Pacific Northwest
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Searching for Holy Grails: A Glaring Lack of Definition

Are glare metrics dead yet?

Bob Davis

Senior Staff Lighting Scientist / Engineer

U.S. DEPARTMENT OF ENERGY BATTELLE

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Searching for Holy Grails: A Glaring Lack of Definition

UPDATES:

CIE JTC7
IES D-GONE
IES LOPS
Future?

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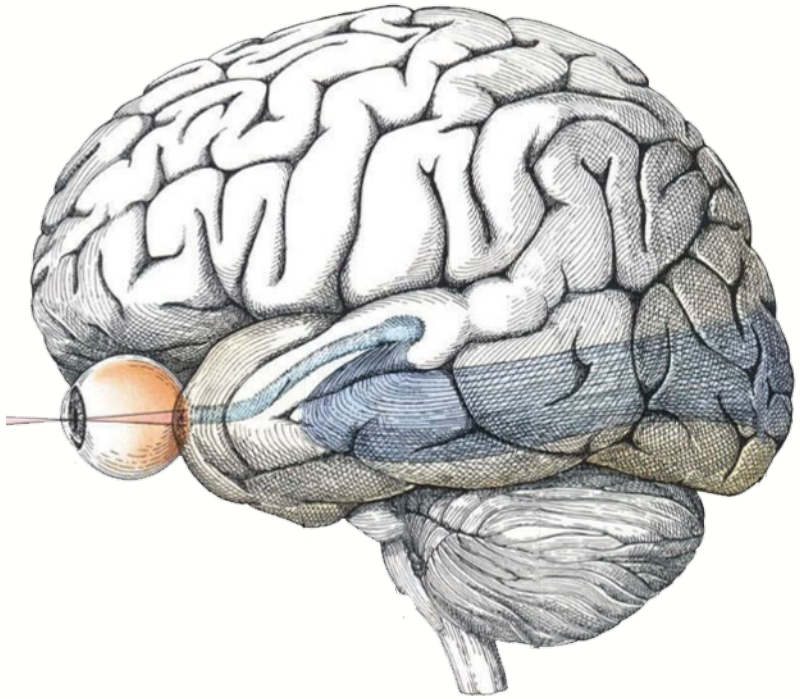
STIMULUS



RESPONSE

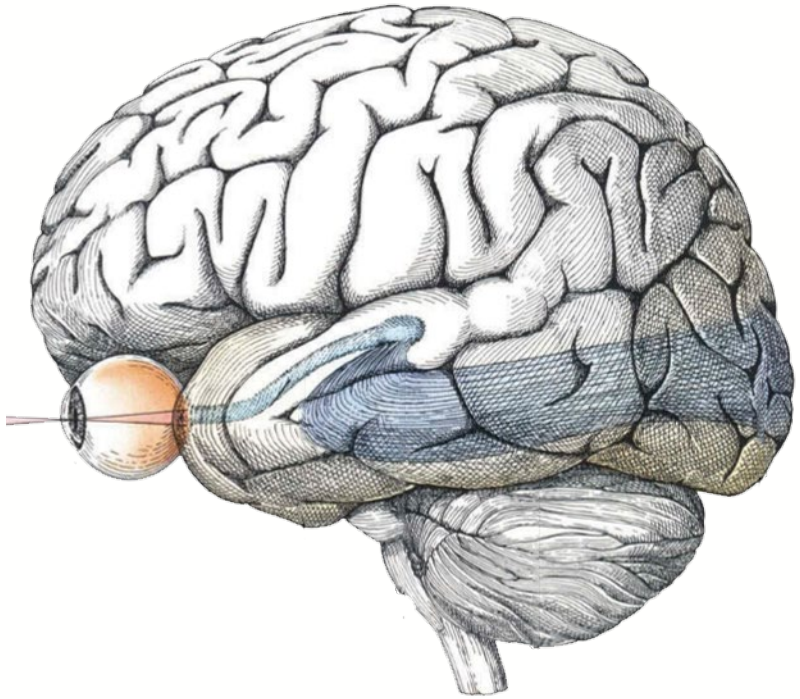
- Discomfort
- Disability

GLARE: the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility

Image: IES 10th Edition Lighting Handbook

$$\frac{L_s}{L_b}$$

STIMULUS



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L_s

L_b

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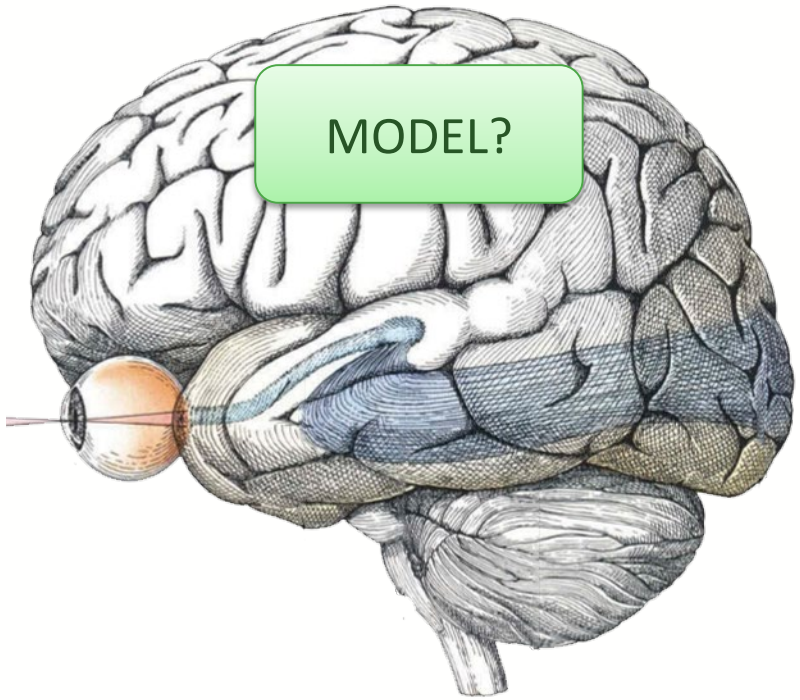
$$\frac{L_s\,\omega_s}{L_b\;p}$$



