resulting in less wastage, reduced uplighting, lower reflection form road surface and fewer light hotspots. The scotopic superiority of LED lamps means that each photopic lumen produced by an LED lamp equals 2.4 scotopic lumens.

In the following sections we shall discuss the concept of scotopic lumens. We shall also look at how this little understood phenomenon makes a difference to lighting bills and how companies investing in LED technology benefit from the better scotopic content of these lights.

The Science behind Scotopic Lumens

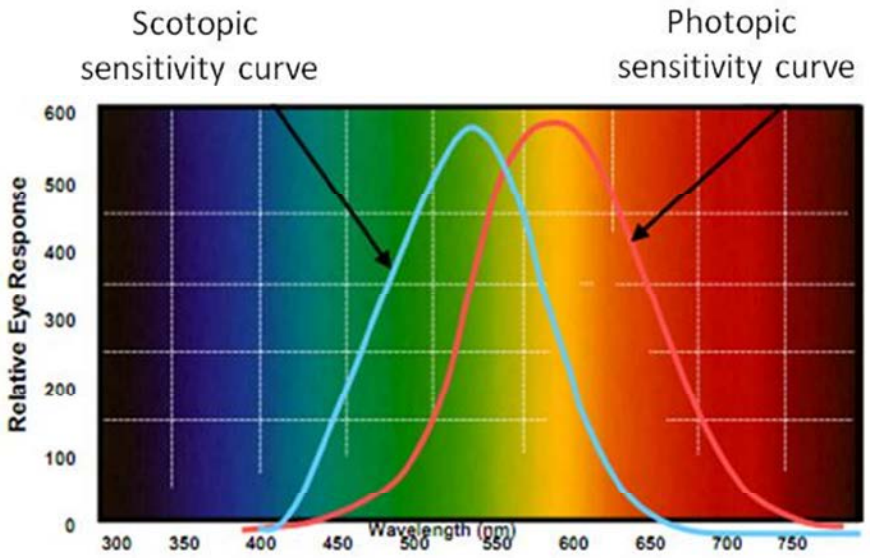


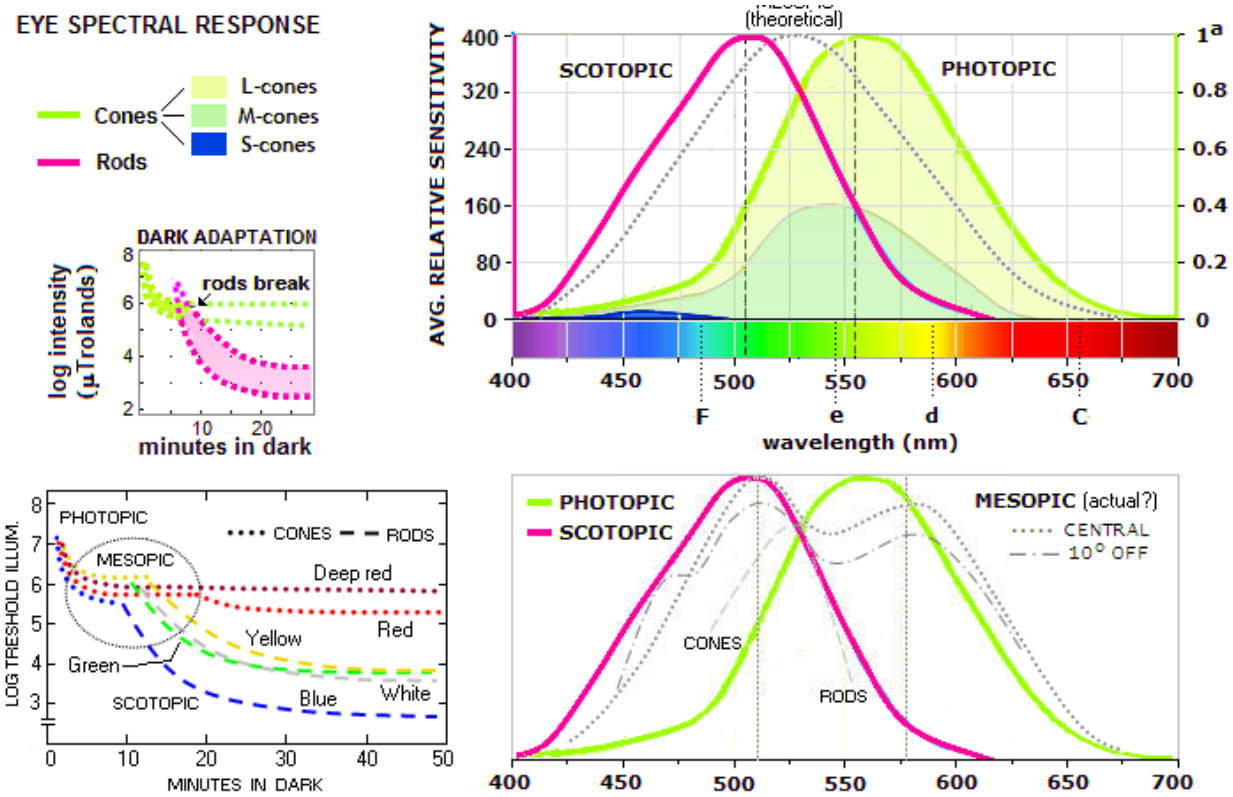
The traditional definition of lumen is based on the response of the cone cells to light. In the schematic diagram of the eye above, the area of the retina marked as the fovea is where the brightest images are formed. The fovea is full of cone cells. Rod cells are found in the area surrounding the fovea. Since the eye lens forms the sharpest images on the fovea, it is the cones that are involved in direct vision under bright light conditions.



