Modeling and Predicting Glare in Lighting Applications

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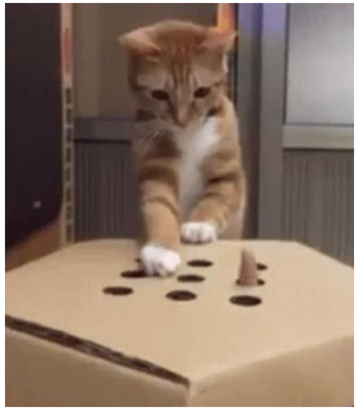
Icahn School of Medicine at Mount Sinai

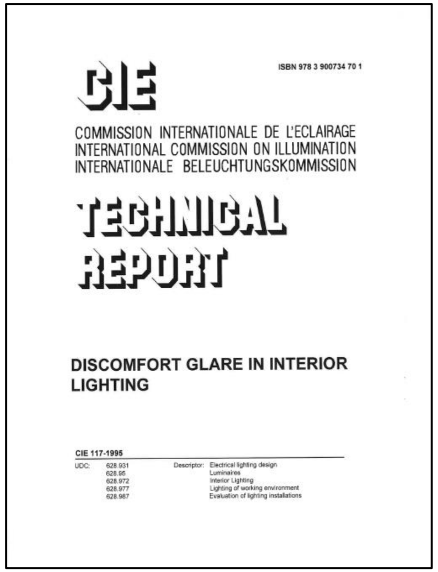
Light and Health Research Center

Glare is "A subject in a swamp"

(Peter Boyce)



- Why do we have different standards for indoor versus outdoor glare?



CIE

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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
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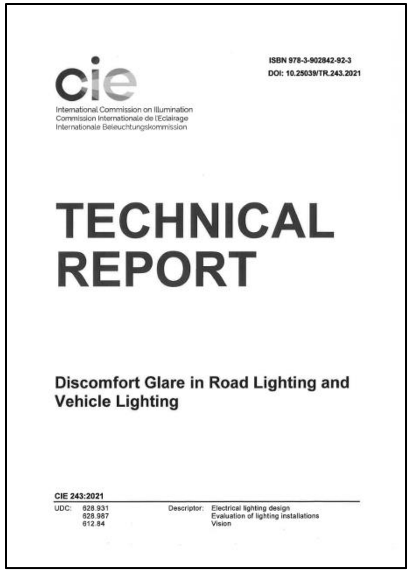
TECHNICAL REPORT

DISCOMFORT GLARE IN INTERIOR LIGHTING

CIE 117-1995

UDC: 628.931, 628.95, 628.972, 628.977, 628.987

Descriptor: Electrical lighting design, Luminaires, Interior Lighting, Lighting of working environment, Evaluation of lighting installations



cie

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

ISBN 978-3-902842-92-3
DOI: 10.25039/TR.243.2021

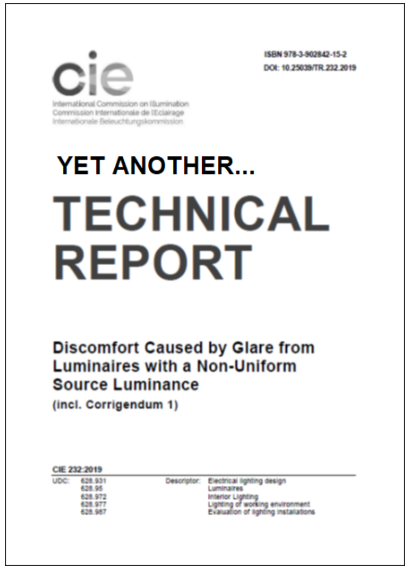
TECHNICAL REPORT

Discomfort Glare in Road Lighting and Vehicle Lighting

CIE 243:2021

UDC: 628.931, 628.987, 612.84

Descriptor: Electrical lighting design, Evaluation of lighting installations, Vision



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ISBN 978-3-902842-15-2
DOI: 10.25039/TR.232.2019

YET ANOTHER...

TECHNICAL REPORT

Discomfort Caused by Glare from Luminaires with a Non-Uniform Source Luminance
(incl. Corrigendum 1)

CIE 232:2019

UDC: 628.931, 628.95, 628.972, 628.977, 628.987

Descriptor: Electrical lighting design, Luminaires, Interior Lighting, Lighting of working environment, Evaluation of lighting installations

- Why do we need new/modified standards when new technologies (i.e., LEDs) arrive?
  - This shouldn't be a game of Whack-a-Mole!

- And, is this only going to get worse with circadian-effective lighting providing higher illuminances at the eyes?

What is disability glare?

