4.401/4.464 Environmental Technologies in Buildings

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L07 Light and Human Vision + Photometry

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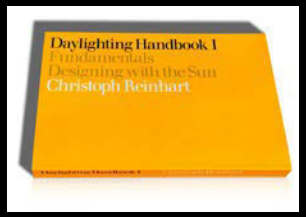
Building Technology Program

Lighting Module

- ❑ Light and Human Vision
- ❑ Daylighting Design Principles
- ❑ Daylight Simulations & Daylight Availability Metrics
- ❑ Visual Comfort and Occupant Behavior
- ❑ Electric Lighting and Controls

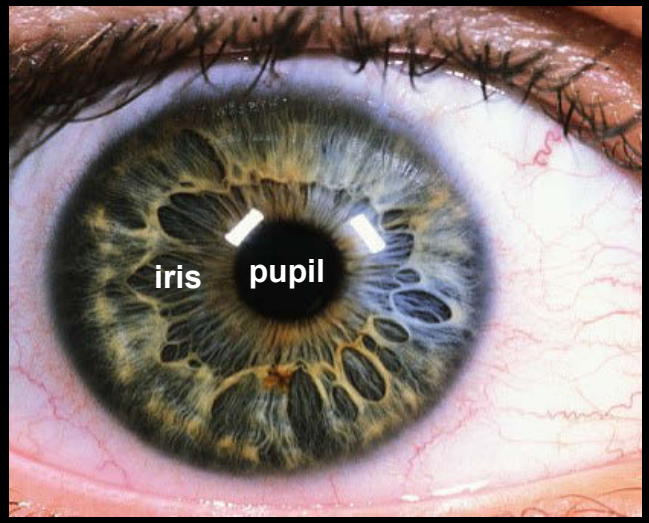
Weekly Reading And Tutorials



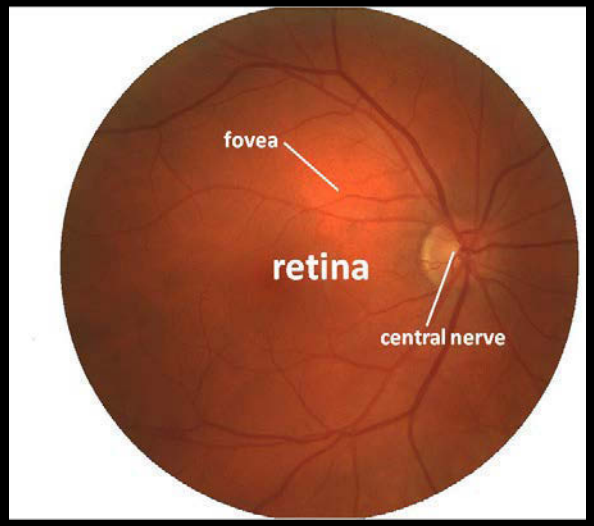
Chapter 4: The Sensor

Light and Human Vision

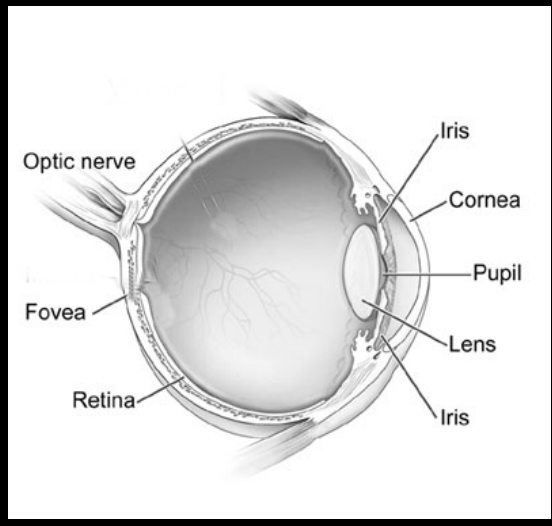
Human Eye



Outside view of a human eye



Ophthalmogram of a human retina.



