Why is outdoor glare such a stubborn problem?

2023 CIE USNC / CIE CNC / CORM Meeting

Naomi J Miller, Pacific Northwest National Laboratory
With input from Dr. Belal Abboushi, Pacific Northwest National Laboratory
Portland, Oregon USA

Discomfort from glare – Human factors study issues

Studying people is messy:

Different in

- Ages
- Visual characteristics
- Recent experiences
- Demeanor and attitude
- Educational understanding

Too often subjects are

- Too eager to please, or too eager to complain
- Moody
- Inconsistent
- Grumpy
- Distracted
- Don’t follow directions

One dude’s glare is another dude’s torture device, and another dude’s source of entertainment.

Discomfort from glare – Measurement/calculation Issues

Questions:

- How does a pedestrian observer experience discomfort from glare?
- Do we measure quantities gazing parallel to the ground? (e.g., vertical illuminance at eye)
- Do we measure quantities "looking" directly at the luminaire? (e.g., orthogonal illuminance)

Does glare response depend on the context?

Do you want to spend time there?

Is it visible from your back yard?

Discomfort from glare – What are the variables?

In the best of all possible worlds, we would collect all the necessary field data to calculate glare using multiple models.

Discomfort glare models	Source					Background			Geometrical properties					
	L_{avg} (cd/m²)	I (cd)	E_d (lx)	L_{max} (cd/m²)	Uniformity correction (k)	L_b (cd/m²)	E_i (lx)	E_a (lx)	R (m)	Solid angle ω (sr)	Visual angle (°)	θ (°)	p	A_p (m²)
Bullough et al. 2008†[2]			■				■	■			■			
Bullough et al. 2011†[16]			■	■			■	■			■			
Lin et al. 2014[9]	■					■				■		■		
Lin et al. 2015[18]			■					■				■		
Schmidt-Clausen and Bindels[4]			■			■						■		
Bennett (CBE)[7]	■					■				■		■		
UGRs[12]		■				■			■				■	
CIE R'$_{UG}$[17]	■				■	■				■			■	
CEN R_{GI}[7]		■												■

L_{avg} = average source luminance
I = source intensity toward the eye
E_d = direct illuminance from source
L_{max} = maximum source luminance

L_b = background luminance
E_i = indirect illuminance
E_a = ambient illuminance

R = distance of source from eye
ω = source solid angle
θ = eccentricity of the source
p = the Guth position index
A_p = projected area of source

Abboushi, B., Fotios, S., & Miller, N. J. (2023). Predicting discomfort from glare with pedestrian-scale lighting: A comparison of candidate models using four independent datasets. *Lighting Research & Technology*, 14771535231162505.

Discomfort from glare – How to measure in the field

Ready to take lighting measurements in the field!

Occluder (“Lollipop”)

Illuminance meter

Luminous intensity meter (for candelas)

Spectrometer (for SPD)

Tape measure or laser equivalent

Camera for documentation. HDRI camera for luminance distribution?

1/3° Luminance meter for L_{max}

Tripod

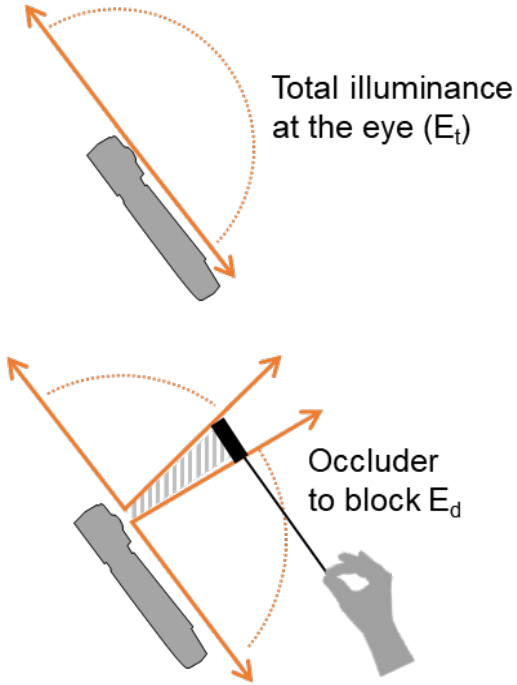
http://www.surfbirds.com/community-blogs/tomstips/2008/11/24/the-geeks-guide-to-carrying-your-gear-while-saving-your-shoulders/