The cones are responsible for the central portion of our visual field also called the foveal angle. The rods on the other hand, are responsible for the rest for the visual field called the peripheral angle.

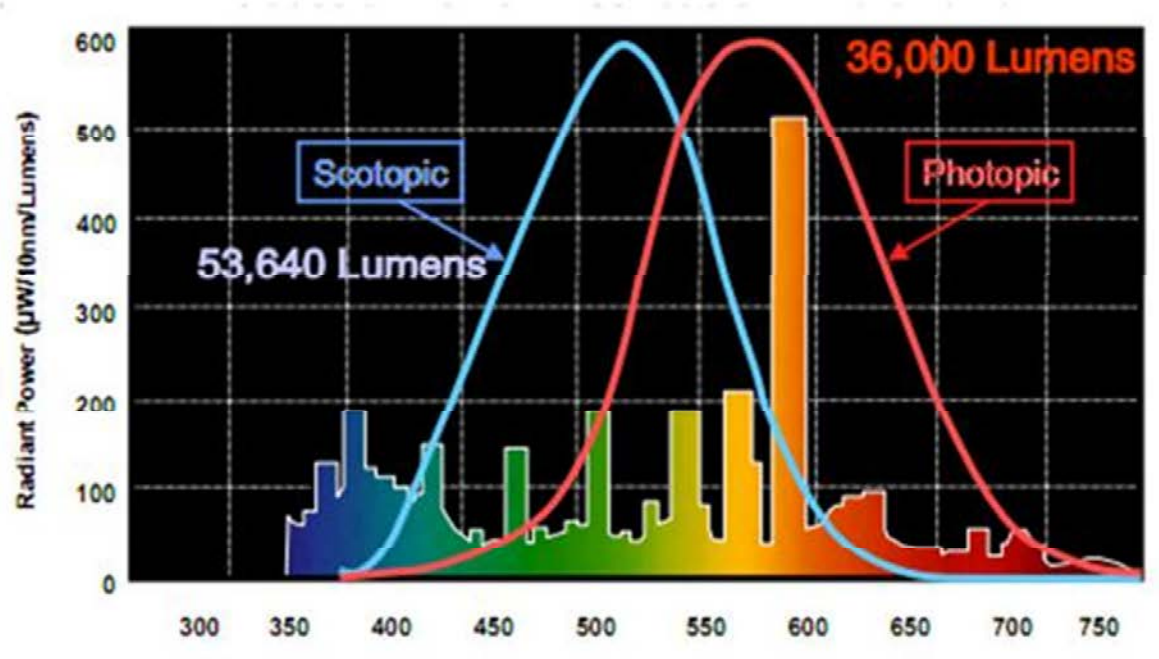
The Unit Lumen (and the Foot candle) estimates the brightness of a light source and is based on the photopic sensitivity curve depicted below.





The photopic sensitivity curve is meaningful at high light intensities. Under bright daylight conditions the rod cells do not play a significant role in visual perception. Under mesopic or medium intensity light conditions like those prevailing in offices, warehouses and under streetlights, the role of rods in vision is significant. Light that selectively stimulates rod cells is therefore more effective in vision under these conditions.