Anatomy of the eye

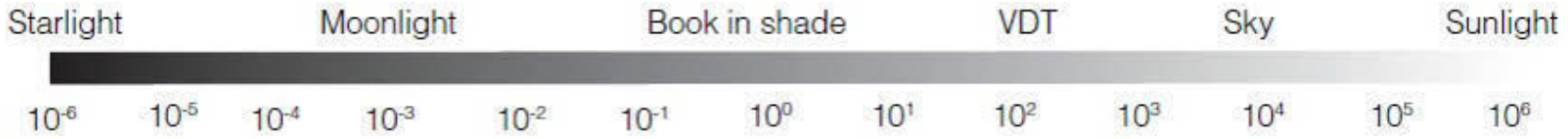
The retina has three types of photoreceptors:

- ❑ Cones
- ❑ Rods
- ❑ Ganglion cells

Day and Night Vision

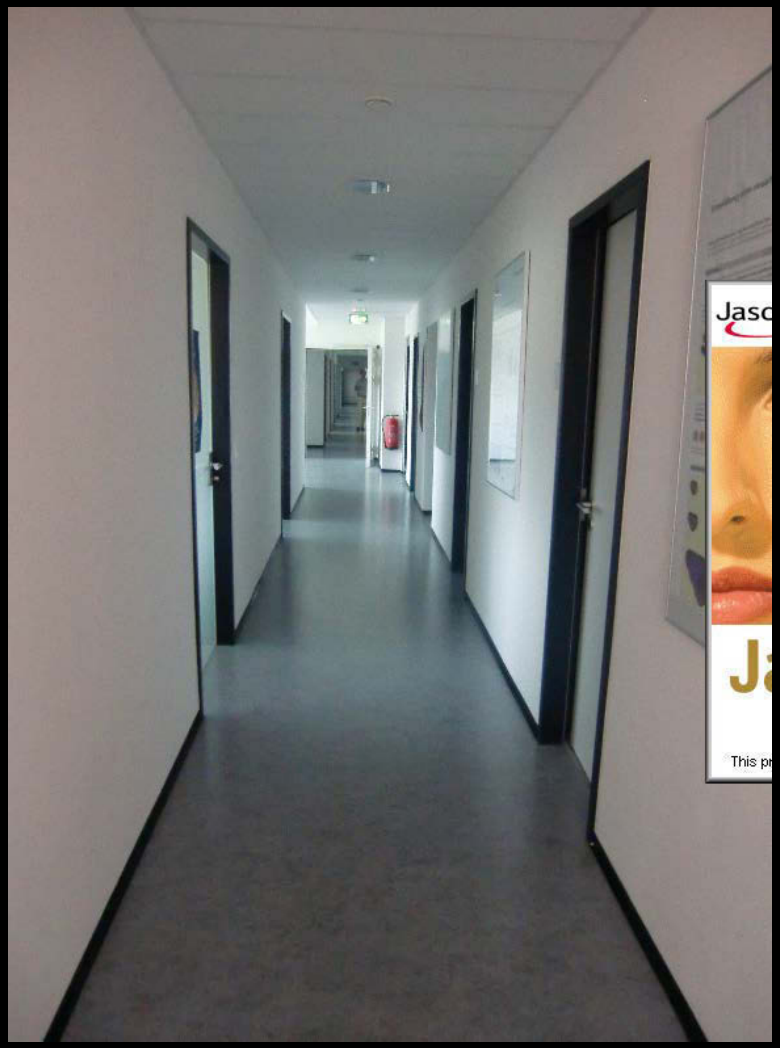
- Photopic (Daytime Vision): The cones of the eye are of three different types representing the three primary colors, red, green and blue (>3 cd/m^2).
- Scotopic (Night Vision): The rods are responsible for night and peripheral vision (< 0.001 cd/m^2).
- Mesopic (Dim Light Vision): occurs when the light levels are low but one can still see color (between 0.001 and 3 cd/m^2).

