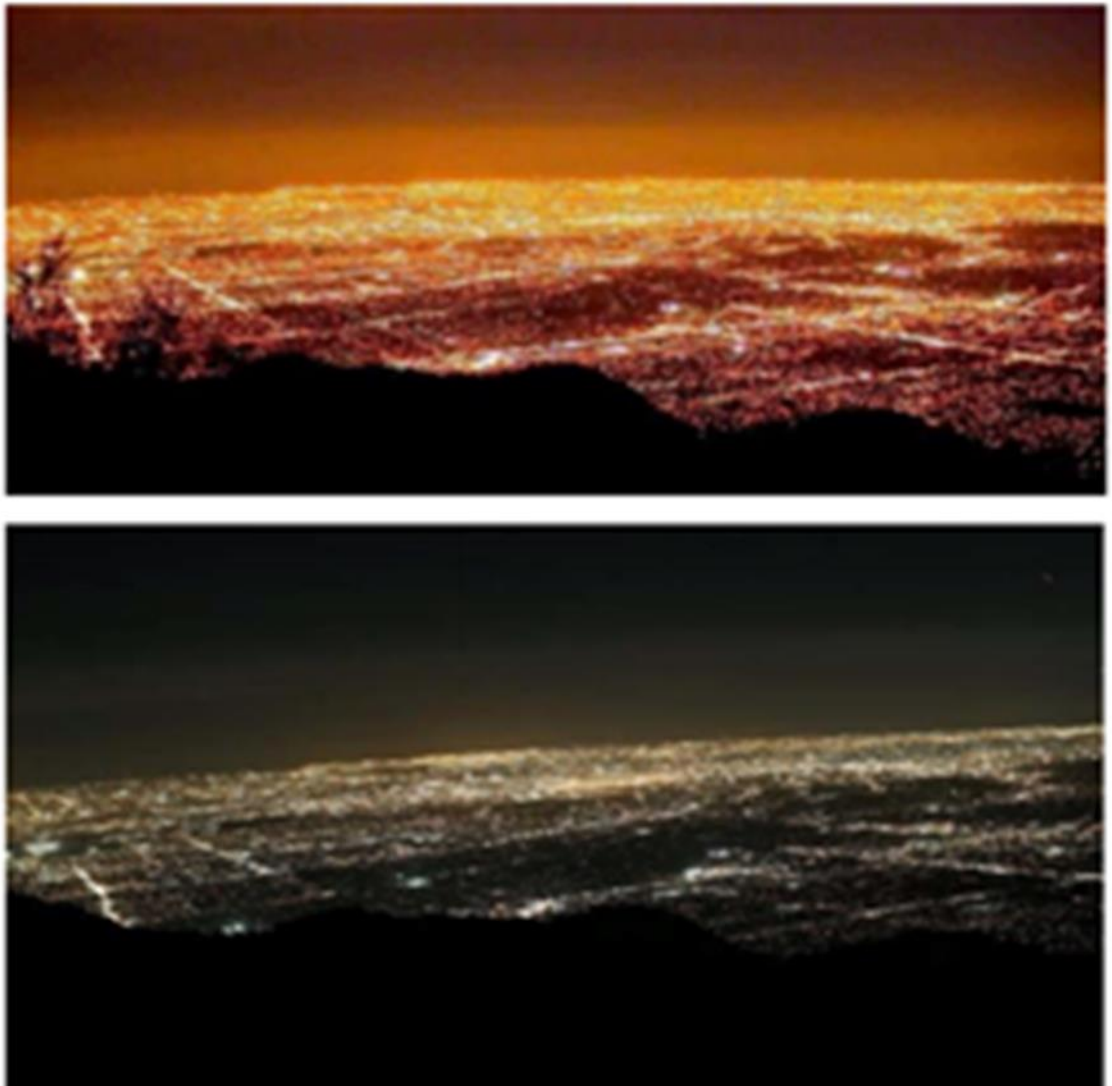
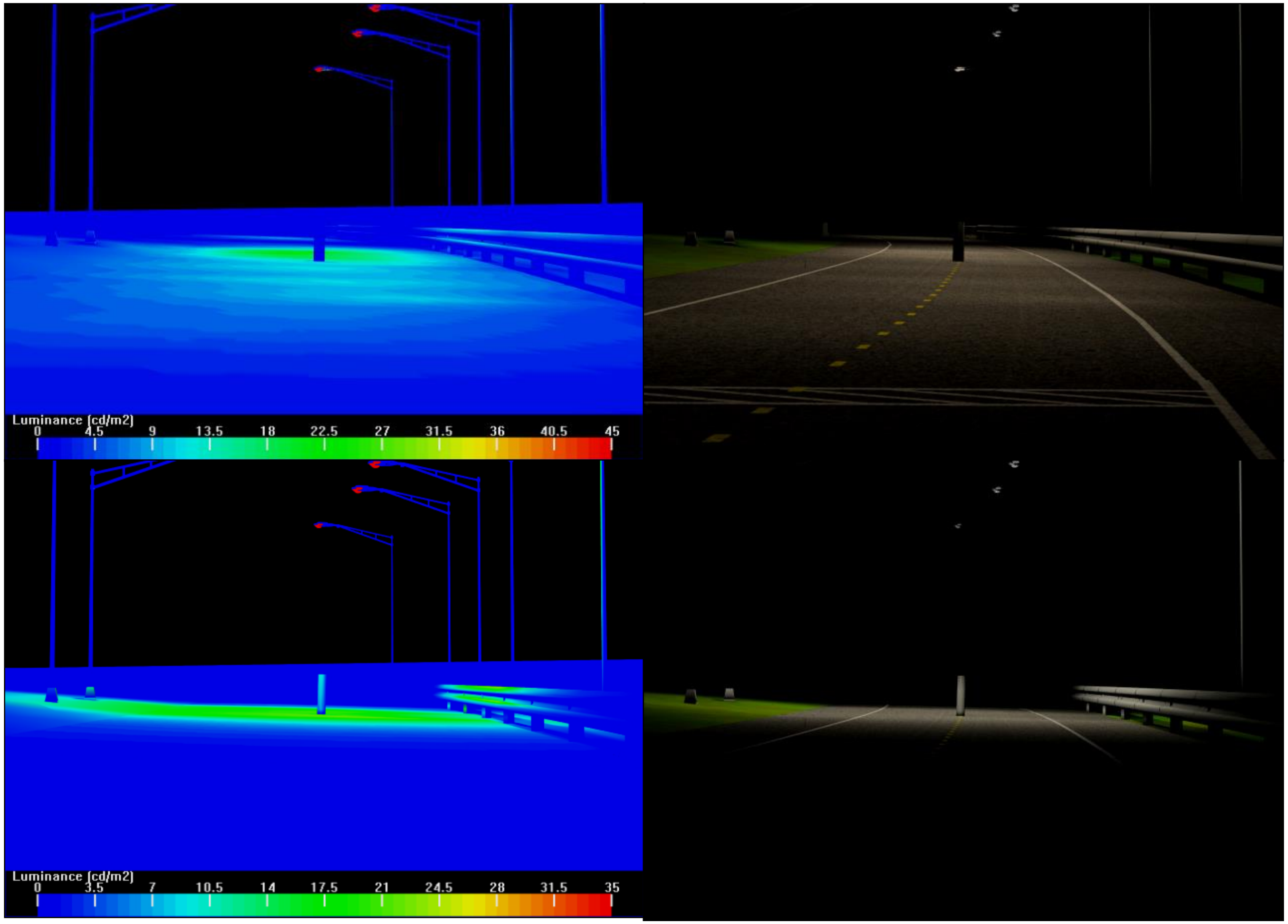
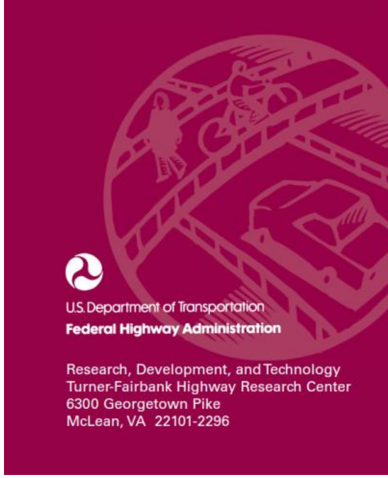
Sky Glow