- Discomfort
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STIMULUS → RESPONSE

DISCOMFORT GLARE METRICS

- Initially developed to deal with fluorescent sources
- Empirically derived characterizations of the stimulus to predict discomfort results from rating scales (de Boer, Hopkinson)
- No underlying theoretical or biological model

Image: IES 10th Edition Lighting Handbook

Discomfort Glare Metrics

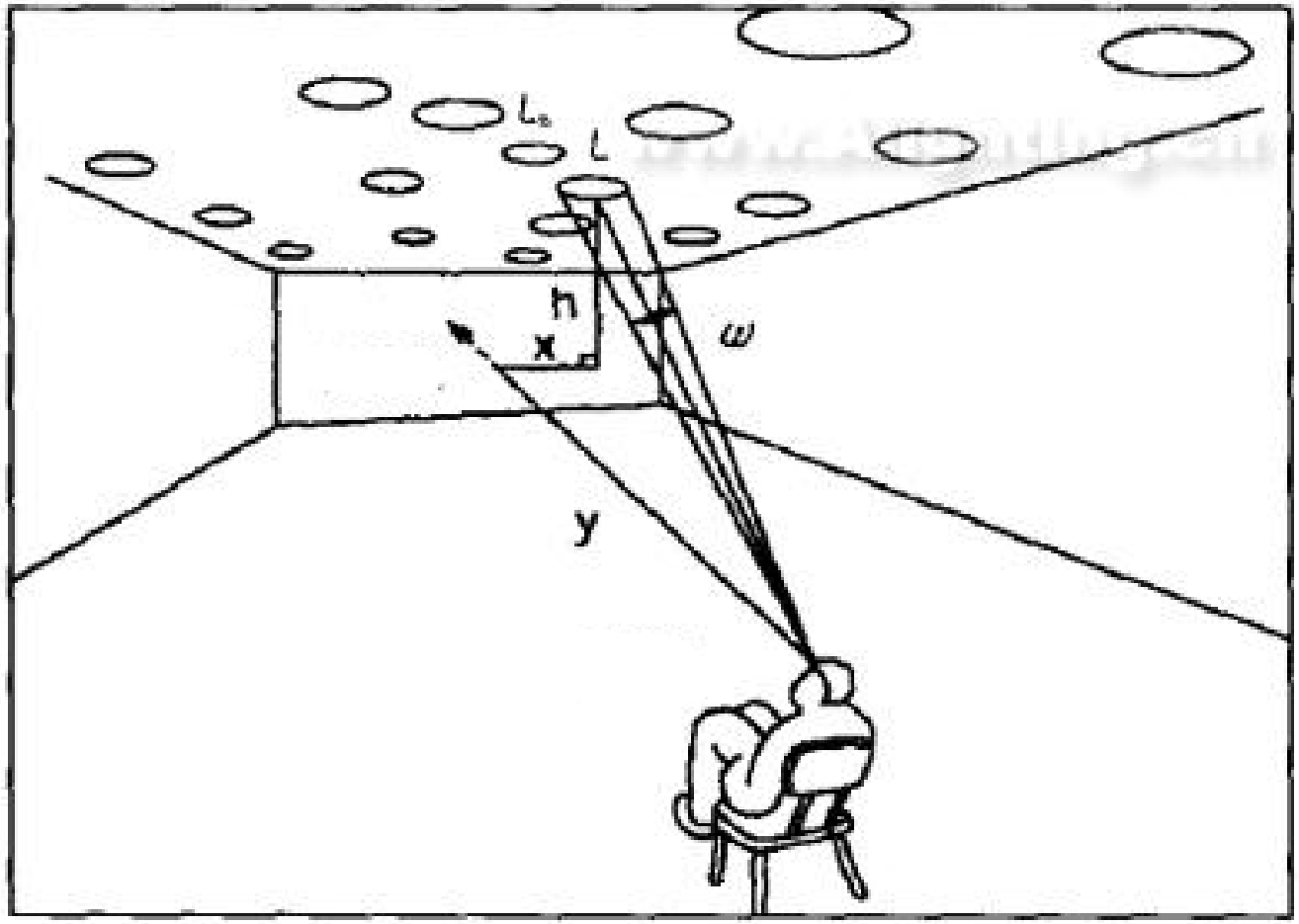
Metric/Index	Year	Source	Notes
British Glare Index (BGI)	1950	IES – London (1967)	Small sources, no daylight
Visual Comfort Probability (VCP)	1963	IES - New York	Uniform, medium-size, no daylight
CIE Glare Index (CGI)	1979	CIE	Combine & correct BGI & VCP
Daylight Glare Index (DGI)	1982	Research	Modified BGI for daylight
Glare Rating (GR)	1994	CIE 112-1994	Exterior
Unified Glare Rating (UGR)	1995	CIE 117-1995	Refinement of CGI
UGR for small sources (UGR_{small})	2002	CIE 147-2002	
Daylight Glare Probability (DGP)	2006	Research	
BUG Rating	2011	IES	Exterior

