

**LED spectra and the way we
perceive its Lighting
“THE MESOPIC VISION”**

John Rooymans, Lemnis Lighting, Holland (Crompton Greaves Ltd)

Were we come from

- ❑ **Leading developer of LED applications for general lighting**
 - ❑ World's most efficient LED lighting applications (> 65 lumen / Watt on lamp level)
 - ❑ Dimmable products in Home & Commercial applications
 - ❑ Low cost and easy to use solutions for off-grid Solar LED applications
 - ❑ Targeted, energy saving spectra for Outdoor and Greenhouse segments

- ❑ **Founded in 2005 by Gemex (technology) and Tendris (capital & organization)**
 - ❑ Mission: help reduce global CO2 emissions by offering market-driven, energy-efficient LED lighting solutions
 - ❑ Rewarding, not penalizing, sustainable behaviour: create a win/win for all

- ❑ **Started market entry in late 2006 with a Retrofit product (Pharox I) and expanded into Outdoor and Greenhouse in 2007 and Solar in 2009**
 - ❑ Sold over 3 million units to date
 - ❑ Offices in Netherlands, US, China, Singapore and building presence in South Africa

Awards, Partners and Endorsers



Clinton Climate Initiative:
Preferred supplier



Former President Bill Clinton, USA with the Pharox in 2007



WEF:
Technology Pioneer 2009 Award



U2 singer Bono and TNT CEO Peter Bakker with the Pharox in 2009



World Bank:
Lighting Africa 2009 Award (Solar LED)



Former Prime Minister Tony Blair, UK with the Pharox in 2009



Fast Company: 2010
Top 10 "most innovative consumer goods companies"

Dutch Prime Minister Balkenende, The Netherlands with the Pharox in 2009



Dutch Postcode Lottery:
Mass roll out of Pharox
2,5 million Pharox lamps



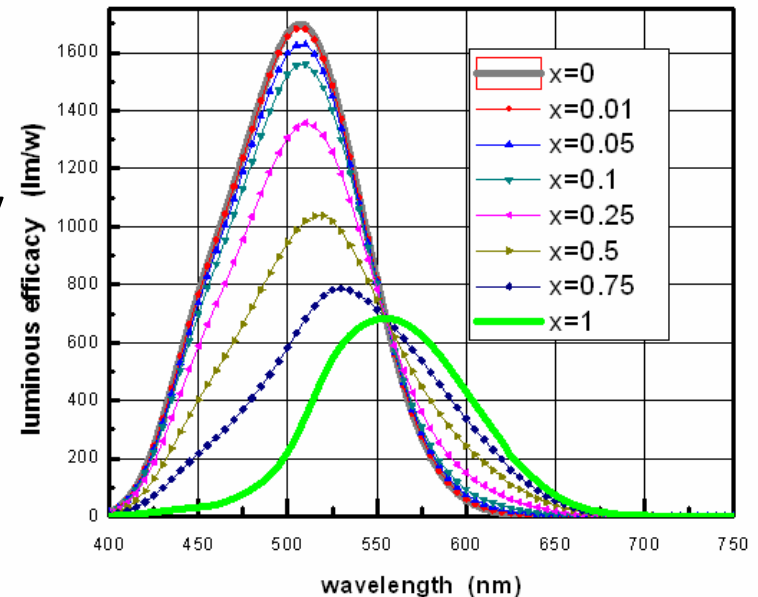
€ 11 million marketing campaign made LED a household phenomenon in the Netherlands



TV commercial with Pharox 300 and the Dutch Minister of Environment

A new vision on light

- The human eye experiences light different under varying intensities
- A lux meter does not work that way
- Light perception is not the same under composed colors
- Leds allow optimal spectral combinations
- Science got confused about the lumen standard



Source: Harvard edu. J. Rooymans

Sam Berman, D. Jewett, B. Benson, T.M. Law
Lawrence Berkeley National Laboratory :

“Our results measuring power and pupil size indicate that photopic luminous efficacy is an inadequate metric by which to judge the efficacy of indoor illumination”

Invitation of the TU/e, TU/delft, TU/tw 2010 to Led industry, Kema, NEN, NLA, Metrologic institutes



Met LED lampen is het mogelijk het kleurspectrum van de lichtbron af te stemmen op de wisselende eigenschappen van het menselijk oog onder verschillende omstandigheden, de wensen van klanten en op de specifieke eisen voor bepaalde toepassingen, zoals verlichting thuis, kantoor en werkruimteverlichting, (mesopische) straatverlichting, gewasspecifieke verlichting van kassen om de groei van planten te bevorderen, verlichting gericht op stimulering van alg groei en vele andere toepassingen.