View from Mt Wilson of light pollution in Los Angeles, before and after LED deployment



Luminance Contrast

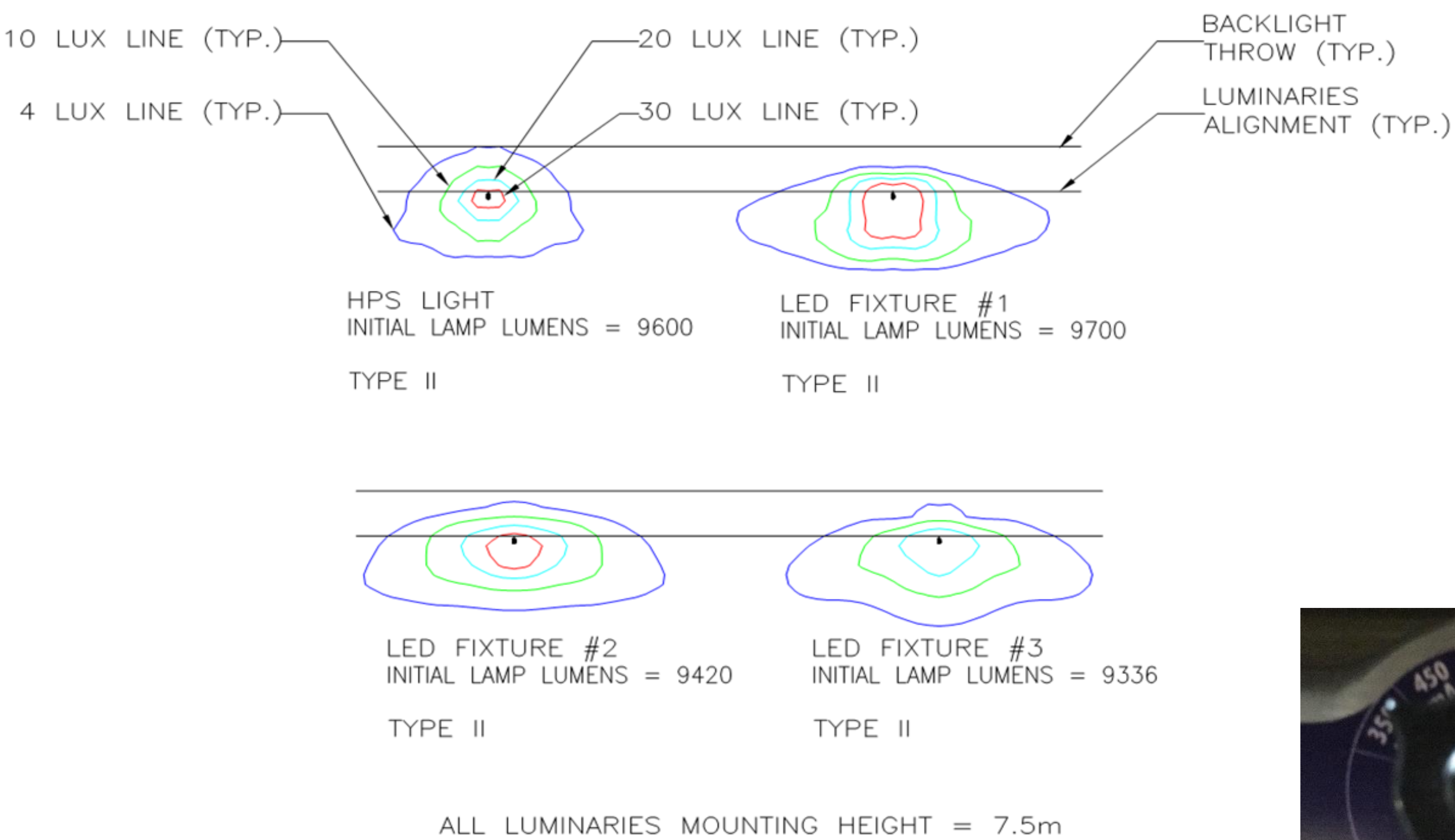


The interpretation of these results is an important aspect of this project. As mentioned, the results of the experiments show that the impact of overhead lighting spectrum on driver visual performance is limited to specific situations. It is important to note that, in many situations, the broad-spectrum light source did not improve driver visual performance over the narrow-spectrum light source, but neither did it worsen driver visual performance. Other studies have shown benefits of the use of broad-spectrum light sources beyond providing better visual performance. In user preference studies, broad-spectrum light sources were preferred for their user comfort and acceptance.[23,101] Other research has shown that broad-spectrum sources provide for better object contrast, thus increasing the detection of objects along the roadside. These results indicate that broad-spectrum lighting is a valid choice in general and likely a desirable choice for roadway lighting.

Lighting Design

- Many Roads are over-lit – Demand energy efficient design. Use defined standards (TAC or IESNA)
- Use energy efficient product. Not all products are equal
- When undertaking a LED conversion drill down and undertake an assessment. Simply replacing a 100W HPS with a 50W LED may lead to improperly lit roads.
- Not all roads require lighting – Consider retroreflective pavement and delineator as alternate