- Reduction in visibility caused by luminous veil due to scattered light in the eye
  - Reduced contrast → reduced visibility

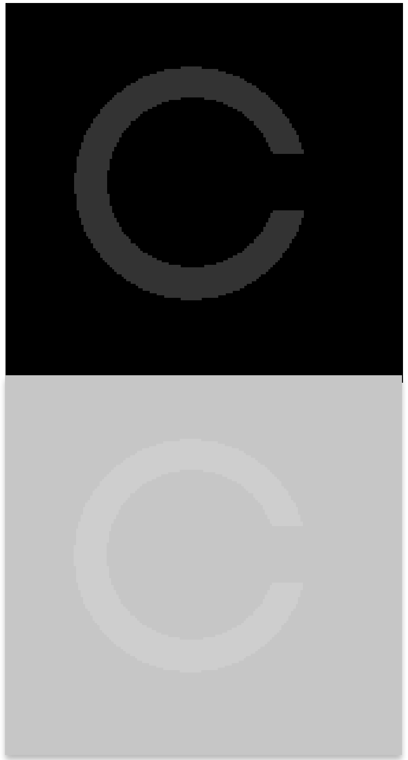
What is discomfort glare?

- Annoying or painful sensation when exposed to a bright light in the field of view
- May or may not accompany disability glare
- Probably the type of glare most people notice and are aware of
- Most commonly measured with subjective rating scales

1: no or just noticeable glare
2
3: satisfactory
4
5: just permissible
6
7: disturbing
8
9: unbearable

What factors influence disability glare?

- Disability glare is primarily a function of photopic illuminance at the eyes and the angular distance between the source and the object of interest (Bullough et al. 2002, 2003)

