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Designers Light Forum

Rethinking urban pedestrian lighting metrics

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

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Learning Objectives

At the end of the this course, participants will be able to:

1. Understand the limitations of current performance specifications for urban lighting
2. Understand the detailed requirements for good intersection lighting
3. Learn promising approaches for new performance specifications for urban lighting
4. Understand the implementation and feasibility challenges in cities for new urban lighting

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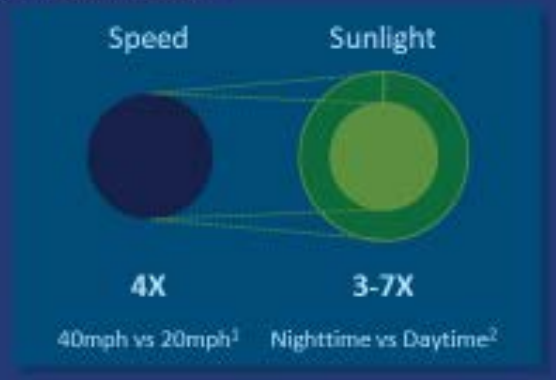
Lack of light is one of the primary factors of pedestrian fatalities

University of Michigan's Transportation Research Institute suggests pedestrians are from 3X to 7X more vulnerable at night than in the daylight[1]



Almost 3 out of 4 pedestrian fatalities occur at night[2]

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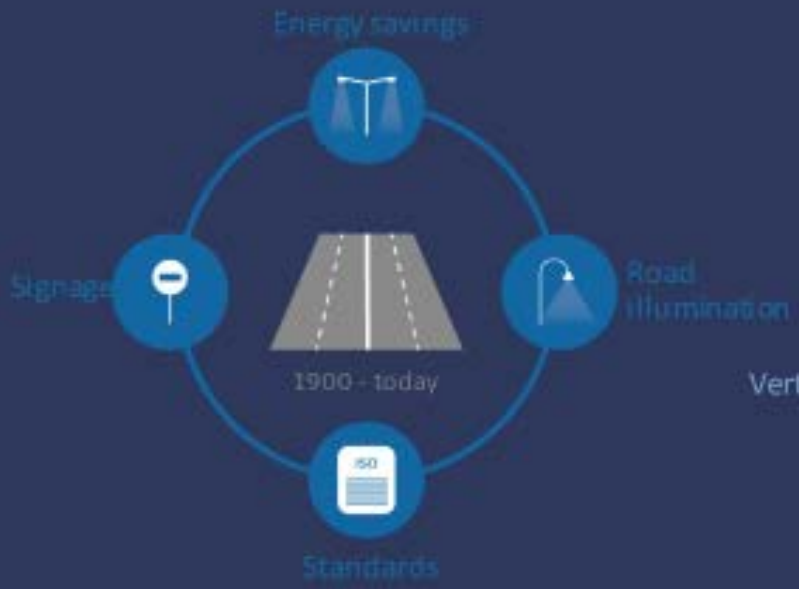
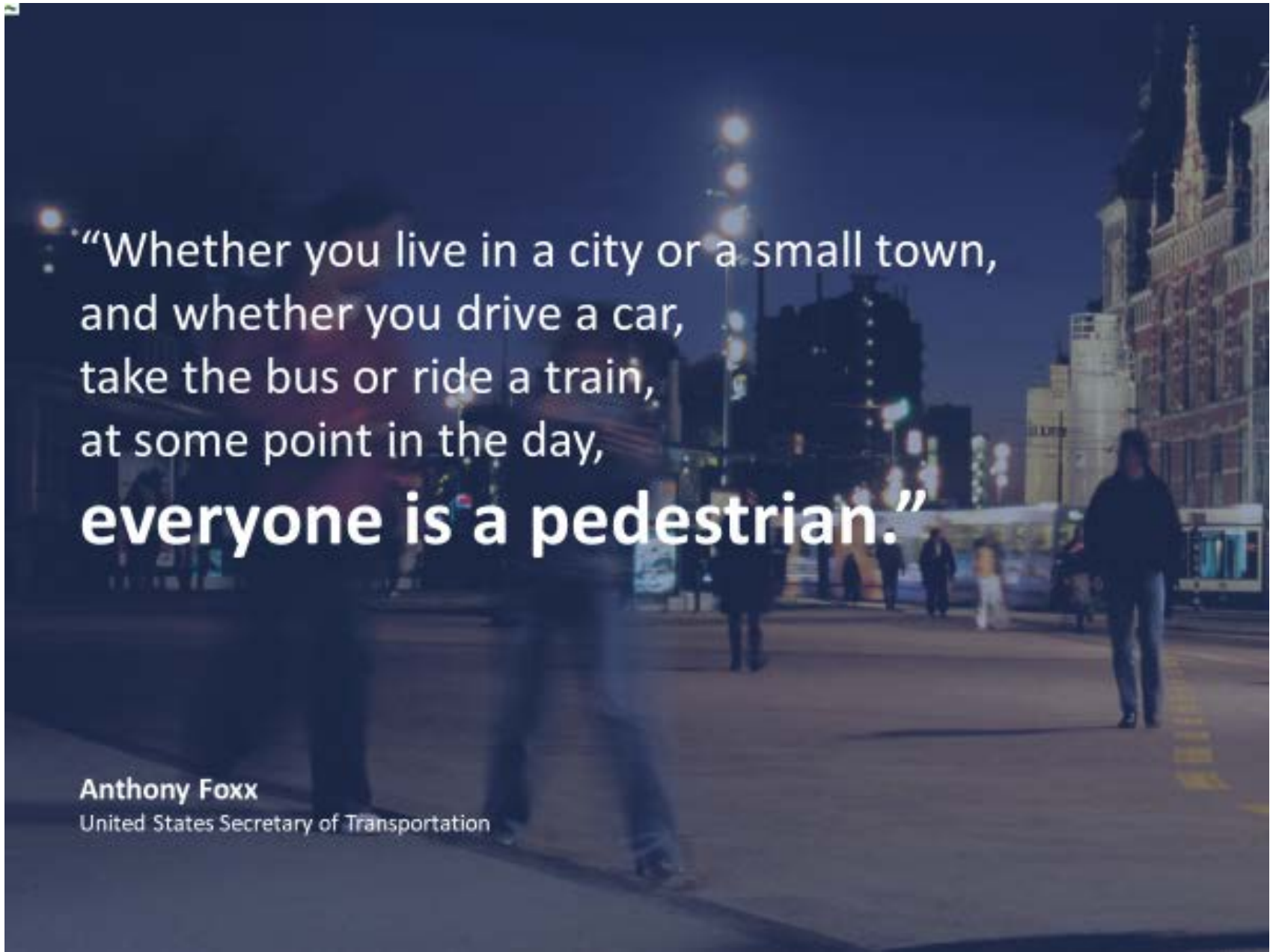
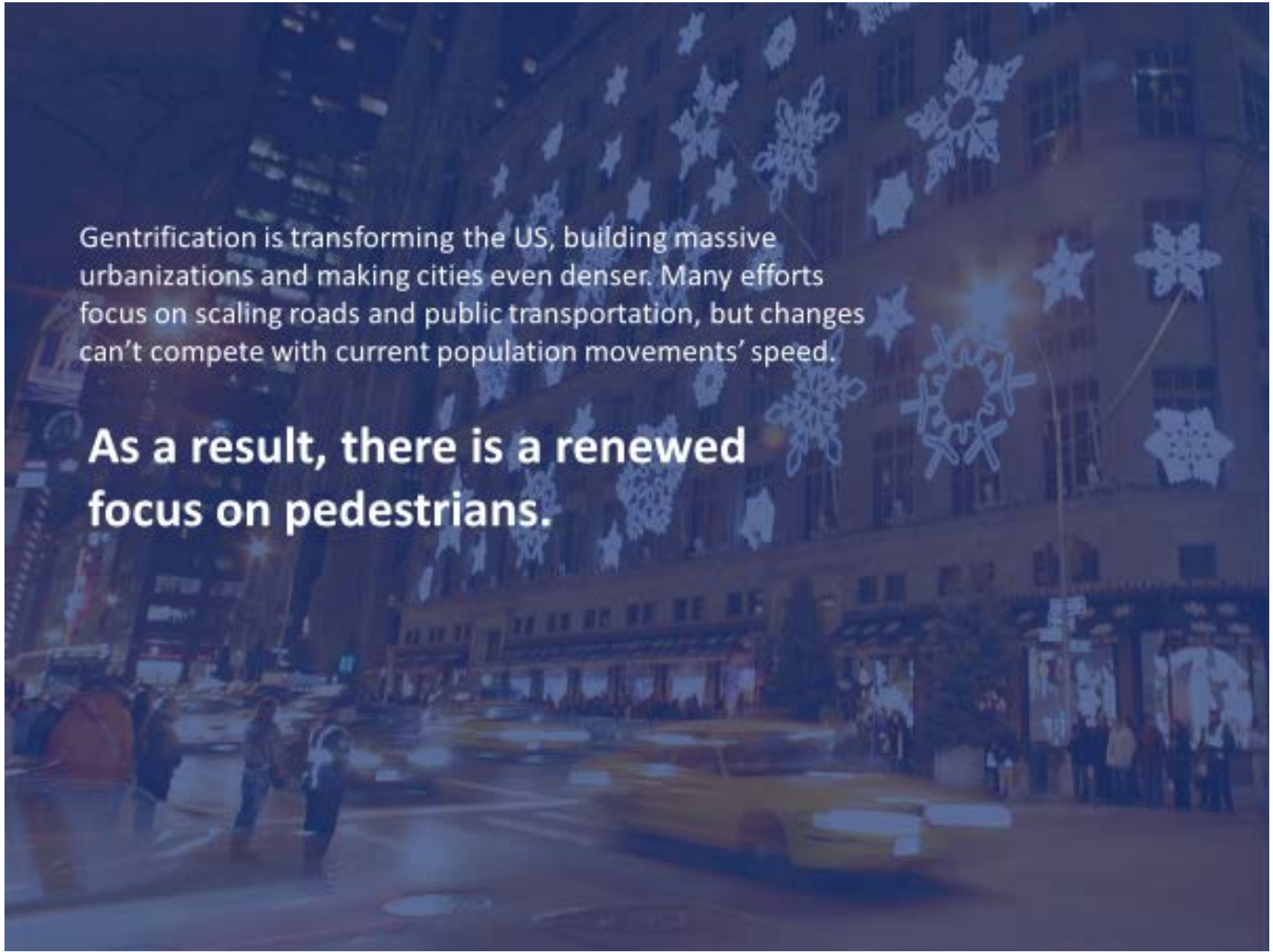
Changing from a road centric lighting...



... to a pedestrian focused system illumination

... requires an integrated approach, done with by truly
understanding the needs of the city,
the citizens and the industry

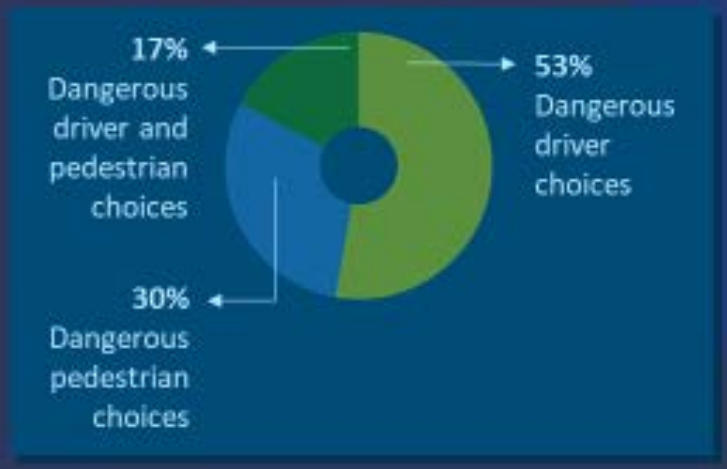

"Whether you live in a city or a small town,
and whether you drive a car,
take the bus or ride a train,
at some point in the day,
everyone is a pedestrian."
Anthony Foxx
United States Secretary of Transportation


Gentrification is transforming the US, building massive urbanizations and making cities even denser. Many efforts focus on scaling roads and public transportation, but changes can't compete with current population movements' speed.
As a result, there is a renewed focus on pedestrians.


WAIT
FOR
WALK
SIGNAL
With the increase of people and cars interacting with each other, Pedestrian Safety urban projects are sweeping the nation. 15 US Cities are already committed to Vision Zero projects. San Francisco alone is spending $120M!
Pedestrian traffic fatalities can and should be prevented!

Within pedestrian safety,
urban intersections
emerge as the primary area
of concerns

70% of accidents with pedestrians are at least partial fault of drivers



Almost 3 out of 4
pedestrian fatalities
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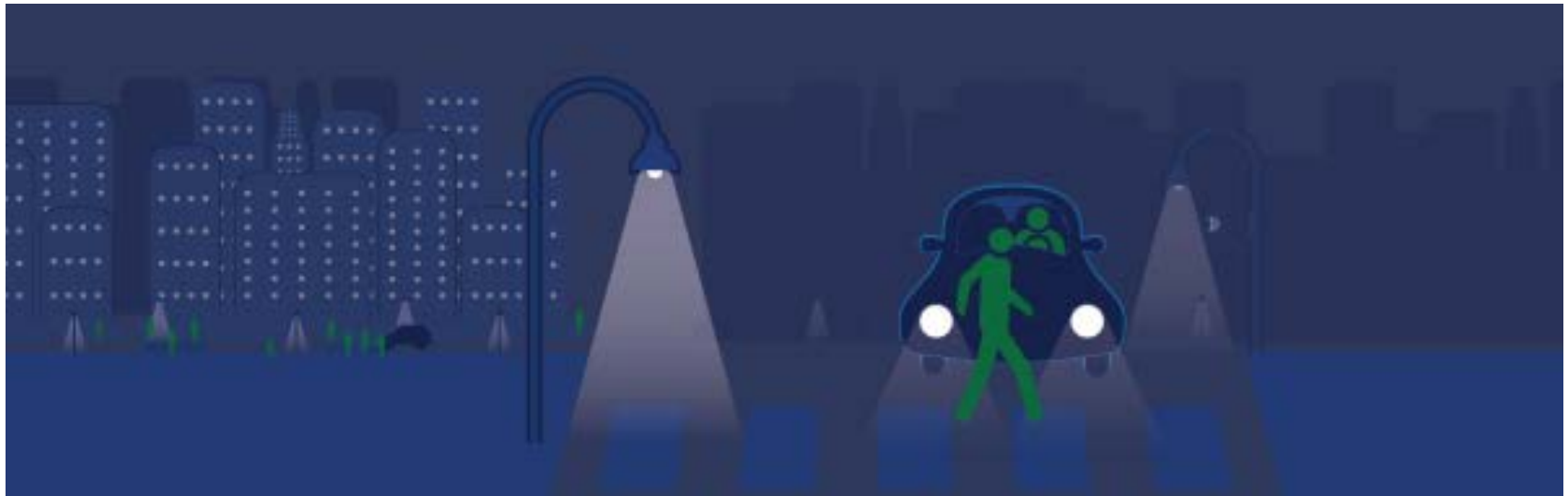
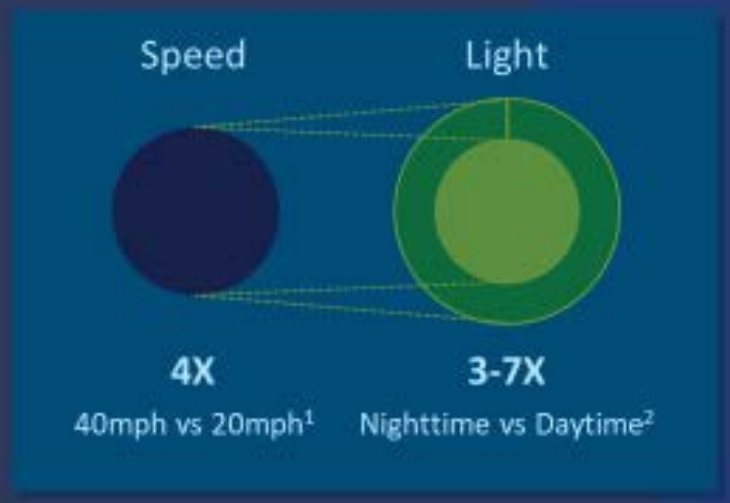


Lack of lighting is one of the primary factors of pedestrian fatalities

University of Michigan's Transportation Research Institute suggests pedestrians are from 3X to 6.8X more vulnerable at night than in the daylight[1]



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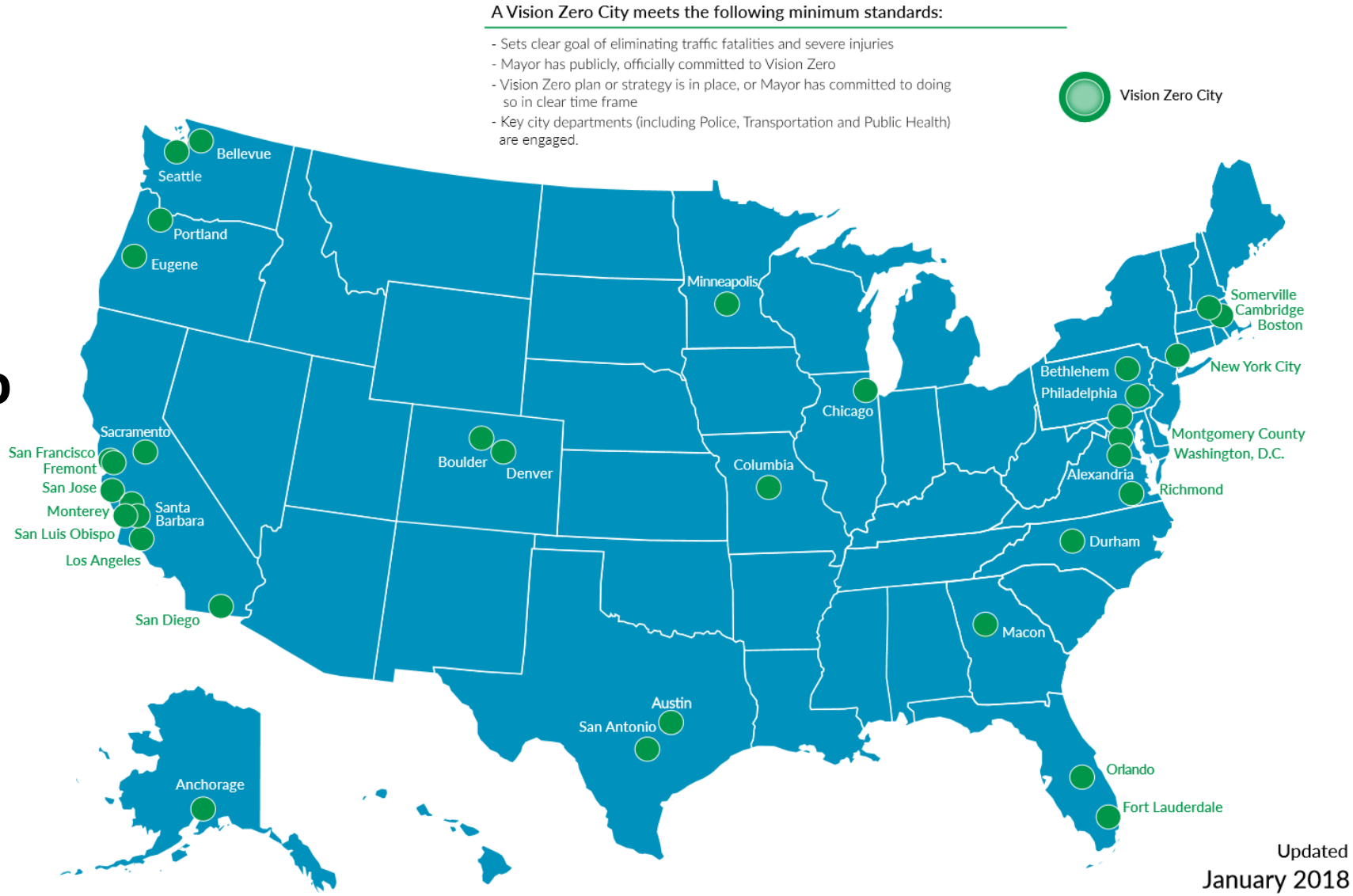
Across the US, 18 cities have already launched **Vision Zero programs to combat pedestrian deaths**