- Consider adaptive lighting system
- ***TAC Roadway Lighting Efficiency and Power Reduction Guide*** is a good source of reference

LED Luminaire Efficiency



Adaptive Lighting

- “The ability to vary lighting levels to suit activity levels.” – Activity levels will typically decline during the evening.
- Becoming accepted practice as it is in many published documents (ie; TAC, CIE, IMSA, IESNA)
- Why now? – Lighting controls have developed to the point where they are easy to install and can be cost effective.

Table 3. Lighting Design Criteria for Streets

STREET CLASSIFICATION	PEDESTRIAN AREA CLASSIFICATION	AVG. LUMINANCE L_{avg} (cd/m^2)	AVG. UNIFORMITY RATIO L_{avg}/L_{min}	MAX. UNIFORMITY RATIO L_{max}/L_{min}	MAX. VEILING LUMINANCE RATIO LV_{max}/L_{avg}
MAJOR	HIGH	1.2	3.0	5.0	0.3
	MEDIUM	0.9	3.0	5.0	0.3
	LOW	0.6	3.5	6.0	0.3
COLLECTOR	HIGH	0.8	3.0	5.0	0.4
	MEDIUM	0.6	3.5	6.0	0.4
	LOW	0.4	4.0	8.0	0.4
LOCAL	HIGH	0.6	6.0	10.0	0.4
	MEDIUM	0.5	6.0	10.0	0.4
	LOW	0.3	6.0	10.0	0.4

L_{avg} - minimum maintained average pavement luminance
L_{min} - minimum pavement luminance
LV_{max} - maximum veiling luminance

Table 4 - Recommended Values for High Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways			
	E_{avg} (lux/fc)	EV_{min} (lux/fc)	E_{avg}/E_{min}*
Mixed Vehicle and Pedestrian	20.0/2.0	10.0/1.0	4.0
Pedestrian Only	10.0/1.0	5.0/0.5	4.0

E_{avg} - minimum maintained average horizontal illuminance at pavement
E_{min} - minimum horizontal illuminance at pavement
EV_{min} - minimum vertical illuminance at 1.5m above pavement
*Horizontal only

