DLC STAKEHOLDER MEETING 2018

July 9 - 11 • Boston, MA

Discussion Session:
SSL V5.0: Quality of Light

Facilitators

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Session Objective: Gather Input

Provide us your questions, suggestions, concerns, or issues for DLC in addressing these quality topics or using these metrics

Format and Ground Rules

- 15-20 minutes per topic
- One speaker at a time; one minute per speaker
- Try to avoid rabbit holes and off topic tangents 
- Emphasis on gathering input
- Keep it positive and have fun! 

Quality of Light Topics

- Color Quality
- Glare
- Distribution
- Flicker

Some Key Questions and Issues

- What is the value of DLC addressing these topics and metrics?
- What are the unintended consequences?
- Required threshold vs. reporting value to enable differentiation vs. reporting distribution data?
- Applying application dependent metrics at the product level

Required threshold vs. reporting value to enable differentiation

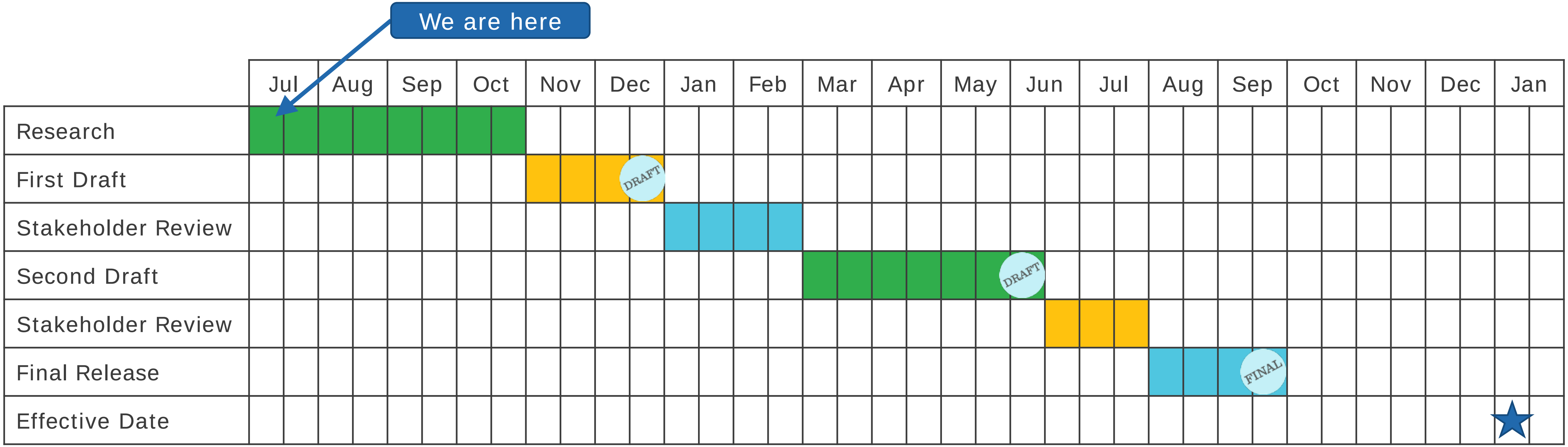
3 Options to Consider

1. DLC provides manufacturers the option of reporting a particular quality metric on the QPL
2. DLC requires manufacturers to report a particular quality metric on the QPL
3. DLC defines a minimum standard threshold value for a particular quality metric and requires manufacturers to meet it to be on the QPL

Applying application dependent metrics at the product level

- Some standards/metrics have been introduced to apply application metrics at product level using standardized assumptions
- Examples:
  - **Glare – Unified Glare Rating (UGR)** – *CIE 190-2010: Calculation and Presentation of Unified Glare Rating Tables for Indoor Luminaires*
  - **Distribution – Target Efficacy Rating (TER)** – *NEMA LE6-2014: Procedure for Determining Target Efficacy Ratings for Commercial, Industrial, and Residential Luminaires*
- Benefits vs. unintended consequences

V5.0 Proposed Timeline



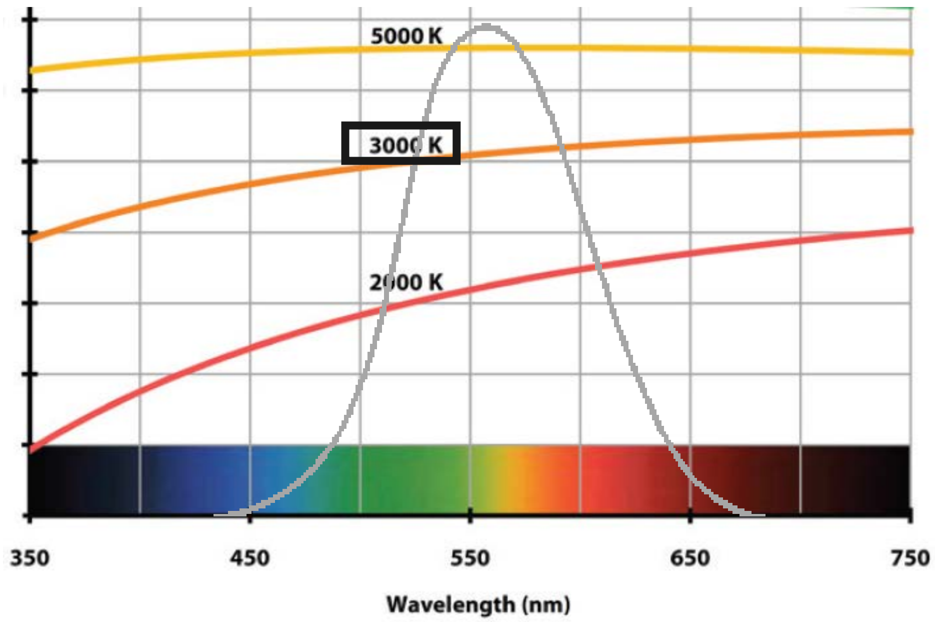
Target Effective Date: January 1, 2020

Color Quality

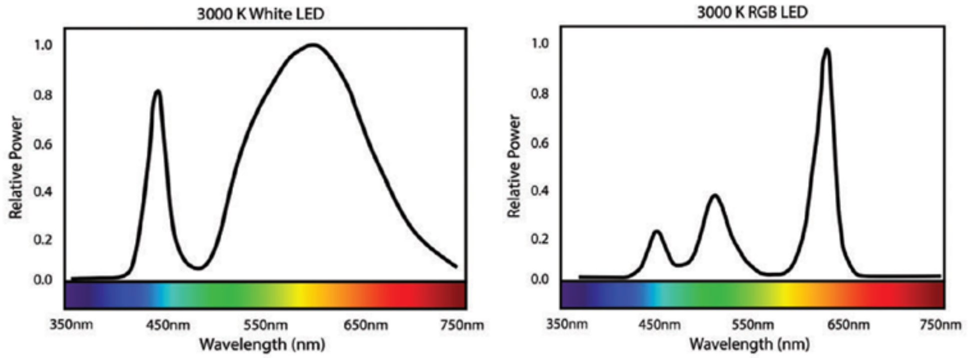
How to address?

Why do we care, especially now?