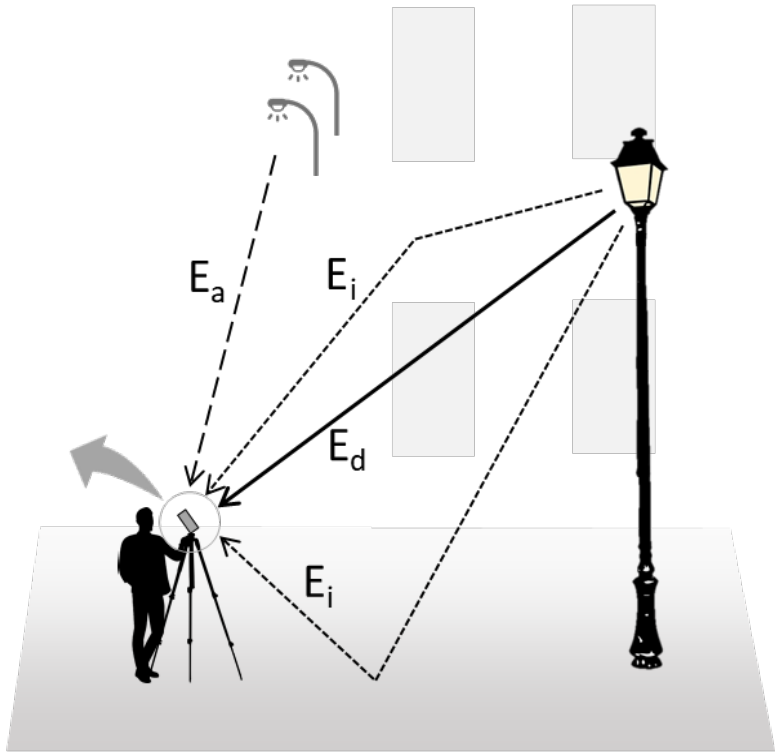
Discomfort from glare – Measurement Issues

In the field:

- How do we measure
  - Total illuminance at the eye from the environment (E_t)
  - Direct illuminance from luminaire (E_d)
  - Indirect illuminance from luminaire (E_i)
  - Ambient illuminance from the environment (E_a)