Table 5 - Recommended Values for Medium Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways			
	E_{avg} (lux/fc)	EV_{min} (lux/fc)	E_{avg}/E_{min}*
Pedestrian Areas	5.0/0.5	2.0/0.2	4.0

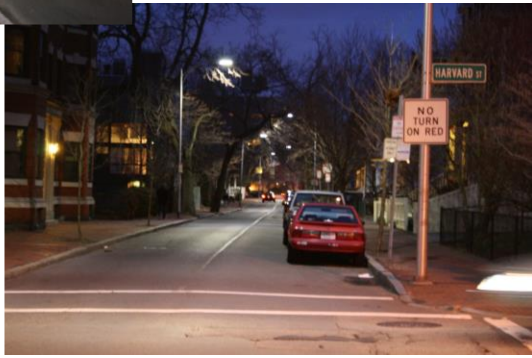
E_{avg} - minimum maintained average horizontal illuminance at pavement
E_{min} - minimum horizontal illuminance at pavement
EV_{min} - minimum vertical illuminance at 1.5m above pavement
*Horizontal only

Table 6: Recommended Values for Low Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways			
	E_{avg} (lux/fc)	EV_{min} (lux/fc)	E_{avg}/E_{min}*
Rural/Semi-Rural Areas	2.0/0.2	0.6/0.06	10.0
Low Density Residential *(2 or fewer dwelling units per acre)*	3.0/0.3	0.8/0/08	6.0
Medium Density Residential *(2.1 to 6.0 dwelling units per acre)*	4.0/0.4	1.0/0.1	4.0

E_{avg} - minimum maintained average horizontal illuminance at pavement
E_{min} - minimum horizontal illuminance at pavement
EV_{min} - minimum vertical illuminance at 1.5m above pavement
*Horizontal only

Typical Street



IES RP-8 Recommendations

Roadway lighting levels	9 lux average
	0.6 cd/m^2
Sidewalk lighting level	2 lux minimum vertical
Light trespass level (TM-11-00)	8 lux pre-curfew maximum
	3 lux post-curfew maximum

Existing Condition

Roadway lighting levels	20 lux average
	1.3 cd/m^2
Sidewalk lighting level	2.5 lux minimum vertical
Light trespass level	25 lux maximum
Power/unit	185 watts

Test Installation Condition Pre-curfew

Roadway lighting levels	12 lux average
	0.8 cd/m^2
Sidewalk lighting level	3 lux minimum vertical
Light trespass level	6.9 lux maximum
Power/unit	86 watts

Alternative Method of Defining Light Levels

DESIGN CRITERIA FOR STREETS (S-CLASS)

Base Value for Class: 6

Table 23. Street design level selection criteria.

Parameter	Options	Criteria	Weighting Value
Speed	High	> 45 mi/h (70 km/h)	1
	Moderate	35–45 mi/h (55–70 km/h)	0.5
	Low	< 35 mi/h (55 km/h)	0
Traffic Volume	High	> 15,000 ADT	1
	Moderate	5,000–15,000 ADT	0
	Low	< 5,000 ADT	-1
Median	No	No median	1
	Yes (or one-way)	Must be glare blocking	0
Intersection/Interchange Density	High	> 5 per 1 mi (1.6 km)	1
	Moderate	1–5 per 1 mi (1.6 km)	0
	Low	< 1 per 1 mi (1.6 km)	-1
Ambient Luminance	High	LZ3 and LZ4	1
	Moderate	LZ2	0
	Low	LZ1	-1
Guidance	Good	> 100 mcd/m^2 lx	0
	Poor	< 100 mcd/m^2 lx	0.5
Pedestrian/Bicycle Interaction	High	> 100 pedestrians per h	2
	Moderate	10–100 pedestrians per h	1
	Low	< 10 pedestrians per h	0
Parked Vehicles	Yes	Parked vehicles present	1
	No	No parked vehicles present	0

Table 24. S-Class lighting design levels.