The most efficacious light looks yellow-green



Source: IES HB-10-11 (Figure 1.13, Blackbodies in visible range)



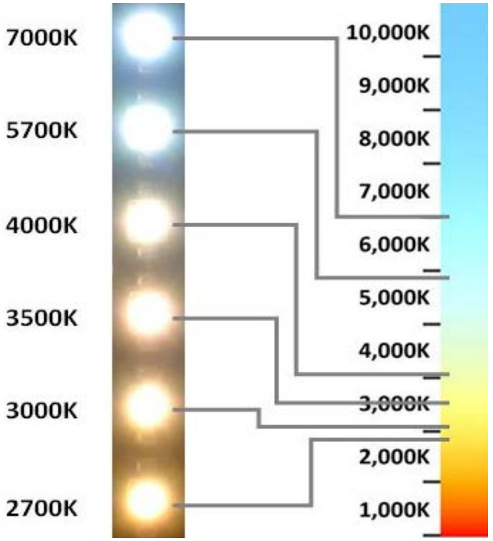
Source: IES DG-1-16 (Figure 6 and 7, Mike Wood)

LEDs

- Spectrum customization available that was not possible before
- Need for guidance to drive development
- Obvious shortcomings of established metrics and assumptions
- New metrics available and in development

Color Quality

- **Color Appearance (of light source)**
  - **Describes how the light itself looks.** Color perception includes the effects of spectrum and other factors such as adaptation, brightness, contrast.



Source: https://ledcorporations.com/kelvin-aka-cct-correlated-color-temperature/

- **Color Rendering**
  - **Effect of an illuminant on the color appearance of objects** (by comparison with their color appearance under a reference illuminant).

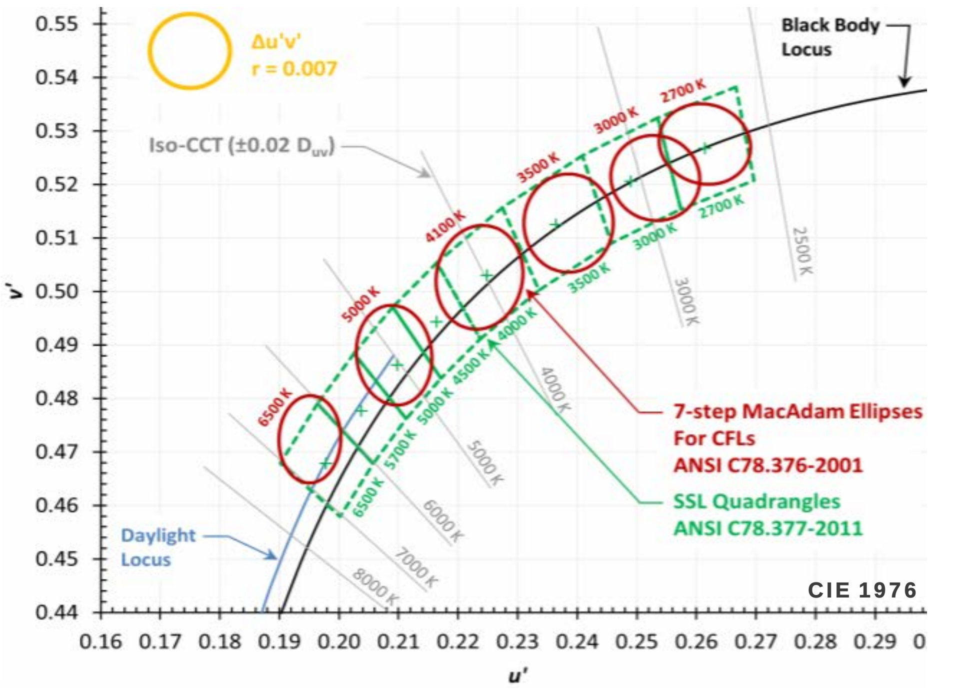
Source: International Lighting Vocabulary, CIE S 017/E:2011

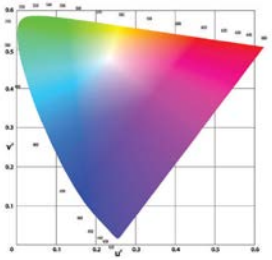
Source: Don Slater, NightTime Design

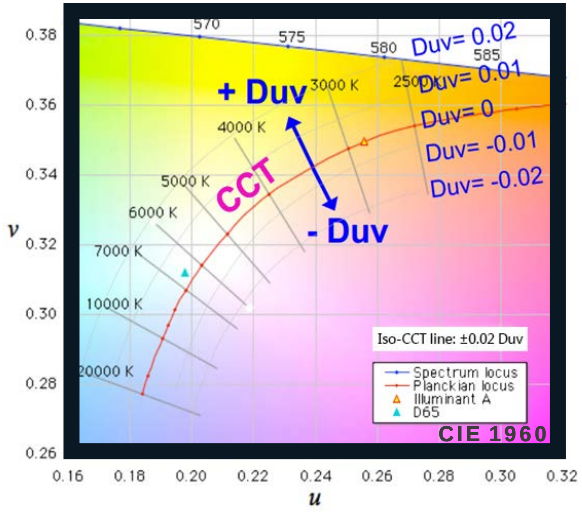
Color metrics: Color Appearance

- **CCT** *(DLC QPL)*:
  - Estimates how warm or cool a light source looks
  - Based on chromaticity coordinates and ANSI binning
  - Does not indicate if two light sources look the same

- **Duv** *(adds information)*:
  - Indicator how greenish or pinkish a source appears
  - Does not indicate if two light sources look the same







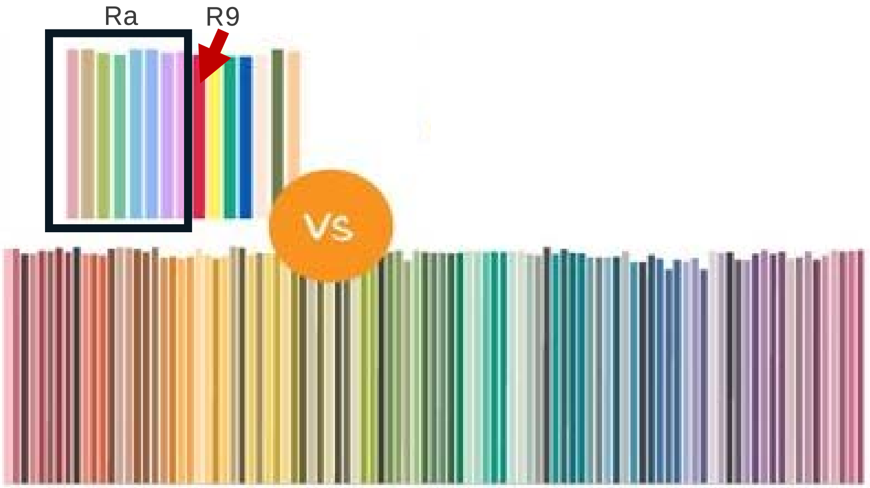
Source: PNNL, Color Maintenance of LEDs (Figure 4)

