2019 DLC

April 1 - 3 • St. Louis, MO

STAKEHOLDER MEETING

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Glare metrics

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LEDs have come a *LONG* way in 10 years….

- Efficacy is AWESOME!
- Color is STELLAR!
- Output is IMPRESSIVE!
- Optics are OUTSTANDING!
- Dimmability is ….. getting there…





But…

- Flicker is FLAKY
- Glare can be **gosh awful** if you are not paying attention


Principal Flavors of Glare

- Disability Glare
  - Really not sensory glare, but visibility reduction for interior or exterior
  - Light source close to axis of view that creates scatter (the “veil”) that obscures the visual image on the retina
  - Mechanism fairly well understood
  - Can be calculated (L_v *is veiling luminance, E= illuminance at eye,* θ *= angular displacement from axis of view*)

$$L_v(\theta) = [10E/\theta^2] \text{ for } 1^\circ < \theta < 30^\circ$$

Images courtesy of The International Dark-Sky Association

Principal Flavors of Glare

- Discomfort Glare
  - Light source in the field of view brighter than the luminance to which the observer is adapted
  - Causes discomfort
  - Mechanism poorly understood
  - Many mediocre discomfort glare metrics exist
  - Visual Comfort Probability (VCP) worked for lensed 2x4 troffers but not small sources, indirect lighting, or non-uniform sources such as parabolic louvers or LED arrays
  - Unified Glare Rating (UGR) is somewhat better at predicting glare response, but still falls short for small sources and non-uniform sources

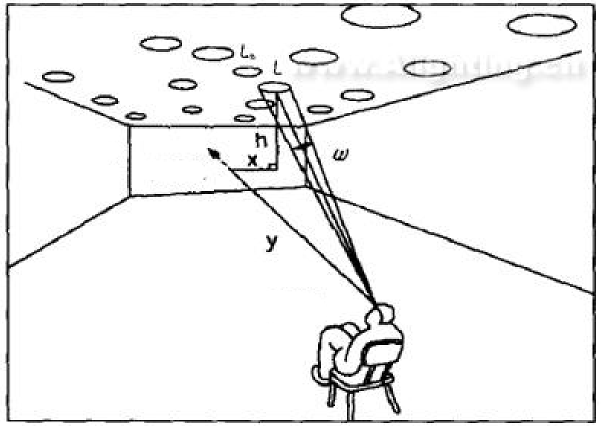
Discomfort Glare Metric Landscape

Metric/Index	Year	Research or Standard	Note
British Glare Index (BGI)	1950	Research	
Visual Comfort Probability (VCP)	1963	IES	Interior
Discomfort Glare Index (DGI)	1972	Research	
European Glare Limiting Method	1972	Research	
CIE Glare Index (CGI)	1979	Research	
Glare Rating (GR)	1994	CIE 112-1994	Exterior
Unified Glare Rating (UGR)	1995	CIE 117-1995	
UGR for small sources (UGR_{small})	2002	CIE 147-2002	
Max. luminance above 53° FOV	2003	IES	
Discomfort Glare Probability (DGP)	2005	Research	
Discomfort Glare	2008	Research	
BUG Rating	2011	IES	Exterior

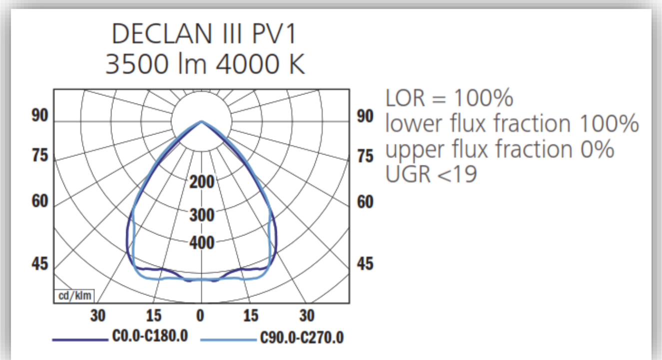
Unified Glare Rating (UGR)

Formula & Common Use

- UGR evaluates glare sensation of a space from a particular observer position
  - $UGR = 8\log\left(\frac{0.25}{L_b}\sum\frac{L^2\omega}{p^2}\right)$, a function of
    - Luminance of each luminaire (L)
    - Background luminance (L_b)
    - Observer's position in relation to the lights
  - The formula produces a value between 5 and 30
  - Not originally a luminaire glare metric
- In Europe, UGR is commonly listed in product spec sheets for the worst case viewing position (one luminaire)



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



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UGR Standardization

UGR Formula Standardization

CIE 117:1995 Discomfort Glare in Interior Lighting

- Formally recommend UGR: ***unifying*** several early glare ratings
- UGR Tabular method

Also reference in several U.S. Standards and publications

- IES RP-1-12, RP-7-17, Handbook
- WELL Standard

UGR Table

CIE 190:2010 Calculation and Presentation of UGR Tables for Indoor Lighting Luminaires