UGR -- DGP -- BUG

Unified Glare Rating (UGR)

$$UGR = 8\log\left(\frac{0.25}{L_b}\sum\frac{L^2\omega}{p^2}\right)$$

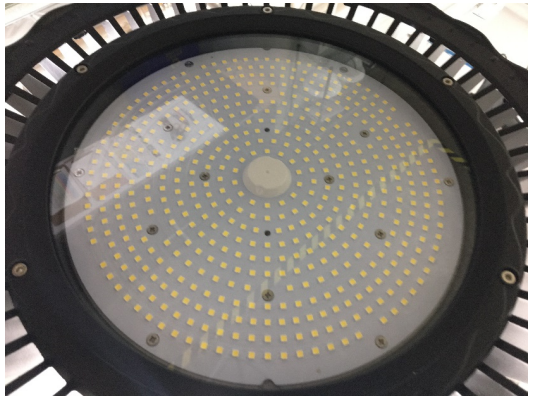
$5 \leq UGR \leq 30$



UGR	Hopkinson's Rating Scale
<10	Imperceptible
<13	Just Perceptible
<16	Perceptible
<19	Acceptable
>22	Unacceptable
>25	Just Uncomfortable
>28	Uncomfortable

Metrics for Discomfort Glare - Issues w/ Stimulus

- L_s - uses average luminance and assumes uniform luminance over luminous area (luminaire aperture)
  - Bare LEDs can be over 1 million cd/m^2 (compare to T5HO fluorescent lamps at 25-30,000 cd/m^2)



Metrics for Discomfort Glare - Issues w/ Stimulus

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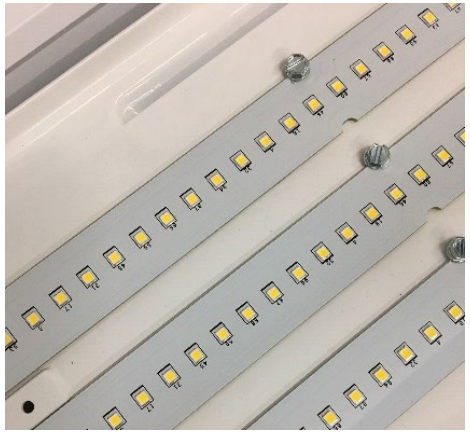
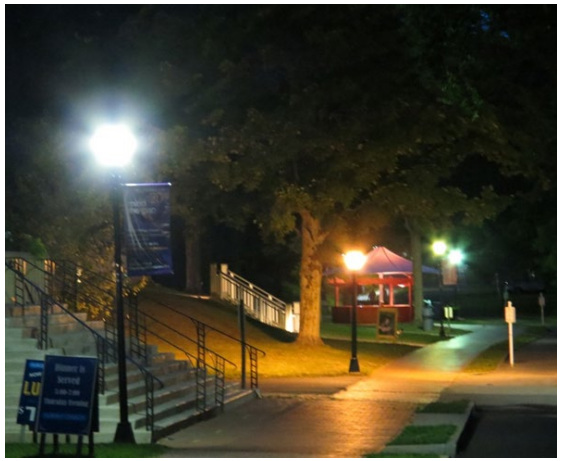
- L_b – can be difficult to define – local? global? adaptation?





Metrics for Discomfort Glare - Issues w/ Stimulus

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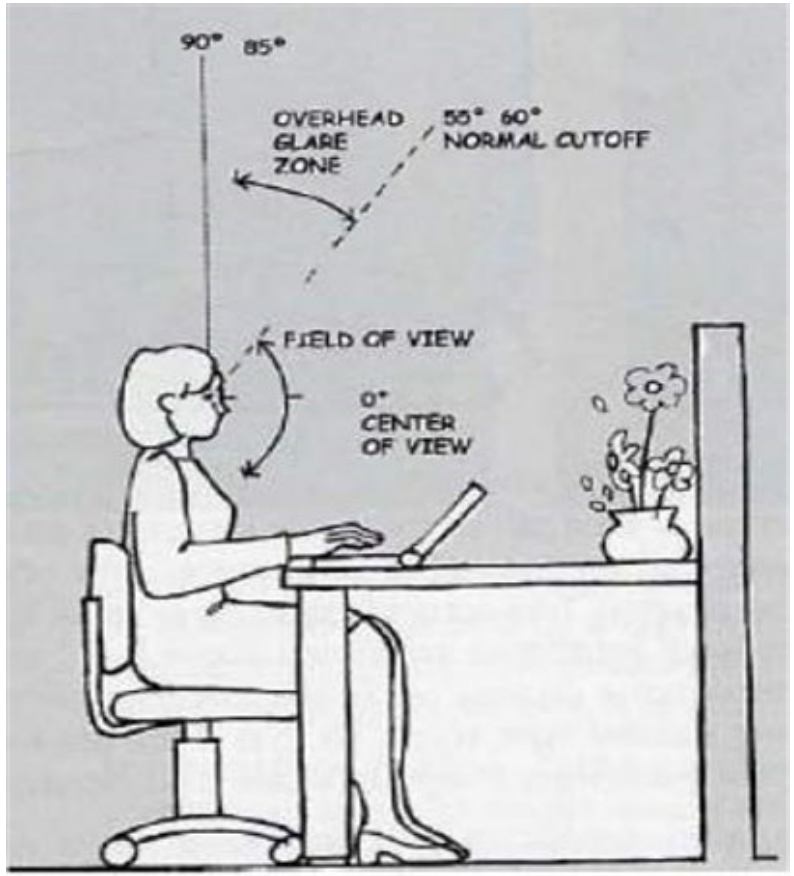
- ***p*** – assumes horizontal line of sight and a cutoff at about 55 from horizontal



Source picture: IES DG-18-08

Metrics for Discomfort Glare - Issues w/ Stimulus

- L_s - uses average luminance and assumes uniform luminance over luminous area (luminaire aperture)
- L_b – can be difficult to define – local? global? adaptation?
- ***p*** – assumes horizontal line of sight and a cutoff at about 55 from horizontal
- Does not account for differences in SPD

Metrics for Discomfort Glare - Issues w/ Response

- Three order sequences: ascending, descending, and randomised.
- Substantial bias due to order effects.
- "This demonstrates the need for caution when interpreting subjective evaluations of discomfort due to glare and estimating the robustness of glare indices derived from studies that used Hopkinson's scale and procedure."