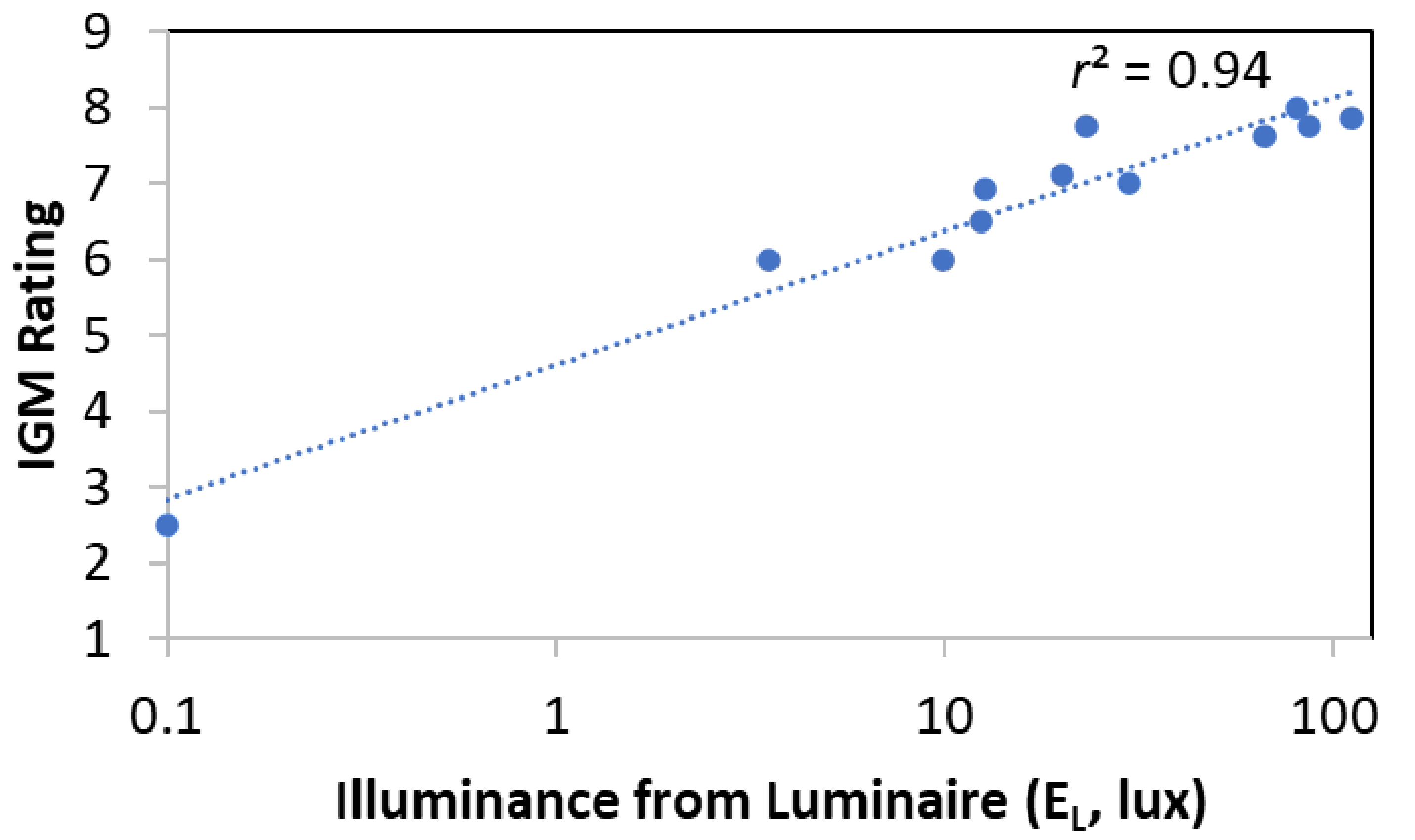


What influences discomfort glare?

- Illuminance from light source
- Brightness of immediate surround
- Ambient light level
- Spectral distribution
- Maximum luminance of light source

Generated by Dall-E

Illuminance and discomfort glare



Bullough et al. (2008)

Background light level and discomfort glare

www.fixturelab.com

Ambient light level and discomfort glare

Influence of luminaire spectrum on discomfort glare

- Sources with more short-wavelength (“blue”) content or higher correlated color temperature (CCT) are judged as more glaring than other sources, even for the same (photopic) intensity (Flannagan, 1999; Bullough et al., 2002, 2003)

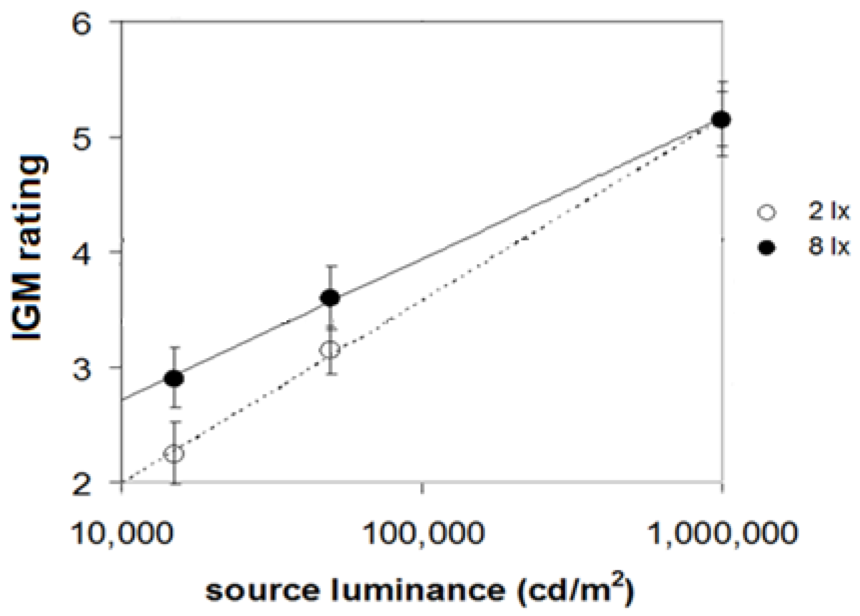
450 nm 510 nm 590 nm 650 nm 700 nm

Influence of maximum luminaire luminance on discomfort glare

- The sky (excluding the sun) produces tens of thousands of lux at the eyes
  - Not especially glaring
- Typical ceiling-mounted luminaires might produce hundreds of lux at the eyes
  - Can be quite glaring

Maximum luminaire luminance and discomfort

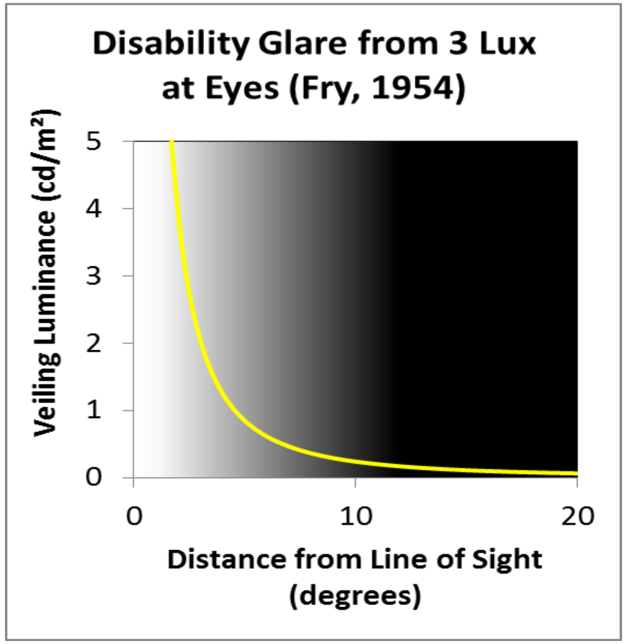
- Higher maximum luminances result in greater visual discomfort
- If a light source is small (<0.3º in visual angle), the effect of the maximum luminance is minimal
- Streetlighting and vehicle lighting sources are often <0.3º; pedestrian scale and indoor lighting sources are often >0.3º