De brede introductie van deze mooie technologie in de markt vereist een herbezinning van de wijze waarop de prestaties van deze lichtbronnen worden gepresenteerd en bewaakt. De kwaliteit en prestaties van deze lichtbronnen zijn namelijk niet aan te geven met de klassieke, gloeilampverbonden maat voor lichtopbrengst als effectief beschikbare lichtsterkte op de werkvlakken (lux), de geproduceerde lichtstroom (Lumen) en met een levensduur, die wordt uitgedrukt in het minimaal aantal uren dat de bron met lichtbehoud licht geeft.

Faculteit Electrical Engineering

A handwritten signature in blue ink, appearing to read 'Backx', is written over a horizontal line.

Prof.dr.ir. Ton Backx,
decaan

Faculteit Industrial Design

A handwritten signature in blue ink, appearing to read 'Brombacher', is written over a horizontal line.

Prof.dr.ir. Aarnout Brombacher,
groepsleider BPD

Compact translation

LEDs allow tuning of the light spectrum to the condition of the human eye under varying light conditions indoor and outdoor, light to grow plants and for production of algae and many other applications.

Introduction of this beautiful technology requires a review of the quality and performance since they can not properly be expressed in the classic “incandescent” bulb related measures for effective available light (Lux), the produced flux (Lumen) and lifetime.

Vision with the rods and cones

S/P ratio

The human eye contains rods and cones. The rods are highly effective at low light levels (dawn, night) Cones are effective at daylight. Under both conditions the eye responds dynamically and with different sensitivities and varying spectral compositions.

Daylight sensitivity is called Photopic, using the cones and the peak sensitivity is at 555 nm .

Night vision sensitivity is called Scotopic and makes use of the rods in the eye. The rods peak sensitivity is at 507 nm and is about 2.7x more than the photopic sensitivity.

The S/P ratio indicates for a lamp how much more efficient the lamp is under night vision conditions than the photopic standard.

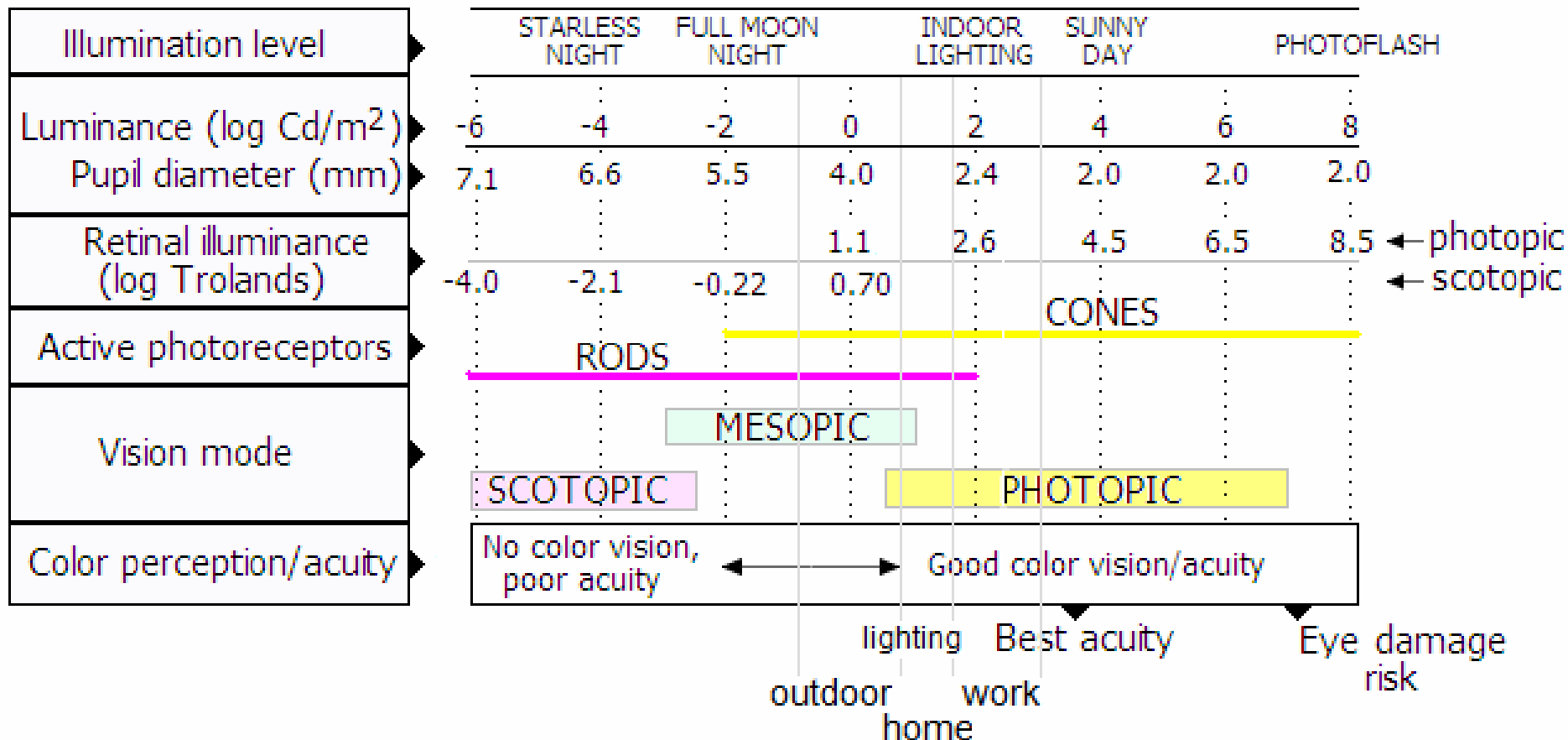
Lemnis developed lamps with S/P ratio's of up to 4 and incorporates the S/P knowledge in all lamps produced, also domestic and office lamps.