Discomfort Glare Criteria	
A	Just Intolerable
B	Just Uncomfortable
C	Satisfactory
D	Just Not Perceptible

Kent, M., Fotios, and Altomonte, S. (2018) *Building and Environment*, 136. pp. 56-61.

CIE JTC7: Luminaires with non-uniform luminances (CIE 232-2019)

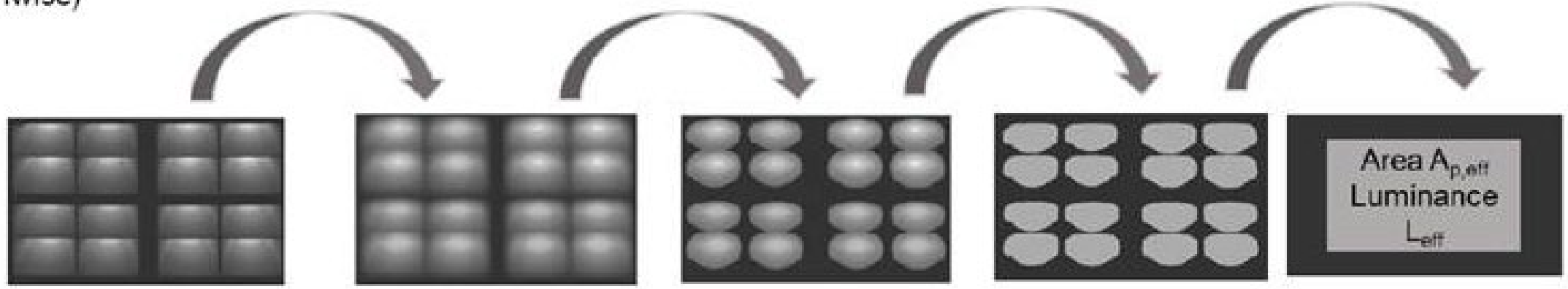
Step 1
2 or 4 High resolution luminance images (50° and 65° from normal, cross and lengthwise)

Step 2
Filter image to correct for eye resolution (Gaussian with 12 mm FWHM at luminaire)

Step 3
Remove pixels below luminance threshold (500 cd/m²)

Step 4
Calculate total area and average luminance of pixels above threshold luminance

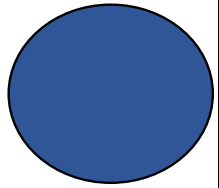
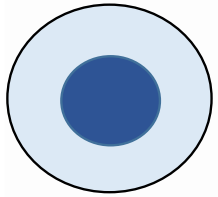
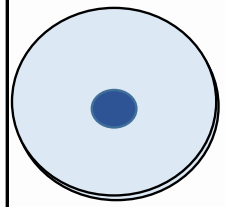
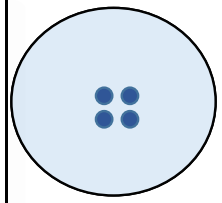
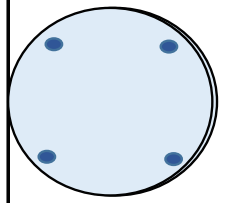
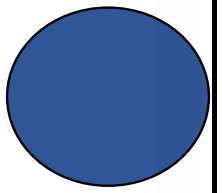
Step 5
Group all sources within a luminaire into one source with an effective projected area and effective luminance



$$UGR' = \mathrm{UGR} + 8\log\frac{L^2{}_{eff}\omega_{eff}}{L^2{}_s\,\omega}$$

Photos courtesy of Acuity Brands Lighting

IES D-GONE Committee – Street, Area, Sports Lighting?

	Approx 5.7" dia.	Approx 1.8" dia.	Approx 0.57" dia.	(4) Approx 0.29" dia.	(4) Approx 0.29" dia.	Approx 5.7" dia.
						
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Luminous flux, lm	317					3173
Luminous intensity, cd	64.9					649
Average luminance of the luminaire, L_s, cd/m^2	6,000					60,000