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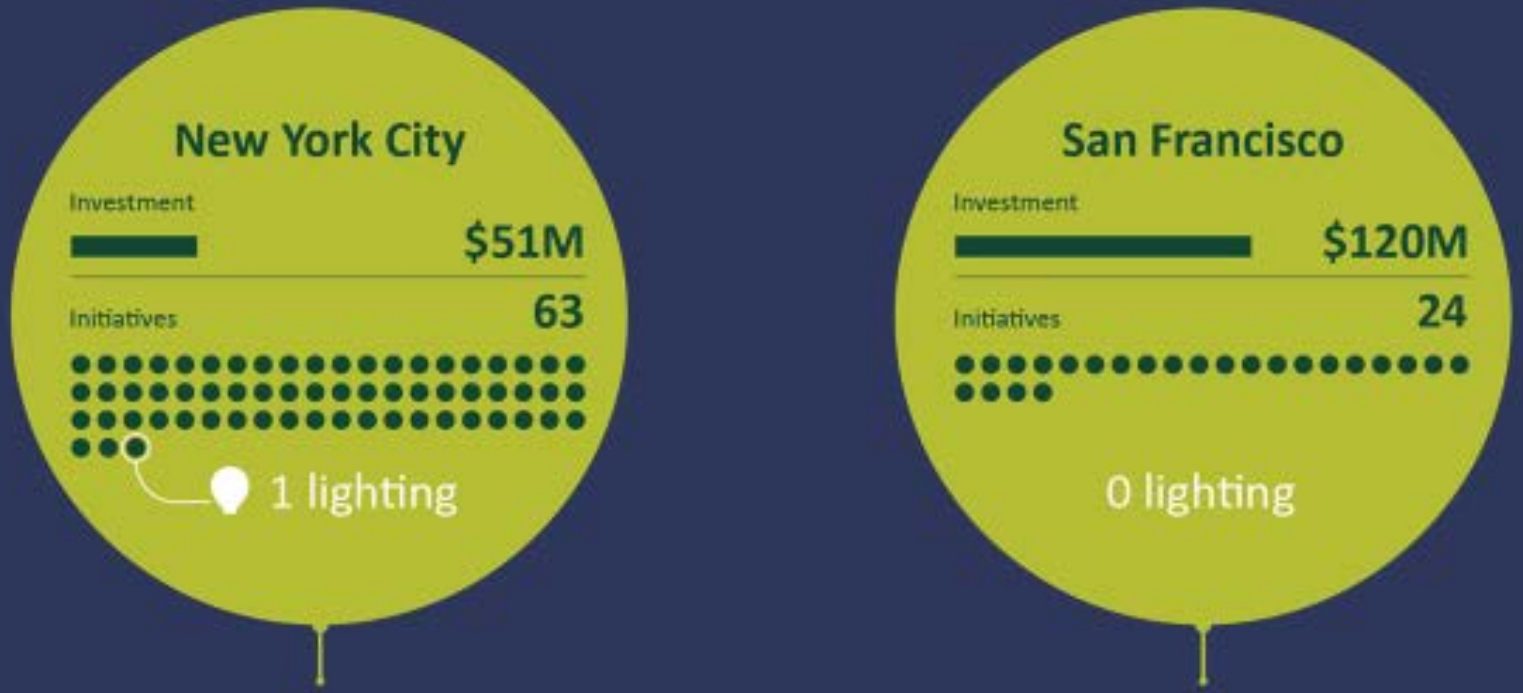
Significant funding is invested
into alleviating incidents



However...

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… is the investment addressing the problem?

Most efforts are focused on changes to physical infrastructure, speed control or signaling, improvements that are very intrusive with large investment and long implementation time. While these efforts in large part have reduced pedestrian deaths, they don't directly address the 3/4 of deaths happening at night.

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Changing from a road centric lighting...

... to a pedestrian focused system illumination

... requires an integrated approach, done with by truly
understanding the needs of the city, the citizens and the industry

Leora Radetsky

Vertical illuminance recommendations

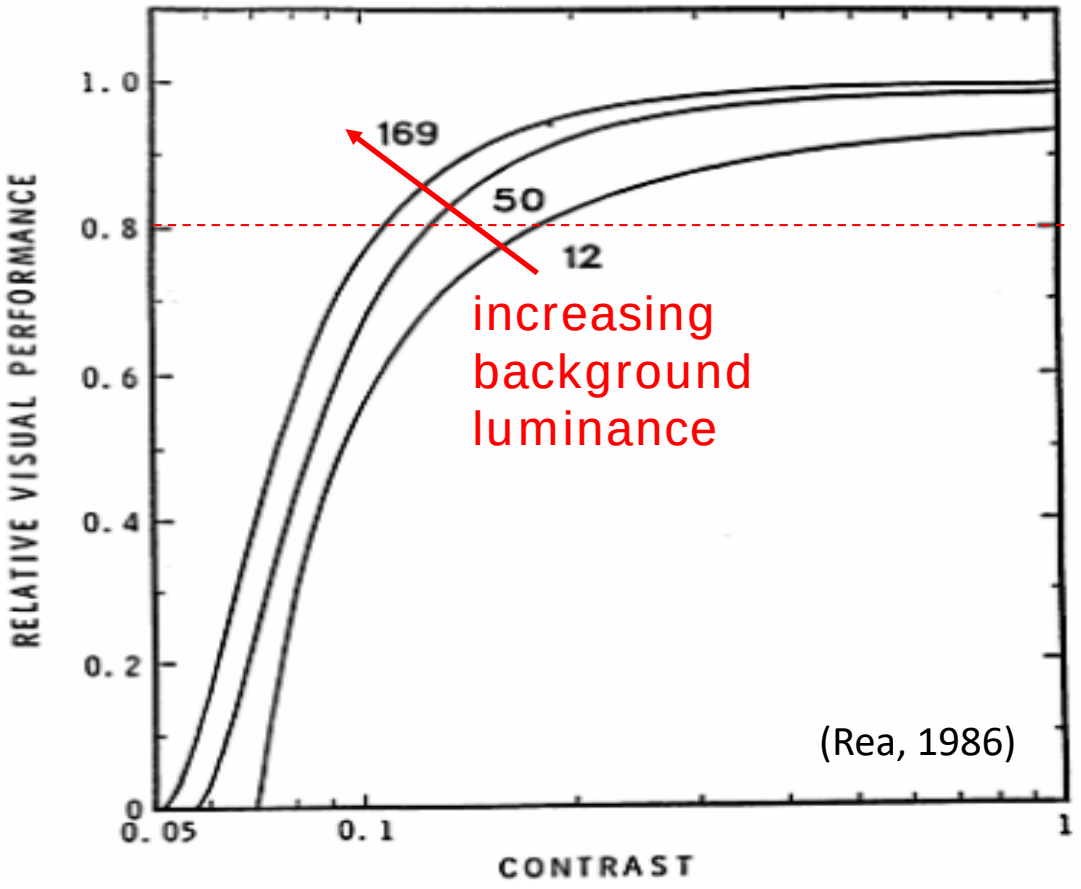
- ANSI/IES RP-8: Roadway Lighting (IESNA, 2014)
  - Minimum vertical illuminance (E_v) of 10 lux for walkways in high pedestrian conflict areas with mixed pedestrian-vehicle use
  - Minimum vertical illuminance (E_v) of 2 lux for walkways in medium pedestrian conflict areas
- Increasing E_v can provide better visibility of pedestrians (Hasson et al., 2002)
- 10 lux E_v sufficient for pedestrian detection (Gibbons et al., 2006; Edwards et al., 2007)
- But is an E_v of ~10 lux all that we need to know?

Approach to the problem

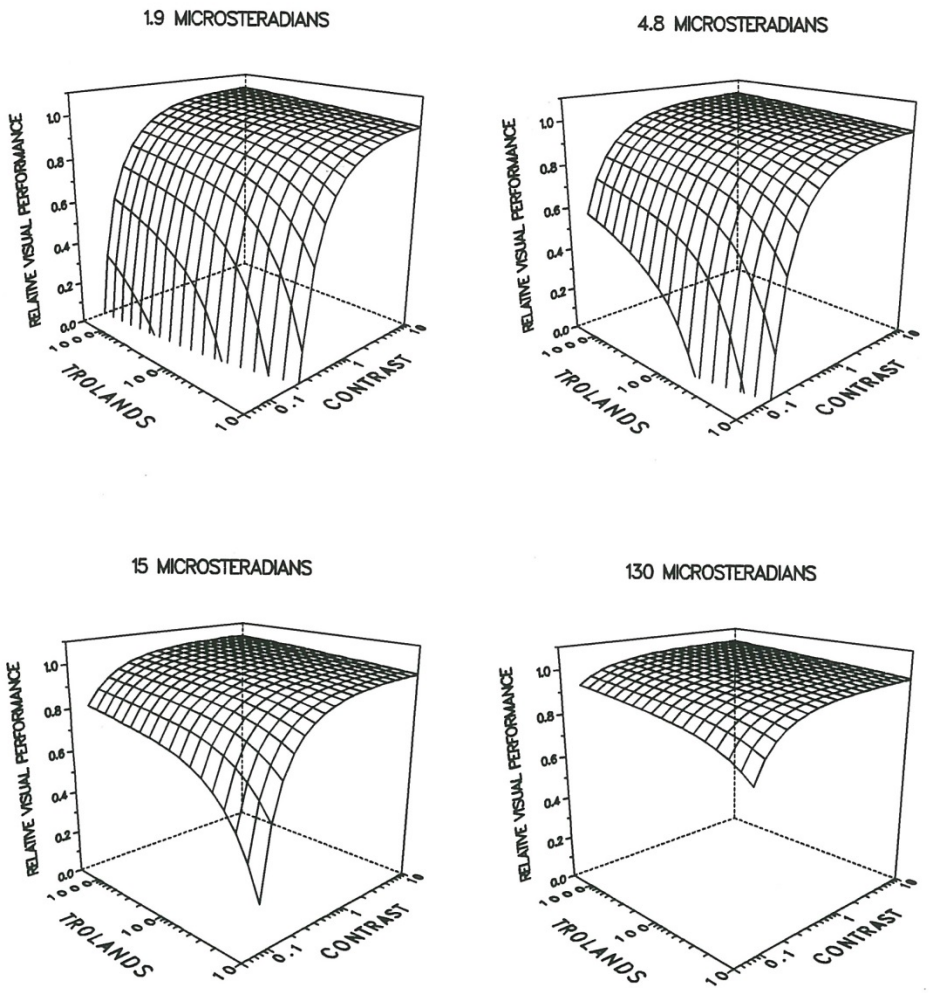
- Photometric simulations
- Visual performance analyses
- Outdoor visibility experiment
- Develop performance specifications
- Real-world evaluations

Relative visual performance

- The relative visual performance (RVP) model (Rea and Ouellette, 1991) is a quantitative model based on speed and accuracy of visual processing
- RVP value is a function of age, background luminance, luminance contrast and visual size
- Good visibility can be obtained when RVP>0.8



RVP: Plateau and escarpment



(Rea and Ouellette, 1991)

Once high visual performance is achieved, further increases in light level do not improve visibility

Other metrics (e.g., VL – the ratio between an object's actual and threshold contrast) increase indefinitely with increasing light level or contrast

For example:

VL = 6 RVP=0.90

VL =32 RVP=0.97

RVP and light levels

- Higher E_v does not always provide better visibility (e.g., pedestrian in black [ρ=10%], size=2 ft x 3 ft, background luminance [L_b]=1 cd/m²):

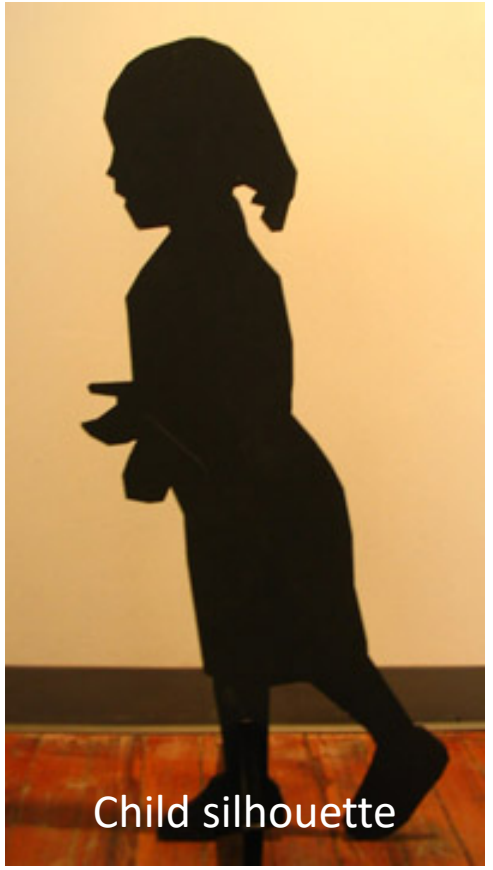
  40 year old driver, 150 ft. away

  (SSD: 40 miles/hour, distance traveled in 2.5 seconds)

  E_v=11 lux Contrast= 0.65 RVP=0.96

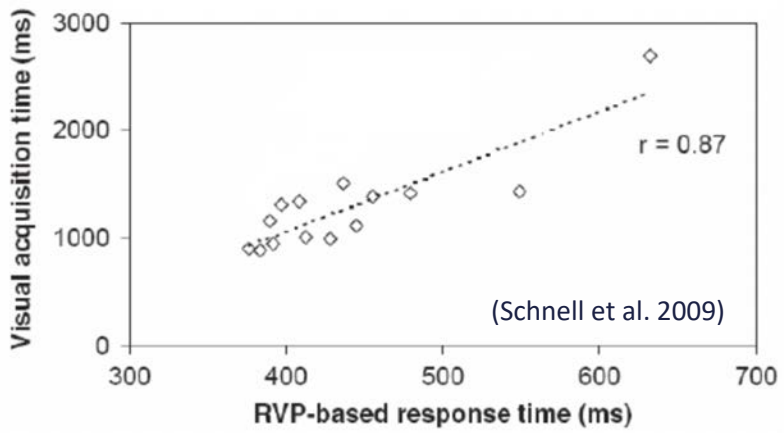
  E_v=30 lux Contrast= 0.05 RVP=0.32

- RVP values are used to evaluate visibility for different crosswalk lighting designs

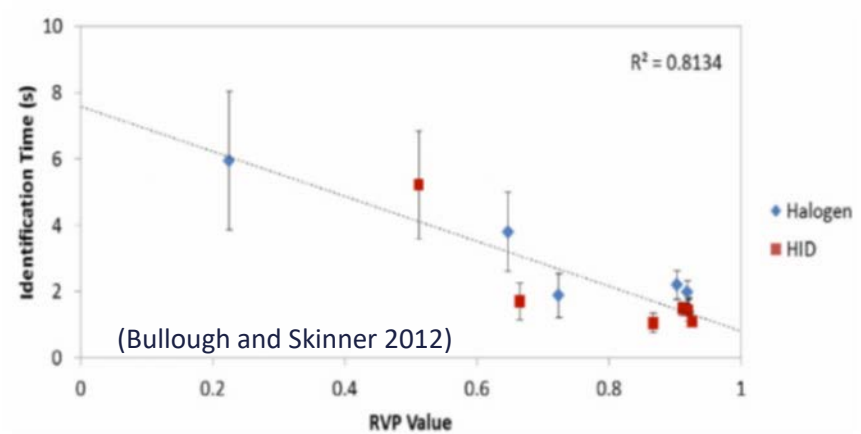

Child silhouette

Validations of the RVP model

Highway Sign Legibility

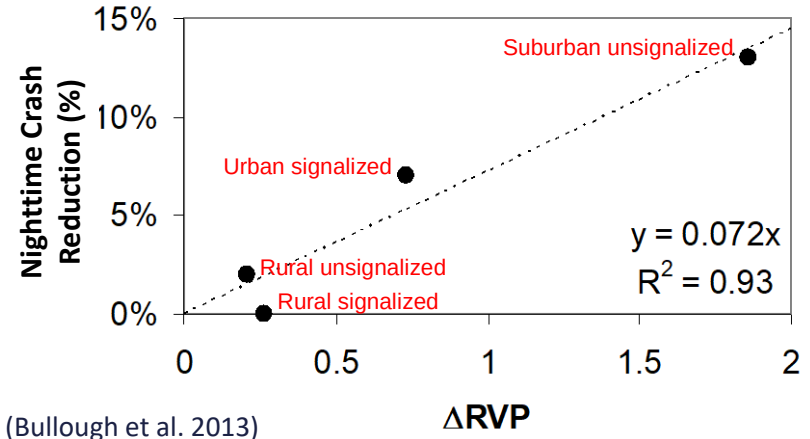


Roundabout Hazard Detection



RVP has been shown to be predictive of nighttime sign legibility, hazard detection and crash avoidance

Intersection Nighttime Crash Frequency



(Bullough et al. 2013)

Philips\LRC collaboration

- Assess visibility of pedestrians in crosswalks
  - Use RVP to quantify visibility
- Project goal
  - Evaluate two existing lighting installations
  - Evaluate best-available LED solution
  - Demonstrate (pending)
- Constraint: Pole locations stay the same