- Standard conditions
- Use of uncorrected UGR table

$$UGR(\Phi) = UGR(\Phi_0) + 8\log\left(\frac{\Phi}{\Phi_0}\right),$$

$$\Phi_0 = 1000 \text{ lm}$$

Reflectances:											
Ceiling (cavity)		0,7	0,7	0,5	0,5	0,3	0,7	0,7	0,5	0,5	0,3
Wall		0,5	0,3	0,5	0,3	0,3	0,5	0,3	0,5	0,3	0,3
Reference plane		0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Room dimensions		Viewed crosswise					Viewed endwise				
X=2H	Y=2H	8,9	10,5	9,3	10,8	11,1	10,7	12,2	11,0	12,5	12,9
	3H	10,5	11,9	10,8	12,2	12,6	12,4	13,8	12,8	14,2	14,5
	4H	11,0	12,3	11,4	12,6	13,0	13,1	14,5	13,5	14,8	15,2
	6H	11,5	12,7	11,9	13,1	13,5	13,6	14,8	14,0	15,2	15,6
	8H	11,7	12,9	12,2	13,3	13,7	13,8	14,9	14,2	15,3	15,7
	12H	12,0	13,2	12,5	13,5	14,0	13,8	15,0	14,3	15,3	15,8
4H	2H	9,6	11,0	10,0	11,3	11,7	11,0	12,4	11,4	12,7	13,1
	3H	11,4	12,5	11,8	12,9	13,3	13,0	14,1	13,4	14,5	14,9
	4H	12,0	13,0	12,4	13,4	13,9	13,9	14,9	14,3	15,3	15,7
	6H	12,7	13,5	13,1	14,0	14,4	14,5	15,4	15,0	15,8	16,3
	8H	13,0	13,8	13,5	14,2	14,7	14,7	15,5	15,2	16,0	16,4
	12H	13,4	14,1	13,8	14,6	15,0	14,8	15,6	15,3	16,0	16,5
8H	4H	12,4	13,2	12,8	13,6	14,1	14,0	14,8	14,5	15,3	15,8
	6H	13,2	13,8	13,7	14,3	14,8	14,8	15,4	15,3	15,9	16,4
	8H	13,6	14,2	14,1	14,7	15,2	15,0	15,6	15,5	16,1	16,6
	12H	14,1	14,7	14,6	15,1	15,7	15,2	15,7	15,7	16,2	16,8
12H	4H	12,4	13,1	12,9	13,6	14,1	14,0	14,8	14,5	15,2	15,7
	6H	13,2	13,8	13,8	14,3	14,8	14,8	15,4	15,3	15,9	16,4
	8H	13,7	14,3	14,3	14,8	15,3	15,1	15,6	15,6	16,1	16,7

UGR Thresholds/Limits

EN 12464-1:2002/2011
Lighting of Work Places – Part 1: Indoor

- UGR limits (UGR_L) defined for different spaces and usage
- Based on the UGR tabular method

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 and meeting rooms	500	19	80
3.6	Reception desk	300	22	80
3.7	Archives	200	25	80

UGR < 19 is the most commonly referenced threshold

UGR for LED Lighting

CIE Technical Committee is developing a correction factor for UGR to better predict glare from LED luminaires

Indoor Discomfort Glare – UGR – Used in Europe

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

UGR	Discomfort Glare Criterion
10	Imperceptible
13	Just perceptible
16	Perceptible
19	Just acceptable
22	Unacceptable
25	Just uncomfortable
28	Uncomfortable

Unified Glare Rating (UGR):

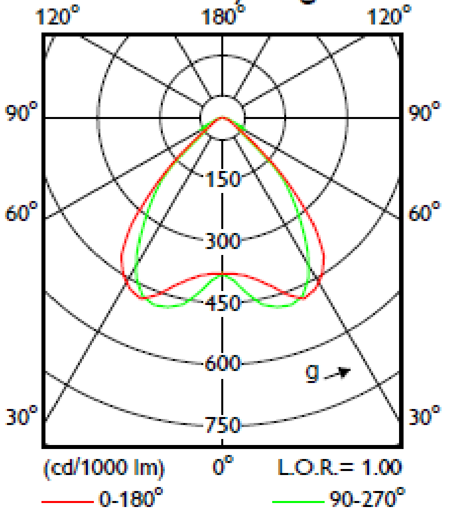
- The best of the competing metrics, although it's still not fully predictive for interior lighting
- Based on scale above
- Can be calculated for a specific room and lighting layout, a typical room layout, or for an individual luminaire
- Similar to VCP tables of yore

UGR on a luminaire cut sheet

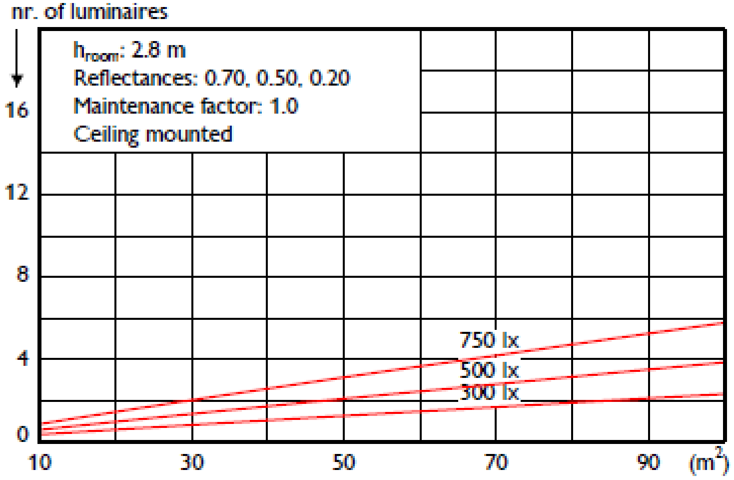
BY470P 1 xGRN130S/840 WB GC

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 0.50 0.30	0.80 0.50 0.10	0.70 0.50 0.30	0.70 0.50 0.20	0.70 0.50 0.10	0.70 0.30 0.10	0.50 0.30 0.10	0.50 0.10 0.10	0.30 0.30 0.10	0.30 0.10 0.10	0.00 0.00 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

Discomfort Glare - Background

Reasons glare metrics don't work very well

- Average luminance over luminaire aperture is most commonly used for luminaire luminance. This is a highly inaccurate assumption now that we have luminaires with visible arrays of LEDs. It misstates the AREA and the LUMINANCE.