S/P ratio of Lemnis streetlight moonlight lamps rank up to $S/P = 4$

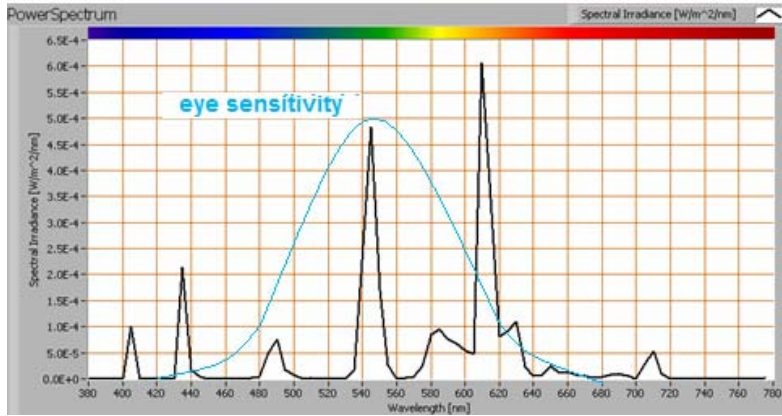
The S/P ratio

S/P ratio stands for how much we see with the rods and how much we see with our cones. The lumen metrics relate only to the cone vision.