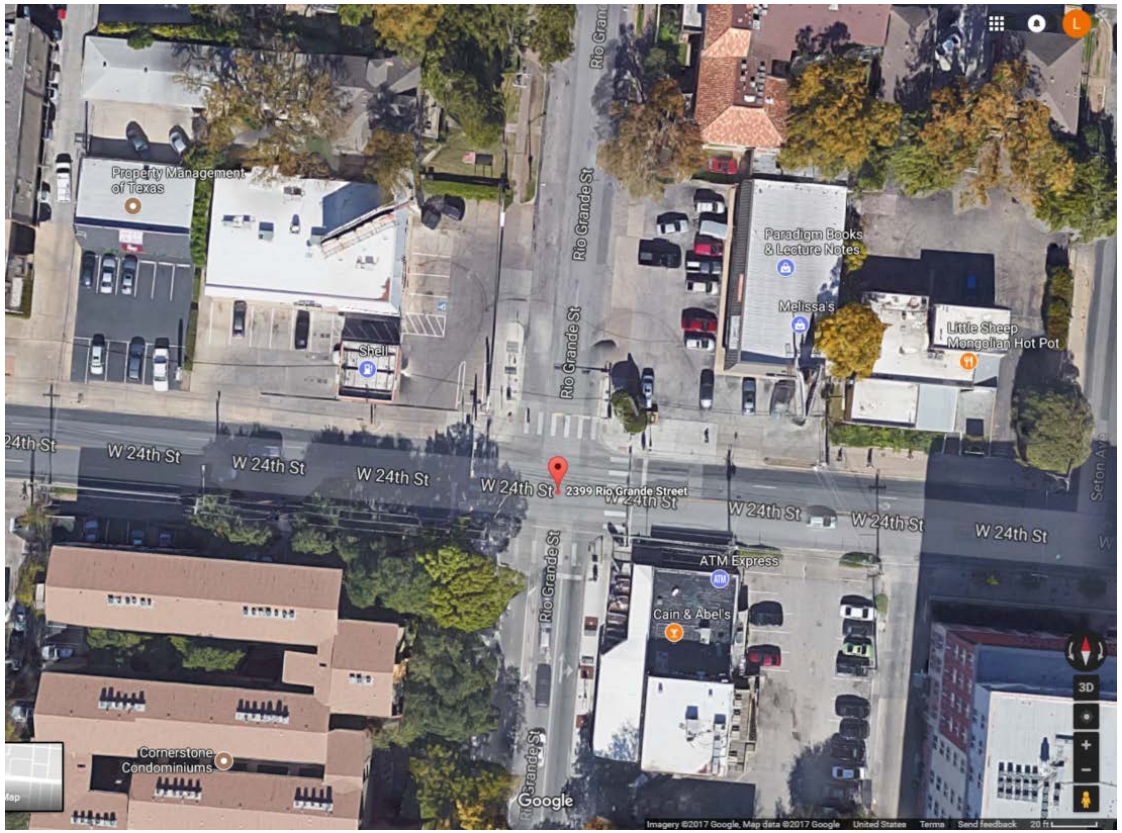
Existing lighting

Intersection 1

3-lane intersection, suburban

Intersection 2

4-lane intersection, urban



Existing lighting

Intersection 1

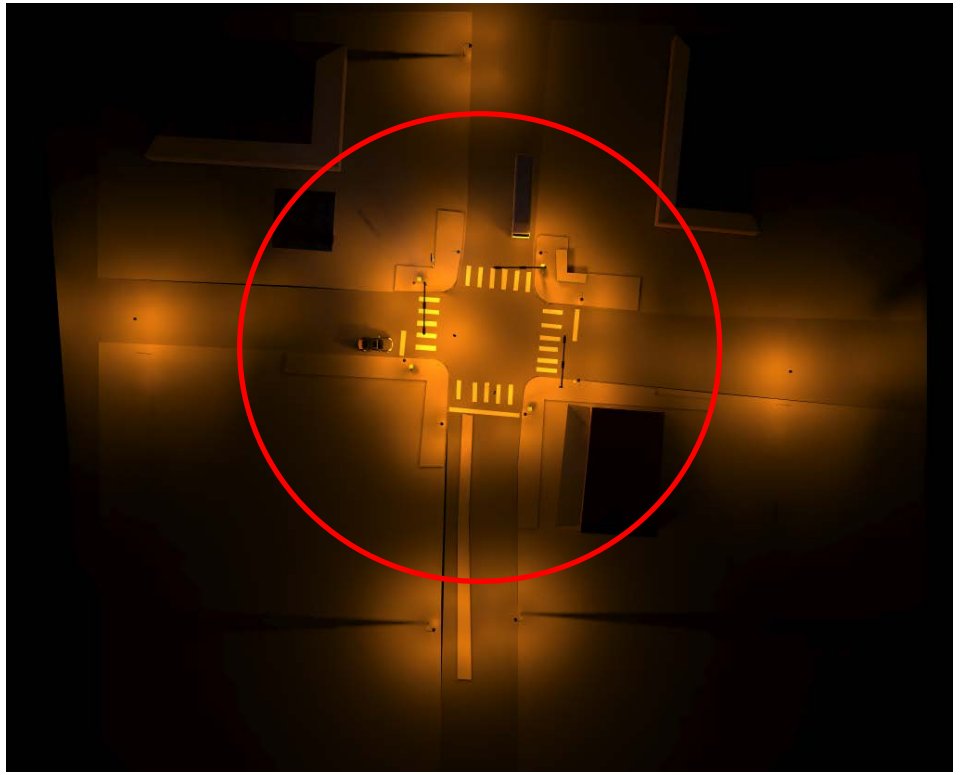
Three 250 W HPS streetlights

Total power demand: 876 W

Intersection 2

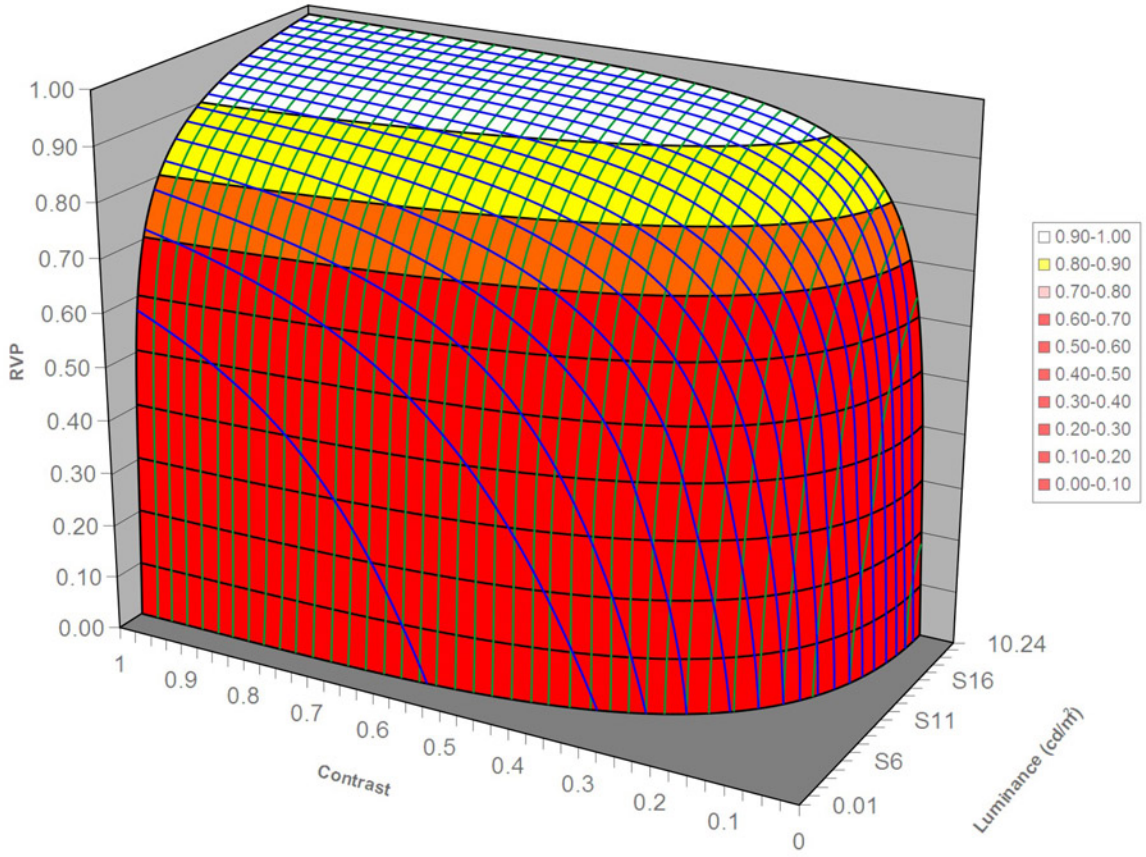
Eight 100 W HPS teardrops + one 250 W HPS streetlight

Total power demand: 1316 W



RVP inputs

- Observer age
- Background luminance
  - Pavement illuminance, reflectance
- Target contrast
  - Target illuminance, reflectance
- Target size (solid angle)
  - Length, width
  - Distance to target



Visibility for crosswalks

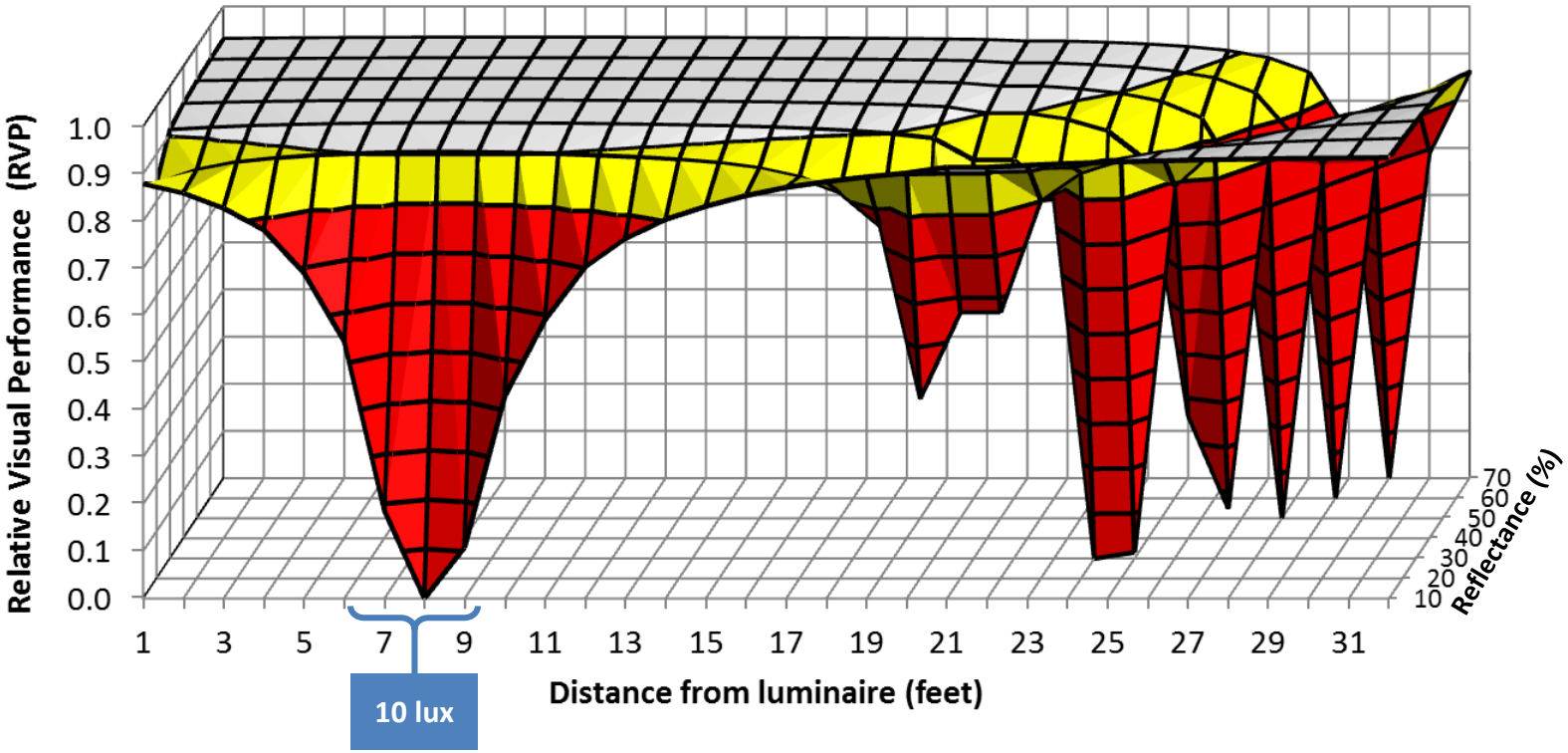
- Step 1: Calculate illuminance in photometric software
  - Centerline through crosswalk (vertical Illuminance)
  - Horizontal illuminance in intersection
- Step 2: Export illuminance values
- Step 3: RVP calculations in Excel calculator
  - One foot by one foot plane touching pavement
  - Plane faces driver approaching intersection
  - Plane reflectance varies from 10% - 70%
  - Driver is 40 years old and 150 feet away

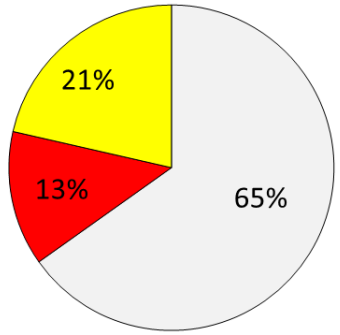
Surface	Reflectance
Black fabric	2%
White cotton coat	68%
White paint	75% – 90%
Asphalt pavement	5% - 20%
Concrete pavement	10% - 50%
Soils, sand	5% - 45%
Vegetation	5% - 25%

Link to RVP Calculator

Intersection 1 (suburban, 3-way)

- 250 W Type II HPS – existing (1 – 10 lux)



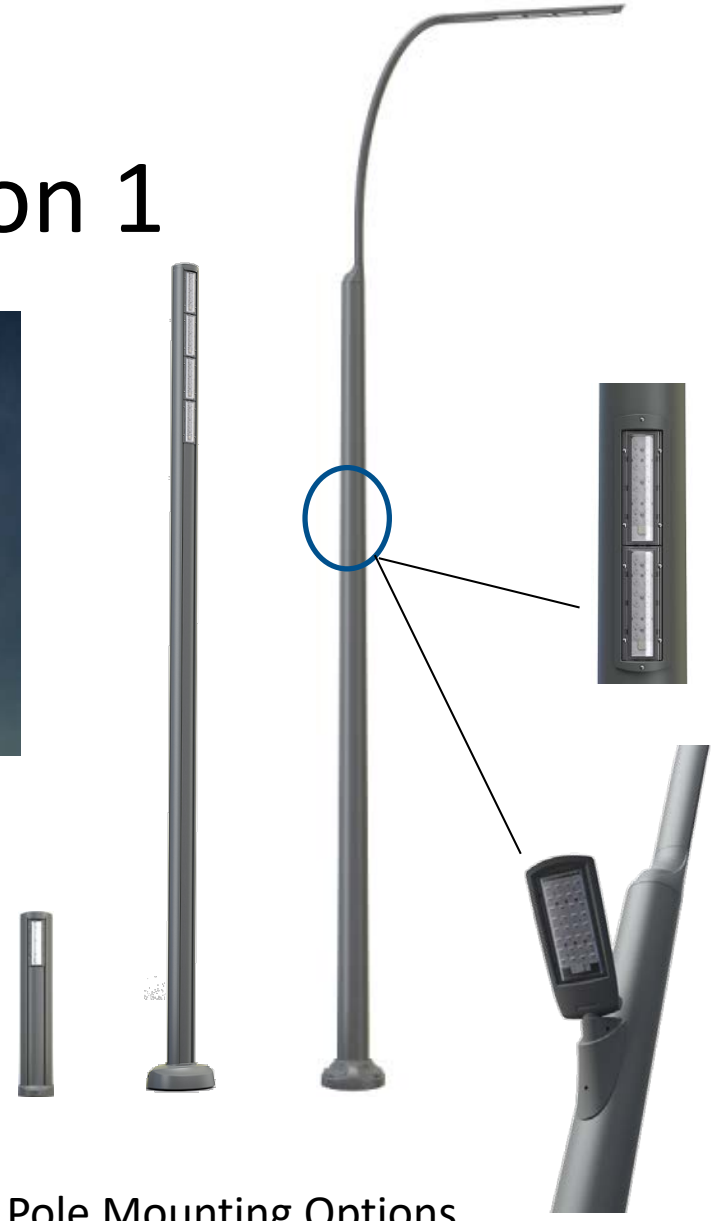


- Better visibility closer to the luminaire
- Light colored clothing generally increases visibility

Color Key: 0.1 – 0.8 0.8 – 0.9 0.9 – 1.0

LED technology intersection 1

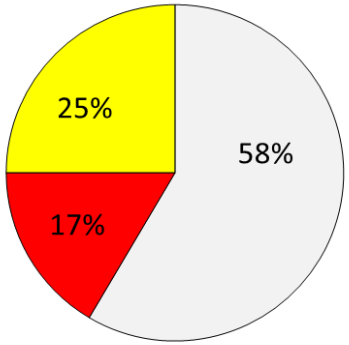
- Functional lighting combined with ambience lighting
- One visual signature, a uniformity through all the objects
- Wide range of options for different type of applications
- Simplicity in the process of design & specification

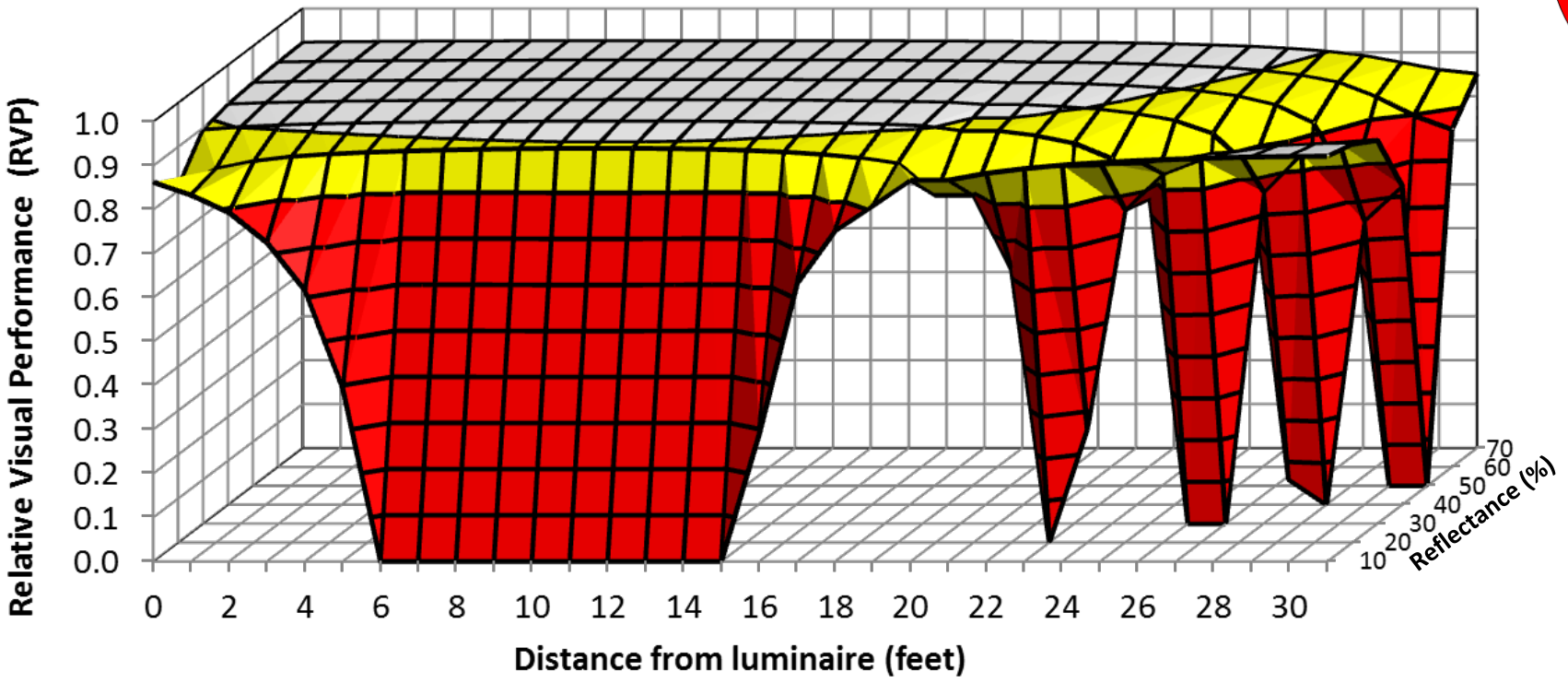


Mid Pole Mounting Options

Intersection 1 (suburban, 3-way)