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	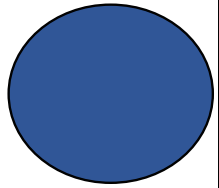	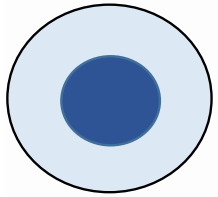	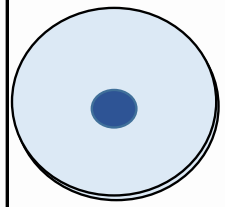	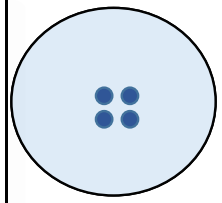	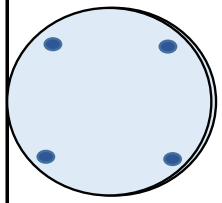	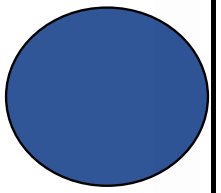
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	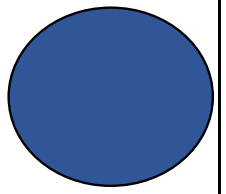	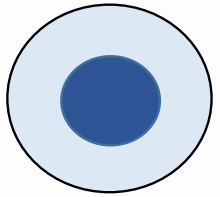	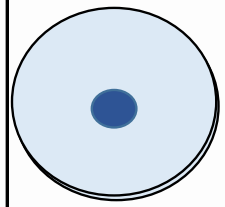	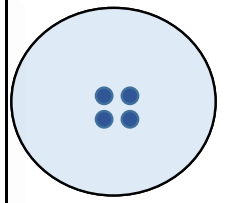	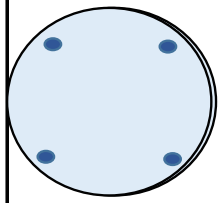	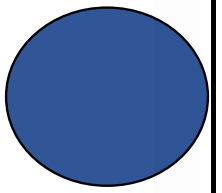
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Luminance of the luminous parts >500 cd/m^2, L_{eff}, cd/m^2	6,000	59,914	598,273	598,273	598,273	60,000

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	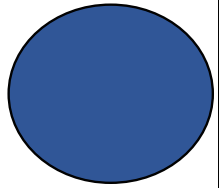	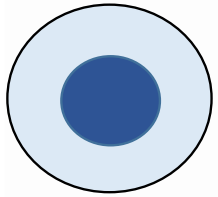	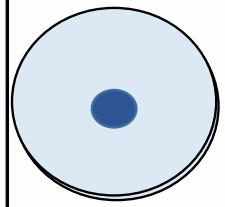	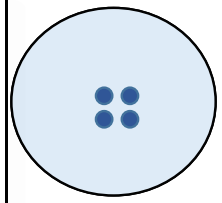	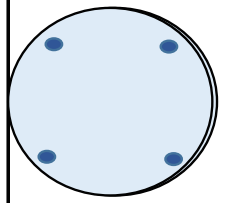	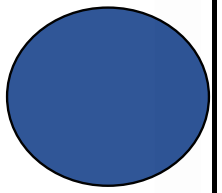
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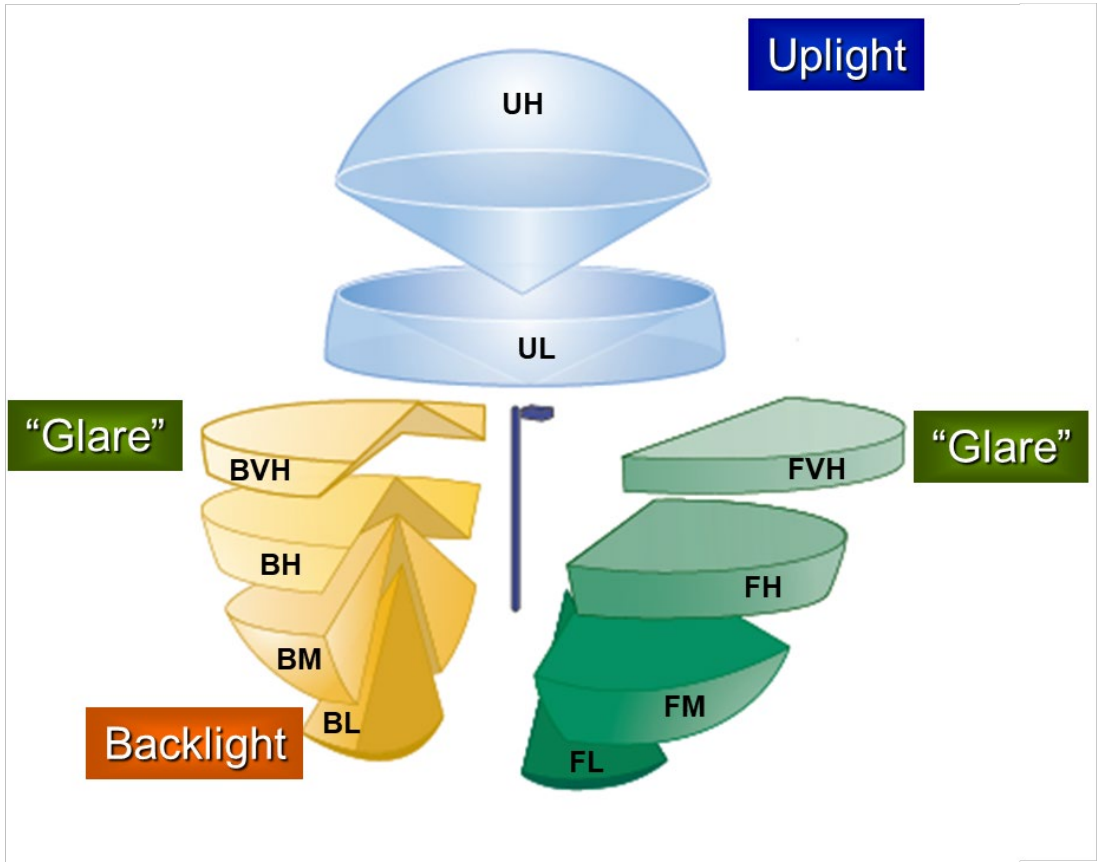
Luminance of the luminous parts >500 cd/m^2, L_{eff}, cd/m^2	6,000	59,914	598,273	598,273	598,273	60,000
Alternative UGR value UGR' (source area is area above 500 cd/m2 threshold)	13.7	21.6	29.6	29.6	29.6	29.7