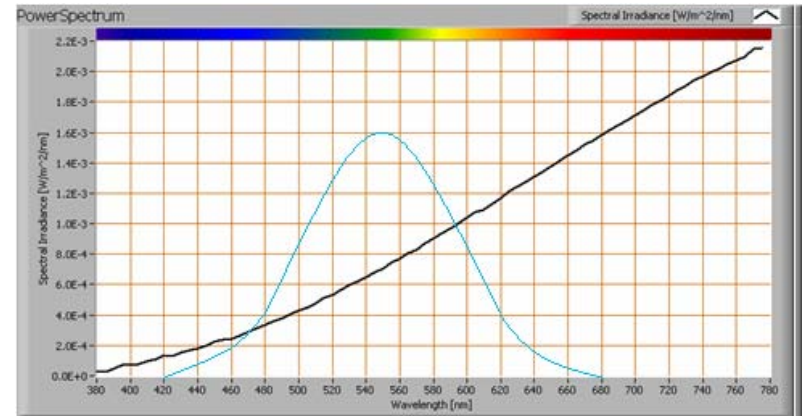
ILLUMINANCE AND VISUAL FUNCTION



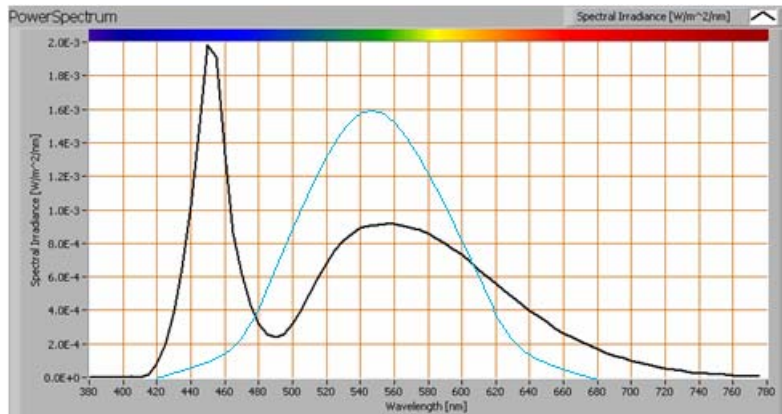
Spectra of lamps



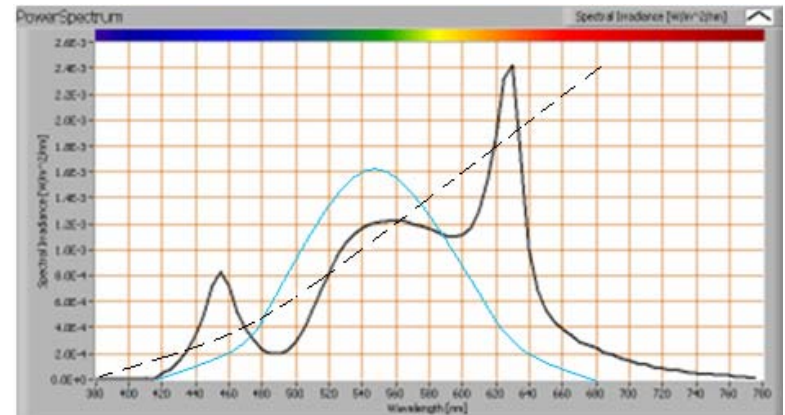
Fluorescent (CFL) 9W



Incandescent 60W

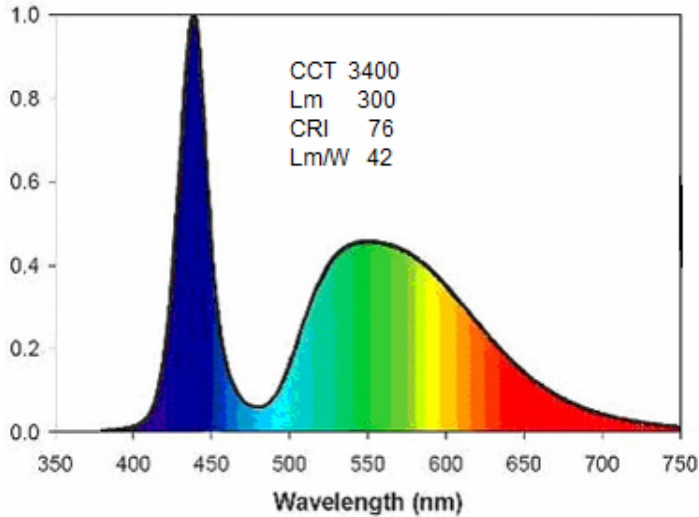


Lumiled, Nichia, Osram white LED 6000K



Lemnis LED 2800K CRI 94

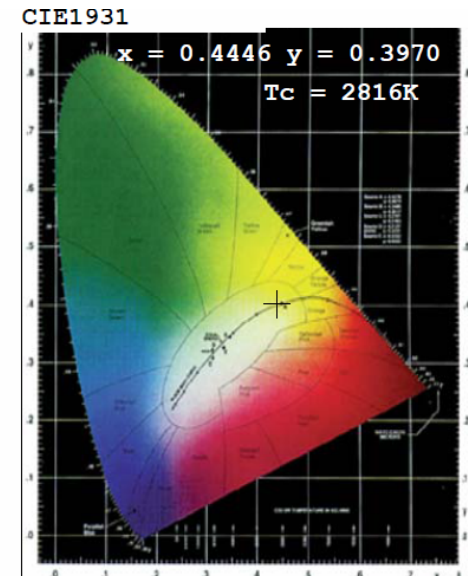
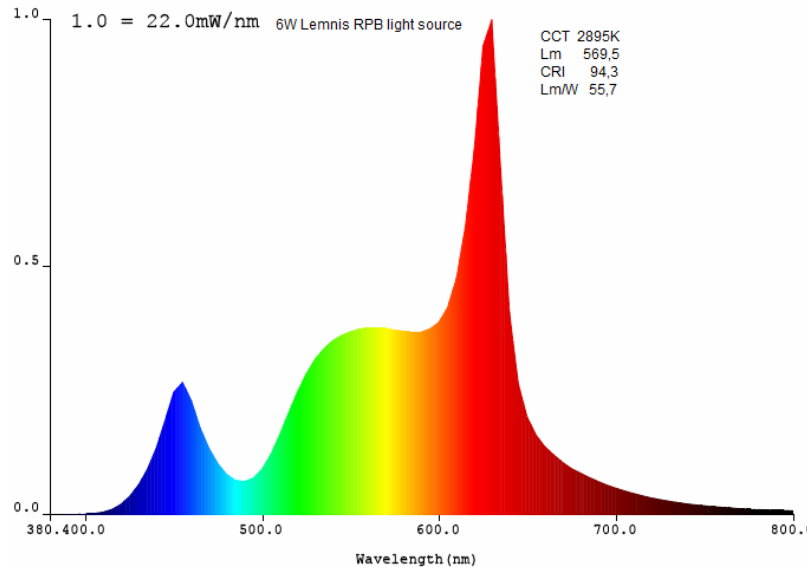
Spectral Power Distribution



Standard industrial LED's CRI ~ 75

Observe the different spectral power distribution for warm white lamps at 2800K and having >80 lm/W

Lemnis spectrum CRI > 94



Something fundamentally wrong !