Bullough and Sweater Hickcox 2012

Quantifying disability glare

- The apparent veiling luminance (L_v) can be determined by:
  - Illuminance at the eye (E, lux)
  - Distance between light source and line of sight (θ, degrees)
  - $L_v = 9.2E/[\theta(\theta + 1.5)]$ (Fry 1954)
    L_v is in cd/m²
  - L_v is added to luminance of target (L_t) and background (L_b)

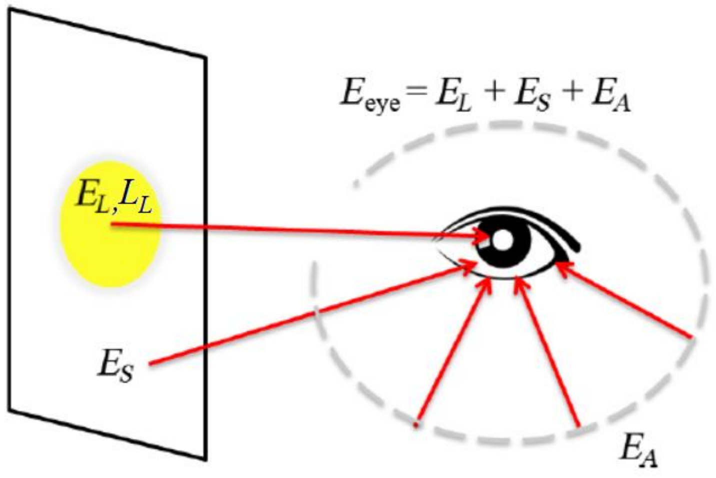


Without glare:
Contrast (C) = $|L_t - L_b|/L_b$

With glare:
Contrast (C) = $|L_t - L_b|/(L_b + L_v)$

Quantifying discomfort glare: Integrated Glare Metric (IGM)

- Based on a ***direct view*** of the luminaire
  - Why? That is what people recall when asked to judge discomfort glare
- Illuminance from luminaire (E_L): ↑
- Illuminance from surround (E_S): ↓
- Ambient illuminance (E_A): ↓
- Maximum luminaire luminance (L_L): ↑

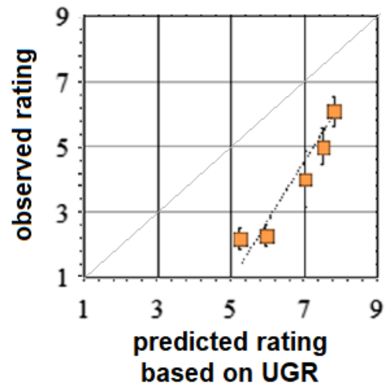


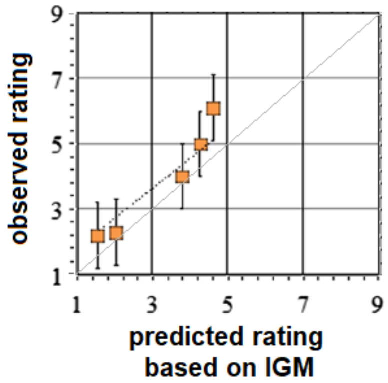
- **DG** = $\log(E_L + E_S) + 0.6 \log (E_L/E_S) - 0.5 \log(E_A)$
- **IGM** = $3.4 + 6.4 \log DG - 1.4 \log(50{,}000/L_L)$

(Bullough et al. 2008)

Quantifying discomfort glare (cont'd.)

- Common glare metrics include:
- VCP (Visual Comfort Probability; IES 2000): Defined for diffuse large-area fluorescent luminaires mounted in regular arrays
  - Expressed as percentage of occupants who would not object to the lighting
- UGR (Unified Glare Rating; CIE 2002): Also defined for diffuse large-area luminaires, either individual luminaires or arrays
  - Expressed as a numerical rating from 10 (no discomfort) to 31 (intolerable discomfort)
  - Modifications address small luminaire size
  - Post-hoc additions address luminaires with high-luminance elements
- Neither system incorporates glare spectrum