Even simple illuminance isn't simple



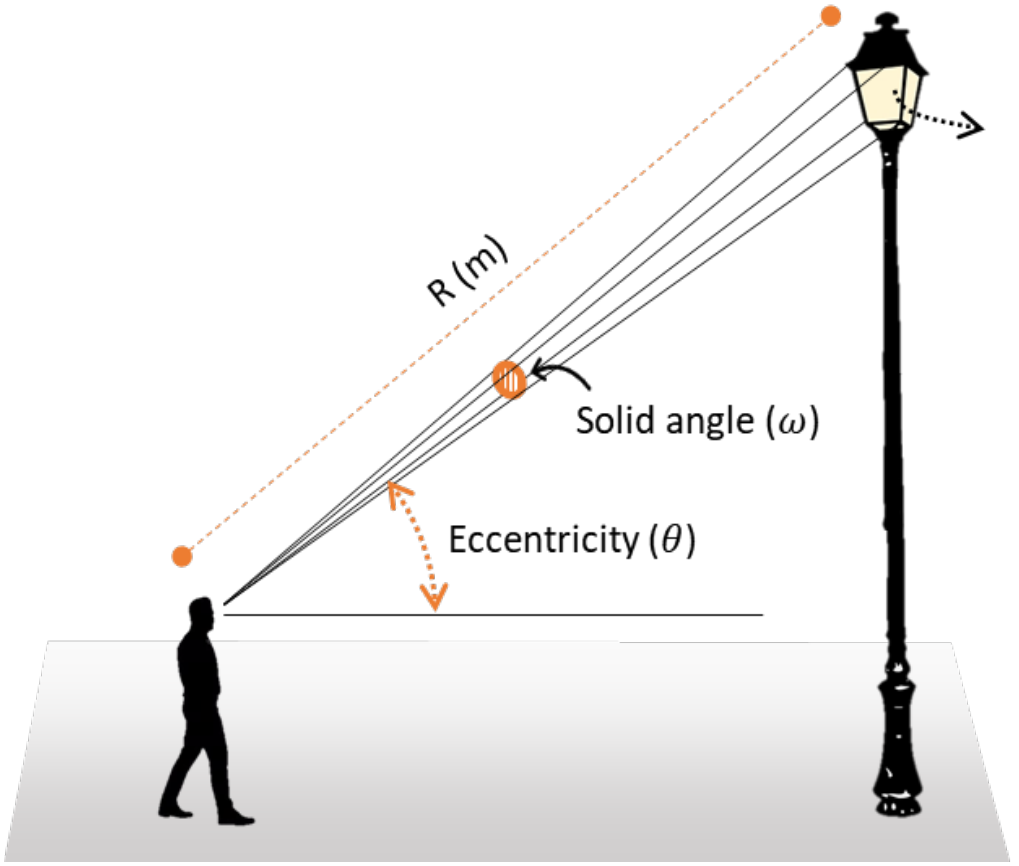


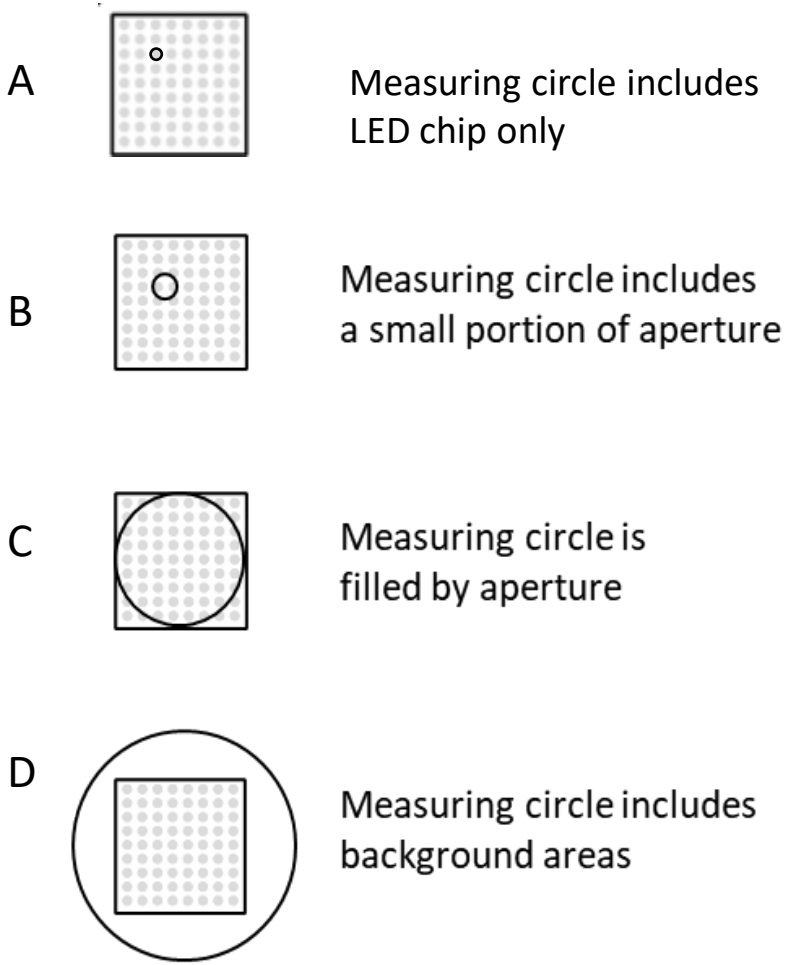
Abboushi, B., & Miller, N. J. (2022). What to measure and report in studies of discomfort from glare for pedestrian applications. *Lighting Research & Technology*, 14771535221087133.

Discomfort from glare – Measurement Issues

In the field:

- If luminance distribution matters, how to measure L_{max} in LED array? Does absolute max value matter, or just a threshold value of >50,000 cd/m^2, for example?