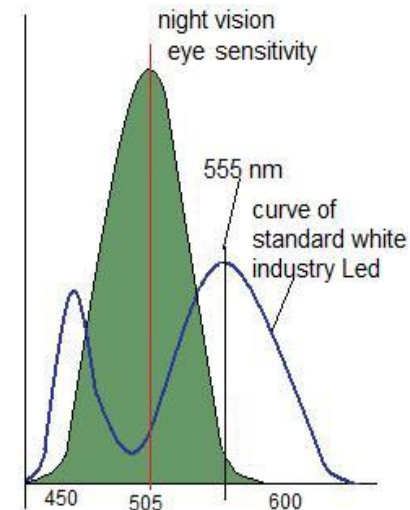
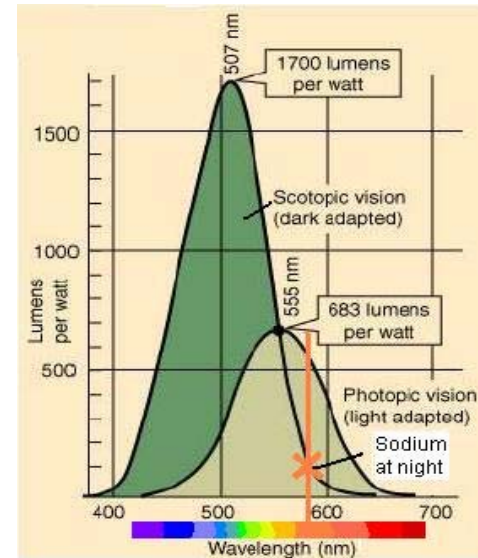
All directives and standards are based on photopic lumen

This is a serious problem because our eyes behave totally different at night than during daytime.

To benefit max of the high sensitivity of the rods it is necessary to provide light with the right wavelength and low intensity. Too much light will reduce the amplifying effect of the rods. The goal is more sight with less light.

Recent studies show that the ratio between Scotopic and Photopic vision, the so called **S/P** ratio, is a base which can be used to multiply the lumen with to express the real light perception.

White Leds in the current industry are based on blue chips with 3P or 4P phosphors to convert the blue light into white light with a peak at 555 nm. In mesopic lighting intensities or special Spectral Distributed light is the maximal eye sensitivity shifted towards 505 nm. Most Industrial leds produce the lowest output at that wavelength.



Some old findings: Lumen multiplier by Ian Lewin

Effectiveness of Sources, normalized to HPS		
<u>Source</u>	<u>Color Temp.°(K)</u>	<u>LEM*</u>
Metal Halide	4,000	7.8
LED	3,900	7
Incandescent	2,900	2.7
High Pressure Sodium	2,200	1 (ref. level)
Low Pressure Sodium	1,800	0.53

*Lumen Effectiveness Multiplier for Mesopic response equivalent to HPS, all at 0.1 cd/m²

Comparison of Source Effectiveness Centered in the Mesopic Scale

9/98 <http://www.patmullins.com/lem.html>

Dr. Ian Lewin, President Illuminating Engineering Society of North America (IESNA). 1999-2000

In The Dark About The Lumen

IAEEL newsletter2/95

The present definition of the lumen is based on experiments performed in the 1920s and may be inaccurate for nighttime tasks such as driving, writes guest author **Mark Rea**. A redefined "nighttime lumen" could force us to reconsider the efficacies of light sources for street lighting, leading away from high-pressure sodium lamps towards sources such as metal-halide lamps.

Light source	Photopic lm/W	Scotopic lm/W
Incandescent	14.7 (1.00)	20.3 (1.00)
High Pressure Sodium	127.0 (8.64)	80.6 (3.97)
Metal Halide	107.0 (7.28)	181.0 (8.92)
"Full Spectrum" Fluorescent	54.5 (3.71)	108.0 (5.34)

http://www.iaeel.org/IAEEL/NEWSL/1995/tva1995/HumFa_2_95.html

The industry recommends (2009)

Opm: Lemnis is het oneens met de zeer beperkte vermenigvuldigingsfactor en de limitering tot 0,6 cd/m² in deze aanbeveling

<http://www.lightenergysource.com/Scotopic.htm>

Scotopic Enhanced Lighting Saves Energy

Both vision and brightness are enhanced with scotopically enhanced lighting. Adoption of light sources with high S/P ratios will lead to substantial energy savings if vision and brightness are maintained at the same levels as achieved with standard lighting.

Pictures are worth a thousand words.

You will see some astonishing results.

A 50% reduction in direct energy consumption and a reduction of relevant HVAC loads is achievable.