$$UGR = 8 \cdot \log\left(\frac{0.25}{L_{Background}}\right)\sum_n\left(\frac{L^2\omega}{p^2}\right)$$

where

$L = $ *Luminance of the luminous area*

$\omega = $ *size of the luminous area*

$p = $ *Guth position index*

$L_{Background} = $ *Background Luminance*

$n = $ *number of luminaires*

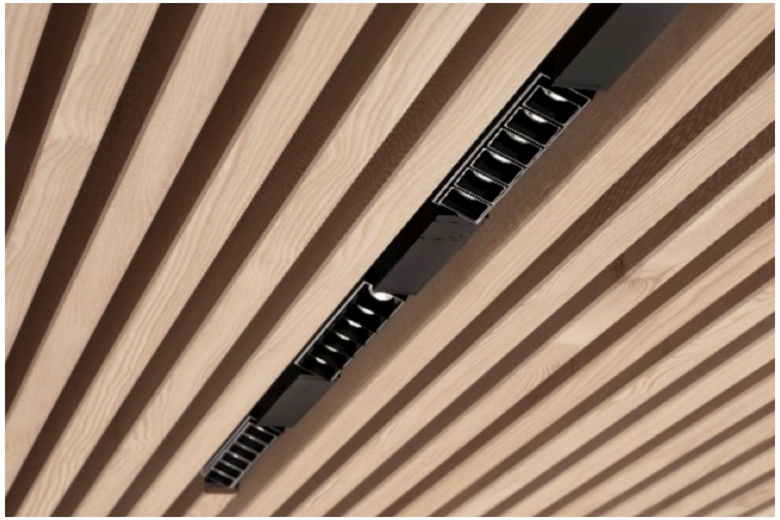
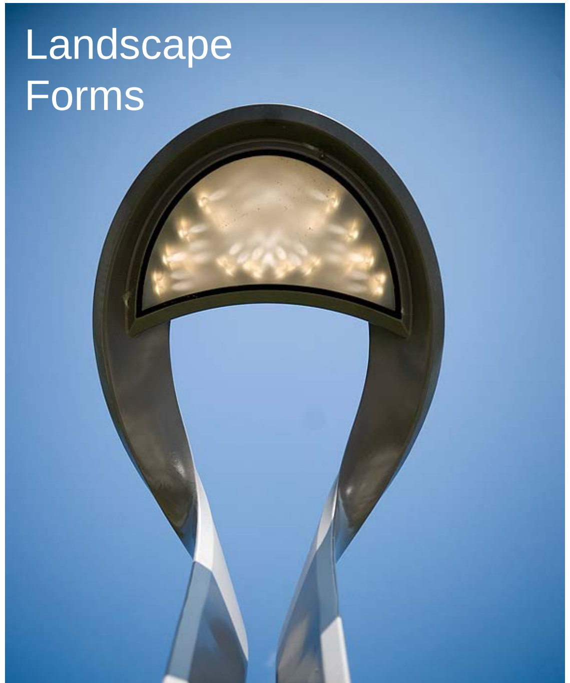
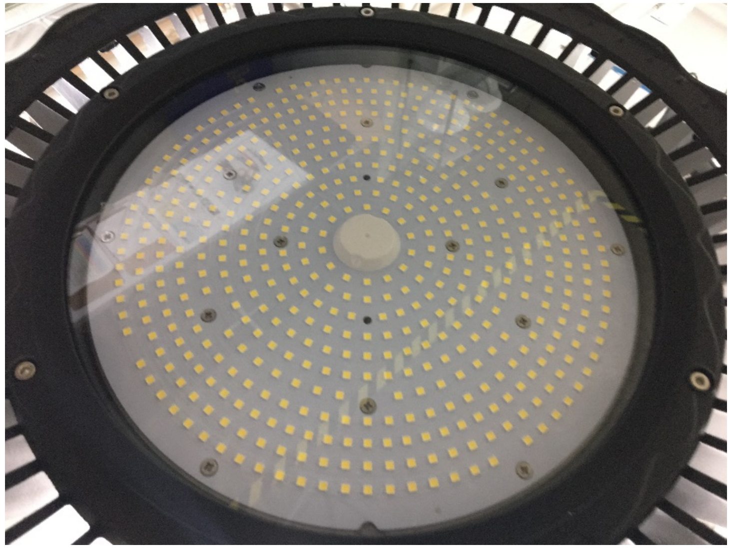


Photo: Zumtobel

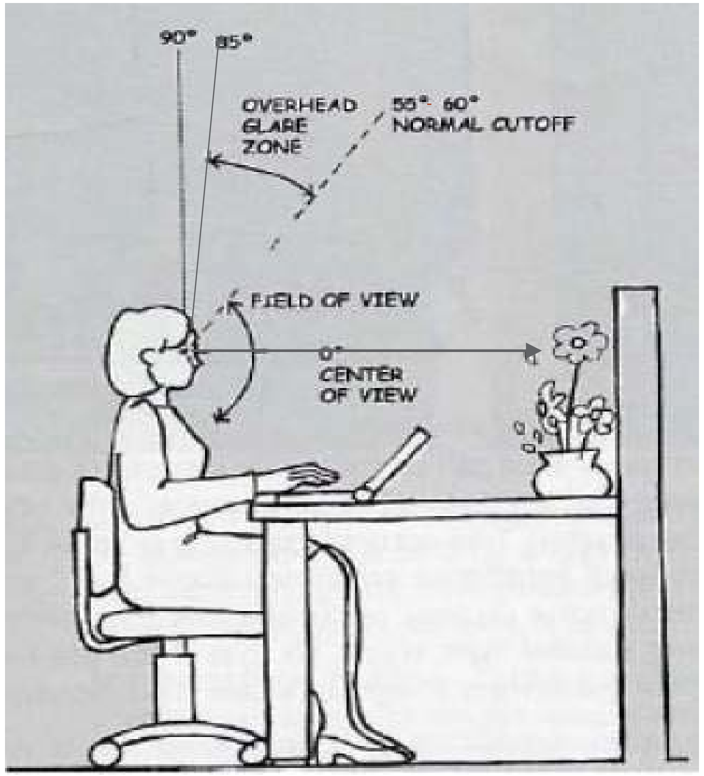




Discomfort Glare - Background

Reasons glare metrics don’t work very well

- Position index assumes discomfort disappears as luminaire image vanishes from visual field (approx. 55° above axis of view). Also, assumption that observer doesn’t look above horizontal when experiencing a room.