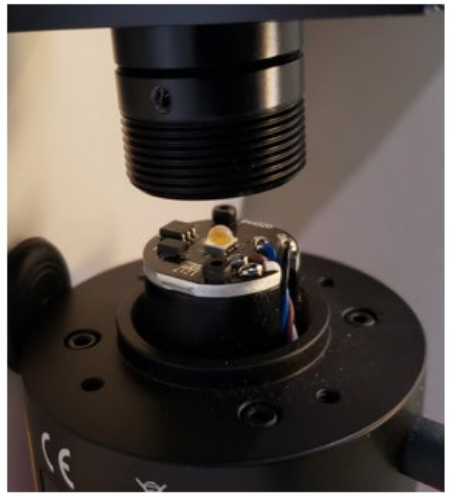




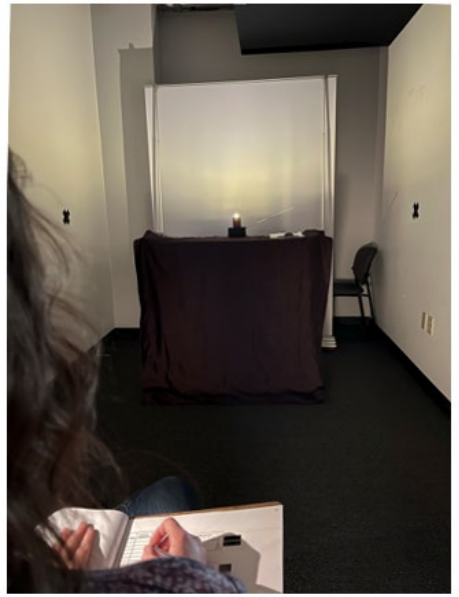
Discomfort from glare – L_{max} Measurement Issues

Luminance measurement example:

- LED measured so capture angle sees LED chip only
- LED measured from observer's eye
- Which one is correct?



38,660 cd/m²
Luminance of 3.2 mm wide LED chip only, from distance of approx. 0.15 m to maximize fill of 0.3° capture angle, using closeup lens