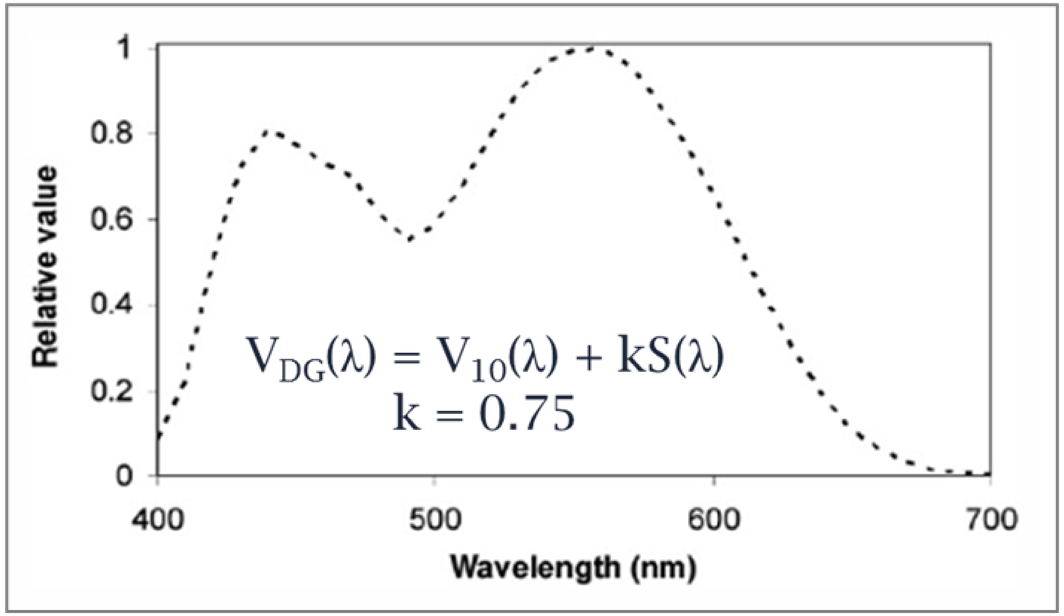


(Mou et al. 2017)

Illuminance from luminaire: 100 lx; Background luminance: 75 cd/m^2

Quantifying spectral impact on discomfort

- A combination of large-field photopic sensitivity, $V_{10}(\lambda)$, and short-wavelength cone sensitivity, $S(\lambda)$, provides a rectifying variable for discomfort ratings, $V_{DG}(\lambda)$
  - Difference between CCTs of 2700 K and 5900 K: Factor of 1.28 (relatively small differences for nominally “white” light sources)



Analysis: Discomfort glare from circadian-effective lighting

- Illuminance from the luminaire (E_L) depends upon its luminous intensity toward the occupant ↑
- Maximum 0.3°-width luminance of the luminaire (L_L) depends upon size
  - Smaller size results in higher luminance ↑
- E_L and L_L are spectrally weighted by $V_{DG}(\lambda)$
- Illuminance from the immediate surround (E_S) comes from the ceiling ↓
- Ambient illuminance (E_A) comes from the walls ↓
  - Higher wall reflectance results in higher illuminance
- Based on a ***direct view*** of the luminaire
  - That's what people recall when asked to judge discomfort glare

- **DG** = $\log(E_L + E_S) + 0.6 \log(E_L/E_S) - 0.5 \log(E_A)$
- **IGM** = $3.4 + 6.4 \log DG - 1.4 \log(50{,}000/L_L)$