Class	Average Luminance (cd/m^2)	Max UR (avg/min)	Max UR (max/min)	Veiling Luminance Ratio
S1	1.2	3	5	0.3
S2	0.9	3.5	6	0.4
S3	0.6	4	6	0.4
S4	0.4	6	8	0.4
S5	0.3	6	10	0.4

1 cd/m^2 = 0.292 ft-lamberts

DESIGN CRITERIA FOR ROADWAYS (H-CLASS)

Base Value for Class: 5

Table 21. Roadway design level selection criteria.

Parameter	Options	Criteria	Weighting Value
Speed	Very High	> 60 mi/h (100 km/h)	1
	High	45–60 mi/h (75–100 km/h)	0.5
	Moderate	< 45 mi/h (75 km/h)	0
Traffic Volume	High	> 30,000 ADT	1
	Moderate	10,000–30,000 ADT	0
	Low	< 10,000 ADT	-1
Median	No	No median	1
	Yes	Must be glare blocking	0
Intersection/Interchange Density	High	< 1.5 mi (2.5 km) between intersections	1
	Moderate	1.5–4 mi (2.5 km–6.5 km) between intersections	0
	Low	> 4 mi (6.5 km) between intersections	-1
Ambient Luminance	High	LZ3 and LZ4	1
	Moderate	LZ2	0
	Low	LZ1	-1
Guidance	Good	> 100 mcd/m^2 lx	0
	Poor	< 100 mcd/m^2 lx	0.5

Table 22. H-class lighting design levels.

Class	Average Luminance (cd/m^2)	Max UR (avg/min)	Max UR (max/min)	Veiling Luminance Ratio
H1	1	3	5	0.3
H2	0.8	3.5	6	0.3
H3	0.6	3.5	6	0.3
H4	0.4	3.5	6	0.3

1 cd/m^2 = 0.292 ft-lamberts

Measuring and using light in the melanopsin age

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Irradiance Toolbox

Title	HPS 100W			Chart input	Pigment	Melanopic

Page 1

1) Select mode — 5nm spectral data

i. Enter spectral power distribution in column AH
ii. Check using the chart opposite that the data is 5nm resolution
iii. Skip sections 2 and 3: these inputs are not applicable in this mode

2) Details of light measurement

Light source	A	n/a
Units	L	n/a
Amount	100.00	n/a

3) For blackbody or narrowband sources

Blackbody temperature	4200	n/a		
Narrowband peak	420	n/a		nm
Narrowband FWHM	42	n/a	Peak spectral irradiance	600

4) Photopic illuminance

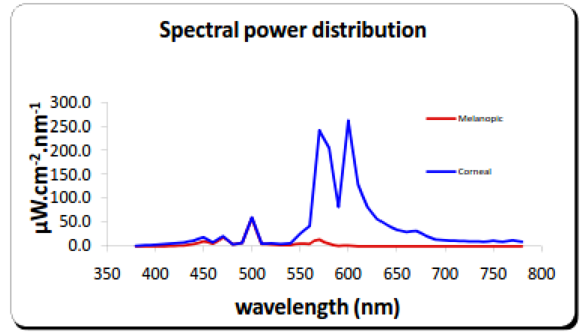
Optional prefix	Sensitivity	λ_{max}	Subscript	Curve	lux
Photopic	Visibility	555.0	n/a	V(λ)	11,904.27

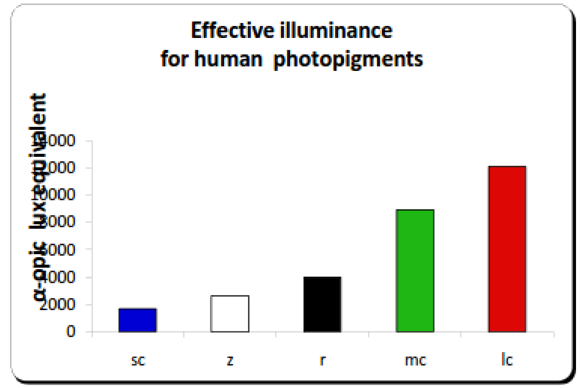
5) Human retinal photopigment complement (all weighted)