Source: http://www.asensetek.com/knowledge-duv/

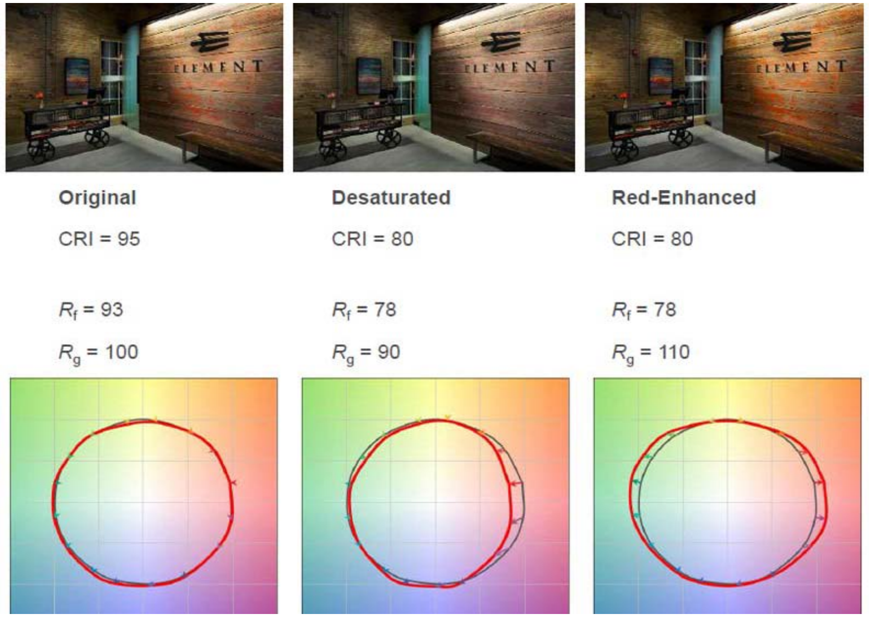
Color metrics: Color Rendering

- **CRI** *(considered in current DLC QPL)*:
  - Uses reference source (Planckian radiator and daylight, no transition at 5000K)
  - Higher is better, max. 100
  - Ra based on only 8 samples
  - 7 specialty samples (e.g. R9)

- **TM-30** *(current optional reporting DLC QPL)*:
  - Uses reference source (Planckian radiator and daylight, transition 4500-5500K)
  - No 'best' value established, depends on application
  - Uses 99 samples
  - Provides multiple tools to evaluate color rendering properties
  - CIE 224:2017 Colour fidelity index for accurate scientific use



Source: https://www.forge.co.uk/knowledge-zone/led-standards/tm-30-15-quick-guide

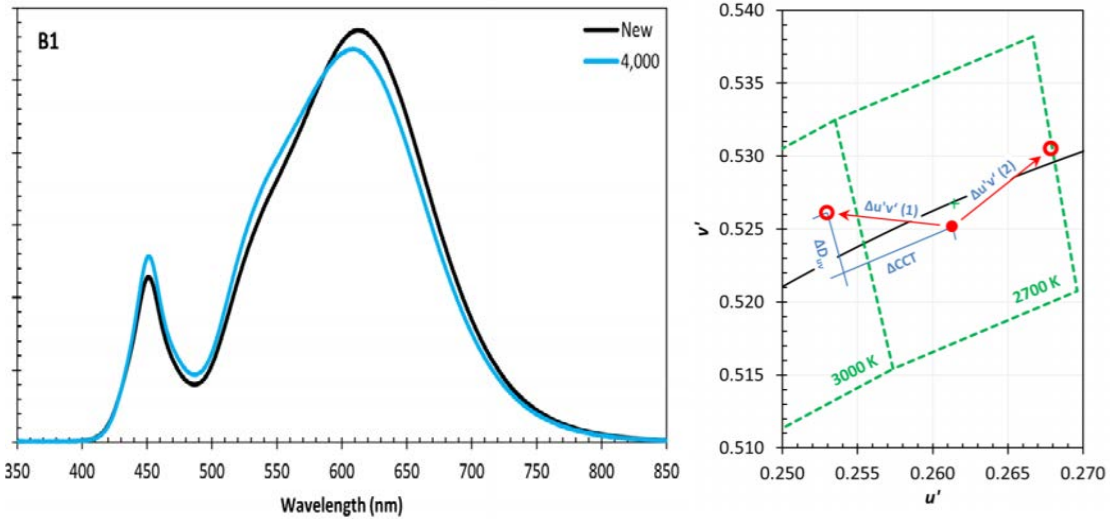


Source: DOE/IES 2015, Understanding and Applying TM-30-15

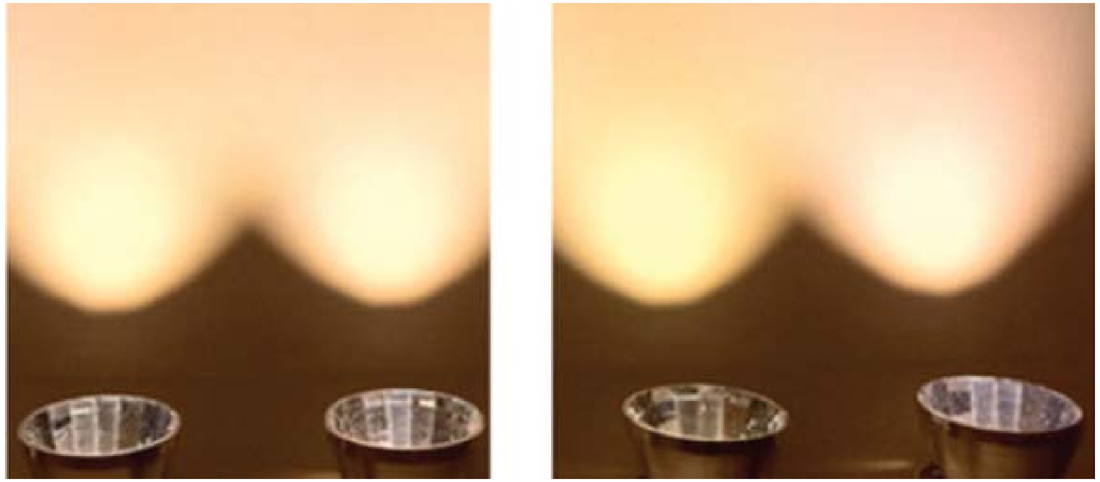
Color Quality Control

Color shift: the difference or change in (u', v') coordinates, Δu'v'

- Color Maintenance / Stability
  - Evaluates how well performance is maintained **over time** (Δu'v' <0.007, Energy Star)
- Color Consistency / Uniformity
  - Evaluates how well performance is maintained **from product to product**
- Color Angular Uniformity
  - Evaluates how well performance is maintained **throughout the light beam**



Source: PNNL, Color Maintenance of LEDs in Laboratory and Field Applications (Figure 5 and 7)



Source: IES DG-1-16 (Figure 50, Maria Thompson)

Limitations - How to address with what is available?

- Color metrics are based on averaged findings and mathematical transformations; perception and preference can vary by individual, culture and application needs
- ALL metrics are imperfect (constant work on updates)
- New metrics still lack threshold recommendations

Fixture testing:

- Spectroradiometers
  - use with integrating sphere (overall spectrum already collected now)
- Calculation software and spreadsheets / toolboxes

Questions for Stakeholders:

1. What **metrics** should DLC investigate further and what **metrics** do you have concerns about?
2. What is the **value** of adding additional metrics for color quality (e.g. TM-30, Duv, SPD)?
3. What **unintended consequences** could occur?
4. **Required** threshold vs. **reporting** value to enable differentiation vs. **reporting** spectral data?
5. Is it relevant to include **color consistency**, **color maintenance**, and/or **color angular uniformity** into reporting/requirements?

Glare

How to address?

Why do we care, especially now?

The brightest, most efficient light is a glare bomb

LEDs

- Small scale and high output
- Often array or bundle of small high brightness sources
- Often high luminance values and ratios
- Optics and distribution increasingly important
- Spectrum consideration

Glare – Indoors and Outdoors

8 defined **glare** categories.