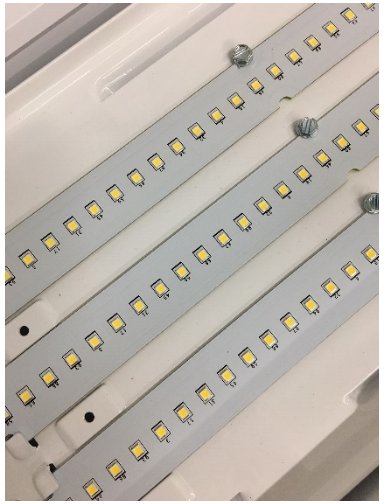


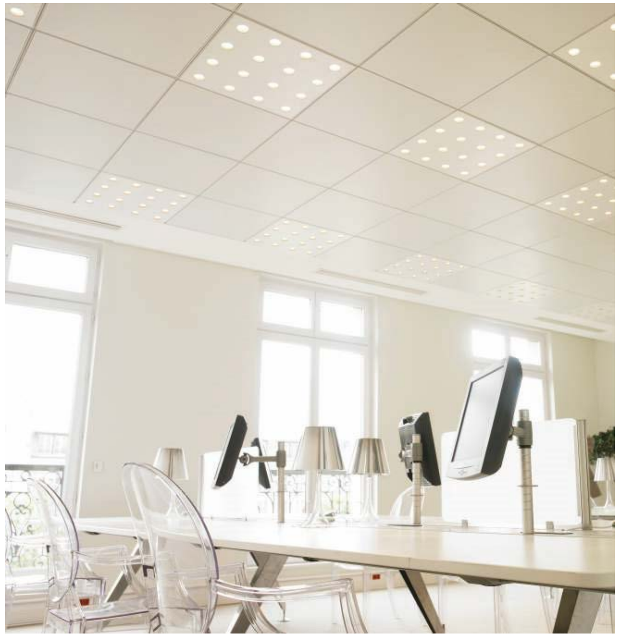
Source picture: IES DG-18-08

Discomfort Glare - Background

More reasons glare metrics don't work very well

- No consideration of how SPD affects the discomfort glare response.
- What is the background luminance? Area behind LED, the ceiling area, the dark night sky, or adaptation luminance?

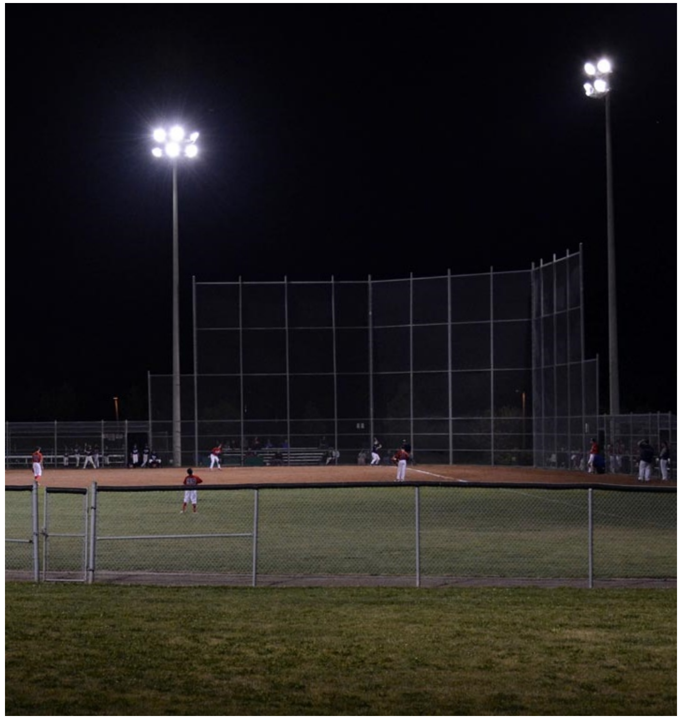




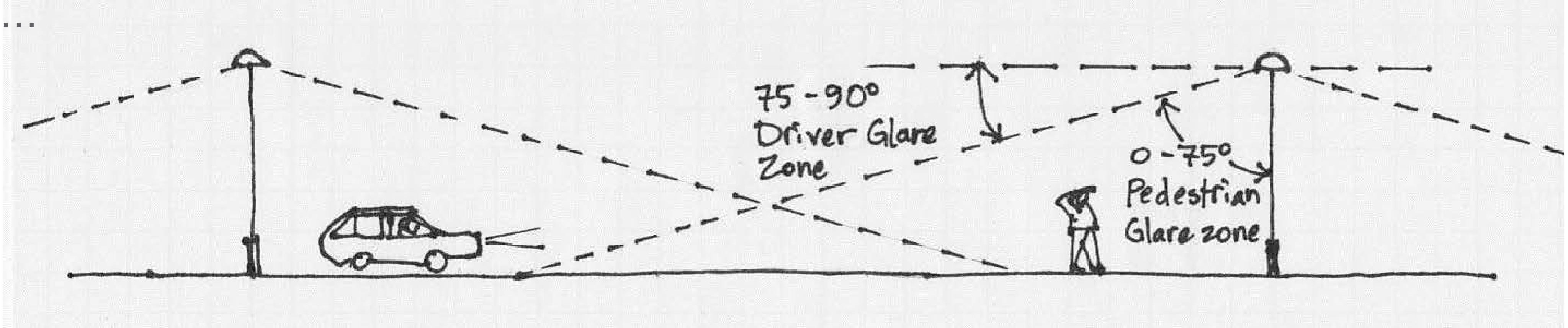
Discomfort Glare - Background

The CIE and IES have been wrestling with glare metrics:

- CIE Joint Technical Committee 7 – looking at modification to UGR for non-uniform luminance luminaires
- IES DGONE Committee – trying to find a metric to document and predict glare from outdoor street and area lights and sports lighting at night
- IES LOPS Committee – Need glare metric for RP on pedestrian outdoor spaces. Recognition that driver discomfort glare angles are not same as pedestrian glare angles. Recognition that BUG system works poorly for pedestrians.
- Others…

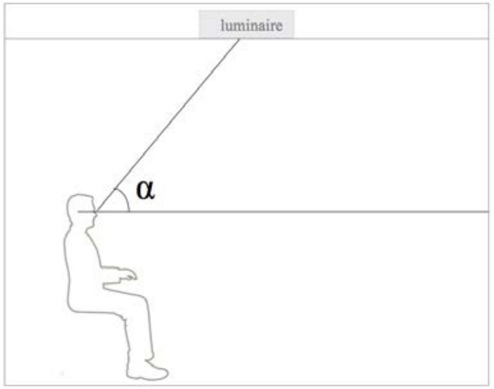


Town of Oakville, ON, Canada



Well Standard Glare Requirements

- Glare control
  - Luminaire shielding (cutoff angle, measured from nadir) for different luminaire luminance
    - 75° for 20,000-50,000 cd/m^2
    - 70° for 50,000-500,000 cd/m^2
    - 60° for 500,000 cd/m^2
  - Luminaire luminance < 8,000 cd/m^2 above α=53° from horizon
  - UGR ≤ 19

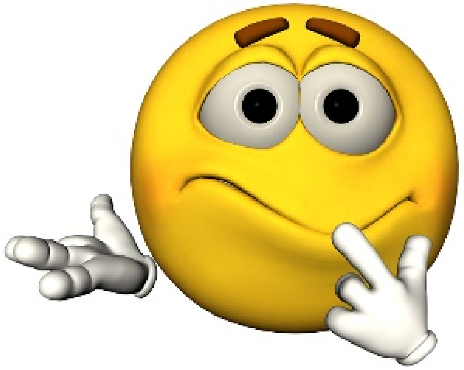


??????????

Indoor Discomfort Glare

Unified Glare Rating (UGR):

- Generally relies on the .ies file defined aperture for luminaire "luminous area"
- Larger luminous areas = lower UGR values (= more comfortable)
- What do we do about LEDs????
- Bare LEDs can be 1.5 million cd/m^2 or higher (compare to T5HO fluorescent lamps at 25-30,000 cd/m^2)



CIE JTC7 approach to dealing with luminaires with non-uniform luminances

Revise UGR luminous area assumption:

- Take HDRi image of luminaire from 50° and 65° from luminaire nadir, and filter image for blur. Sum areas with luminance >500 cd/m^2 into effective luminous area. Calculate effective solid angle.

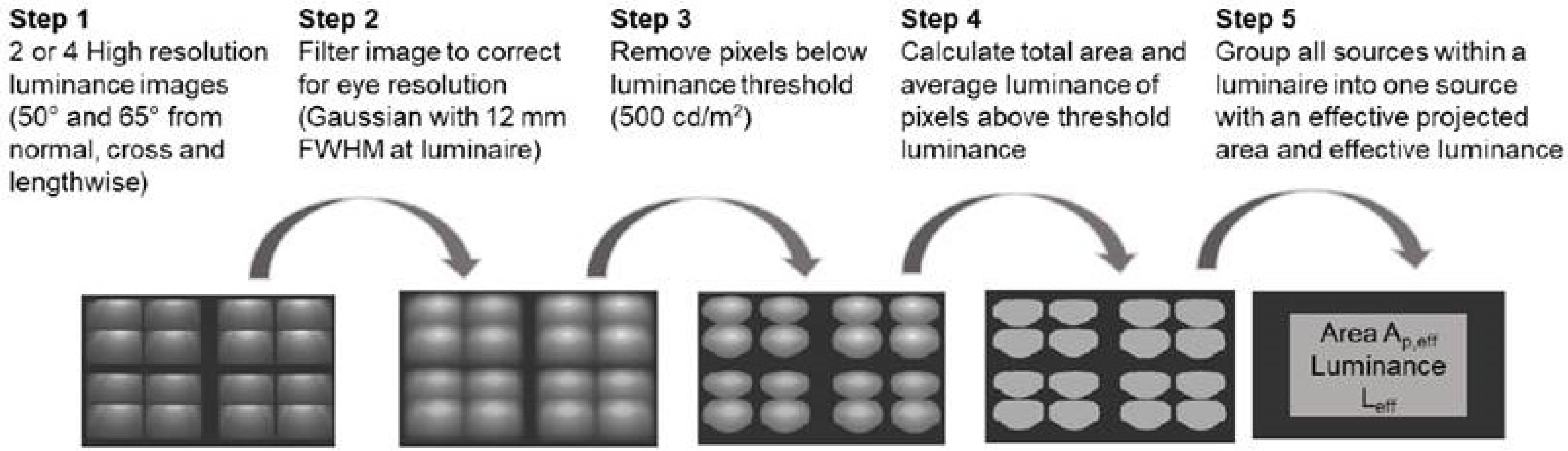


Figure 2 – Overview of the measurement and image processing steps that are required to obtain the effective projected area and effective luminance. Note that the effective solid angle of the source ω_{eff} is equal to the effective projected area $A_{p,eff}$ divided by the measurement distance squared.