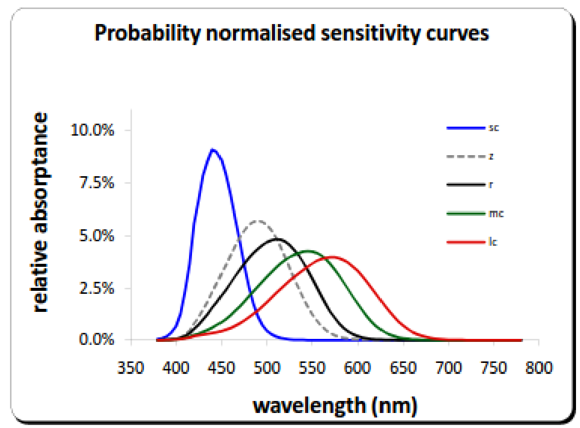
Prefix	Sensitivity	λ_{max}	α in $N_\alpha(\lambda)$	Curve	α-opic lux
Cyanopic	S cone	419.0	sc	$N_{sc}(\lambda)$	1,700.58
Melanopic	Melanopsin	480.0	z	$N_z(\lambda)$	2,647.27
Rhodopic	Rod	496.3	r	$N_r(\lambda)$	3,969.21
Chloropic	M cone	530.8	mc	$N_{mc}(\lambda)$	8,920.17
Erythropic	L cone	558.4	lc	$N_{lc}(\lambda)$	12,080.54

6) Unweighted summations from 380 to 780 nm inclusive

Quantity	Units	Amount
Irradiance	μW/cm²	3,154.16
Photon flux	1/cm²/s	9.43E+15
Log photon flux	$\log_{10}$ (1/cm²/s)	15.97







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Irradiance Toolbox

	Title	Cree 4000K 68 watts				
1)	**Select mode**	5nm spectral data				

i. Enter spectral power distribution in column AH
ii. Check using the chart opposite that the data is 5nm resolution
iii. Skip sections 2 and 3: these inputs are not applicable in this mode

Chart input Pigment: Melanopic

2) Details of light measurement

Light source	A	n/a
Units	L	n/a
Amount	100.00	n/a

3) For blackbody or narrowband sources

Blackbody temperature	4200	n/a		
Narrowband peak	420	n/a		nm
Narrowband FWHM	42	n/a	Peak spectral irradiance	460

4) Photopic illuminance

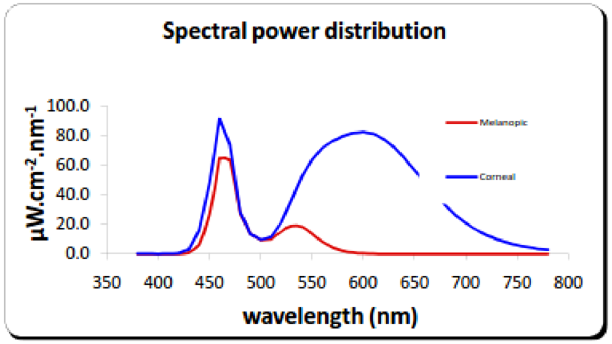
Optional prefix	Sensitivity	λ_{max}	Subscript	Curve	lux
Photopic	Visibility	555.0	n/a	V(λ)	8,549.31