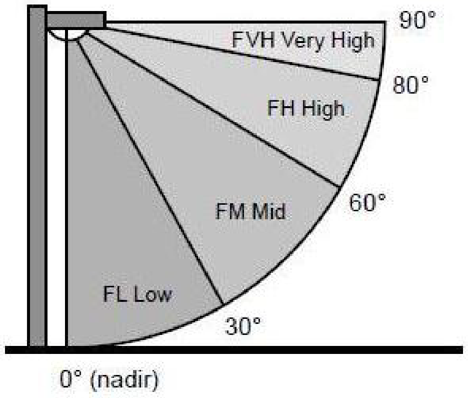
Discomfort and Disability Glare (most common) are experienced when the variations of luminances across the visual field are too great

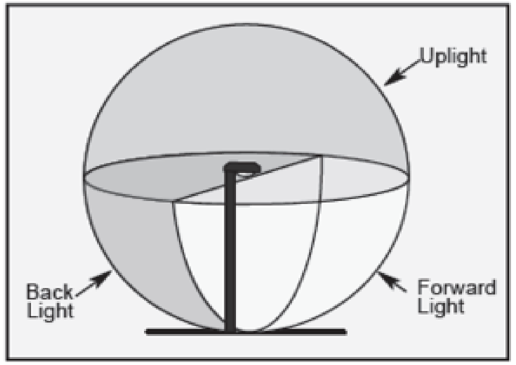
- **Disability Glare (measurable)**:
  - Caused by light scattering in eye, luminous veil over retinal image
  - Reduces visibility, lowers luminance contrast
  - Older and lighter colored eyes experience higher disability glare
- **Discomfort Glare (not yet fully understood)**:
  - Glare producing discomfort, pain, strain and annoyance
  - Has been studies for over 60 years

It is possible to experience disability without discomfort, and conversely, discomfort without disability; however, one often accompanies the other.

Glare metrics: Outdoors

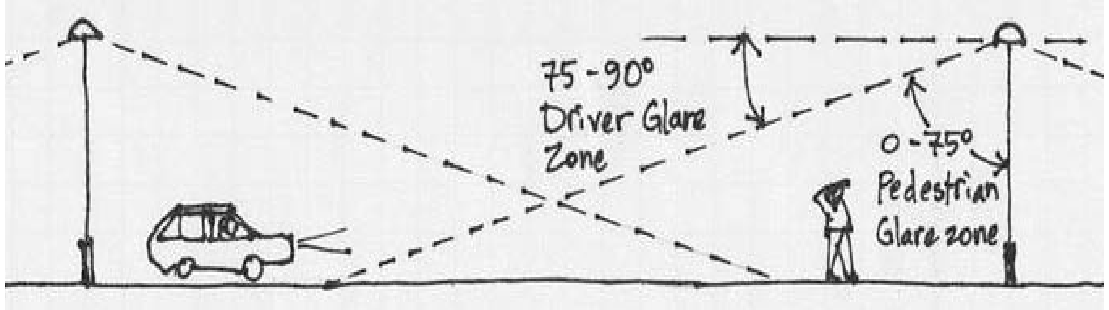
- Disability Glare: **Equivalent Veiling Luminance**
  - Several models (CIE 2002), most recent account for age and larger range of visual angles
  - Input: illuminance at the eye, angle between the line of sight (each glare source)
  - Compares visibility of an object seen in the present of a glare source with the visibility of the same object through a uniform luminous veil





Source: *IES TM-15-11 (Figure 1 and 3)*

- Discomfort Glare**: BUG Rating- Glare portion**
  - Developed by IES 2011
  - Max. zonal lumen values for FH and FVH, BH and BVH zones
  - Further models in review and development by CIE and IES



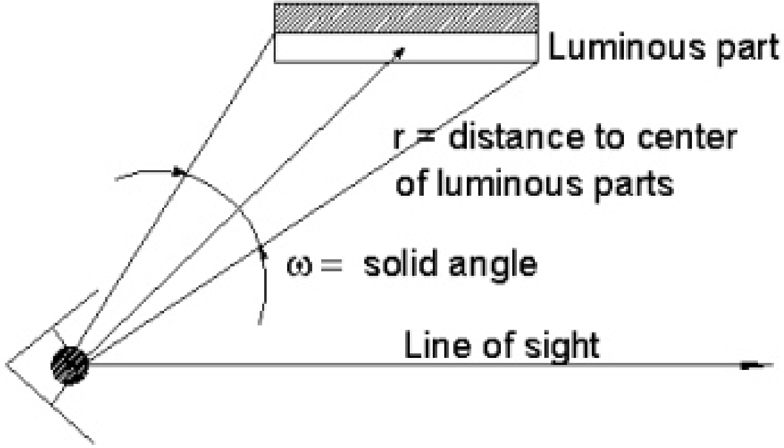
Source: *PNNL, Naomi Miller*

Glare metrics: Indoors

- Discomfort Gare: **Visual Comfort Probability**
  - System used in North America (IES)
  - Estimates the percentage of people who find condition acceptable
  - Input: luminance of glare source, solid angle of the glare source, glare source position index, average luminance of the field of view

- Discomfort Glare: **Unified Glare Rating**
  - System used internationally, CIE 2002, 2010, standard assumptions to document on fixture spec sheets
  - Referenced in recent IES publications
  - Input: luminance of glare source, solid angle of the glare source, background luminance, position index: deviation of the glare source from line of sight

Source: IES RP-7-17 (Figure 16)



Source:https://docs.agi32.com/AGi32/Content/adding_calculation_points/Calculations_UGR_Concepts.htm

Limitations - How to address with what is available?

- One person’s sparkle is another one’s glare (individual variation in sensitivity)
- ALL metrics are imperfect (constant work on updates)
- Glare depends on fixture, site conditions and observer location
- Some fixtures (size, uniformity) not accounted for by metrics

Glare Evaluation According to UGR

ρ Ceiling		70	70	50	50	30	70	70	50	50	30
ρ Walls		50	30	50	30	30	50	30	50	30	30
ρ Floor		20	20	20	20	20	20	20	20	20	20
Room Size X	Y	Viewing direction at right angles to lamp axis					Viewing direction parallel to lamp axis				
2H	2H	14.9	15.6	15.2	15.8	16.0	14.7	15.4	15.0	15.6	15.8
	3H	14.8	15.4	15.1	15.6	15.9	14.6	15.2	14.9	15.4	15.6
	4H	14.7	15.3	15.0	15.5	15.8	14.5	15.1	14.8	15.3	15.6
	6H	14.7	15.2	15.0	15.5	15.7	14.4	14.9	14.7	15.2	15.5
	8H	14.6	15.1	15.0	15.4	15.7	14.4	14.9	14.7	15.2	15.5
	12H	14.6	15.1	14.9	15.4	15.7	14.4	14.8	14.7	15.1	15.4
4H	2H	14.7	15.3	15.0	15.5	15.8	14.5	15.1	14.8	15.3	15.6
	3H	14.6	15.1	14.9	15.4	15.7	14.4	14.8	14.7	15.1	15.4
	4H	14.5	14.9	14.9	15.2	15.6	14.3	14.7	14.7	15.0	15.4
	6H	14.4	14.8	14.8	15.1	15.5	14.2	14.5	14.6	14.9	15.3
	8H	14.4	14.7	14.8	15.1	15.5	14.2	14.5	14.6	14.8	15.2
	12H	14.4	14.6	14.8	15.0	15.4	14.1	14.4	14.6	14.8	15.2
8H	4H	14.4	14.7	14.8	15.1	15.5	14.2	14.5	14.6	14.8	15.2
	6H	14.3	14.5	14.8	14.9	15.4	14.1	14.3	14.5	14.7	15.2
	8H	14.3	14.4	14.7	14.9	15.4	14.0	14.2	14.5	14.7	15.1
	12H	14.2	14.4	14.7	14.8	15.3	14.0	14.1	14.5	14.6	15.1
12H	4H	14.4	14.6	14.8	15.0	15.4	14.1	14.4	14.6	14.8	15.2
	6H	14.3	14.4	14.7	14.9	15.4	14.0	14.2	14.5	14.7	15.1
	8H	14.2	14.4	14.7	14.8	15.3	14.0	14.1	14.5	14.6	15.1
Variation of the observer position for the luminaire distances S											
S = 1.0H		+4.9 / -24.6					+5.1 / -25.1				
S = 1.5H		+7.7 / -28.2					+7.9 / -28.0				
S = 2.0H		+9.7 / -28.9					+9.9 / -31.7				
Standard table		BK00					BK00				
Correction Summand		-4.2					-4.4				
Corrected Glare Indices referring to 1100lm Total Luminous Flux											

The UGR values have been calculated according to CIE Publ. 117 Spacing-to-Height-Ratio = 0.25.