Outdoor: The "G" in BUG Rating (IES TM-15-11)



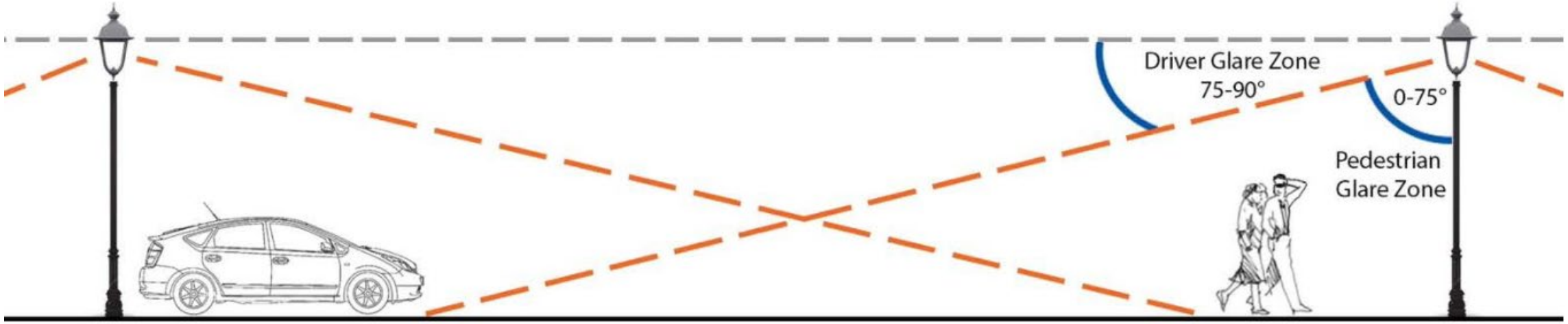
Glare Rating for Quadrilateral Symmetrical Luminaire Types (Type V, Type V Square)

	Secondary Solid Angle	G0	G1	G2	G3	G4	G5
Glare / Offensive Light	FVH	10	100	225	500	750	>750
	BVH	10	100	225	500	750	>750
	FH	660	1800	5000	7500	12000	>12000
	BH	660	1800	5000	7500	12000	>12000

Maximum zonal lumens

IES LOPS – Lighting for Outdoor Pedestrian Spaces (LP-2, RP-33,…)

- Use BUG rating “G” value for now
- Modified UGR may be the answer in the future
- Considering limits to M/P ratios



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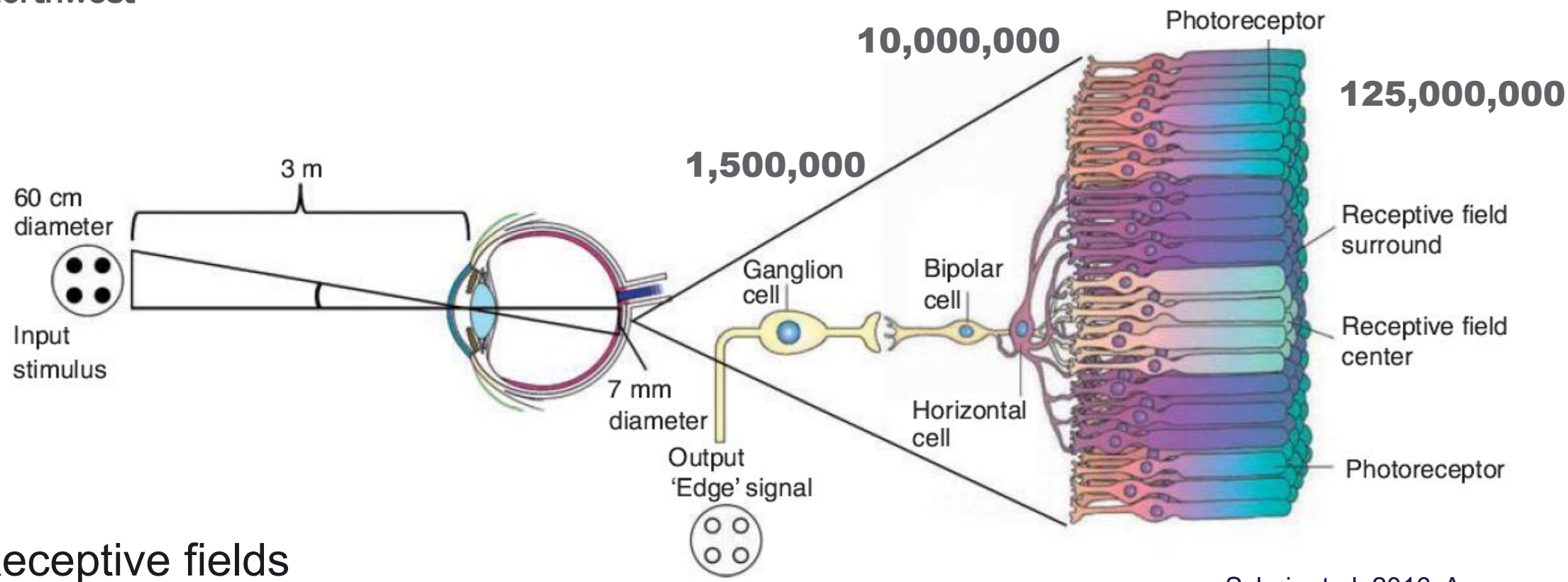
Glare metrics are not dead . . .

. . . YET . . .

. . . but do we need a new start?

Glare metrics: A new beginning??