- 110 W LED (same location, Type IV, 2 – 8 lux)

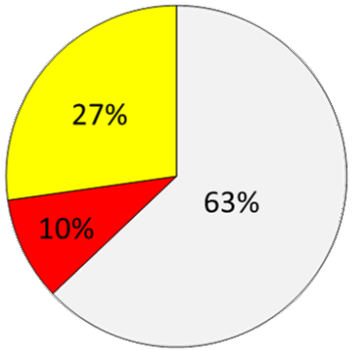


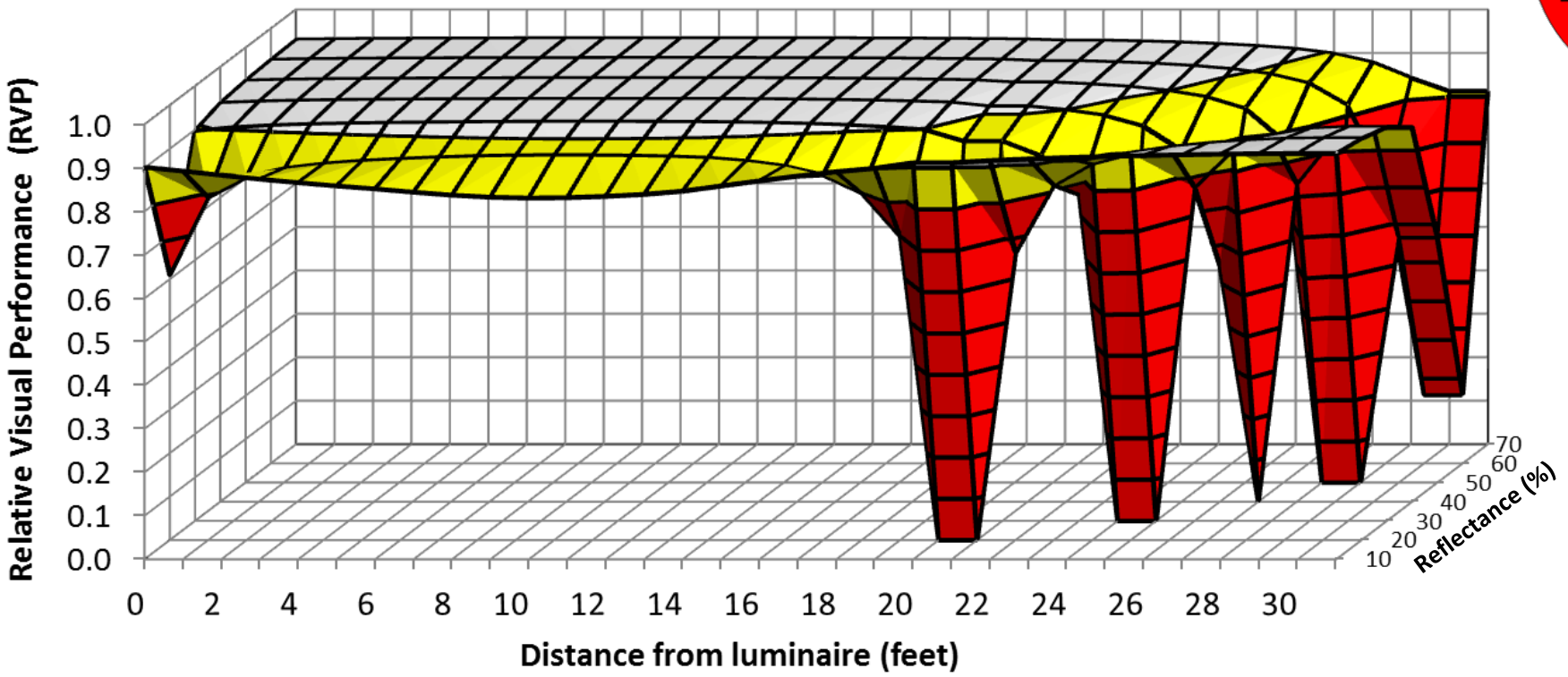


Color Key: 0.1 – 0.8 0.8 – 0.9 0.9 – 1.0

Intersection 1 (suburban, 3-way)

- 145 W LED (same location, Type IV, 2 – 9 lux)





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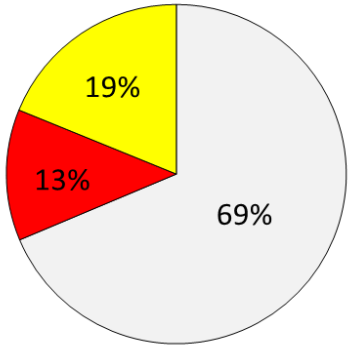
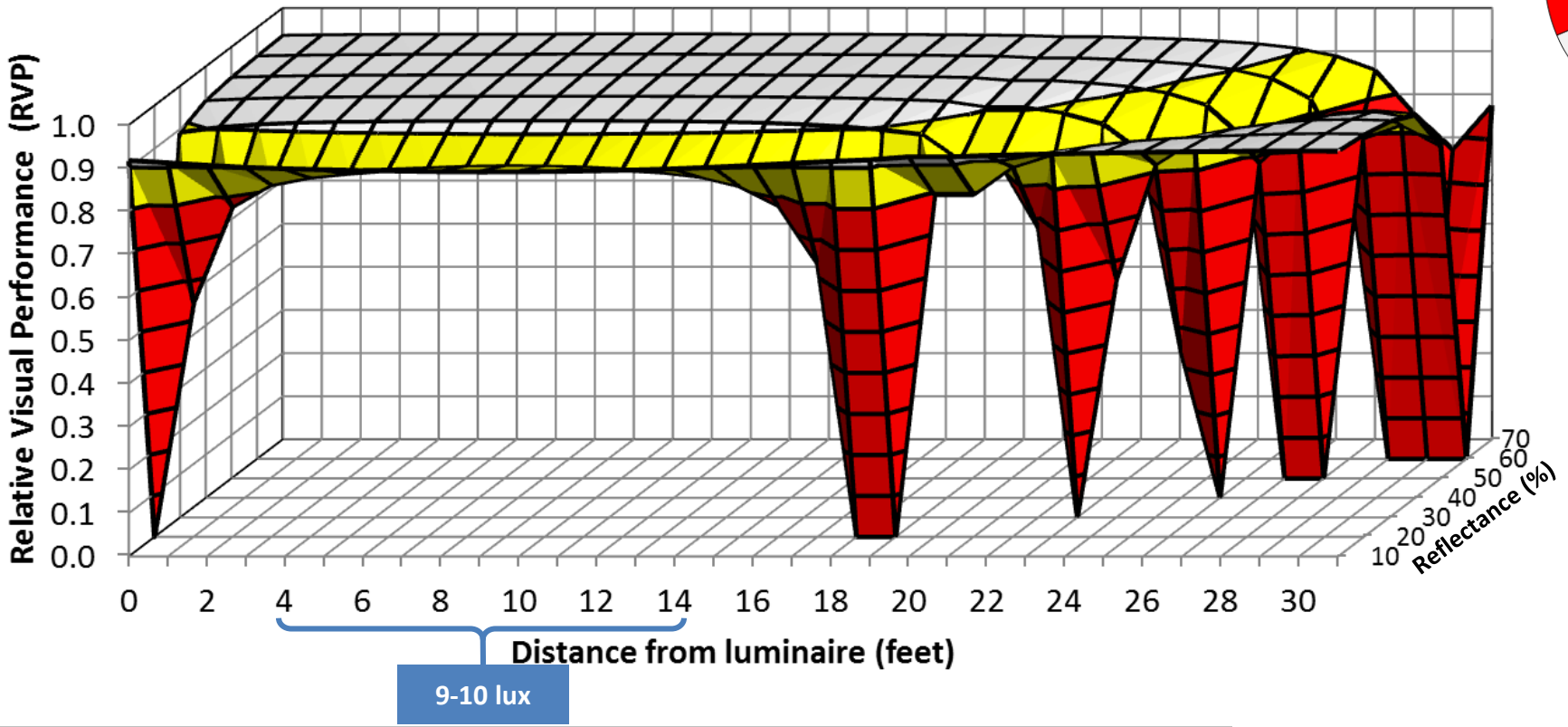
Intersection 1 (suburban, 3-way)

- 180 W LED (same location, Type IV, 2 – 10 lux)





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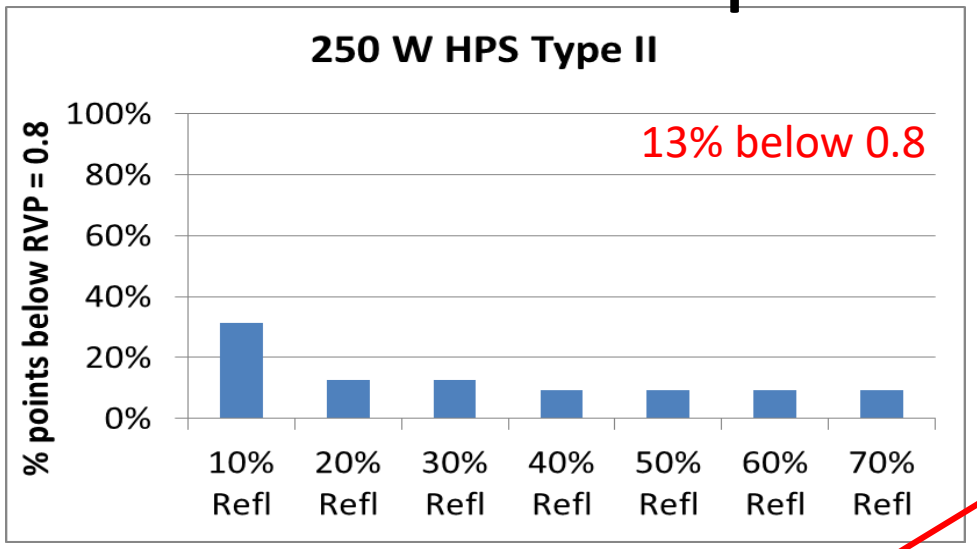
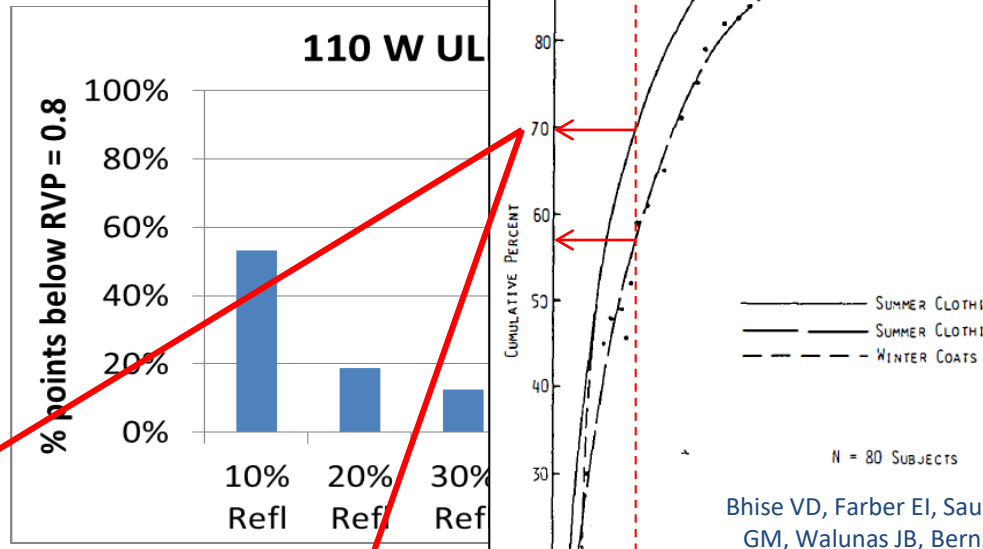
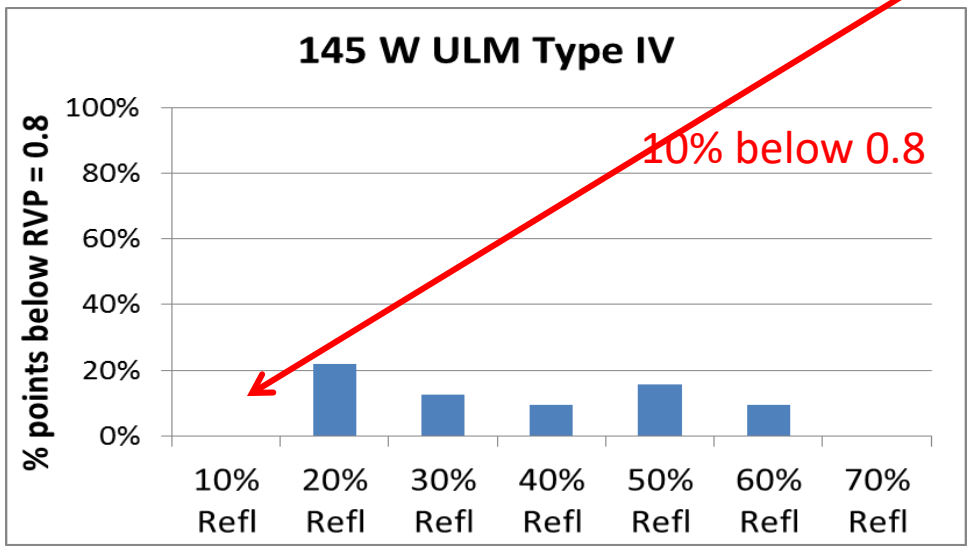
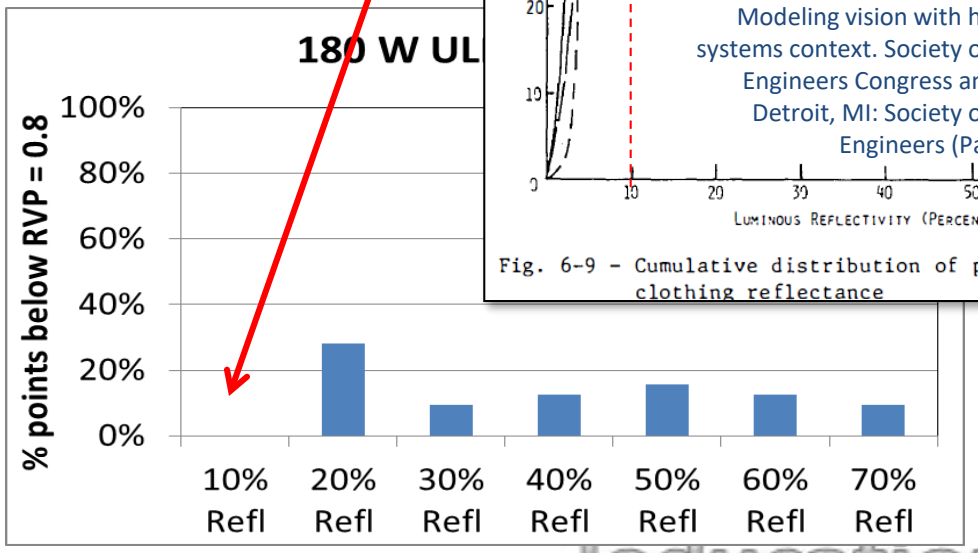
% points below 0.8





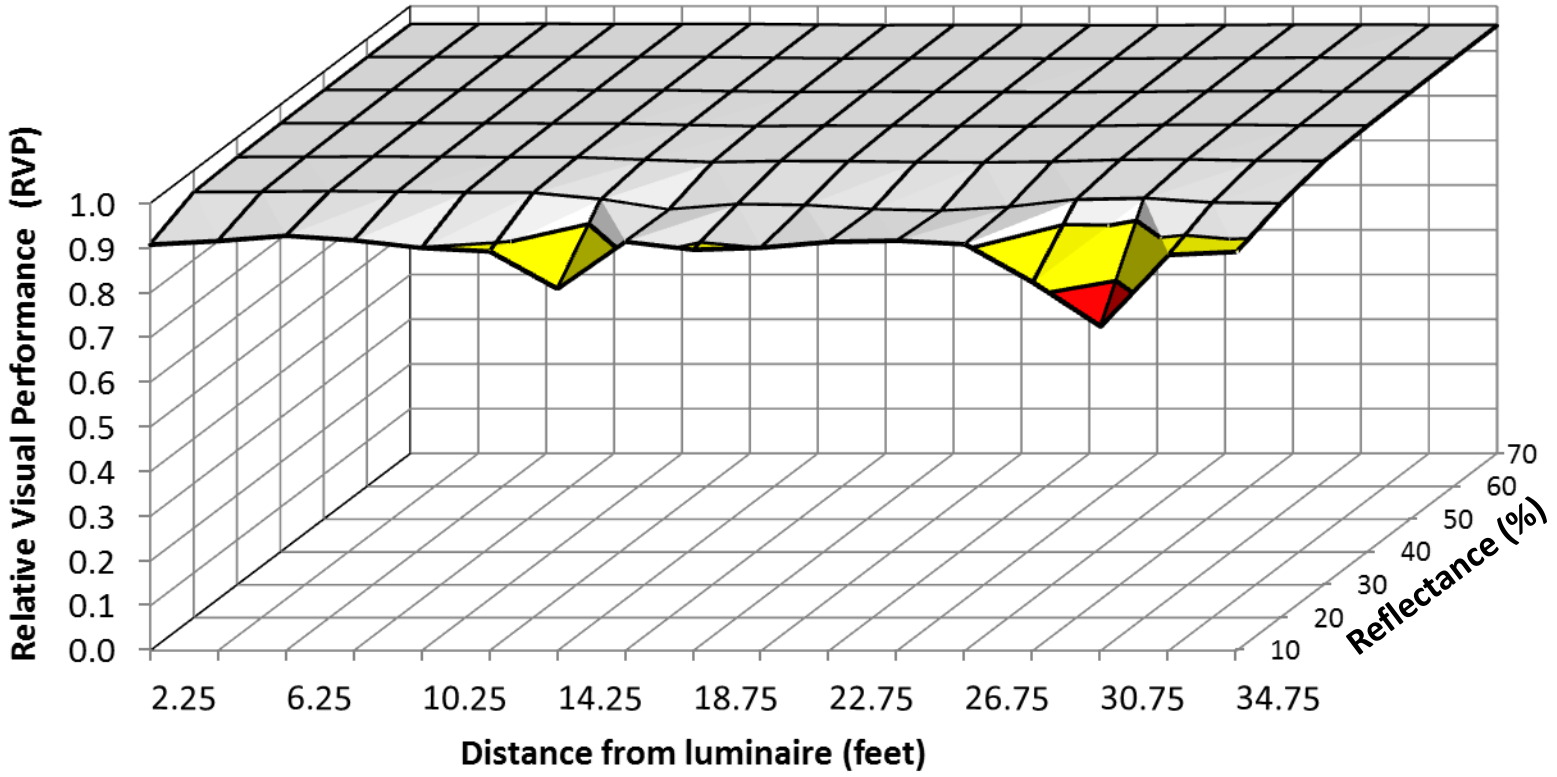


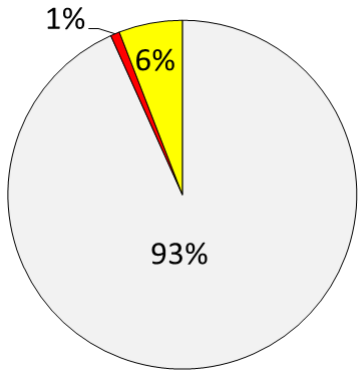


Bhise VD, Farber EI, Saunby CS, Troell GM, Walunas JB, Bernstein A. 1977. Modeling vision with headlights in a systems context. Society of Automotive Engineers Congress and Exposition, Detroit, MI: Society of Automotive Engineers (Paper 770238).