Scotopic lumens are based on the sensitivity of rod cells. And each lamp has a different Photopic and Scotopic lumen rating. In general, lamps with a larger component of blue light in their spectrum have higher scotopic lumen ratings. The S/P ratio is derived by dividing the scotopic lumen rating with the photopic lumen rating of a lamp. The spectral power distribution and the photopic and scotopic lumen ratings of a lamp are shown in the picture below. The S/P ratio for this lamp is 1.49. (S/P ratio = 53640/36000 = 1.49)



Once the S/P ratio is known, Pupil Lumens which are a more accurate estimate of the stimulation of the eyes by a particular light source can be estimated based on formulae developed by scientists at the Lawrence Berkley Laboratory (LBL).

Standard Lumens	S/P Ratio	Brightness Perception	Reading Tasks (Paper, Labeling)	Computer Tasks
P	S/P	P X [S/P]0.5	P X [S/P]0.78	P X [S/P]
36,000	1.49	43,944	49,135	53,640

NOTE – The method described above has been developed by appropriate research but is currently not recognized by IESNA (Illuminating Engineers Society of North America).

Pupil Lumens are a more accurate estimation of the visual performance of a light source. Light sources with a higher S/P ratio have higher Pupil Lumen output and are better at stimulating the eye.

The relevant lumen/watt, S/P ratio, Pupil Lumen and Pupil Lumen/watt data of some of the common lamps is demonstrated in the following table.

Source of Light	Watt	Lumen	Lumens/Watt (Photopic Lumen)	S/P Ratio (Correction Factor)	Pupil Lumens (Paper, Reading	Pupil Lumens/Watt
Low Pressure Sodium	250	32500	130	0.2	9262	37
High Pressure Sodium	365	37000	101	0.62	25484	70
Metal Halide	455	36000	79	1.49	491.35	108
T8 Fluorescent (3000K)	36	2800	78	1.13	3080	86
LED Light	15	1500	100	1.9	2475	165

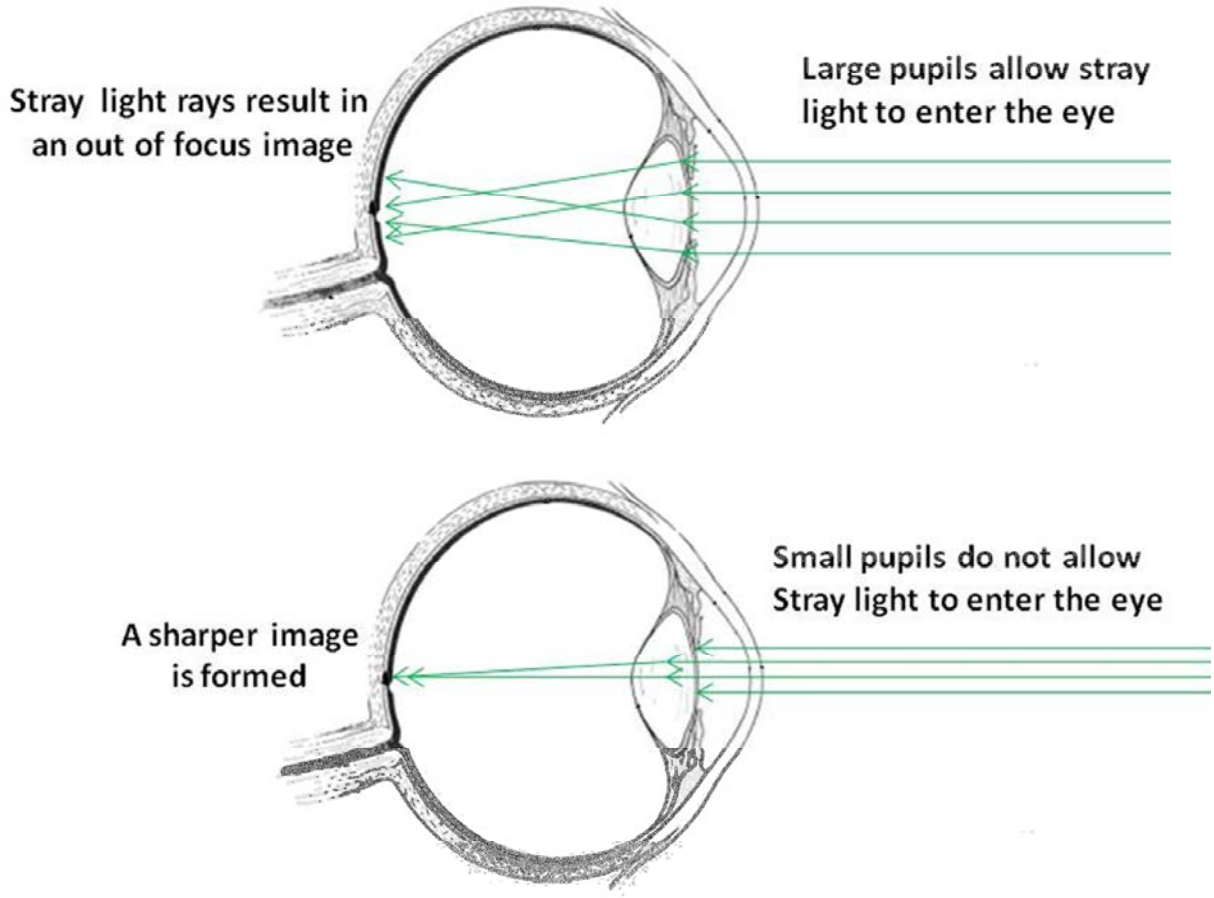
Factoring in the scotopic efficiency of lamps demonstrates that LED lights outperform most other technologies by 100 % or more.