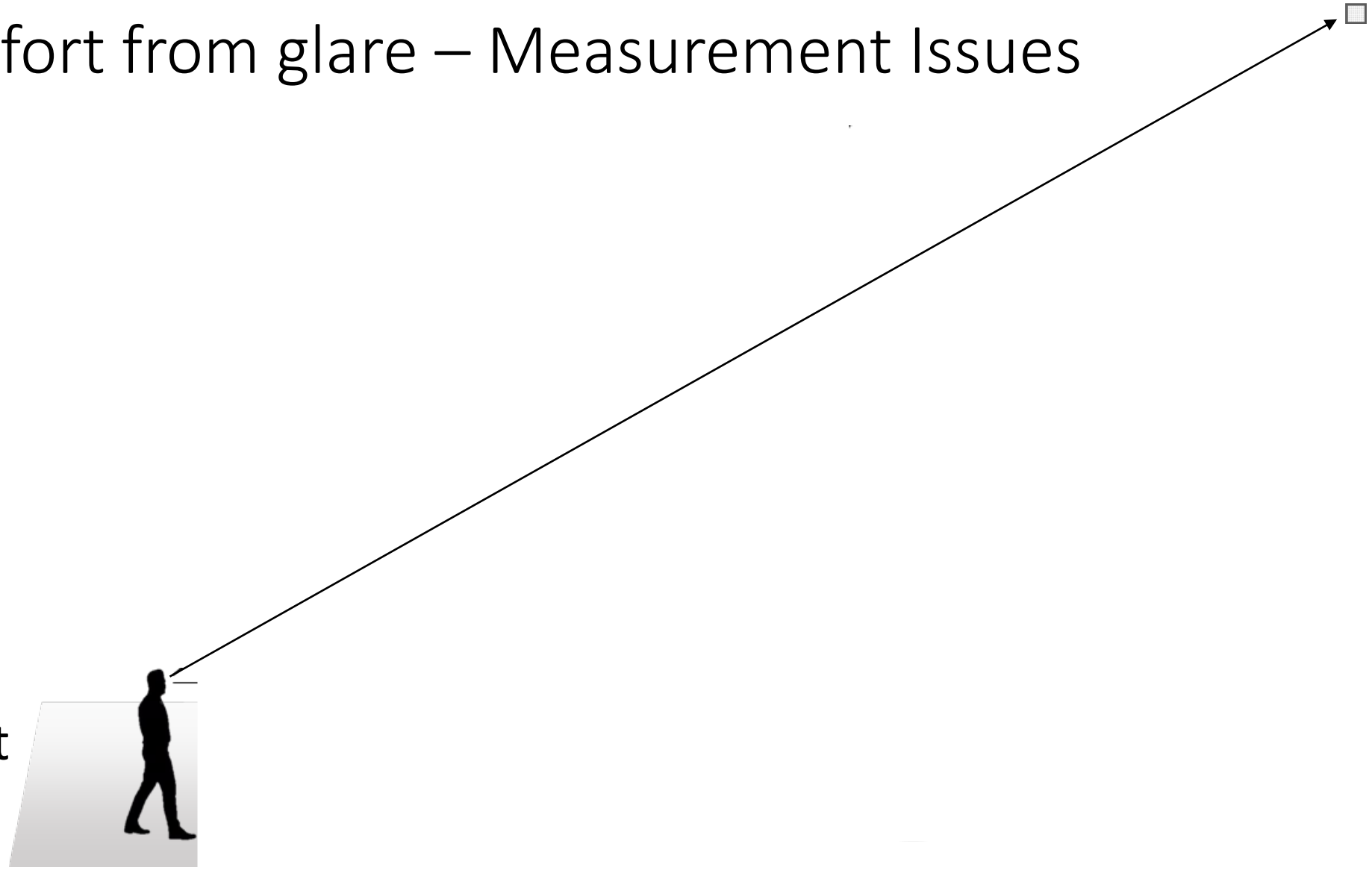


552 cd/m²
Luminance of same 3.2 mm wide LED chip, from participant eye height and location, 3 m distance. (Underestimates luminance since LED image size did not fill the full 0.3° capture angle.)

Discomfort from glare – Measurement Issues

In the field:

- LED array converges to a point source at some view distance. Is L_{max} still relevant?
- Bullough et al. suggests L_{max} is no longer relevant when source size < 0.3°.



Discomfort from glare – Is position index relevant?

Position index:

- Assumes view is always horizontal.
- Suggests that light sources above 60° (not imaged on retina) are not contributing to discomfort.
- If glare sources above 60° don't contribute to glare perception, why do we wear baseball caps outdoors?
- Abboushi glare study (paper in review) shows sources above visual field are sensed as glare and are quantifiable.

Table 3: Mean position indices of the test sources at 80° and 60° elevation angles calculated using the reference at (0°, 20°) under high and low background luminances.

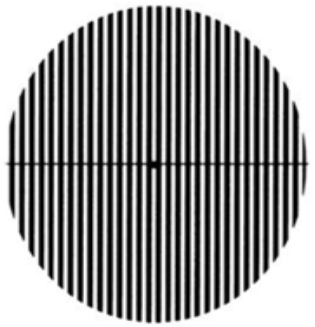
Test source position	Procedure and SPD	Position index		Mean test source luminance [cd/m²]	
		High L_b	Low L_b	High L_b	Low L_b
(0°, 80°)	Matching – cool SPD	28.2	53.4	801,071	231,996
	BCD – cool SPD	34.6	42.2	891,349	370,194
	BCD – warm SPD	51.2	46.1	924,489	362,421
(0°, 60°)	Matching – cool SPD	16.6	13.2	470,829	57,390
	BCD – cool SPD	35.4	14.8	549,521	152,904
	BCD – warm SPD	14.3	13.3	497,344	116,812
(±45°, 60°)	Matching – cool SPD	15.9	15.3	450,248	66,626
(±67.5°, 60°)	Matching – cool SPD	17.8	21.8	506,735	94,915

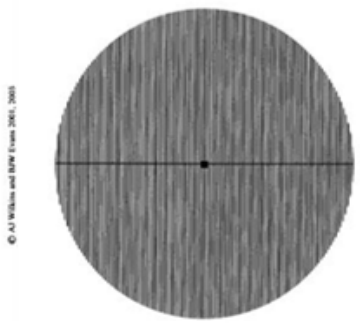
Discomfort from glare – Source patterns issue

Uniformity of source:

Does luminance distribution (spatial frequency) in aperture affect glare response? May depend on…

- Viewing distance
- Amount of diffusion in optics
- Whether observer can resolve luminance variation
- The visual system's spatial contrast sensitivity (maximized at 3 - 4 cycles/degree?)