Intersection 2 (urban, 4-way)

- 100 W Type IV HPS – existing (22 – 46 lux)



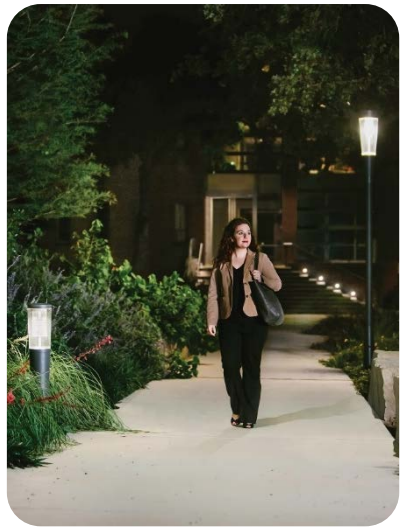


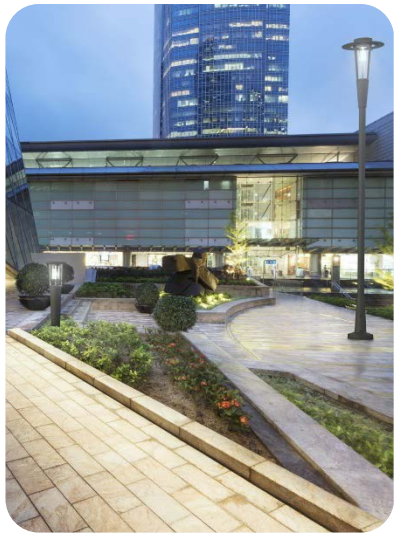
- High light levels result in high RVP values
- Light colored clothing increases visibility

Color Key: 0.1 – 0.8 0.8 – 0.9 0.9 – 1.0

LED technology intersection 2

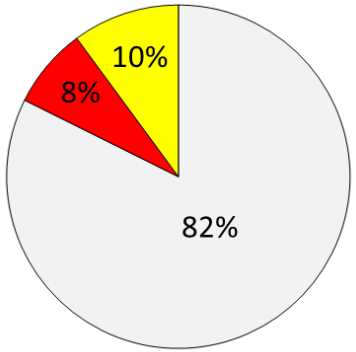
- Vertically-oriented light engine creates transparency during the day and full illumination at night
- Effectively mitigates pixelization and glare without compromising performance
- Light is guided through precision rings without directly exposing viewers to the LEDs
- Provides visual comfort and excellent facial recognition

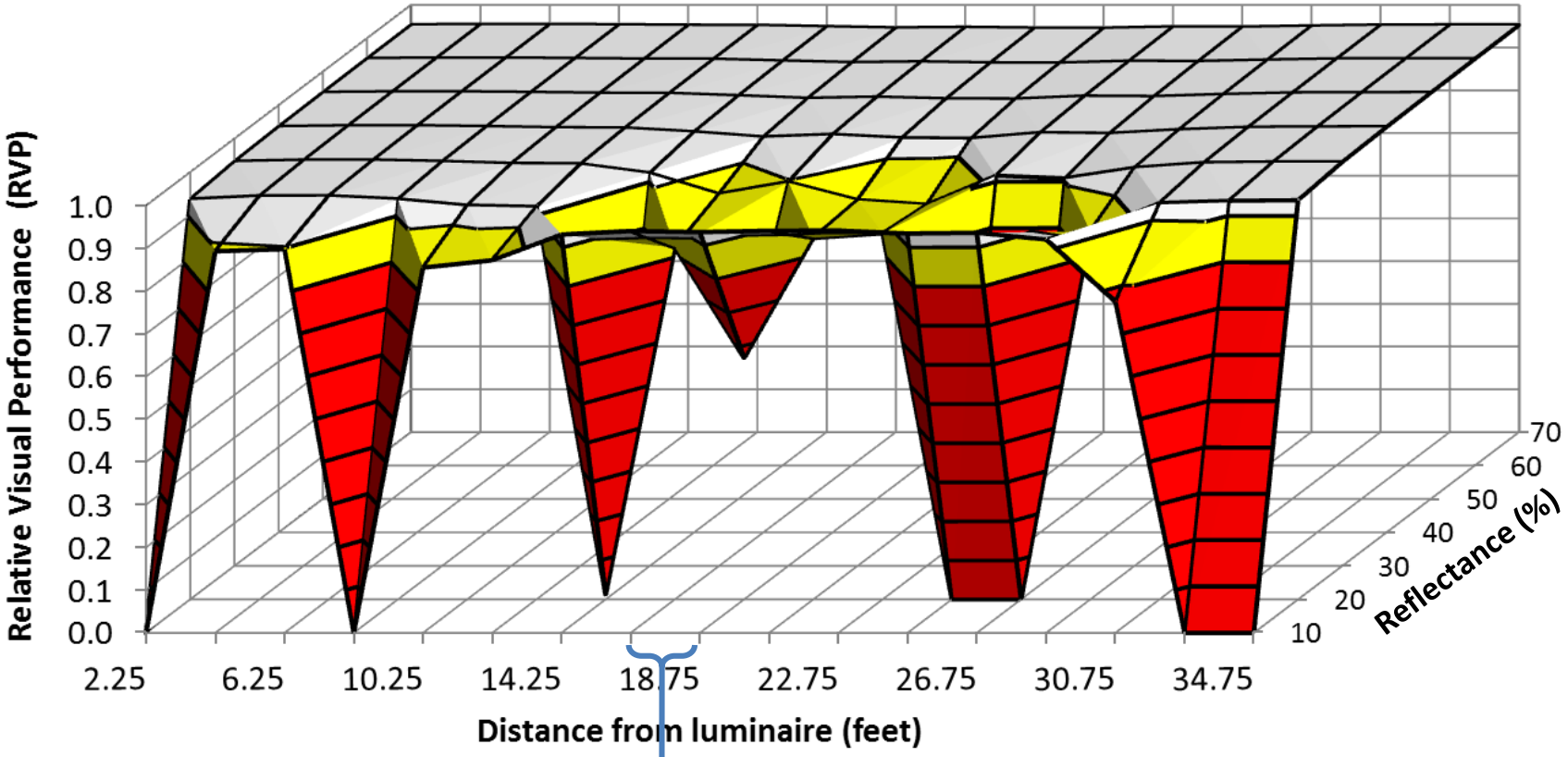




Intersection 2 (urban, 4-way)

- 33 W LED (same locations, Type III, 9 – 36 lux)



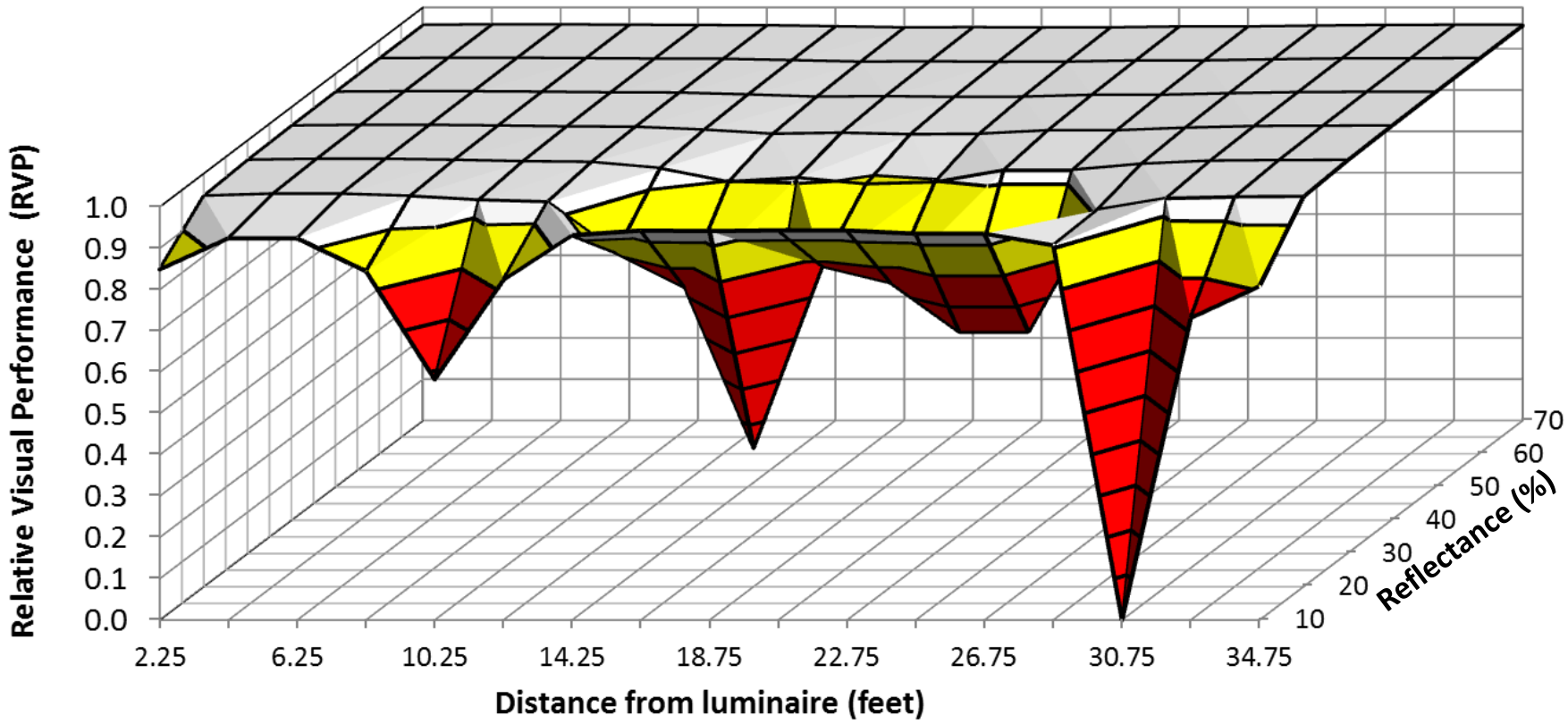


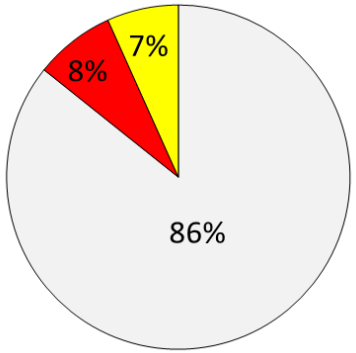
Color Key: 0.1 – 0.8 | 0.8 – 0.9 | 0.9 – 1.0

10 lux

Intersection 2 (urban, 4-way)

- 50 W LED (same locations, Type III, 12 – 48 lux)





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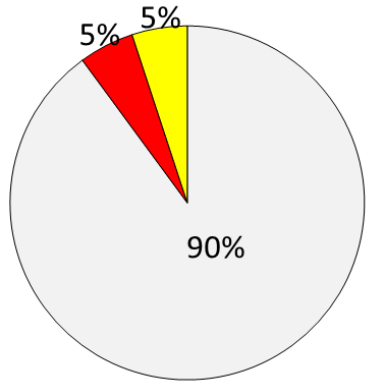
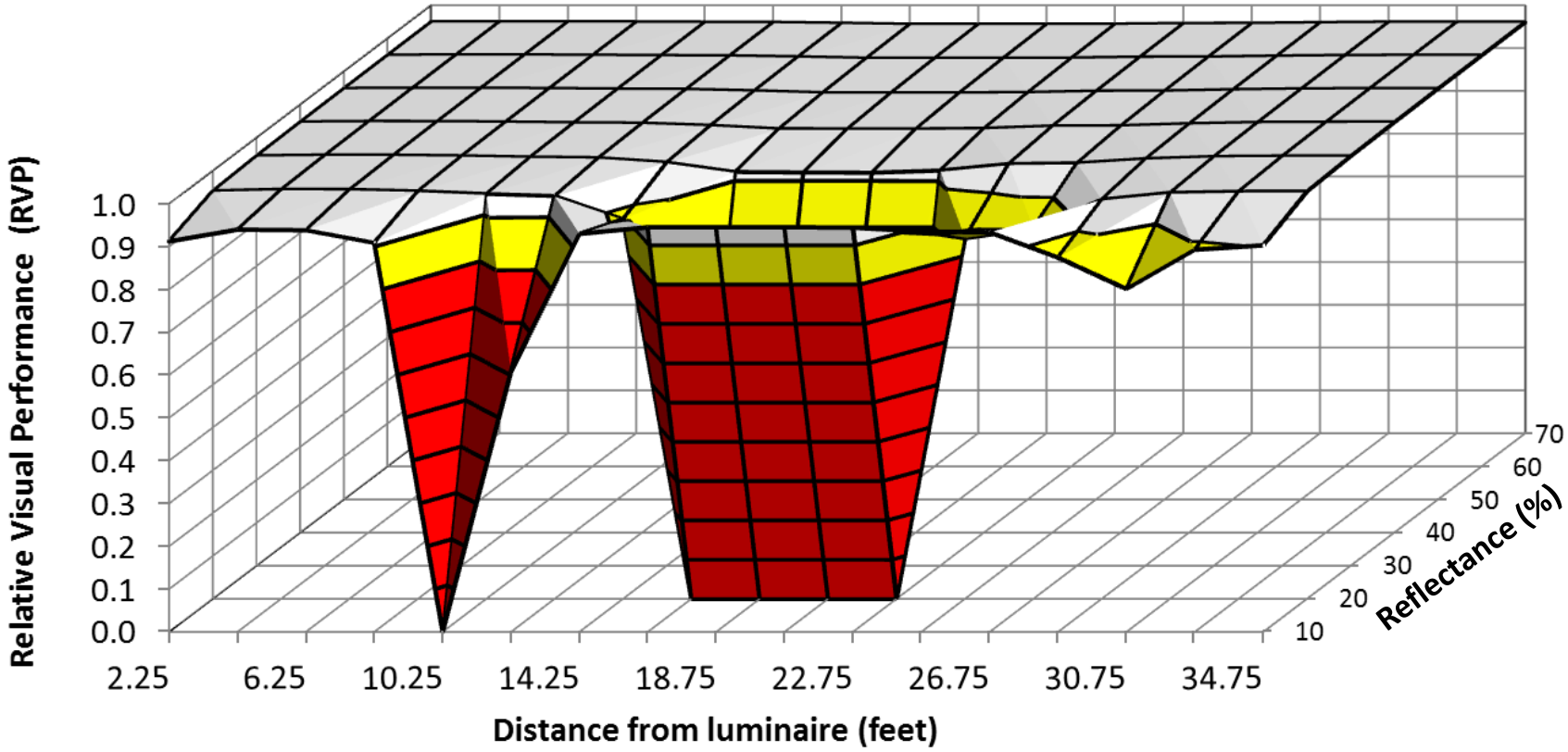
Intersection 2 (urban, 4-way)

- 76 W LED (same locations, Type III, 16 – 68 lux)