IGM Rating Scale
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3: satisfactory
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5: just permissible
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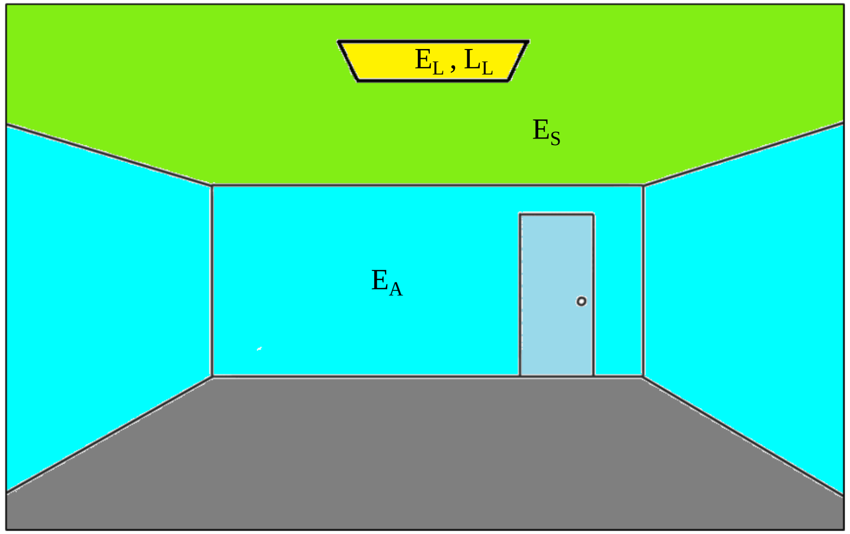
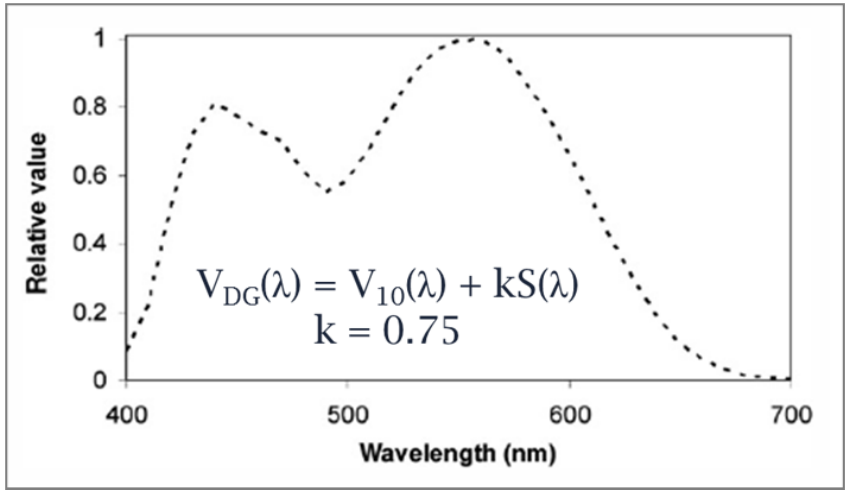
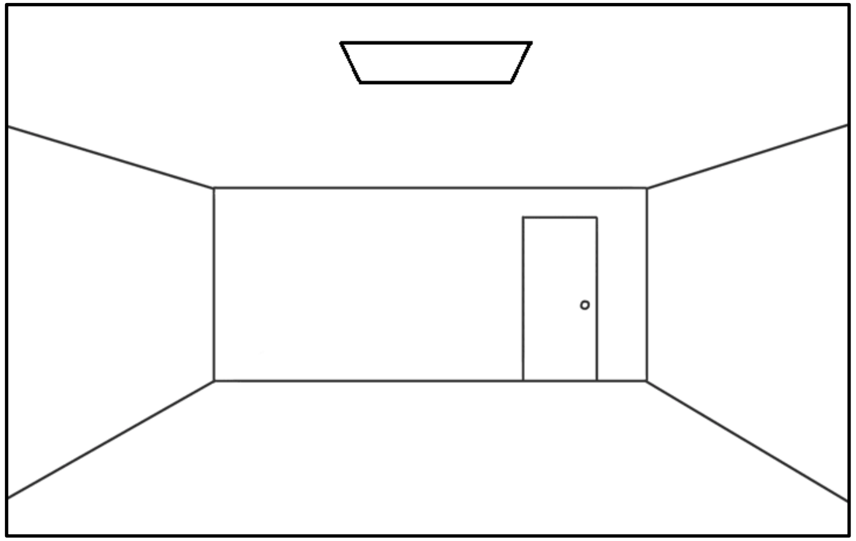
9: unbearable