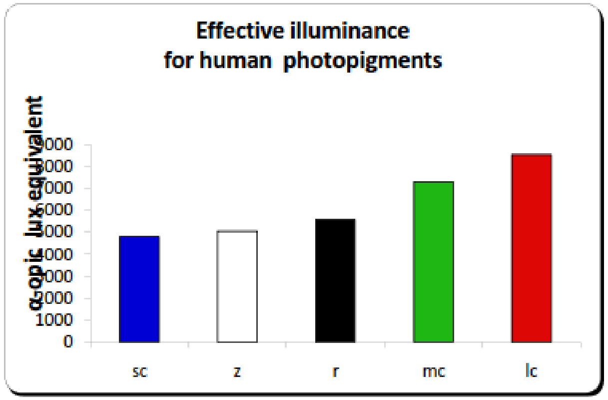
5) Human retinal photopigment complement (all weighted)

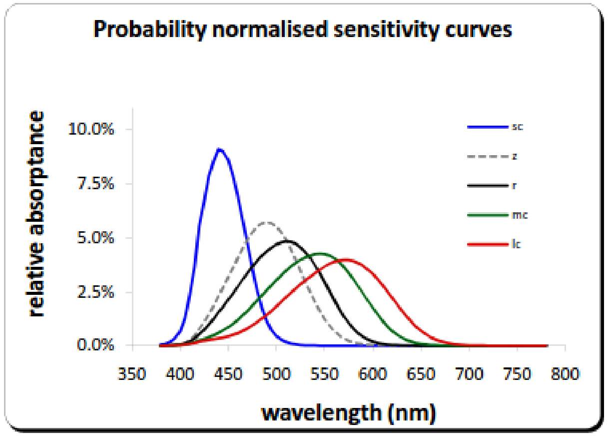
Prefix	Sensitivity	λ_{max}	α in $N_\alpha(\lambda)$	Curve	α-opic lux
Cyanopic	S cone	419.0	sc	$N_{sc}(\lambda)$	4,797.11
Melanopic	Melanopsin	480.0	z	$N_z(\lambda)$	5,049.75
Rhodopic	Rod	496.3	r	$N_r(\lambda)$	5,573.58
Chloropic	M cone	530.8	mc	$N_{mc}(\lambda)$	7,293.88
Erythropic	L cone	558.4	lc	$N_{lc}(\lambda)$	8,529.20

6) Unweighted summations from 380 to 780 nm inclusive

Quantity	Units	Amount
Irradiance	$\mu W/cm^2$	2,881.02
Photon flux	$1/cm^2/s$	8.43E+15
Log photon flux	$\log_{10}(1/cm^2/s)$	15.93







Irradiance Toolbox

Title	Cree 3000K 57W			Chart input Pigment Melanopic Page 1

1) **Select mode** — 5nm spectral data

i. Enter spectral power distribution in column AH
ii. Check using the chart opposite that the data is 5nm resolution
iii. Skip sections 2 and 3: these inputs are not applicable in this mode

2) **Details of light measurement**

Light source	A	n/a
Units	L	n/a
Amount	100.00	n/a

3) **For blackbody or narrowband sources**

Blackbody temperature	4200	n/a		
Narrowband peak	420	n/a		nm
Narrowband FWHM	42	n/a	Peak spectral irradiance	600

4) **Photopic illuminance**

Optional prefix	Sensitivity	I_{max}	Subscrip	Curve	lux
Photopic	Visibility	555.0	n/a	V(λ)	8,097.51

5) **Human retinal photopigment complement (all weighted)**

Prefix	Sensitivity	I_{max}	α in $N_α$(λ	Curve	α-opic lux
Cyanopic	S cone	419.0	sc	N_{sc}(λ)	3,109.38
Melanopic	Melanopsin	480.0	z	N_z(λ)	3,789.03
Rhodopic	Rod	496.3	r	N_r(λ)	4,734.09
Chloropic	M cone	530.8	mc	N_{mc}(λ)	6,678.76
Erythropic	L cone	558.4	lc	N_{lc}(λ)	7,970.95

6) **Unweighted summations from 380 to 780 nm inclusive**

Quantity	Units	Amount
Irradiance	µW/cm²	2,496.44
Photon flux	1/cm²/s	7.32E+15
Log photon flux	log_{10} (1/cm²/s)	15.86