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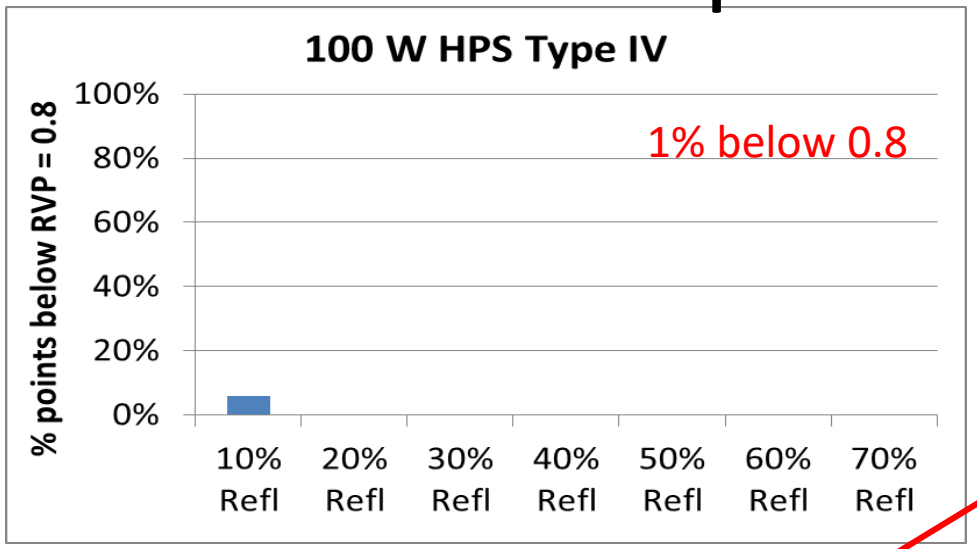
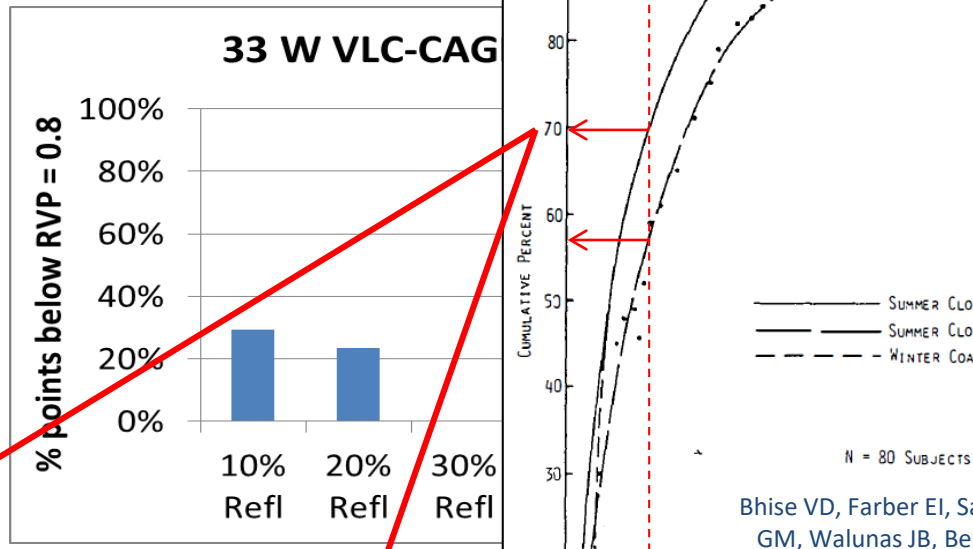
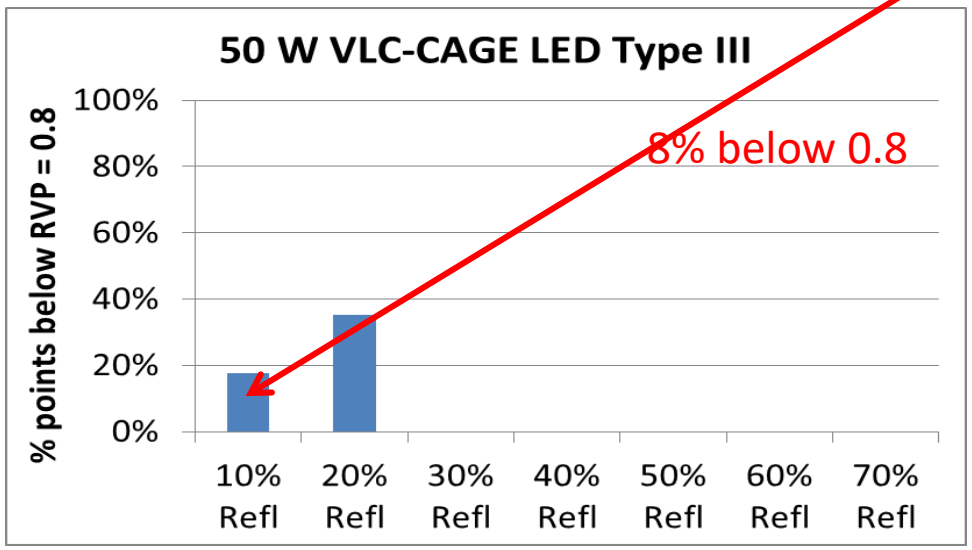
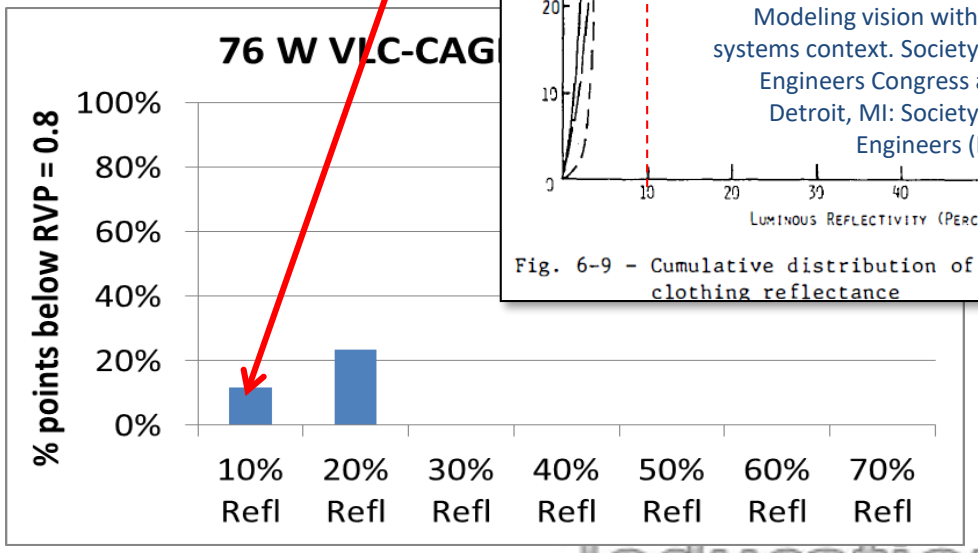
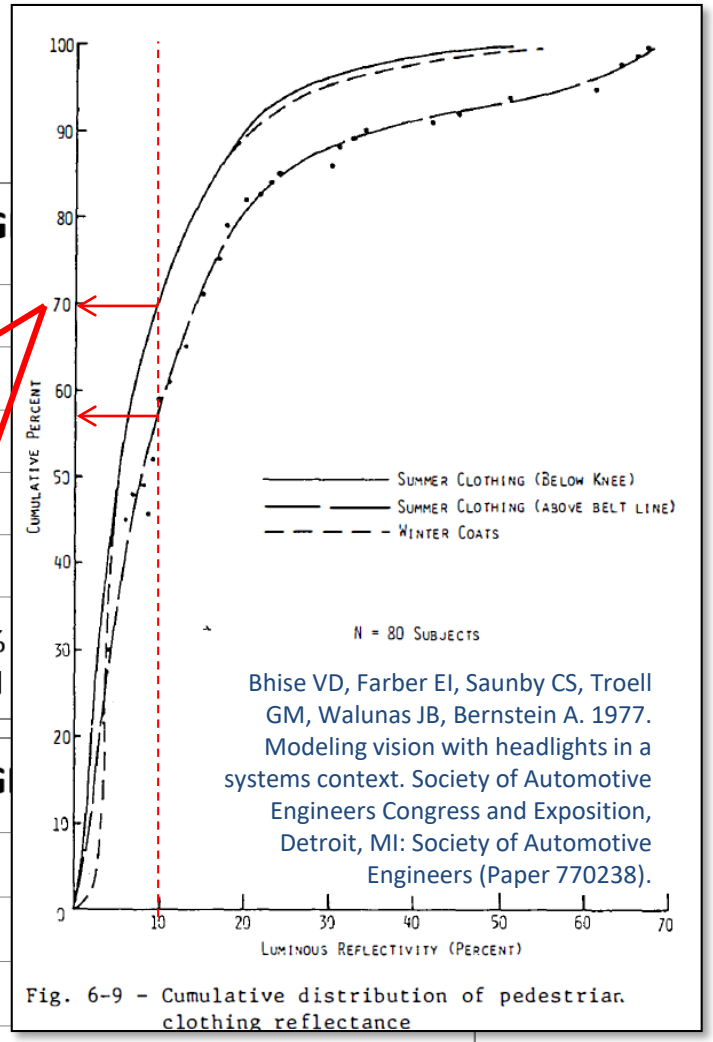
% points below 0.8











RVP summary

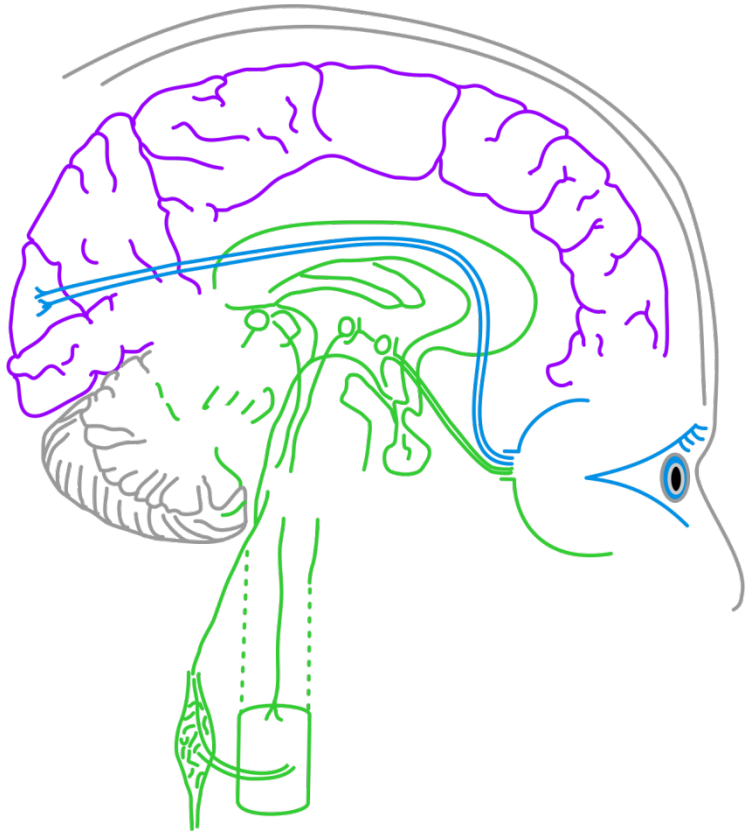
- 10 lux does NOT guarantee good visibility (RVP > = 0.8)
- LED systems can improve visibility but it isn't guaranteed
- Changing luminaire locations and orientation may provide better visibility, but you need think of the right criterion…

CONTRAST, NOT LIGHT LEVEL

Metrics in progress

Glare

Perceived Safety



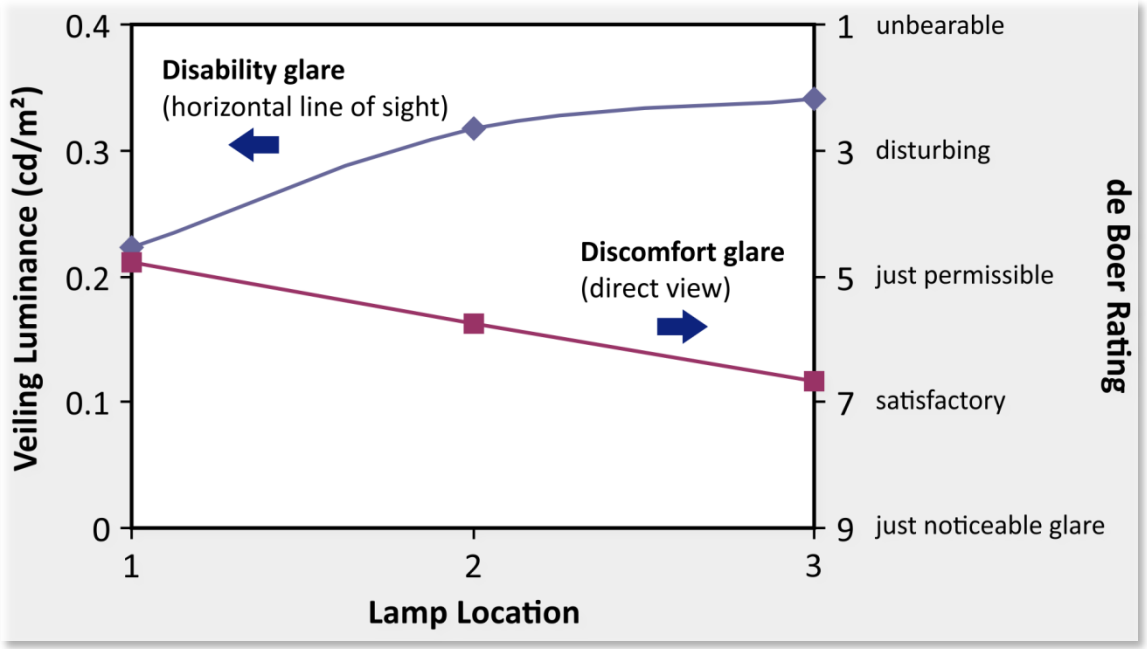
Circadian Disruption

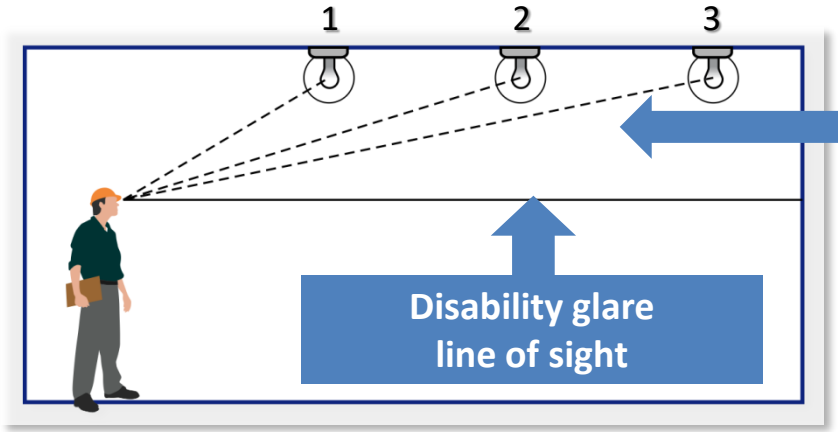
Glare

- Disability glare
  - Reduction in visibility caused by luminous veil due to scattered light in the eye
  - Well-understood quantitatively for decades (Fry 1954)
- Discomfort glare
  - Annoying or painful sensation when exposed to a bright light in the field of view
  - Understood more recently (Bullough et al. 2003, Bullough 2009, Bullough and Sweater Hickcox 2012)

Glare

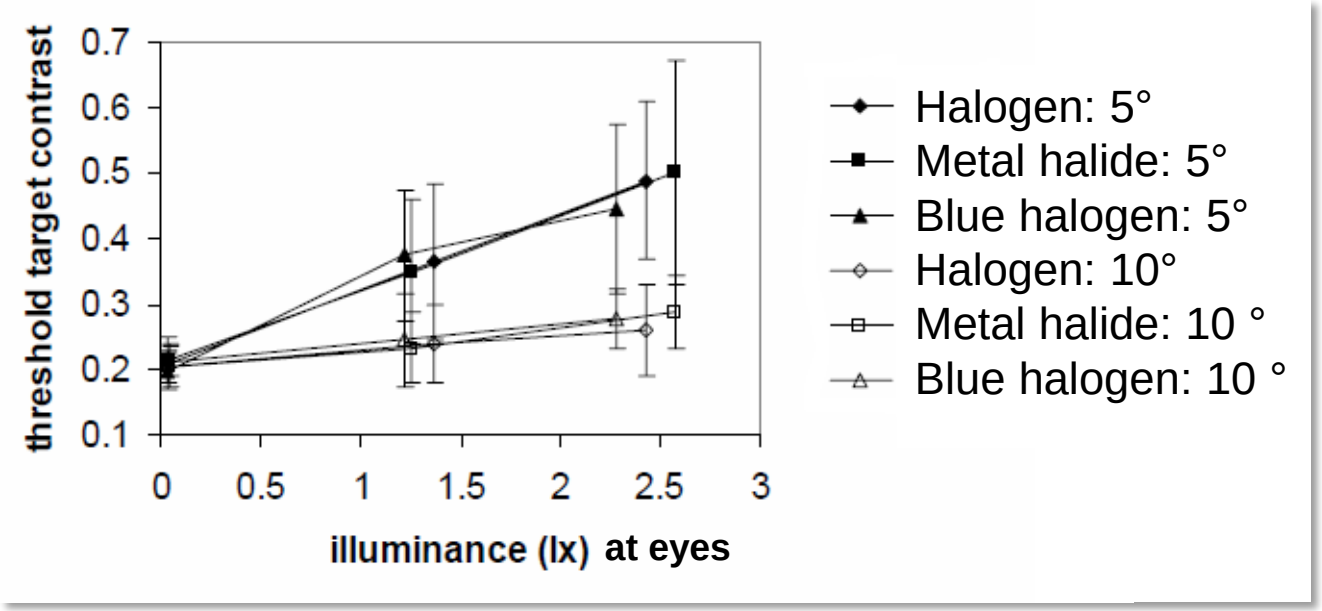
100-watt incandescent lamps





Disability glare

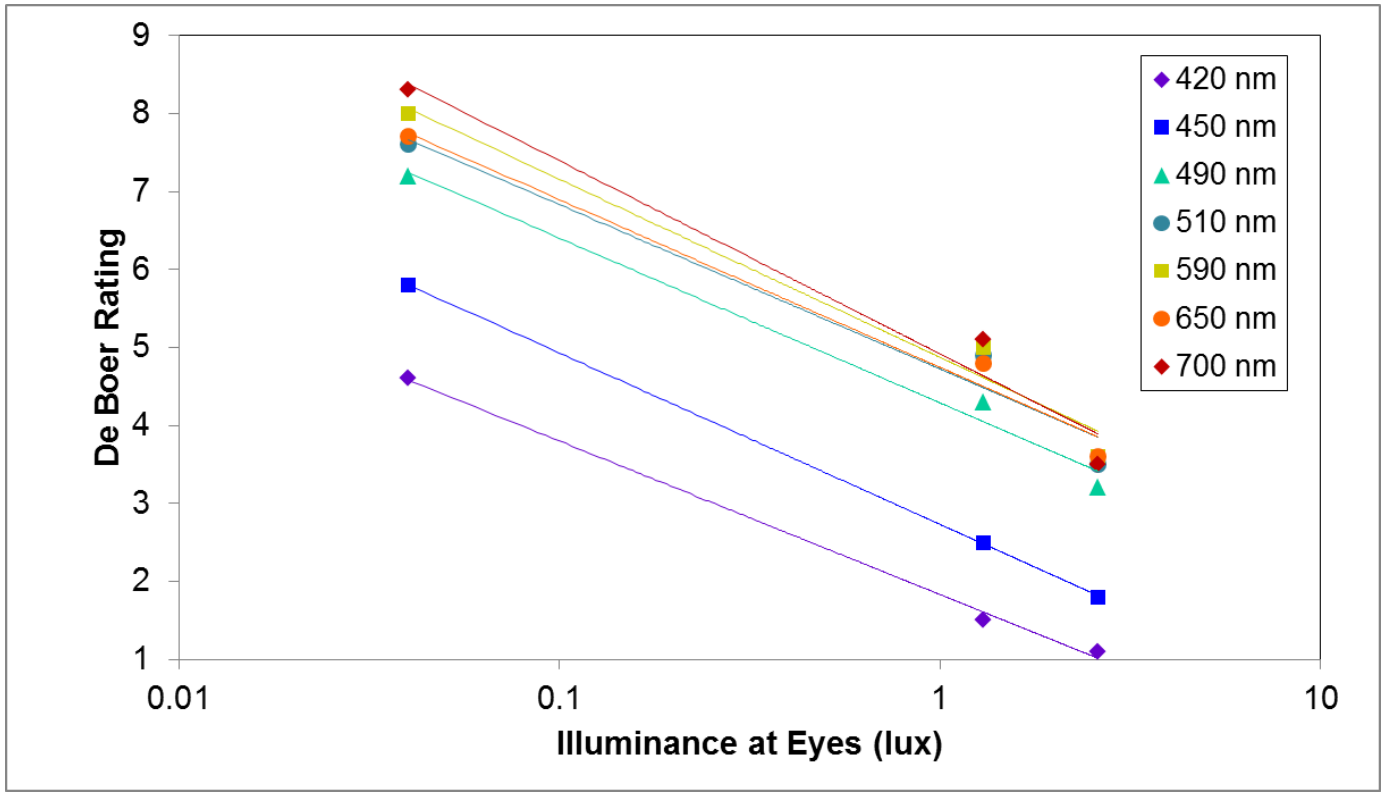
- Disability glare is primarily a function of photopic illuminance at the eyes and the angular distance between the source and the object of interest
(Bullough et al. 2002, 2003)