Source: http://www.carclo-optics.com/optic-12928

Site survey: *Luminance meter or camera*

Fixture lab testing: Photometric reports (zonal lumen reports, .ies files)

Simulations: Lighting simulation software using assumptions (e.g. UGR)

Questions for Stakeholders:

1. What **metrics** should DLC investigate further and what **metrics** do you have concerns about?
2. What is the **value** of addressing glare and adding glare metrics (differentiation over lower-quality products)?
3. What **unintended consequences** could occur?
4. **Required** threshold vs. **reporting** value to enable differentiation vs. **reporting** distribution data?
5. How helpful is it to include **application dependent metrics** (using assumptions) at the product level?

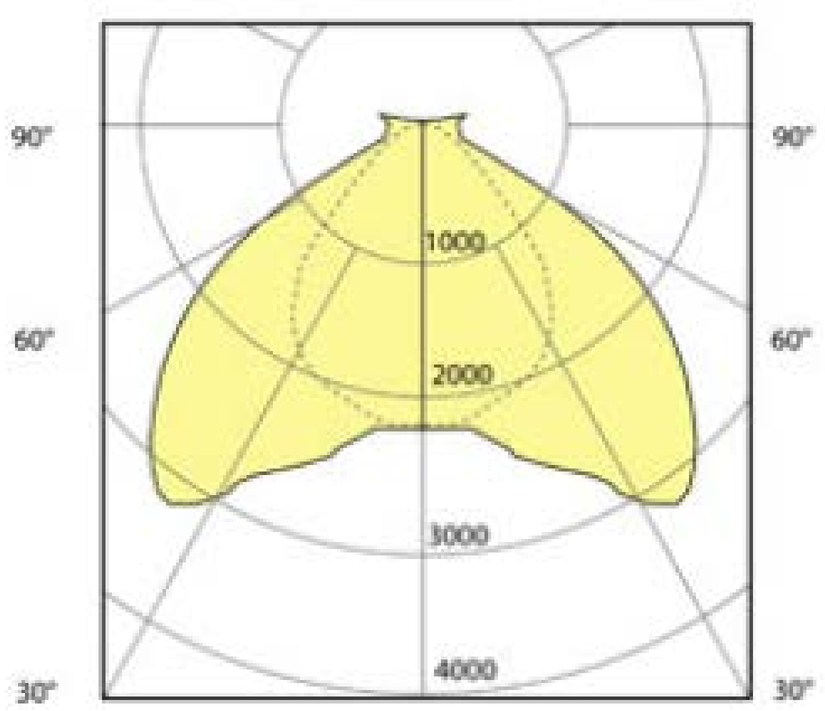
Distribution

How to address?

Quality of Light: Distribution

Distribution affects:

- Energy Consumption (minimizing wasted light output)
- Task performance (enough light to work quickly and accurately)
- Safety (visibility for navigation and distinguishing relevant obstacles)
- Esthetics (shape the architectural environment)
- Wellbeing (mood, atmosphere, visibility)



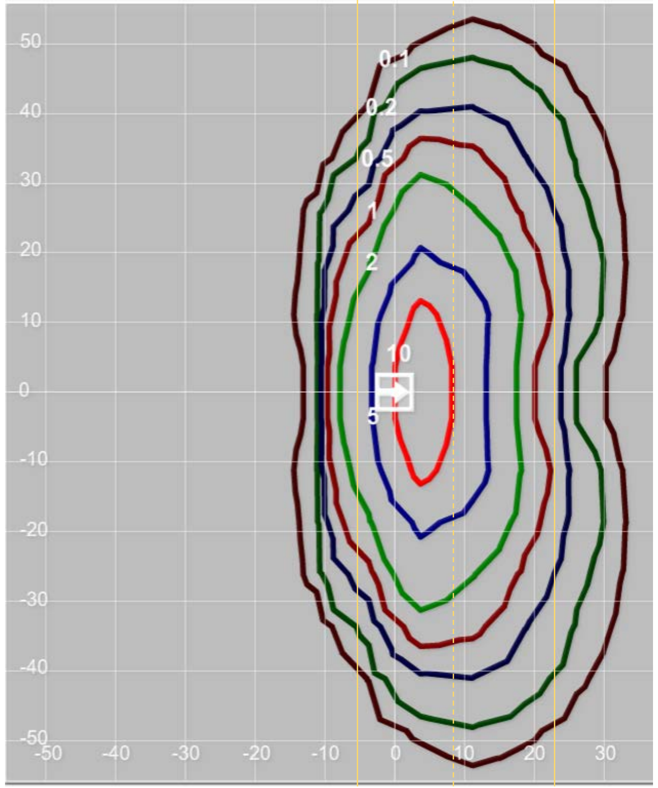
Distribution

Assessments of Distribution could include several factors:

- **Task Plane Efficiency:** What % of luminaire output reaches task plane?
- **Uniformity:** Is the task plane evenly illuminated? Do the bright spots represent wasted light?
- **Shape of Illumination:** Does the shape of the illumination pattern allow for optimal layout of adjacent fixtures (rectangular iso-illumination) or otherwise match the shape of the task area?

Beyond lighting the task, Distribution:

- Determines feel of the space via light on walls and ceiling
- Can define spaces with the sharpness of beam edge
- Allows drivers to see what is just off the roadway