CIE JTC7 Approach*

- Divide candela value at 50° (for example) by effective projected area to get effective luminance.
- Calculate effective solid angle.
- Plug the effective values into the equation:

$$UGR' = UGR + 8\log\frac{L_{eff}^2\,\omega_{eff}}{L_s^2\,\omega}$$

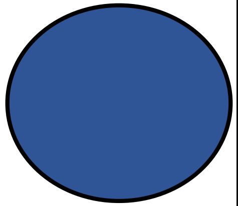
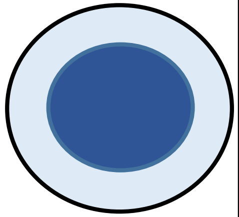
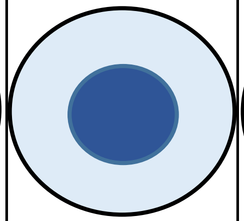
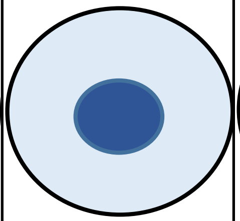
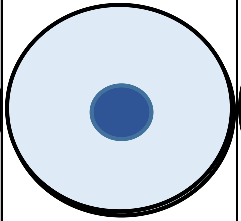
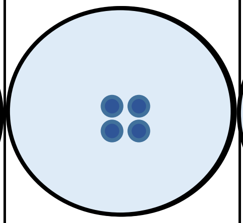
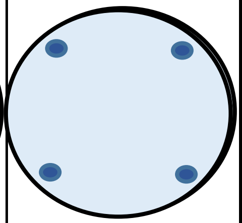
- At the same lumen output, a 10-fold reduction in luminous area will increase the UGR value by 8.
- But, does this make sense in practice?

Photos courtesy of Acuity Brands Lighting

* This JTC7 method is likely to be published by the CIE in July 2019. It is based on a combination of methods by the Leuven and Ilmenau groups. Also see M. C. J. M. Vissenberg "Illumination optics of LED luminaires", Proc. SPIE 10693, Illumination Optics V, 106930L (28 May 2018); doi: 10.1117/12.2315402; https://doi.org/10.1117/12.2315402

The opportunity

- Brad Schlesselman of Musco is chair of DGONE committee, and wants to test UGR for an outdoor glare metric
- He is building two LED luminaires with wide-range dimming and interchangeable masks to demonstrate luminance distribution
- PNNL is collaborating with DGONE on this demo for the upcoming CIE Quadrennial meeting – demonstration of Modified UGR

	Approx 5.7" dia.	Approx 3.2" dia.	Approx 1.8" dia.	Approx 1" dia.	Approx 0.57" dia.	(4) Approx 0.29" dia.	(4) Approx 0.29" dia.
Image							
Description	**Diffuse, full area**	**1/3.16th area**	**1/10th area**	**1/31.6 area**	**1/100th area, concentrated**	**1/100th area, clustered dots**	**1/100th area, separated dots**
Luminance of the luminous parts >500 cd/m^2, L_{eff}, cd/m^2	6000	18,960	59,914	189,327	598,273	598,273	598,273

CIE Meeting proposed mockup

- We are proposing a mockup of the luminaires, two luminance/aperture size combinations at a time.
- Observer is looking at point on the floor in order to preserve a normal viewing geometry in a 9’ ceiling hotel room. Distance from observer eye to luminaire is 8.7’.