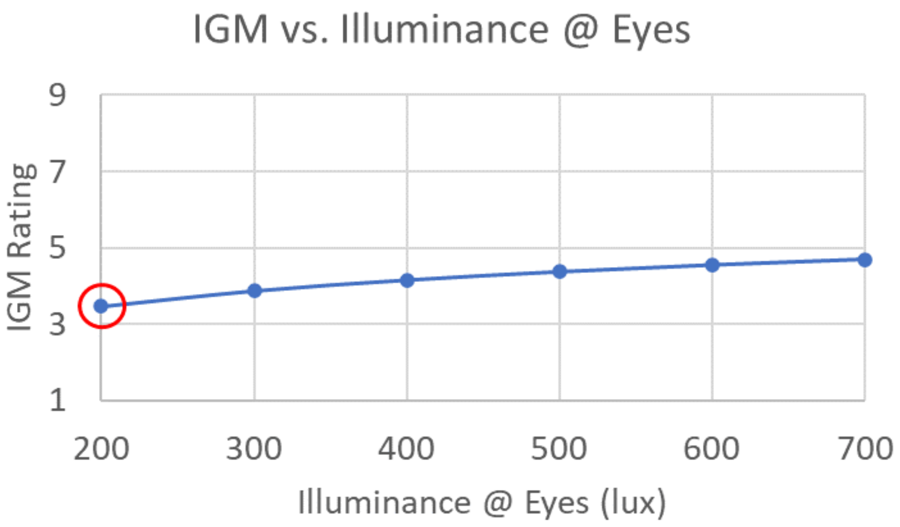


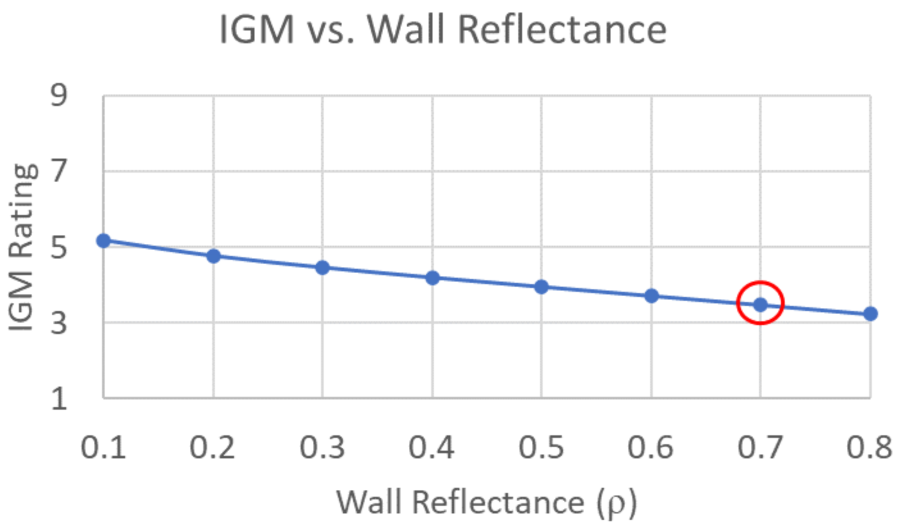
Analyses of Visual Discomfort from Circadian-Effective Lighting

- For an interior room space, assume the following lighting/surface characteristics:
  - Total illuminance at occupant's eyes: 200 to 700 lux
  - Luminaire apparent angular size: 76 (MR16 lamp) to 126,000 (6 × 6 ft) μsr
  - Wall surface reflectance: 0.1 (black) to 0.8 (white)
  - Luminaire CCT: 2700 to 6500 K
- **Default condition**: 200 lux at eyes, 2 × 2 ft troffer, wall reflectance 0.7, 4000 K CCT