ASSIST recommends...  **Calculating unified Luminance by S/P ratio**

Acuity Brands Lighting
Bridgelux
China Solid State Lighting Alliance
Cree
Everlight Electronics Co., Ltd.
Federal Aviation Administration
GE Lumination
ITRI, Industrial Technology Research Institute
Lighting Science Group
Lite-On
NeoPac Lighting
New York State Energy R & D Authority
OSRAM SYLVANIA/OSRAM Opto Semiconductors
Perilight
Philips Color Kinetics
Photonics Cluster (UK)/The Lighting Association
Seoul Semiconductor
United States Environmental Protection Agency
USG
WAC Lighting

Lighting Research Center Technical Staff

Mark S. Rea, Jean Paul Freyssonier

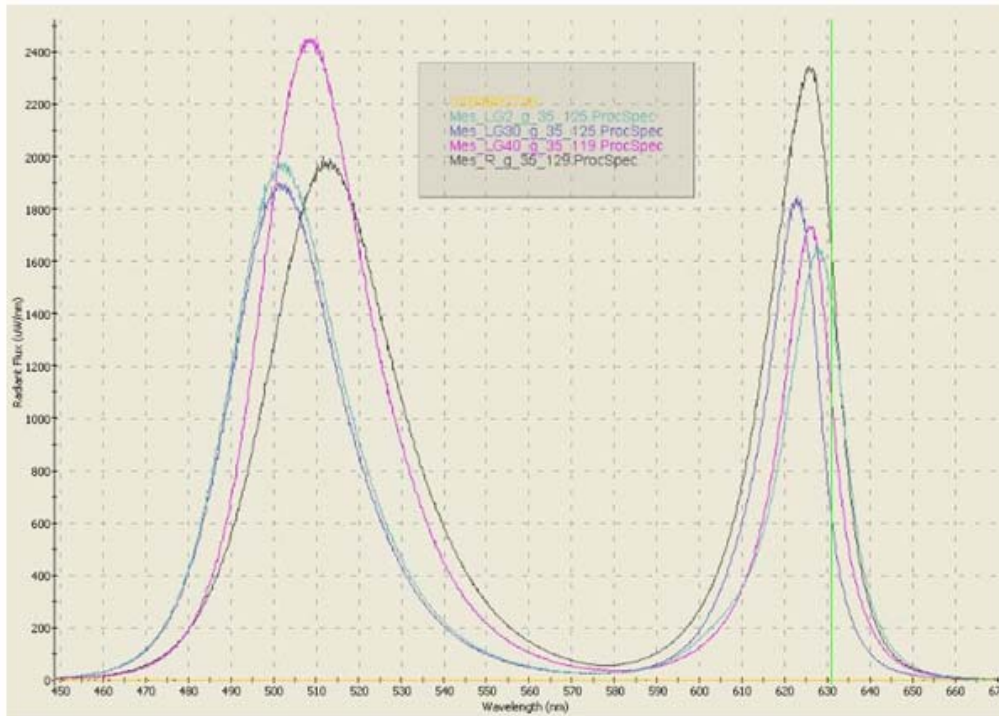
SOX 70W



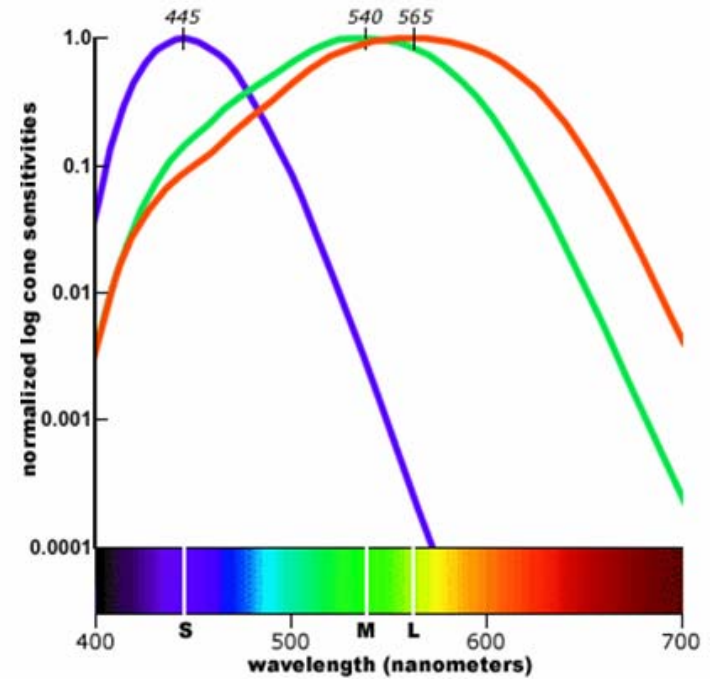
Lemnis ECOwhite
24W



The tone control of light



Lemnis spectral power dsitribution streetlight



Cone sensitivity log normalized

Academic Research

International developments

- **MOVE - Mesopic Optimisation of Visual Efficiency**

Research project under the EC Competitive and Sustainable Growth Program.