Discomfort from glare – Variables we haven't considered before

Ganglion receptive field sizes:

Peripheral receptive field sizes are larger than near the axis of view.

This may explain relative insensitivity to sources in periphery – until observer turns gaze towards it. Metrics may underestimate glare potential as a result.

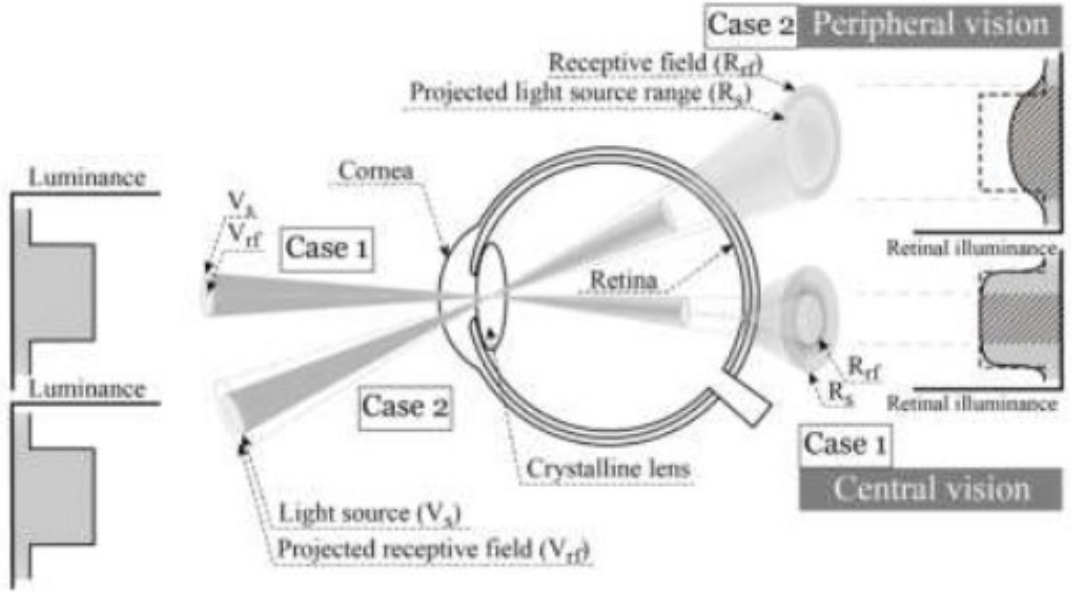


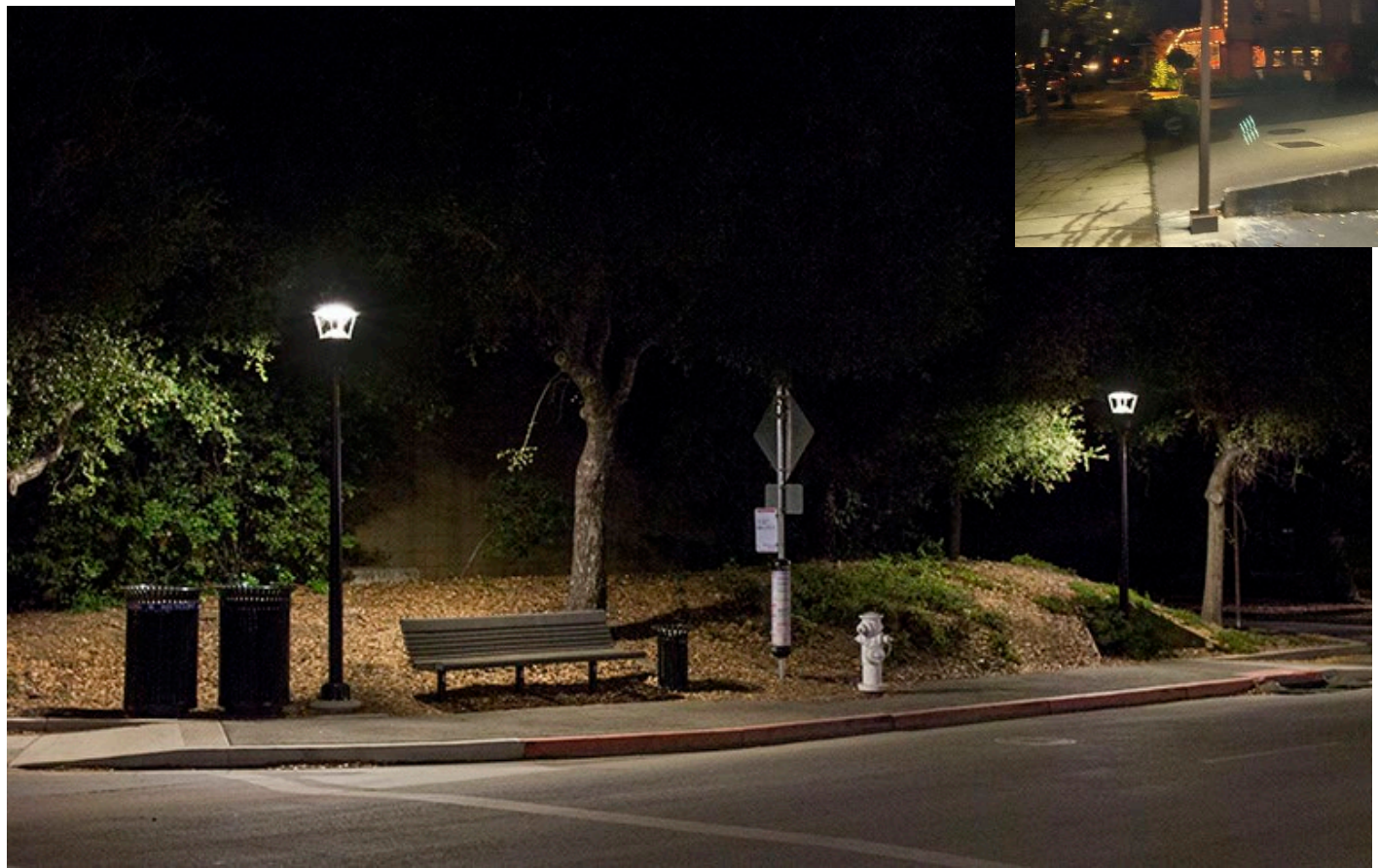
Figure 1 – Relationship between luminance and illuminance

Hara N and Takase K, 2023. visual characteristics in the discomfort glare evaluation model in accordance with the visual system. Proceedings of the 30th Quadrennial session of the CIE, Ljubljana, 2023. pp. 563 - 568.

Discomfort from glare – Measurement Issues

Final questions:

- How to measure adaptation luminance?
  - Full visual field using illum at eye? $L_b = E_{eye}/pi$ (excluding contribution from test light source)
  - A 40° cone of the visual field?
  - Should either of these include the direct light from the luminaire?



Discomfort from glare – A Simpler Metric

Realistic approach needed for outdoor pedestrian glare metrics:

- Pedestrian gaze and visual field are always moving. Horizontal view is unrealistic
- Ease of measurement in field is important
- Reduction of measurement equipment is helpful
- Given variability of humans, accuracy of +/- 30% is probably good enough
- Field and calculated values need to have reasonable agreement

Let's discuss the following:

- Calculations should be based on looking directly (but briefly) at luminaire, avoiding the receptive field size and position index issues
- Direct illuminance at the eye from test luminaire carries the weight in the better DG models. Let's use that.
- Luminance (Lmax or Lavg) are troublesome. How to measure in field? Or in lab? Needs more discussion.
- Effect of luminance distribution needs to be characterized, but could be quantified as a rough adjustment factor added or subtracted from uniform luminance glare value
- Adaptation luminance – Until we have an easy way to measure luminance and luminance distribution, let's stick with illuminance at the eye/pi.

Let's work towards a ***GOOD ENOUGH*** outdoor glare metric.