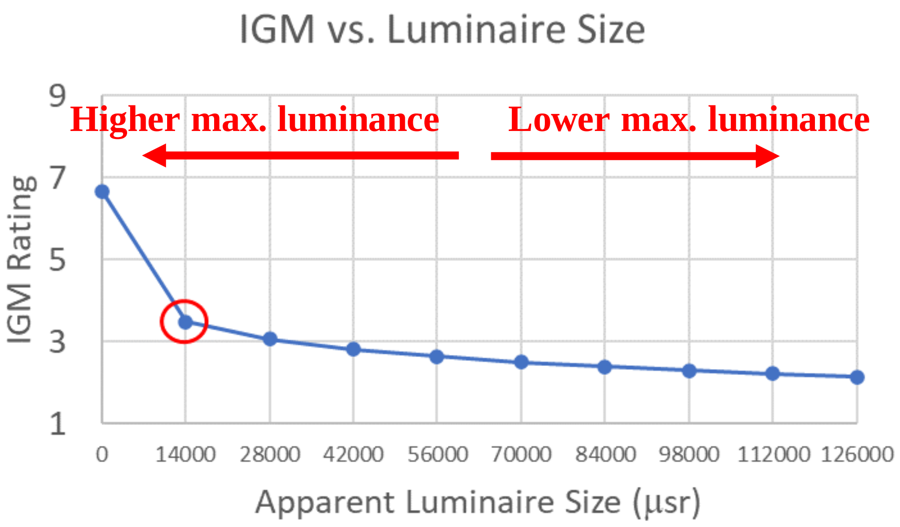


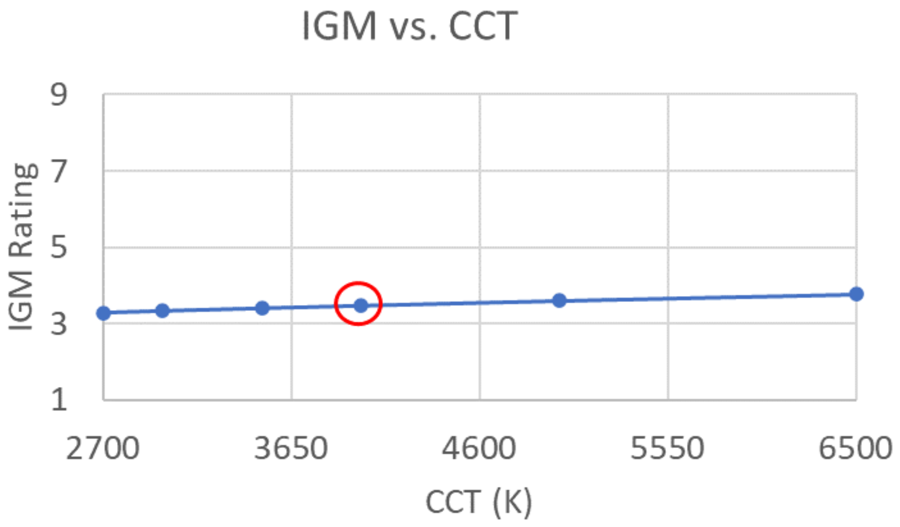
Sensitivity Analysis (Default: ○)





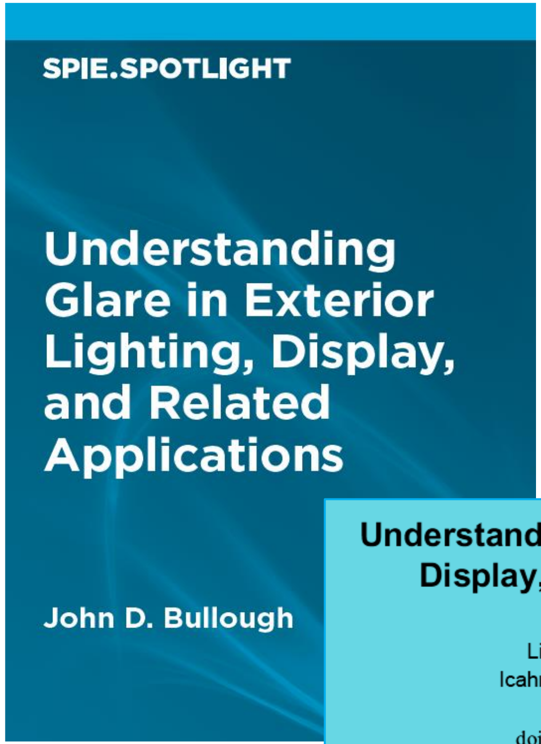
9: unbearable
8
7: disturbing
6
5: just acceptable
4
3: satisfactory
2
1: just noticeable glare

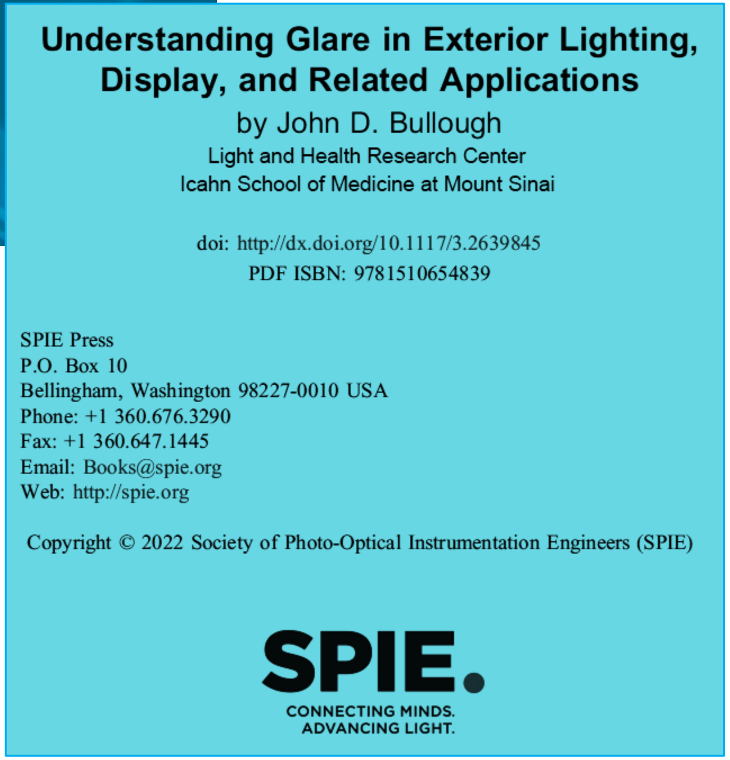




Summary

- Ad hoc glare metrics no longer serve the lighting specification community
- New insights in visual psychophysics have resulted in the ability to assess the effects of not only the amount and distribution of light but also:
  - Spectral distribution
  - Maximum luminance
- Valid glare metrics will make circadian-effective lighting more pleasant and more practical





Understanding Glare in Exterior Lighting, Display, and Related Applications

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