Lamp	Standard Lumens P	S/P Ratio S/P	Brightness Perception PX[S/P]0.78	PX[S/P]	Computer Tasks PX[S/P]
Fluorescent Tubes	78	1.13	83	86	88
LED Lights	100	1.9	138	165	190
Scotopic Benefit of LED Lights			66%	92%	116%

When compared to fluorescent lights in the example above, the LED light is 28 % more efficient when absolute lumen output is compared. But when one considers the scotopic efficiency the gains are far more substantial at 66 – 116 %. These are in line with the results obtained by the US Department of Energy.

Control of Pupil size by Rod stimulation

The size of our pupils is regulated by inputs from Rod cells. Rod cells in turn are stimulated by lamps with higher S/P ratios. A smaller pupil, results in fewer aberrant light rays entering the eyes and sharper images.



Conclusion

When Led lights with superior scotopic performance are used outdoors it can help reduce crime and accidents and make an area look more aesthetically pleasing. This is borne out by the fact that users of LED lit facilities reported a 300% improvement in feeling of safety.

When used indoors, LED lights with a good S/P ratio can help reduce the wattage of lights, improve visual acuity and make indoor areas appear brighter and more attractive.

It is pertinent to note here that the concept of scotopic lights is not yet recognized by IESNA. For legal compliance it is advisable to stick to photopic lumens as described by the IES (Illuminating Engineering Society) or CIE (International Commission on Illumination).

While scientists and engineers are mulling over the standards that would be needed to implement the concept of Pupil Lumens, the US Department of Energy has conducted studies on the potential of light sources with higher scotopic light content and concluded that it is “market ready” and “cost effective solution” for energy savings.

References

1. Bouma, H. Size of the static pupil as a function of wavelength and luminosity of the light incident on the human eye, Nature, 193: 690-69

2. Stiles, W.S., and Wyszecki, G. Rod intrusion in large field color matching, Act.Chrom. 2, 155-163.

3. Berman, S.M., Jewett, D.J., Fein, G., Saika, G., and Ashford, F., Photopic luminance does not always predict perceived room brightness, Lighting Research Technology, 22(1): 37-41

4. Sam Berman, The Coming Lighting Revolution in Lighting Practice, Energy User News, 23-25, 2000.

5. Mojtaba Navvab, Visual Acuity Depends on the Color Temperature of the Surround Lighting, Journal of the IES, 30 (2), 170-175, 2001.

6. Illuminating Engineering Society of North America (IESNA) (Ed: Rea, M.), Lighting Handbook 9th Edition, New York, NY, 2000.

7. Pacific Northwest National Laboratory (for the U.S. Department of Energy), Spectrally Enhanced Lighting Program Implementation for Energy Savings. 2006.

8. United States Department of Energy, Energy Efficiency and Renewable Energy Building Technologies Program, 2008.