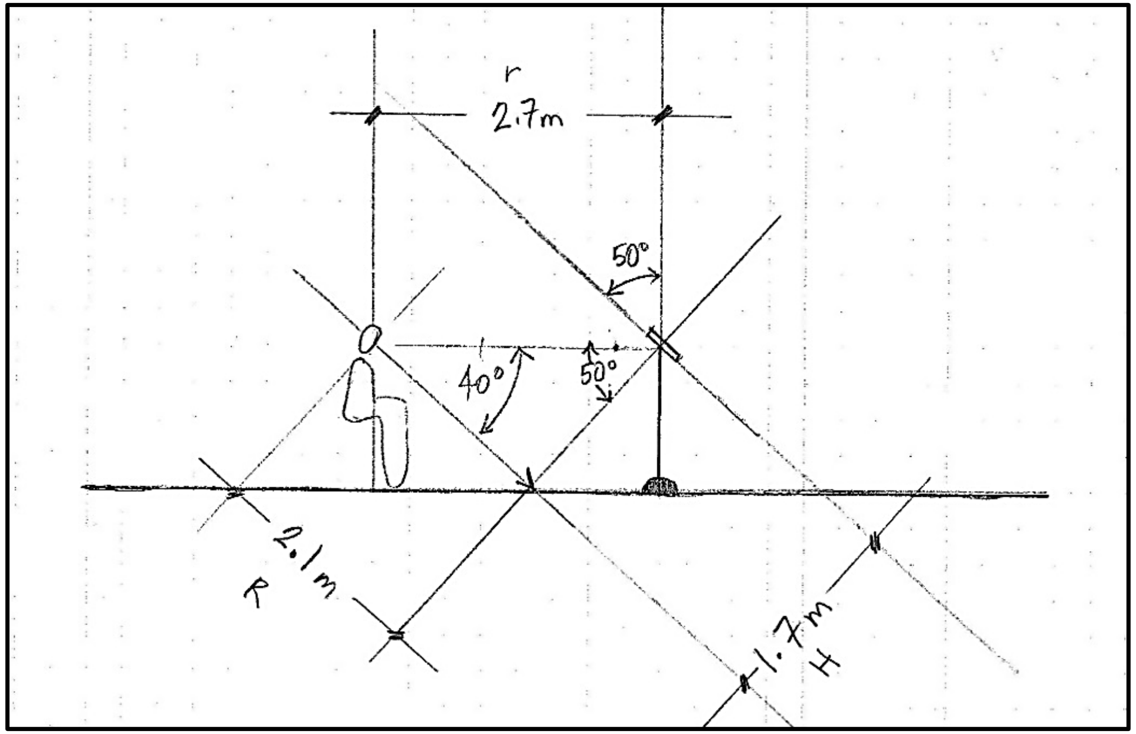


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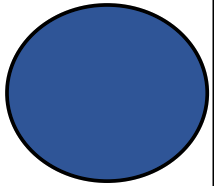
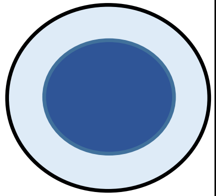
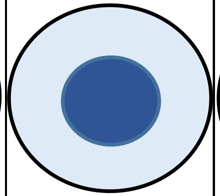
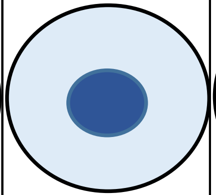
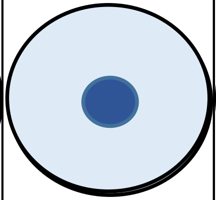
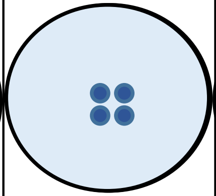
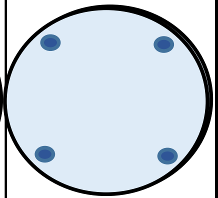
Image							
Description	**Diffuse, full area**	**1/3.16th area**	**1/10th area**	**1/31.6 area**	**1/100th area, concentrated**	**1/100th area, clustered dots**	**1/100th area, separated dots**
Luminaire aperture diameter, m	0.1464	0.1464	0.1464	0.1464	0.1464	0.1464	0.1464
High luminance area diameter, m	0.1464	0.0823	0.0463	0.0260	0.0146	0.0073	0.0073
Luminous area > 500 cd/m^2, m^2	0.0168	0.0053	0.0017	0.0005	0.00017	0.00017	0.00017
Lumens from luminaire	317	317	317	317	317	317	317
Conventional UGR value (source area is full exit window)	8.1	8.1	8.1	8.1	8.1	8.1	8.1
Alternative UGR value UGR' (source area is area above 500 cd/m2 threshold, without visual acuity blurring)	**8.1**	**12.1**	**16.1**	**20.1**	**24.1**	**24.1**	**24.1**
Modified UGR value UGR_{JTC7} (source area defined according to JTC7 method)	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**
Small size UGR extension value, UGR_S	**NA**	**NA**	**NA**	**10.8**	**10.8**	**5.9**	**5.9**

Inquiring minds want to know….

- Is UGR based on one luminaire or an installation of luminaires?
  - Technically an installation of luminaires. But it can be calculated for one luminaire, which is the worst case scenario.
  - Thus, it provides BOTH the capabilities of publishing a UGR value for a single luminaire on a spec sheet, and using it in software such as AGI32 to calculate the predicted glare response to a roomful of luminaires.

- Can modified UGR be adapted for use with outdoor lighting as well?
  - Definite MAYBE. The DGONE Committee may want to sponsor human factors experiments to explore this. Background luminance will need to be a factor.
  - There is work by at least one researcher that shows promise for UGR for outdoor use.

Outdoor: The "G" in BUG Rating

Glare Designation in TM-15-11

- Adopted in policies/standards:
  - ANSI/IES RP-7-17
  - ANSI/IES RP-8-14
  - ANSI/IES RP-20-14
  - USGBC LEED
  - CA Title 24: Part 6 & 11 (CalGreen)

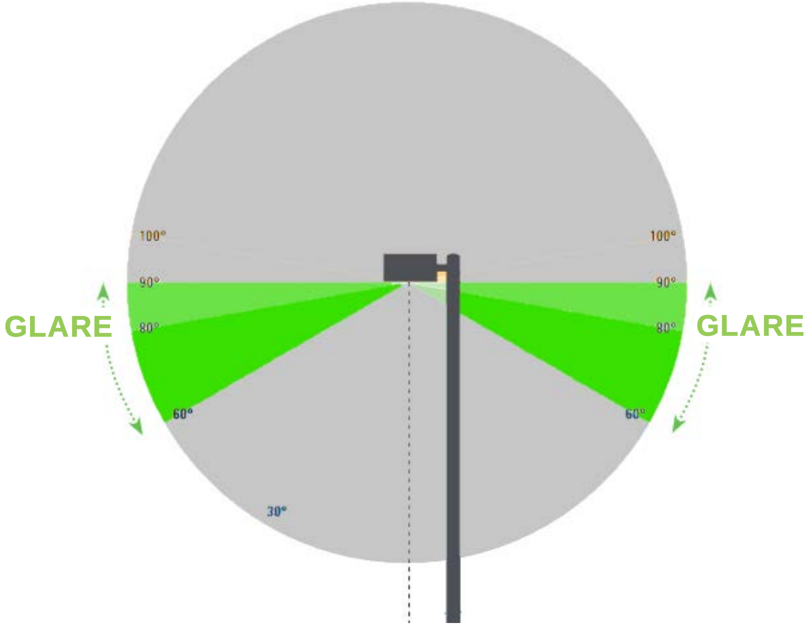


Table A-3: Glare Ratings (maximum zonal lumens)

Glare Rating for Asymmetrical Luminaire Types (Type I, Type II, Type III, Type IV)

Glare / Offensive Light: Secondary Solid Angle	G0	G1	G2	G3	G4	G5
FVH	10	100	225	500	750	>750
BVH	10	100	225	500	750	>750
FH	660	1800	5000	7500	12000	>12000
BH	110	500	1000	2500	5000	>5000