Outdoor Fixture iso-illuminance lines, from www.rabweb.com

Application Example

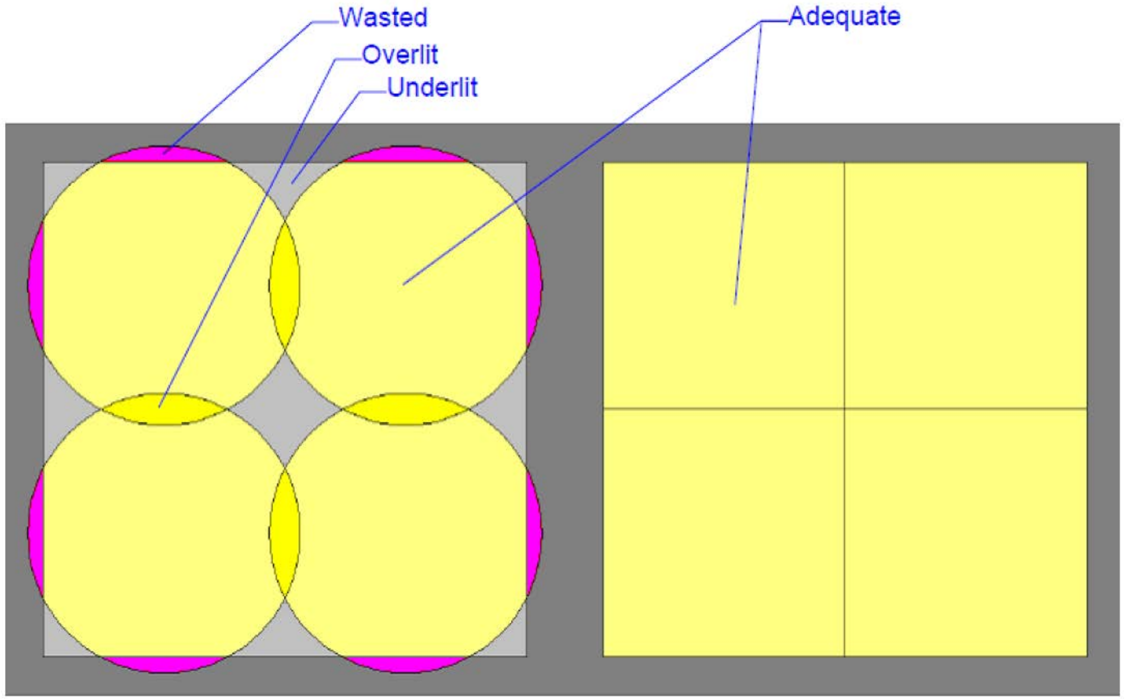


Figure 1 from DOE's Overview of Fitted Target Efficacy (FTE), 2009

Other Distribution Metrics

Fitted Target Efficacy (FTE)

- Created by DOE for Exterior Roadway and Area Luminaires
- Incorporates Task Plane Efficiency, Uniformity, and Shape
  - Rectangular illumination is desirable
  - Symmetrical distribution (side-to-side) is desirable
  - Uniformity held to IES recommended 6:1 Max:Avg

FTE example from ENERGY STAR®

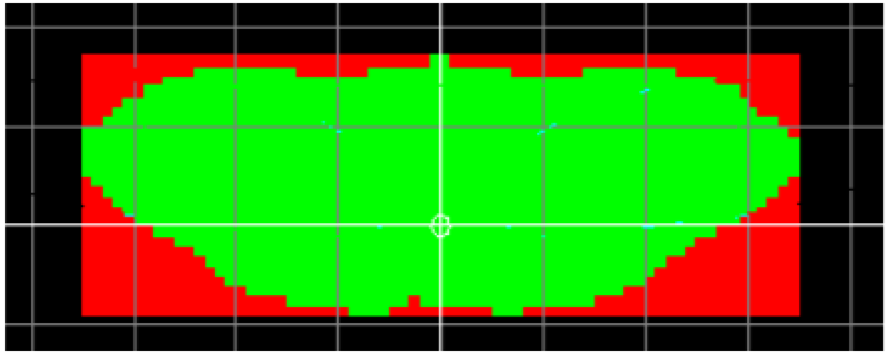


Figure 2. Uniform Pool within Rectangular Target

Target Efficacy Ratio (TER)

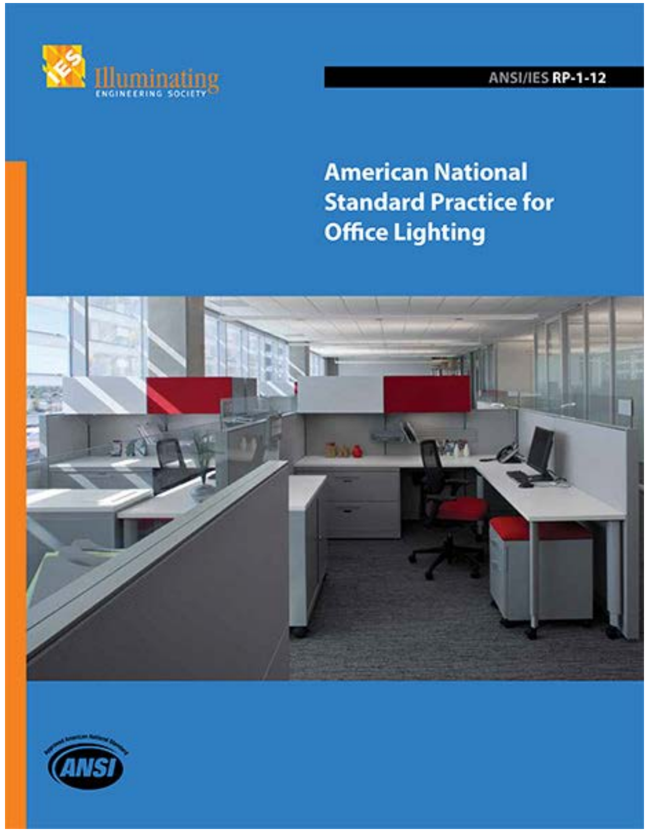
- Created by NEMA for 16 types of Interior & 6 types of Exterior Luminaires
- Calculation for each type differs in Interior reflectances and room cavity ratio, in Exterior area shape and size
  - Rectangular illumination is desirable
  - Uniformity is not considered; all illumination of task area contributes to TER

- Both FTE and TER use units of Lumens per Watt

IES Guidance

IES Recommended Practice Documents

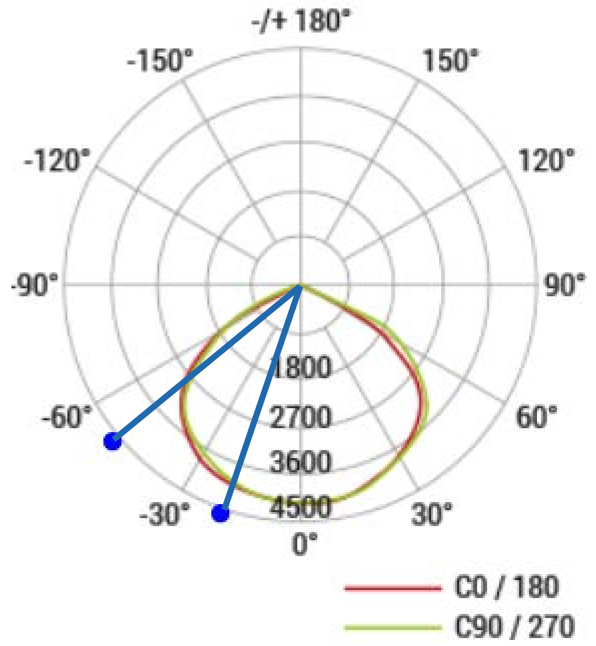
- Emphasize Uniformity in task plane, via various illuminance ratios:
  - Maximum-to-Minimum
  - Maximum-to-Average
- Offer little guidance on evaluating luminaires outside a particular application, mounting and task plane



Existing DLC Distribution Requirement

Zonal Lumen Distribution (ZLD)

- Broad guideline for acceptable distribution performance
- Applies to each Primary Use Designation (PUD), the most detailed level of DLC specification
- Light output within a certain angle must be greater/less than specified % of full luminaire output
  - e.g. High-bay luminaires must distribute ≥30% of output in the 20° - 50° range, as in this polar distribution chart.
- No mention of uniformity or shape
- No assurance of high-quality distribution



Questions for Stakeholders

1. What **metrics** should DLC investigate further and what **metrics** do you have concerns about?
2. What is the **value** of addressing distribution and adding distribution metrics (differentiation over lower-quality products)?
3. What **unintended consequences** could occur?
4. **Required** threshold vs. **reporting** value to enable differentiation vs. **reporting** distribution data?
5. How can we promote Distribution performance while acknowledging the importance of illumination beyond the task plane?
6. Should Distribution metrics be avoided for certain luminaire types?

Flicker

How to address?