- **CIE TC 1-58 “Visual Performance in the Mesopic Range”**

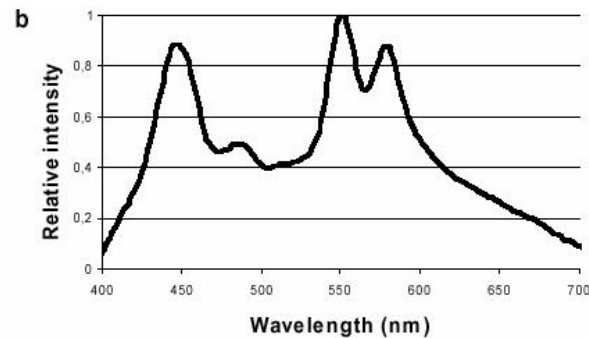
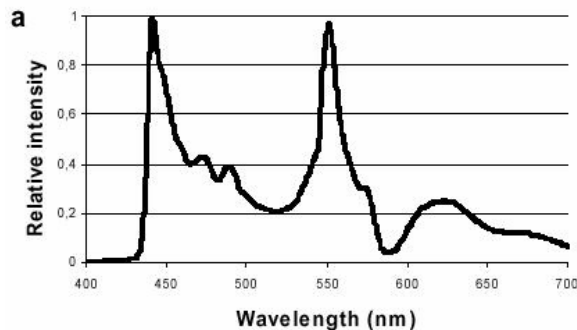
- CIE has established a Technical Committee TC 1-58 to study performance based mesopic photometry. The first meeting of the TC 1-58 was held in Tokyo in June 2004 along the CIE Div1&2 meetings.

- Many other papers issued by science and industry on the topic

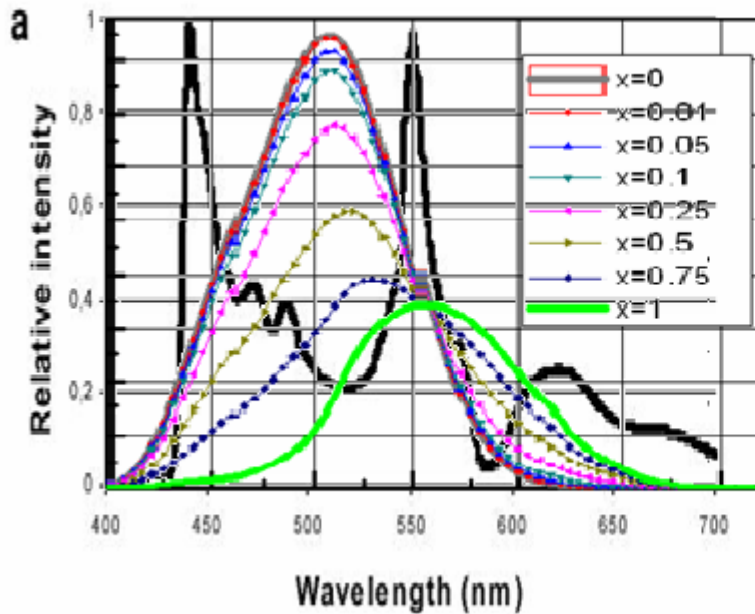
CIE mesopic workgroup TC1-58

- The first draft of the TC1-58 is executed with light stimuli at 440 nm and 555 nm (photopic maximum sensitivity)
- The combined Scotopic/Photopic eye sensitivity peak is at 505 nm. The applied stimuli to test the mesopic effect are there only 20% respectively 40%.

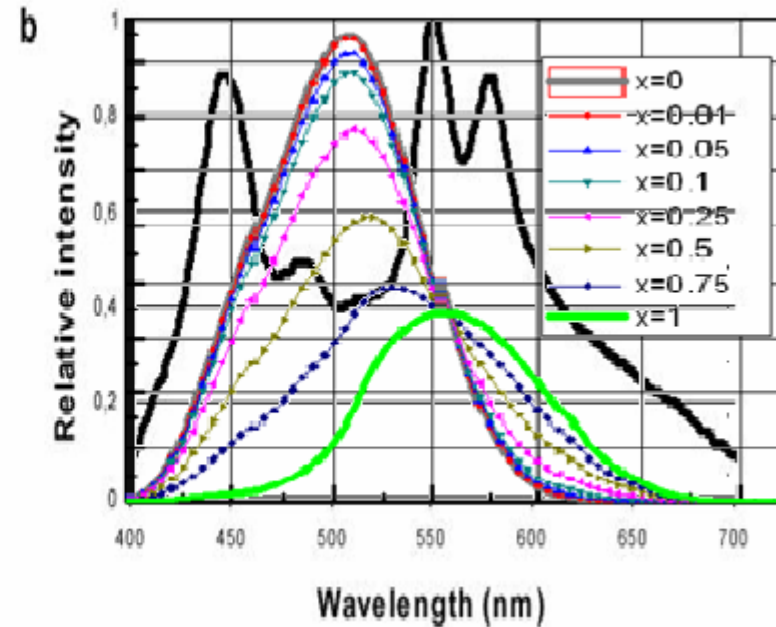
In the opinion of Lemnis an inadequate method to measure mesopic effects. The eye does not represent two vision systems but one advanced integrated dynamic system.