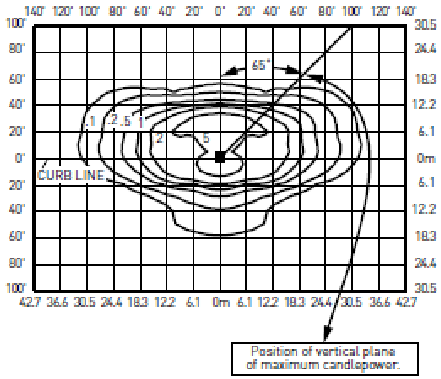
Glare Rating for Quadrilateral Symmetrical Luminaire Types (Type V, Type V Square)

Glare / Offensive Light: Secondary Solid Angle	G0	G1	G2	G3	G4	G5
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

The “G” in BUG Rating

Benefits

- Applicable to individual luminaires
- Provides objective comparison between products
- Glare component can be represented in 2 digits (e.g. "G0" or "G1“)
- Low testing burden: Can use existing photometric data



OSQ-A-**-2ME-U-40K-UL
Mounting Height: 25' (7.6m) A.F.G.
Initial Delivered Lumens: 27,706
Initial FC at grade

Type II Medium Distribution						
Input Power Designator	3000K		4000K		5700K	
	Initial Delivered Lumens*	BUG Ratings** Per TM-15-11	Initial Delivered Lumens*	BUG Ratings** Per TM-15-11	Initial Delivered Lumens*	BUG Ratings** Per TM-15-11
S	18,182	B3 U0 G2	21,696	B3 U0 G3	23,179	B3 U0 G3
U	26,258	B3 U0 G3	27,706	B3 U0 G3	28,285	B3 U0 G3

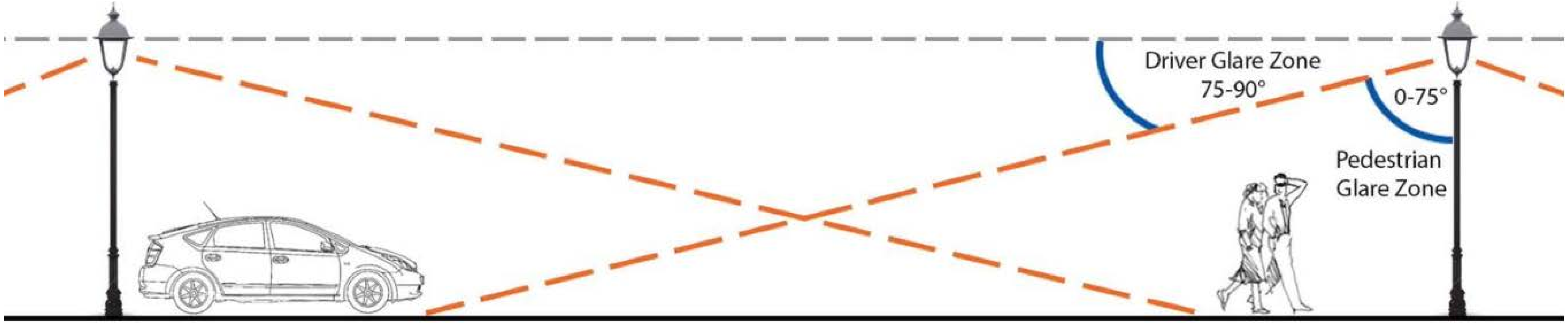
* Initial delivered lumens at 25°C (77°F). Actual production yield may vary between -10 and +10% of initial delivered lumens

** For more information on the IES BUG (Backlight-Uplight-Glare) Rating visit: www.ies.org/PDF/Erratas/TM-15-11BugRatingsAddendum.pdf. Valid with no tilt

The "G" in BUG Rating

Shortcomings

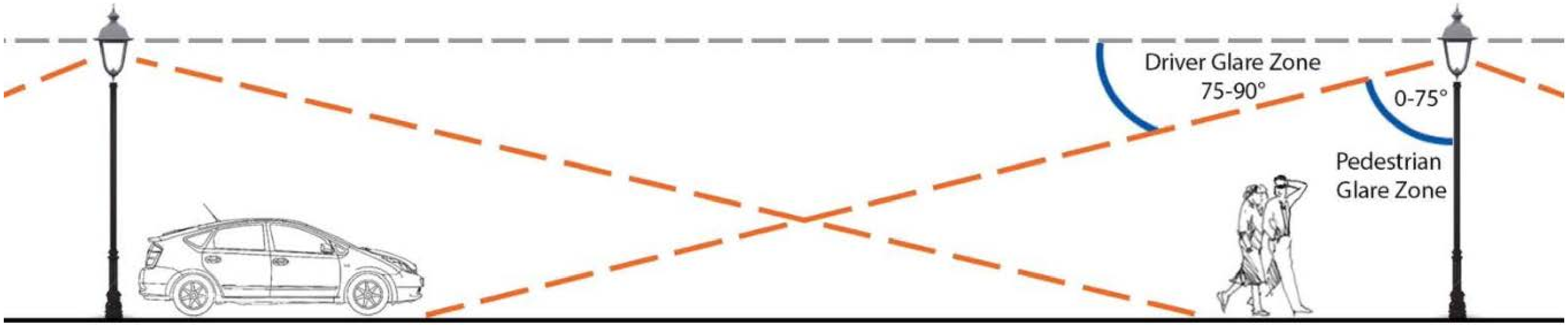
- May not perform well for pedestrians
  - Glare component only between 60°-90° from nadir
- Existing standards use application/lighting zone to determine thresholds
  - BUG limits not defined by fixture type/category



So, what to do for outdoor glare?

Use BUG rating “G” value for now

Modified UGR may be the answer in the future.



Thanks! All done now.

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