- Different spectra do not differentially affect on-axis visual performance, acuity, contrast threshold, or reaction time

Discomfort glare

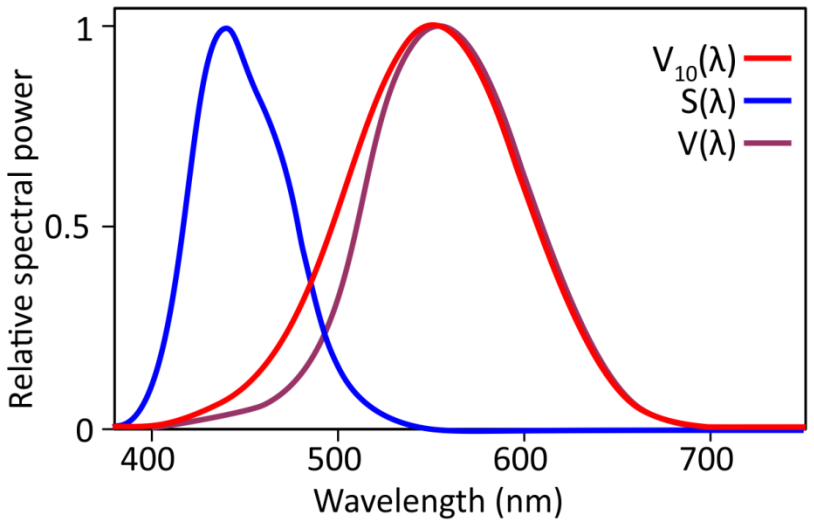
- Short wavelengths increase discomfort glare for the same photopic illuminance at the eyes

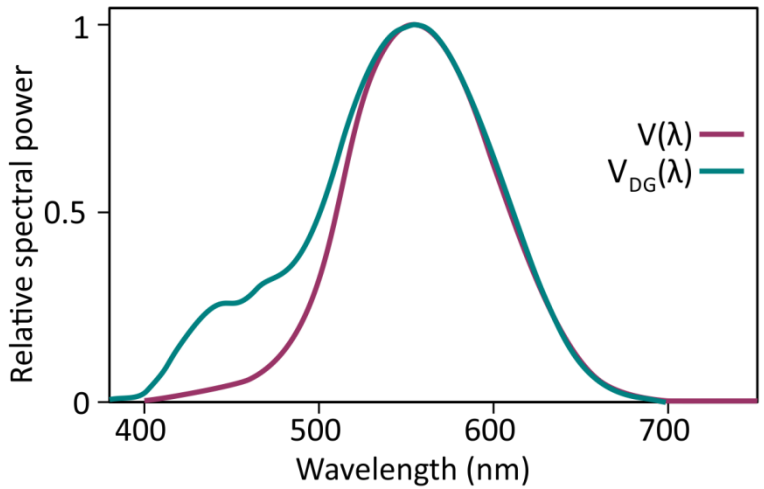


9: Just noticeable
8:
7: Satisfactory
6:
5: Just acceptable
4:
3: Disturbing
2:
1: Unbearable

Spectral sensitivity of discomfort glare (DG)

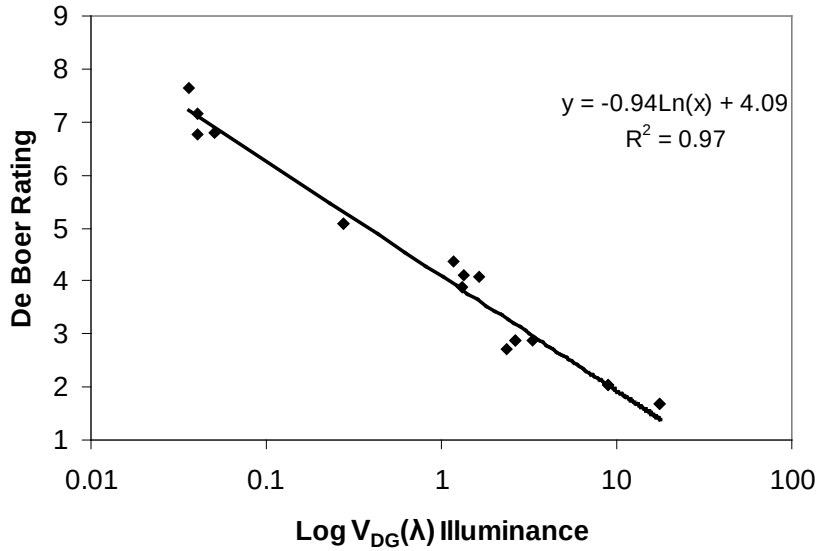
- A combination of $V_{10}(\lambda)$ and short-wavelength cone sensitivity $S(\lambda)$ was the best rectifying variable for discomfort ratings $[V_{DG}(\lambda)]$





$V_{DG}(\lambda) = V_{10}(\lambda) + kS(\lambda)$

$k = 0.19$

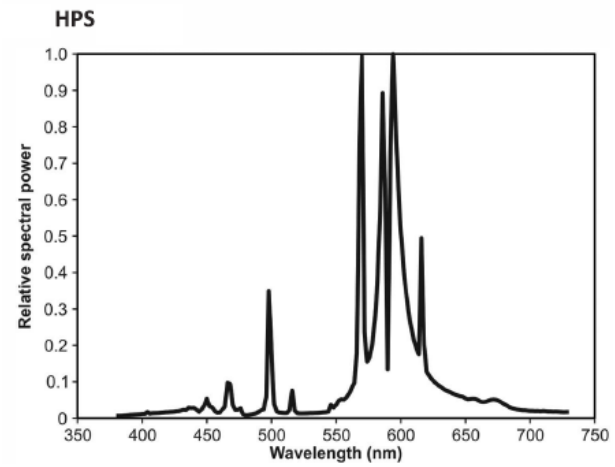


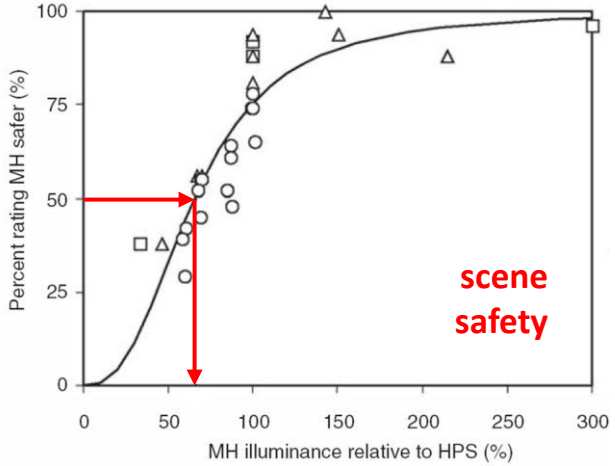
Glare (summary)

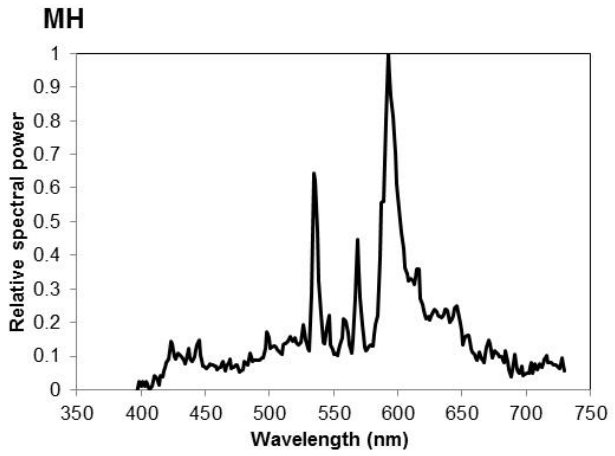
Disability Glare		Discomfort Glare
✓✓✓	Photopic illuminance at the eye	✓✓✓
✓✓	Angle between glare source and line of sight	✓✓
NA	Luminance of the source (> 0.3°)	✓
NA	SPD	✓
NA	Psychological	✓

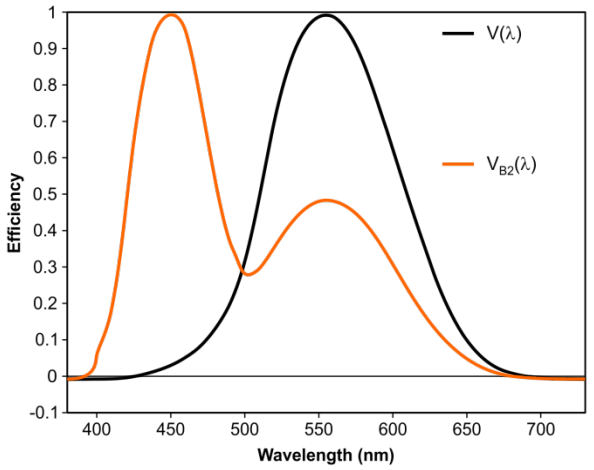
✓✓✓ Most important ✓✓ Very important ✓ Important NA Not applicable

Perceived safety ratings and predictions

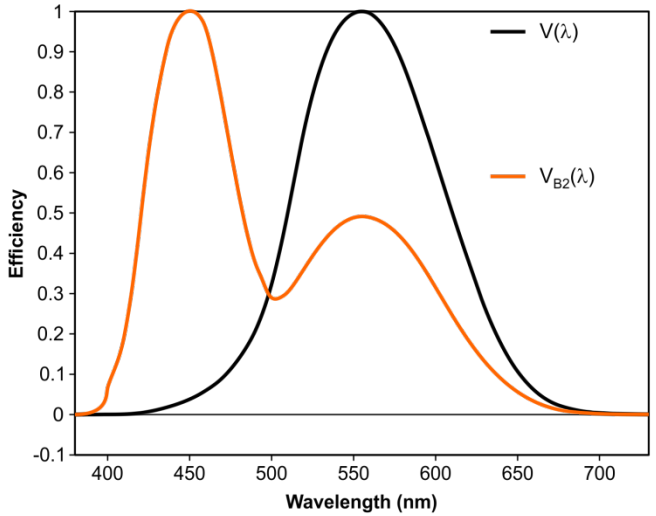


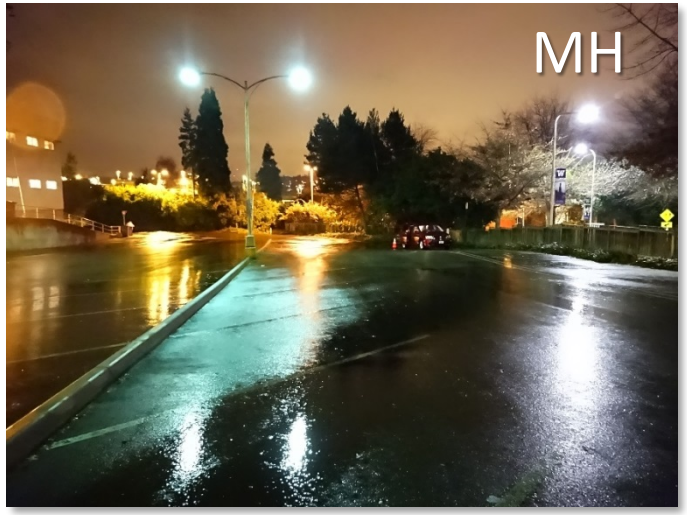




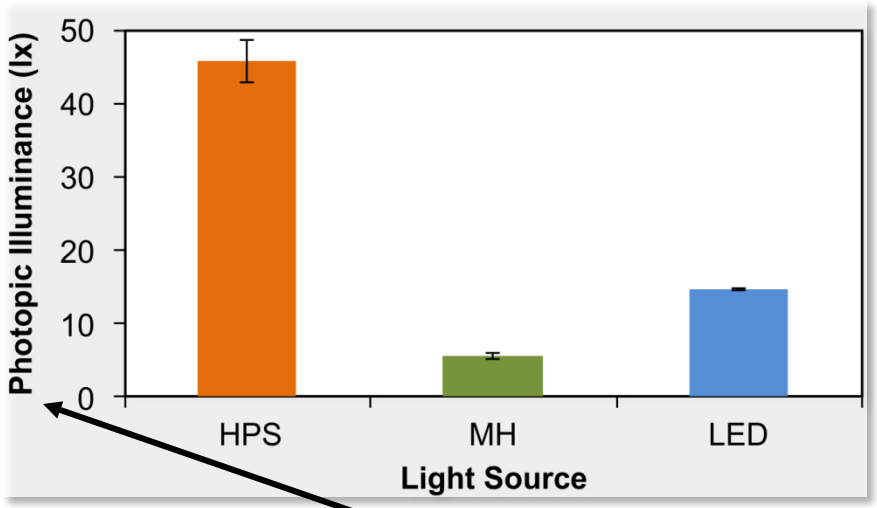


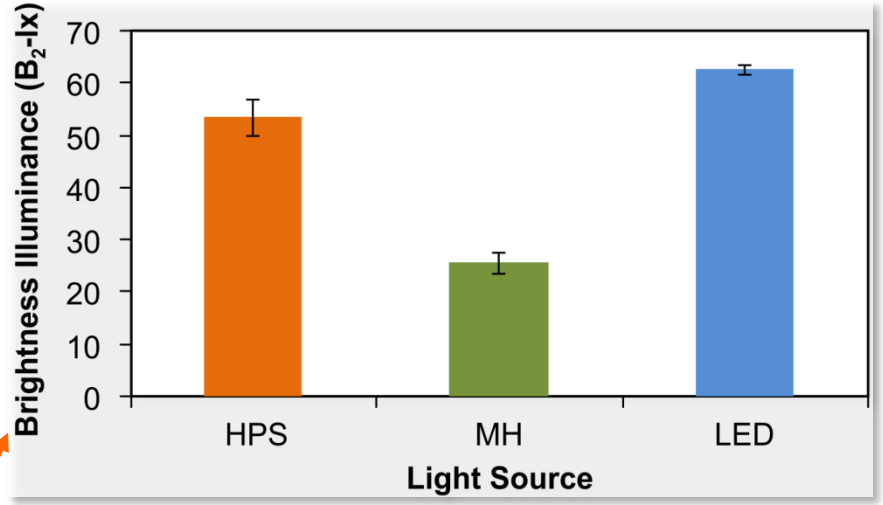
Validation case study – University of Washington

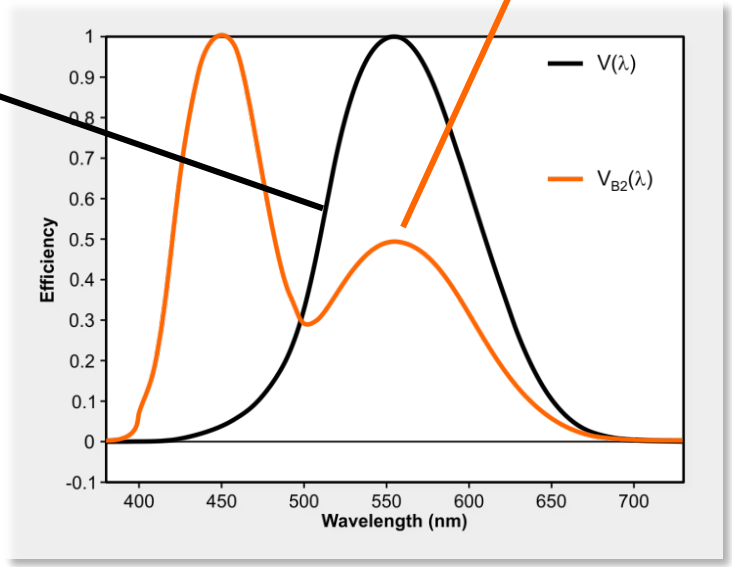




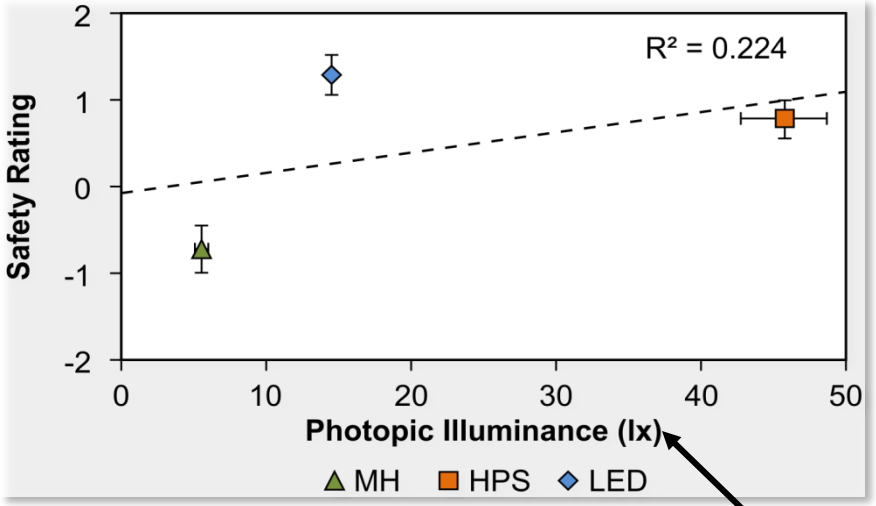
Comparison of photopic illuminance and brightness illuminance