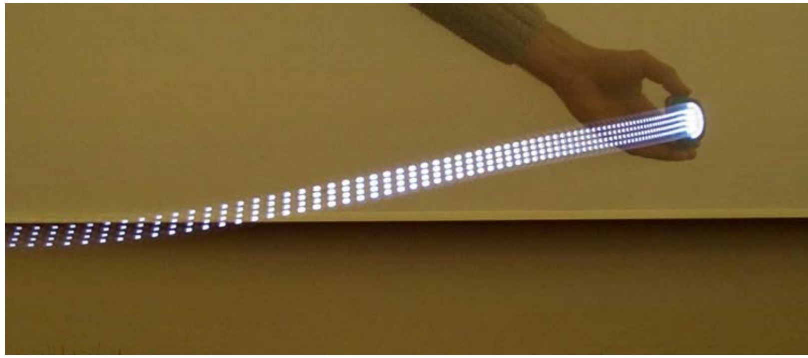
Naomi Miller
Senior Lighting Scientist
Pacific Northwest National Laboratory

Image: Wikipedia.org

The Flicker Problem

Temporal light artifact (TLA): perception from light source whose luminance or spectral distribution fluctuates with time

- **Flicker**: Perception of *visual unsteadiness*… *for a static observer in a static environment. Up to 3 - ~80 Hz*
- **Stroboscopic effect**: change of *motion perception*… for a *static observer in a non-static environment ~80 Hz - ~2000 Hz*
- **Phantom Array effect** (ghost effect): change in *perceived shape or spatial layout of objects*… for a *non-static observer in an otherwise static environment* (e.g. saccade, normal head movement, or while driving) ~80 Hz – ~2500 Hz



Most people can't SEE flicker, but they may be affected by it.

Is flicker really an issue?

- Photoepilepsy – flashing lights (and other repetitive patterns) stimulate epileptic seizures
- Stroboscopic effect – dangerous when working with rotating machinery
- Migraine or severe paroxysmal headache often associated with nausea and visual disturbances
- Increased repetitive behavior among persons with autism
- Asthenopia (eye strain), including fatigue, blurred vision, conventional headache, decreased performance on sight-related tasks, etc.
- Other: panic attacks, anxiety, increased heart rate, vertigo

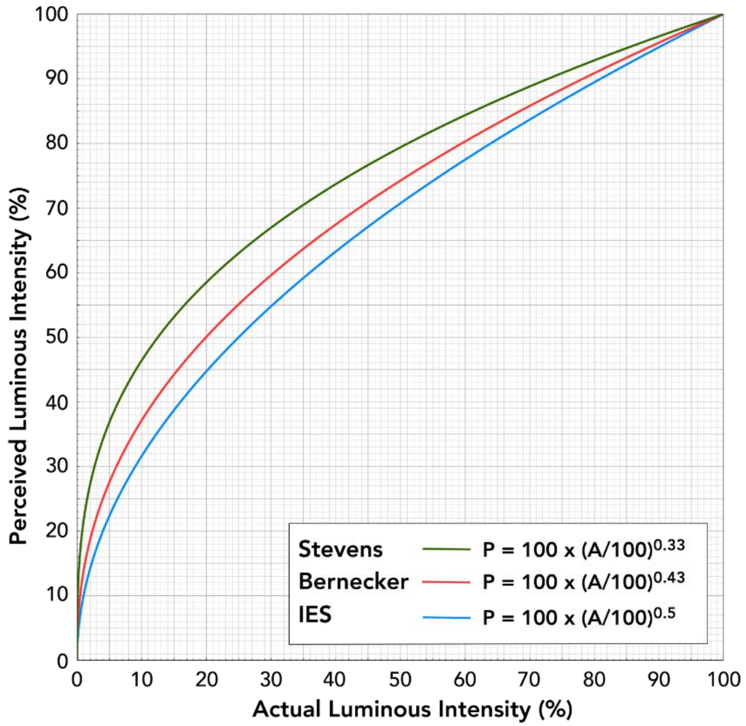
Health.com

- Also: interference with machine vision and imaging devices (video & security cameras, etc.)

Why do we care, especially now?

LEDs

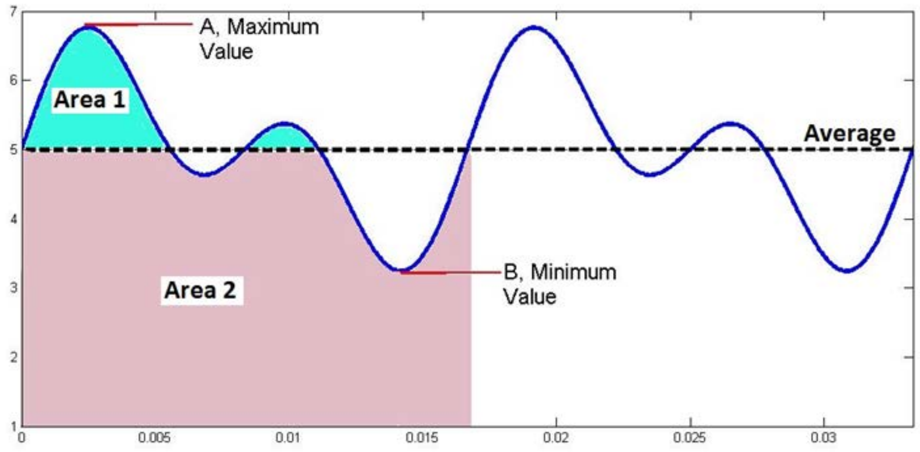
- Inherently fast-responding devices
- No persistence in light output compared to incandescent or fluorescent sources
- Relies on the DRIVER to provide visibly continuous light
- Pairing the driver with a dimmer especially tricky, especially at very low dimming levels, especially if color or white tuning is involved
- Human visual perception is not linear –To get a light source to LOOK like it's dimmed to 10% output, actual output need to be <1% output. Differences between actual and perceived are particularly large at low relative intensity levels

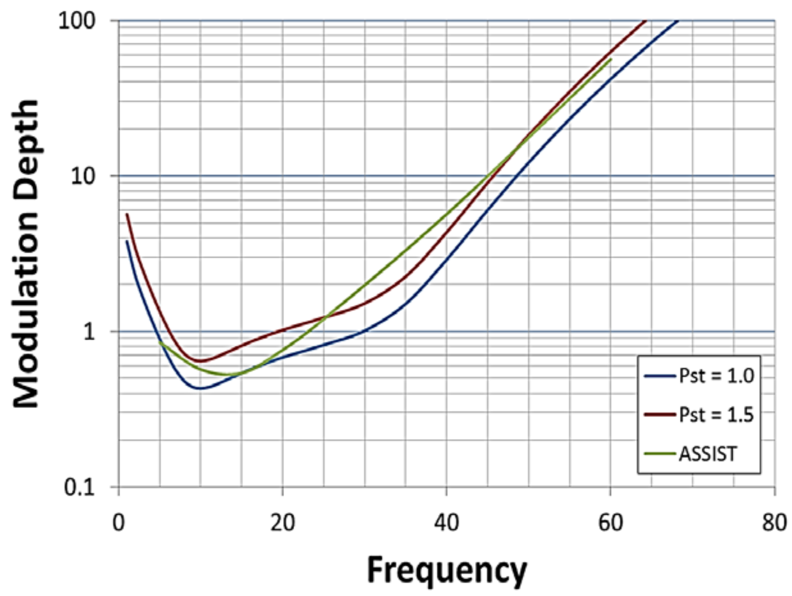


Actual versus perceived dimming levels

Flicker metrics over time

- IES Percent flicker
  - Accounts for average, peak-to-peak amplitude
  - Does not account for shape, duty cycle, frequency
- IES Flicker index
  - Rarely used, but accounts for average, peak-to-peak amplitude, shape, duty cycle
  - Does not account for frequency
- IEC P_{st} – “Flickermeter” (LRC Assist M_p metric similar)
  - “Limitation of voltage changes, voltage fluctuations and flicker” in public electric supply systems, up to 80 Hz
  - Complex; originally developed to quantify power line quality