Lemnis colored mesopic spectra projected on TC58 stimuli



Quasi monochromatic stimuli



Full spectrum stimulus

10W Mesopic residential street lights



Schiphol airport

Real green light with high S/P ratio improve vision and color recognition with 60% energy saving. 88W Sodium lamps (background) are replaced by 36W Lemnis LED lamps (foreground)



Hybride street light

The low energy consumption of the LED lamp enables solar and wind integration. Higher initial system cost competes with high cabling and energy cost



Solar lamp

Equivalent to a 25W bulb. Rigid, long lifetime. With built-in processor for optimal long term use.

Awarded with lighting up Africa award of the World Bank



Tunnel lighting 16W Mesopic



10 streetlamps of 16W replace 3600W TL's



Old

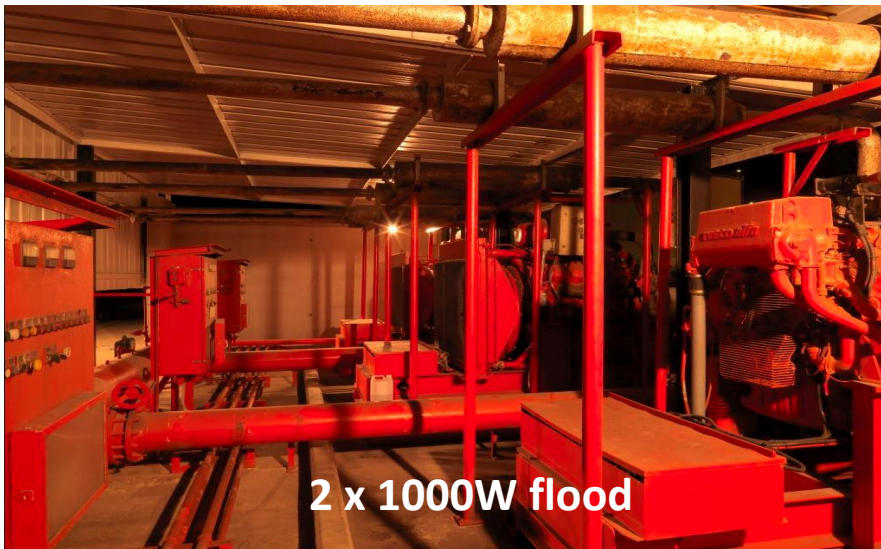
New



12 x 36W



6 x 36W



2 x 1000W flood



2 x 36W

A greener world

With its expert knowledge in LED lighting, Lemnis has developed a revolutionary concept that resulting in the same plant growth compared to conventional solutions, yet with drastic reduction of the energy consumption. Furthermore, with its long lifetime, LEDs reduce maintenance cost. This innovation in greenhouse lighting is the perfect response to the demands of the sector, society and the government.



Stacked greenhouse

Using the height of a greenhouse to the max.
Crops like crest, lettuce are a few centimeter high.
With Lemnis stacked LEDs the greenhouse height of 8 m can be utilized to 3 or 4 layers.



The strawberry lamp with world record photosynthesis efficiency of 2,1 $\mu\text{mol}/\text{m}^2/\text{sec}$. got nominated as most inovative product at the international Hortifair 2009





The range of Lemnis lamps

EFFICIENT LIGHTING

2010

PAR for B2B



- ▶ PAR 38
 - ▶ Power consumption: 12 and 15 watt
 - ▶ Lumen: ~850 and 1200
 - ▶ Color (CCT): ~2700K
 - ▶ Voltage: 110V-240V
 - ▶ On@once
 - ▶ Base: E27 - E26
 - ▶ Lifetime: 25 years

Rods work also indoor



S/P = 1,14



S/P = 2,47

PAR illuminated office

With conventional lighting:

15 kWh

With 210 x 12W PAR lamps:

2,5 kWh

Same lux on all places

Energy saving 12,5 kWh

ROI 8 months



Submersible algae lamps

Algae grow 200 times faster than terrestrial plants.

Based on Lemnis spectral power distribution, submersible algae lamps produce highly efficient bio mass and biofuel in a closed reactor



Our mission, our ambition

Our mission is NO emission

Up to 19% of worldwide electricity is consumed by lighting.

With Lemnis LEDs, 50% of this consumption can be saved.

This is a major positive impact on climate change