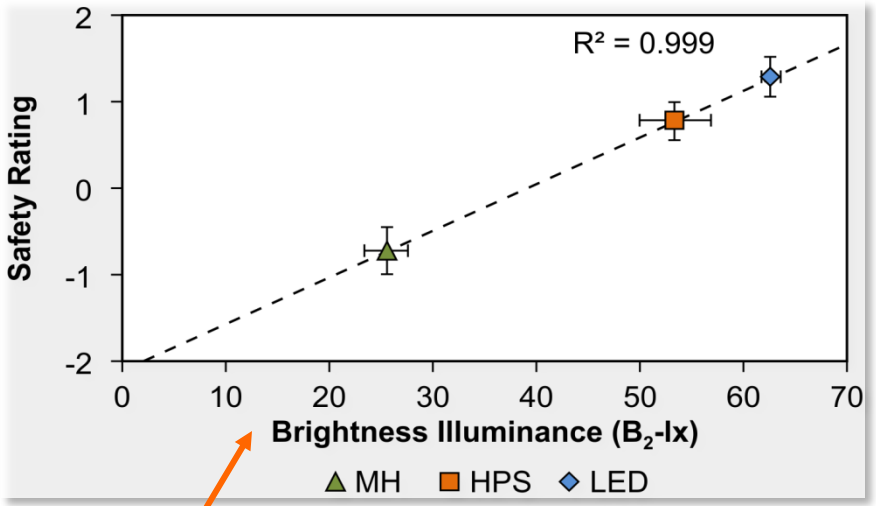


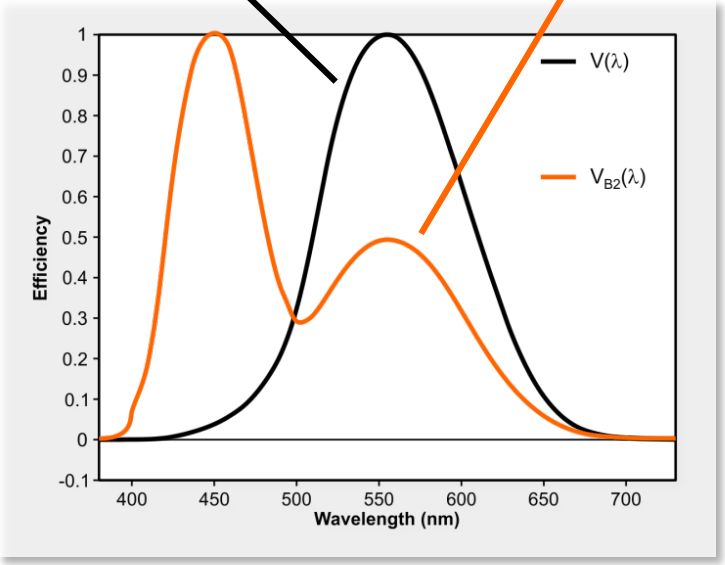




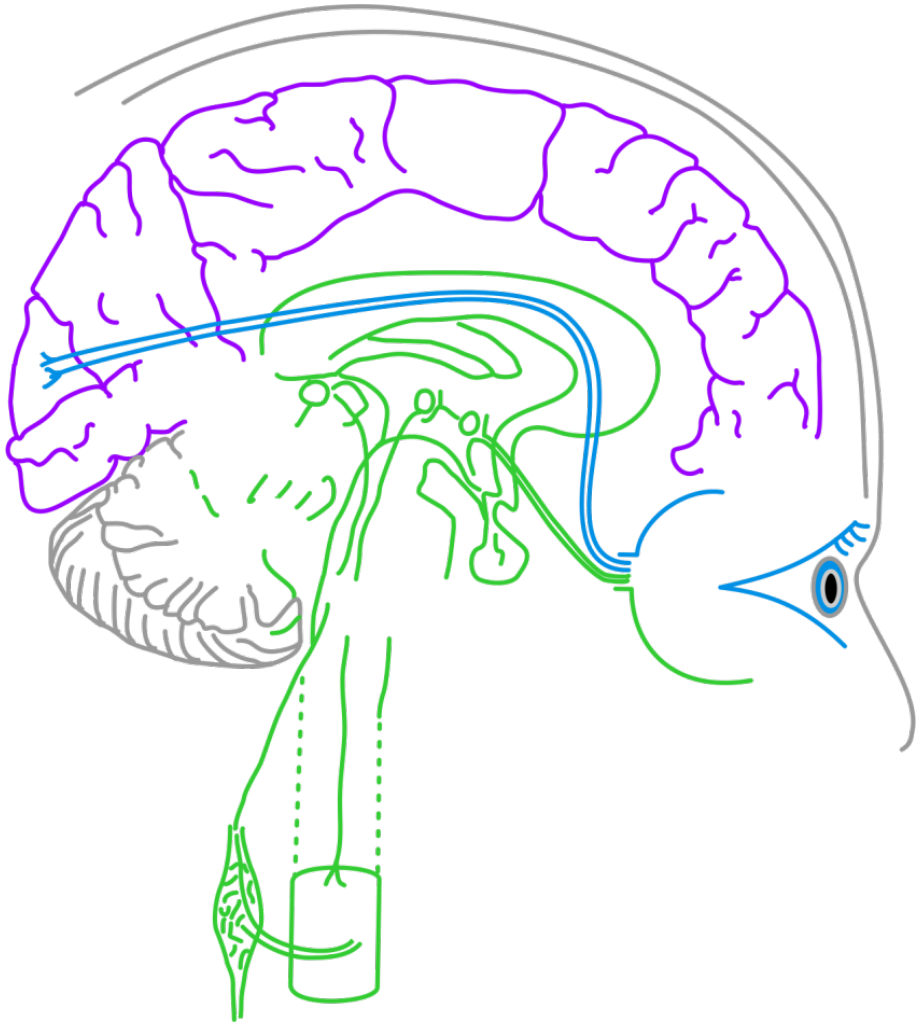
Safety judgements



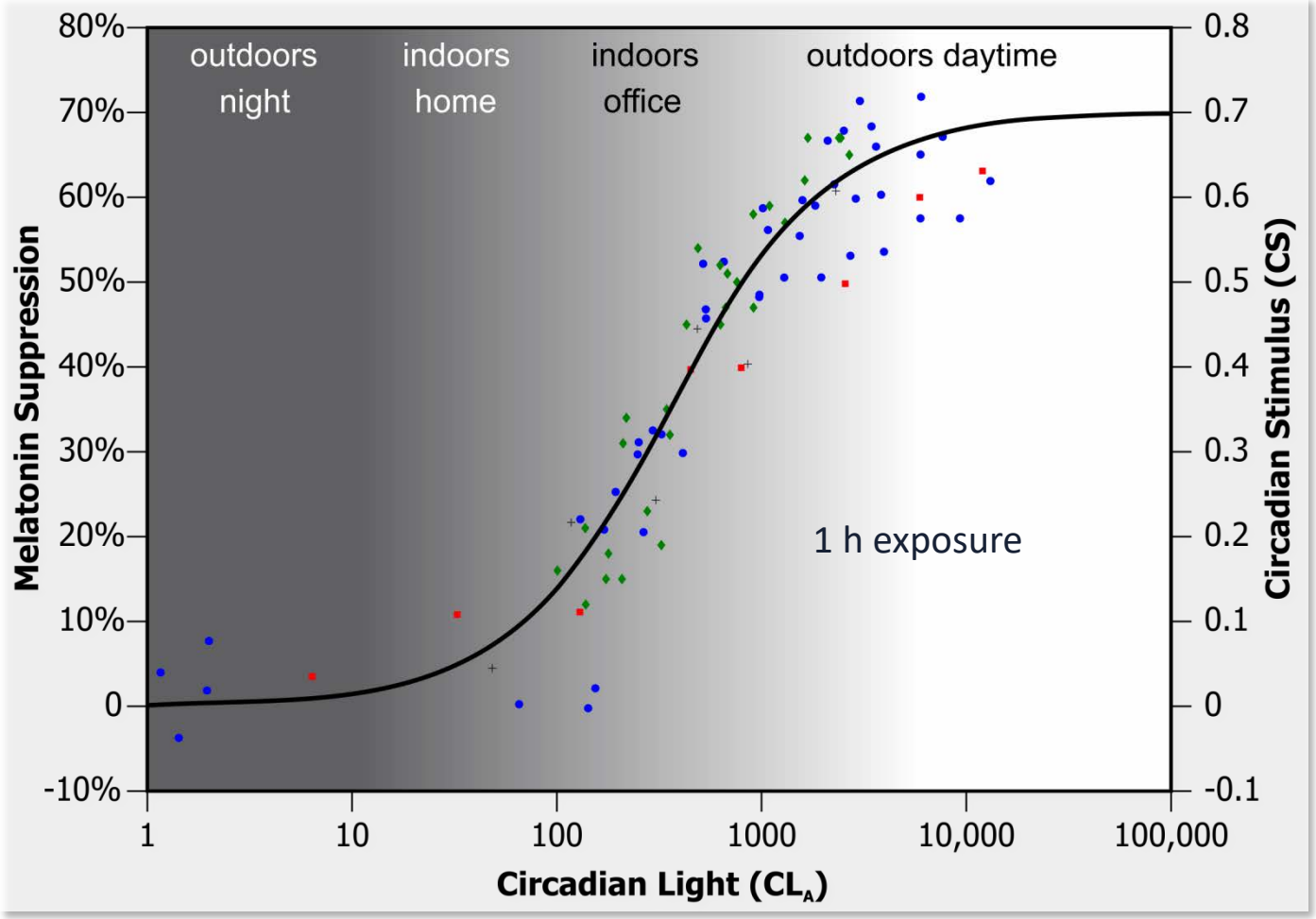




Circadian disruption

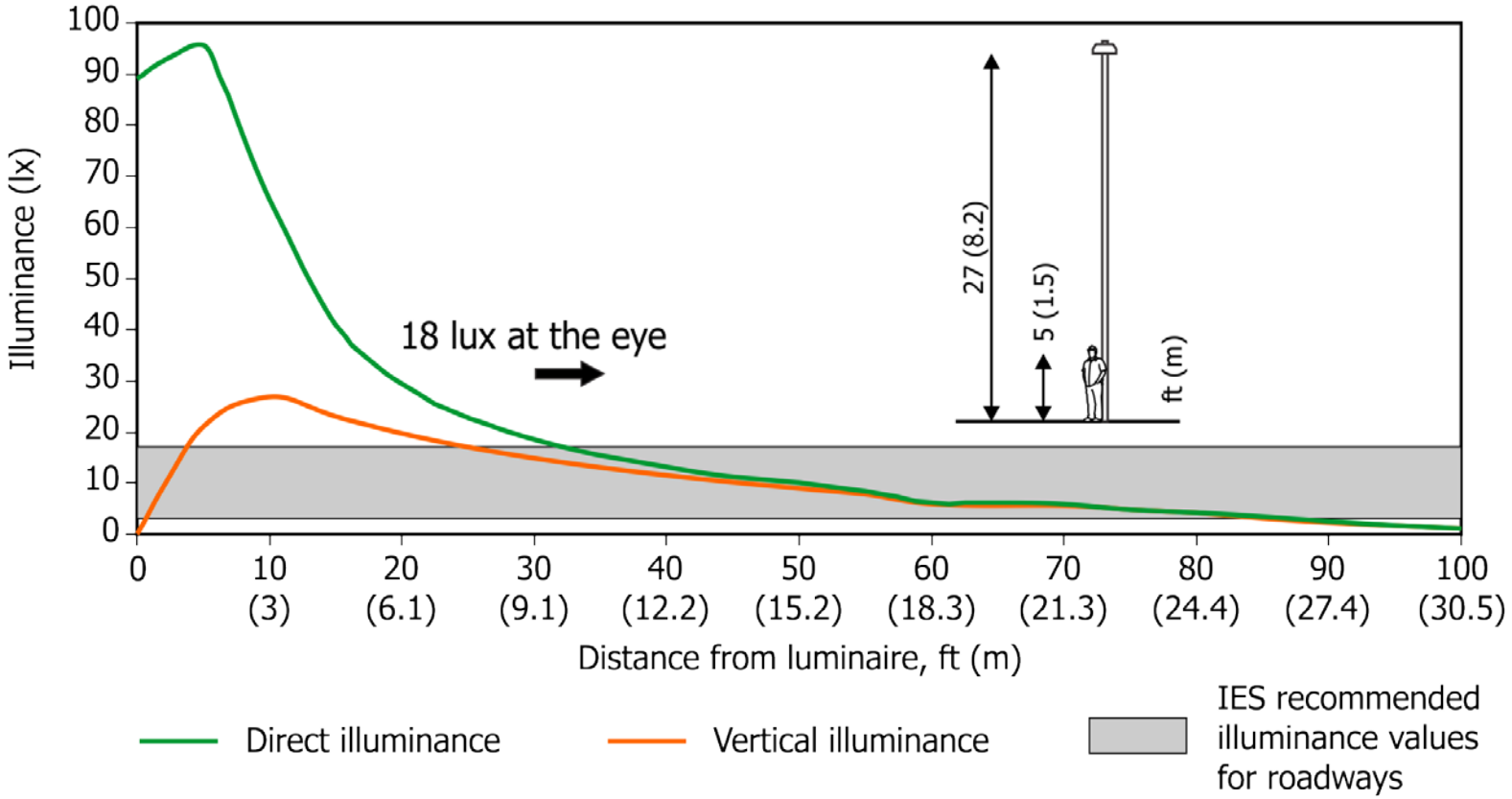


Circadian disruption and melatonin suppression using circadian stimulus



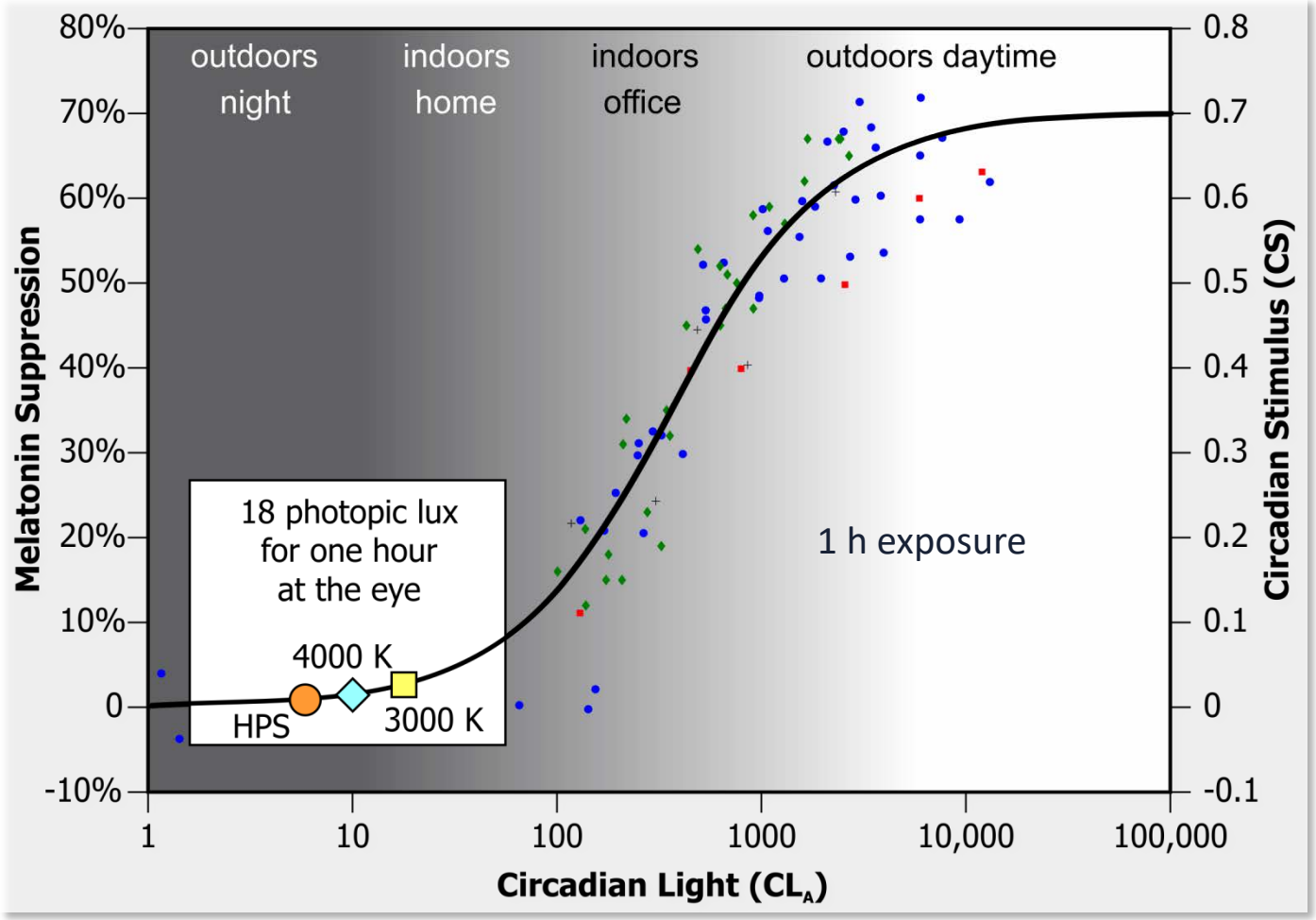
Absolute Sensitivity

IES recommended levels: Amount only



Rea et al. 2010 (rev. 2012). The potential of outdoor lighting for stimulating the human circadian system. *Alliance for Solid-State Illumination Systems and Technologies (ASSIST).* Troy, NY.

Circadian disruption and melatonin suppression using circadian stimulus



Absolute Sensitivity

Evaluation summary

- LED products can improve visibility over HPS products
  - Need the right distribution to increase contrast
  - May need to add luminaires / move luminaires for best performance
- Emerging metrics are being developed to evaluate glare, perceived safety and circadian disruption
- Potential power demand savings **can be 50%** but solutions need to: be based on visibility (not illuminance), decrease glare, increase perceived safety, and prevent circadian disruption

This concludes The American Institute of Architects Continuing Education Systems Course

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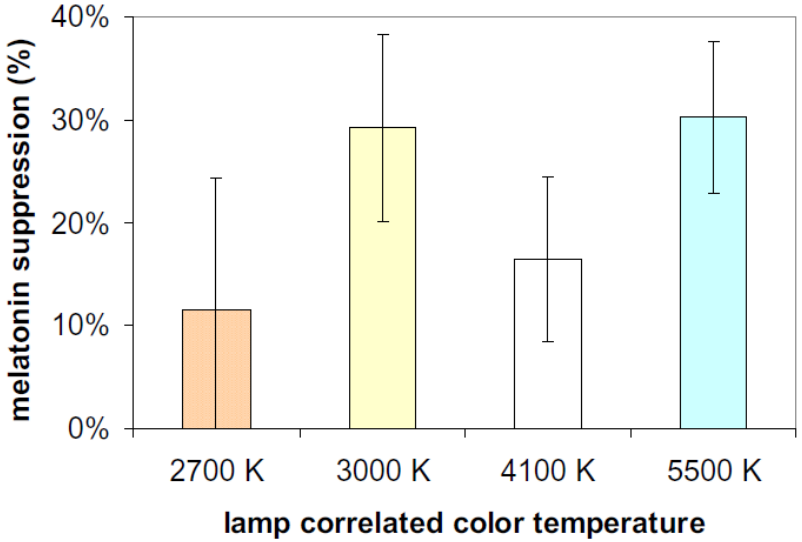
A note on correlated color temperature

- CCT is a common metric for comparing lights differing in spectral content
- It is based on the physical emission properties of a blackbody (or of daylight), not human biophysics
- It is not a particularly useful alternative to characterize discomfort glare, mesopic vision, brightness perception, or circadian stimulus



Rea et al. (2006)