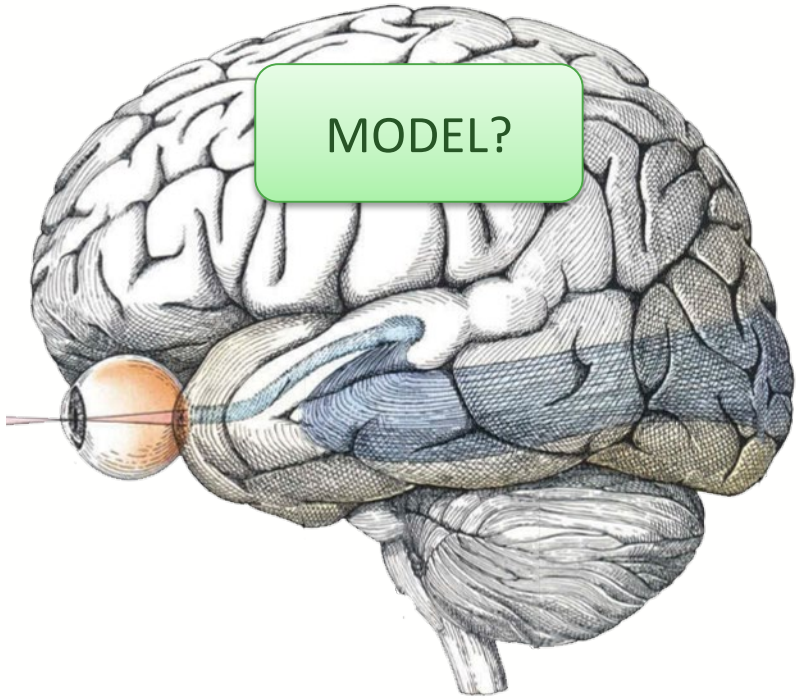
Receptive fields

- Retina is designed to compress data from visual field
- Ganglion cell layers collect data from many photoreceptors to detect visual changes such as edges, luminance contrasts
- Receptive fields affect "hardness" of edges, contrast perception

Scheir et al, 2016, A psychophysical model for visual discomfort based on receptive fields, *LR&T 2016; 0:1-13.*

$$\frac{L_s\,\omega_s}{L_b\;p}$$

STIMULUS



RESPONSE

- Discomfort
- Disability

Simplified geometry
Simplified measurements

HDRI?
VR?

Empirical basis

Visual science basis?

Rating scales

Eye tracking?
Motor responses?
fMRI?

Image: IES 10th Edition Lighting Handbook

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Searching for Holy Grails: A Glaring Lack of Definition

UPDATES:

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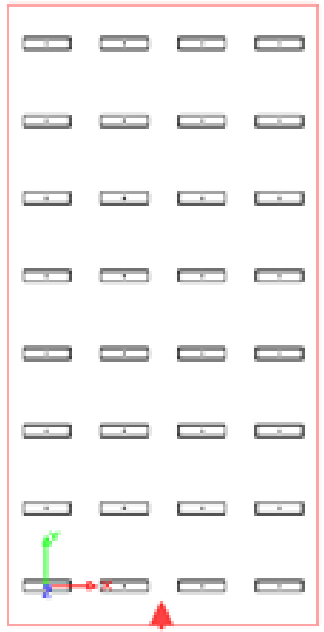
Table of the corrected unified glare ratings (UGR)

Luminaire distance / suspension height above observer's eye: $s/H = 0,25$

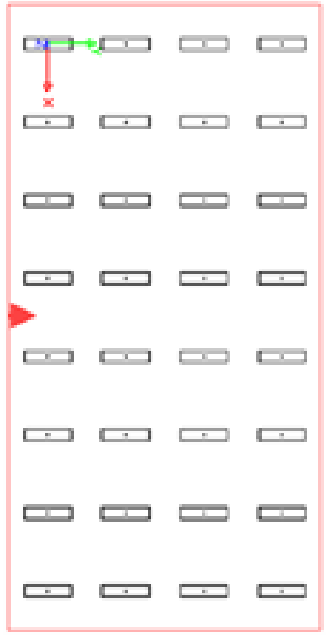
Reflectance values										
Ceiling		**0,70**	0,70	0,50	0,50	0,30	**0,70**	0,7		
Walls		**0,50**	0,30	0,50	0,30	0,30	**0,50**	0,3		
Floor		**0,20**	0,20	0,20	0,20	0,20	**0,20**	0,2		
Room dimensions		**Corrected glare assessments – Luminous flux 3,300 lm**								
X	Y	Viewing direction: oblique					Viewing dire			
$2H$	$2H$	19,8	21,4	20,3	21,9	22,5	16,6	18,		
	$3H$	22,3	23,8	22,8	24,4	25,0	17,8	19,		
	$4H$	23,7	25,1	24,2	25,7	26,3	18,2	19,		
	$6H$	25,2	26,5	25,7	27,1	27,7	18,5	19,		
	$8H$	25,9	27,2	26,5	27,8	28,4	18,6	19,		
	$12H$	26,6	27,9	27,2	28,5	29,1	18,6	19,		
$4H$	$2H$	20,2	21,7	20,8	22,2	22,9	17,9	19,		
	$3H$	23,0	24,3	23,6	24,9	25,5	19,4	20,		
	$4H$	24,6	25,7	25,2	26,3	27,0	20,0	21,		
	$6H$	26,2	27,3	26,8	27,9	28,6	20,4	21,4	21,0	22,0
	$8H$	|27,1|	28,0	27,7	28,7	29,4	20,5	21,5	21,1	22,1
	$12H$	27,9	28,8	28,6	29,5	30,2	20,6	21,4	21,2	22,1
$8H$	**$4H$**	**24,8**	25,8	25,4	26,4	27,1	|20,9|	21,9	21,6	22,5
	$6H$	26,7	27,5	27,3	28,2	28,9	21,7	22,5	22,3	23,2
	$8H$	27,7	28,4	28,4	29,1	29,8	22,0	22,7	22,6	23,4
	$12H$	28,7	29,4	29,4	30,0	30,8	22,1	22,8	22,8	23,5
$12H$	$4H$	24,8	25,7	25,4	26,3	27,1	21,2	22,1	21,8	22,7
	$6H$	26,8	27,5	27,4	28,2	28,9	22,1	22,9	22,8	23,5
	$8H$	27,8	28,5	28,5	29,1	29,9	22,5	23,2	23,2	23,9