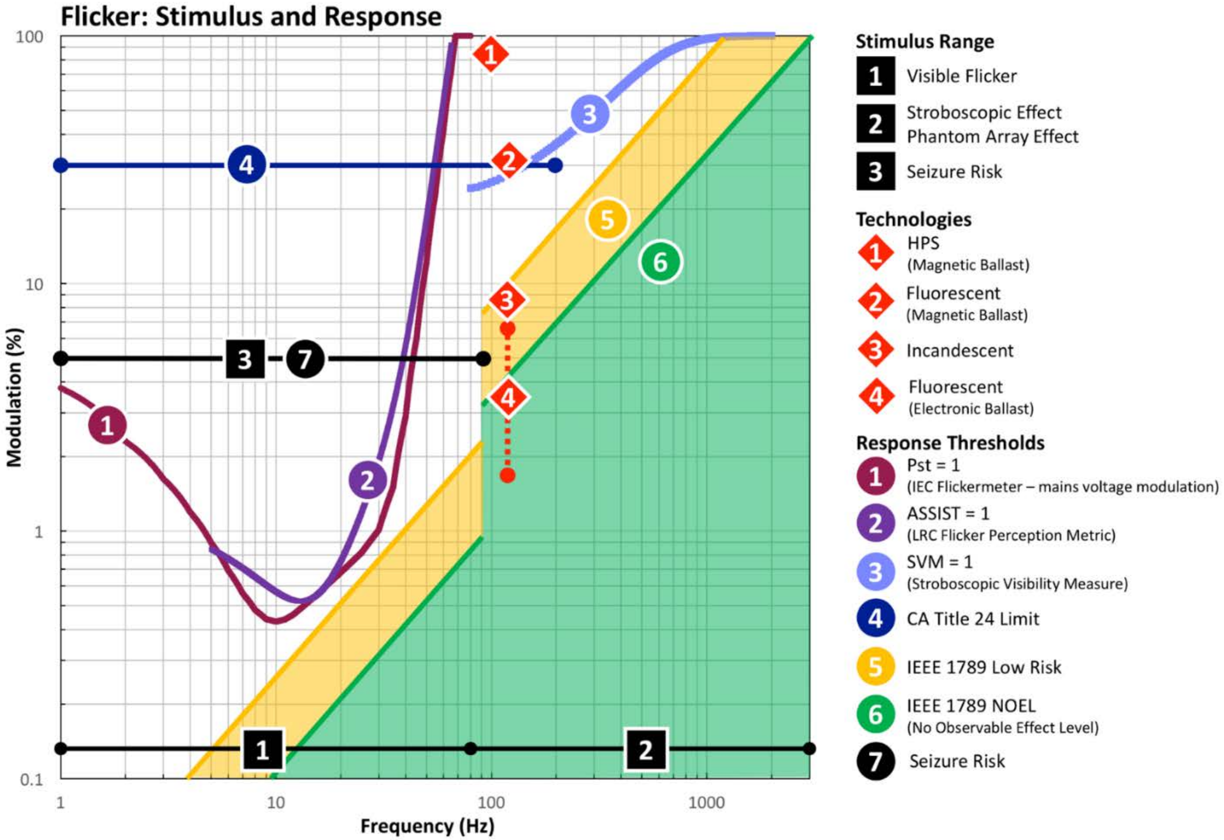




Plot of the visibility threshold (P_{st} = 1 and ASSIST), for visible flicker, expressed in terms of modulation depth, as a function of frequency. The curve is for a single sine wave modulation.

Flicker metrics over time

- IEEE Standard P1789-2015
  - Focused on health risks from flicker, so it's more conservative than for visibility alone
  - Plotted % Flicker (modulation) and frequency for no effect level and low risk level. Simple metric.
  - Hard to evaluate complex waveforms, doesn't account for wave shape, doesn't account for low duty cycle (e.g., dimming).
- Stroboscopic effect Visibility Measure (SVM)
  - Predicts visibility of strobe effect based on wave shape and duty cycles, above 80 Hz.
  - Uses Fast Fourier Transform (FFT) analysis
  - Not complete. Fixed gaze only. No account for sensitive individuals or phantom array effect. Assumes flicker visibility = neurological effect.



NEMA-77-2017 is a combo of P_{st} and SVM. A group of manufacturers has signed on to this standard as a first step.

Testing requirements

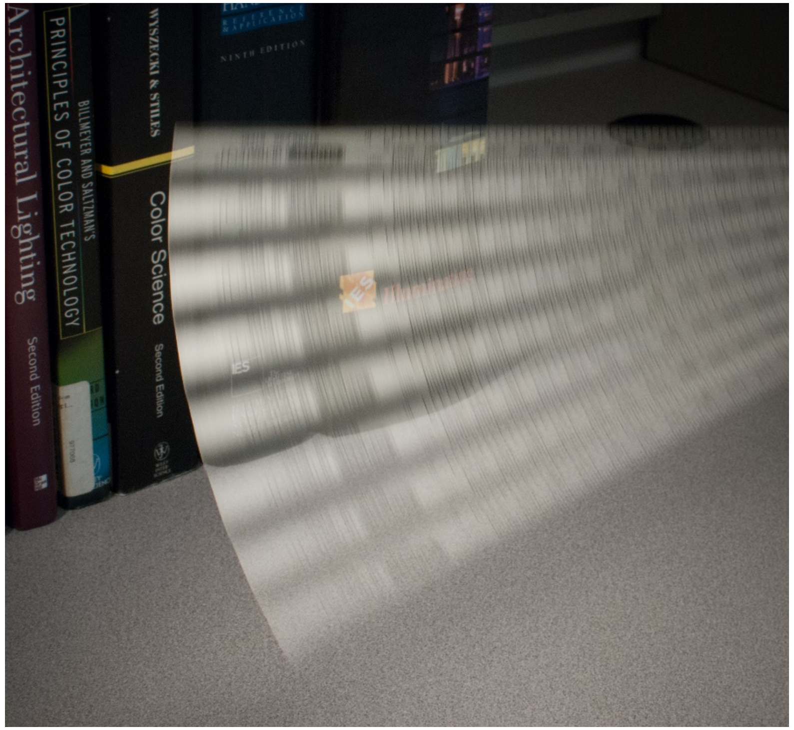
Bench top flicker meters available, reliable, and expensive for collecting waveforms.

https://www.energy.gov/eere/ssl/downloads/characterizing-photometric-flicker

Handheld flicker meters now available, less expensive, and mostly reliable for calculated metrics.

[DOE handheld flicker meter report expected summer 2018]

- Almost all light sources flicker to some extent
- ALL flicker metrics are imperfect
- W-i-d-e individual variation in sensitivity to flicker
- Setting safe levels is difficult -- little neurological data



Questions for manufacturers and utilities:

1. Does leadership in flicker reduction offer differentiation over lower-quality competitors?
2. Reporting metrics vs. waveforms vs. meeting standard values
3. How to define dimmers and dimmed levels?
4. Should standard thresholds vary by application?
5. Are there unintended consequences of establishing flicker metrics?