3 Offices

Ref. no.	Type of interior, task or activity	$\bar{E}_m$ lx	UGR_L -	R_a -
3.1	Filing, copying, etc.	300	19	80
3.2	Writing, typing, reading, data processing	500	19	80
3.3	Technical drawing	750	16	80
3.4	CAD work stations	500	19	80
3.5	Conference a			
3.6	Reception de			
3.7	Archives			



Crosswise View
X=4H, Y=8H



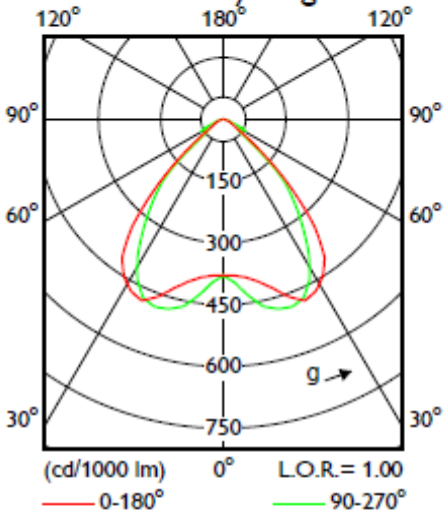
Endwise View
X=8H, Y=4H

UGR on a luminaire cut sheet

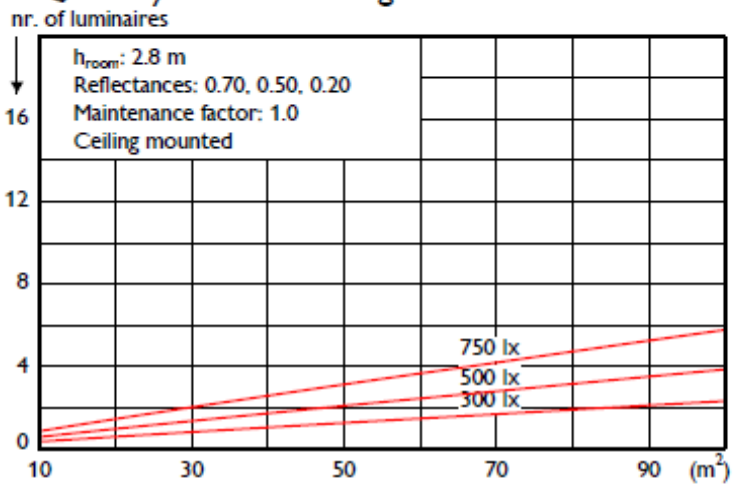
BY470P 1 xGRN130S/840 WB GC

1 x 13000 lm

Polar intensity diagram



Quantity estimation diagram



Light output ratio	1.00
Service upward	0.00
Service downward	1.00
CIE flux code	70 96 100 100 100
S/H ratio crosswise	max. 1.5
lengthwise	max. 1.7
UGRcen (4Hx8H, 0.25H)	23
UTE71-121:	1.00AS + 0.00T

Utilisation factor table

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80	0.80	0.70	0.70	0.70	0.70	0.50	0.50	0.30	0.30	0.00
	0.50	0.50	0.50	0.50	0.50	0.30	0.30	0.10	0.30	0.10	0.00
	0.30	0.10	0.30	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.00
0.60	0.62	0.59	0.62	0.60	0.59	0.53	0.53	0.49	0.52	0.49	0.47
0.80	0.73	0.69	0.72	0.70	0.68	0.62	0.62	0.58	0.61	0.58	0.56
1.00	0.82	0.76	0.80	0.78	0.75	0.70	0.69	0.66	0.69	0.65	0.63
1.25	0.90	0.82	0.88	0.85	0.81	0.77	0.76	0.72	0.75	0.72	0.70
1.50	0.95	0.86	0.93	0.89	0.86	0.81	0.80	0.77	0.79	0.77	0.75
2.00	1.04	0.93	1.01	0.96	0.92	0.88	0.87	0.85	0.86	0.84	0.82
2.50	1.09	0.96	1.06	1.01	0.95	0.93	0.91	0.89	0.90	0.88	0.86
3.00	1.13	0.99	1.10	1.03	0.98	0.95	0.94	0.92	0.93	0.91	0.89
4.00	1.17	1.01	1.14	1.07	1.00	0.98	0.97	0.95	0.95	0.94	0.92
5.00	1.20	1.03	1.16	1.08	1.02	1.00	0.98	0.97	0.97	0.96	0.93

Ceiling mounted

Luminance Table

Plane / Cone	0.0	45.0	90.0
45.0	40200	72449	35583
50.0	21386	53339	14700
55.0	10051	30152	10335
60.0	7226	13031	13348
65.0	5924	6458	14050
70.0	5226	5219	7761
75.0	4335	4439	8265
80.0	3331	3142	5226
85.0	1610	1377	2077
90.0	-	-	-

(cd/m2)

UGR = 23

LVP0050300

2017-02-08