Visible Range



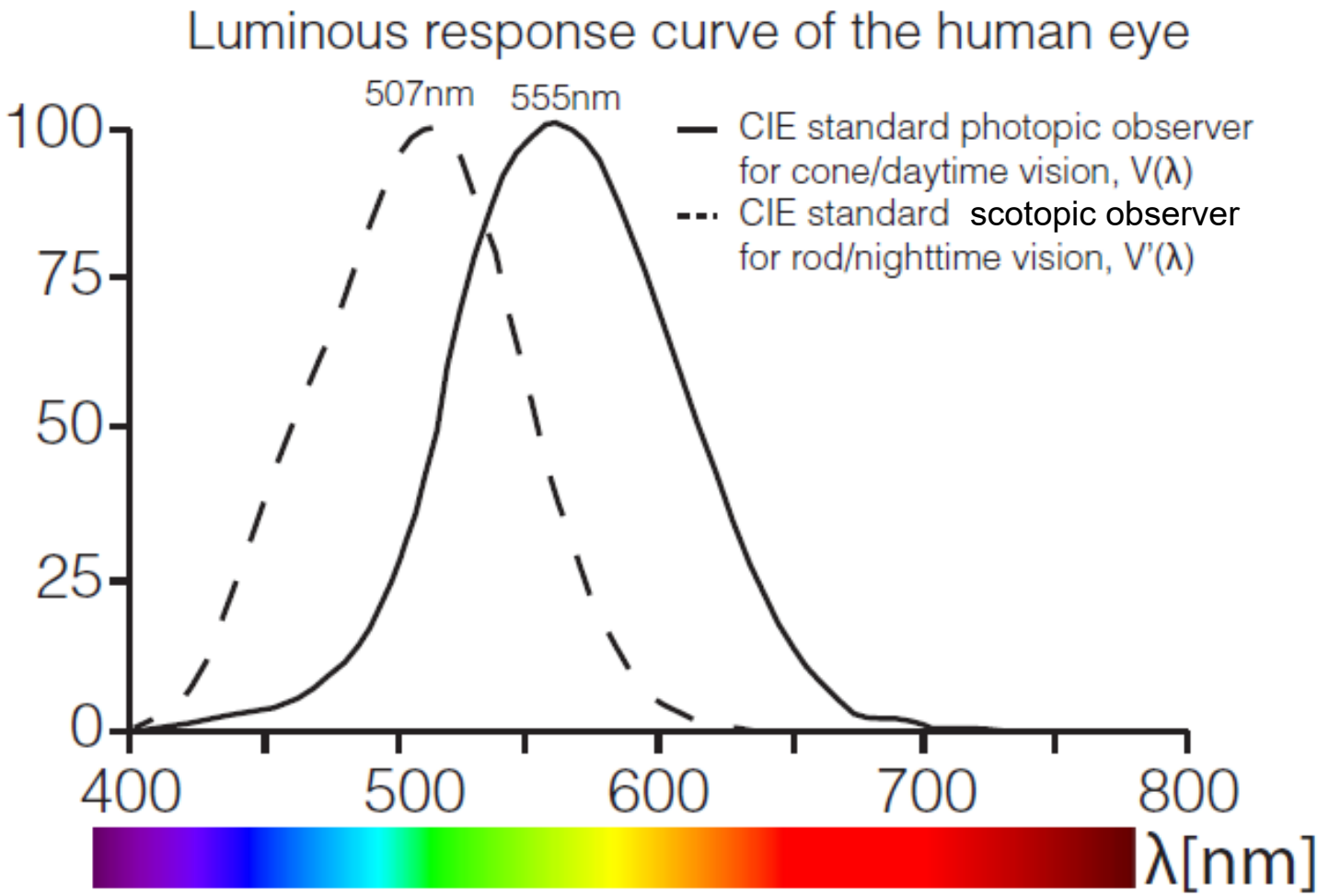
- The human eye can see across twelve orders of magnitude.
- We can adapt to about 2-3 orders of magnitude at a time via the iris.
- Larger ranges take time and require ‘neural adaptation’.

Transition Spaces



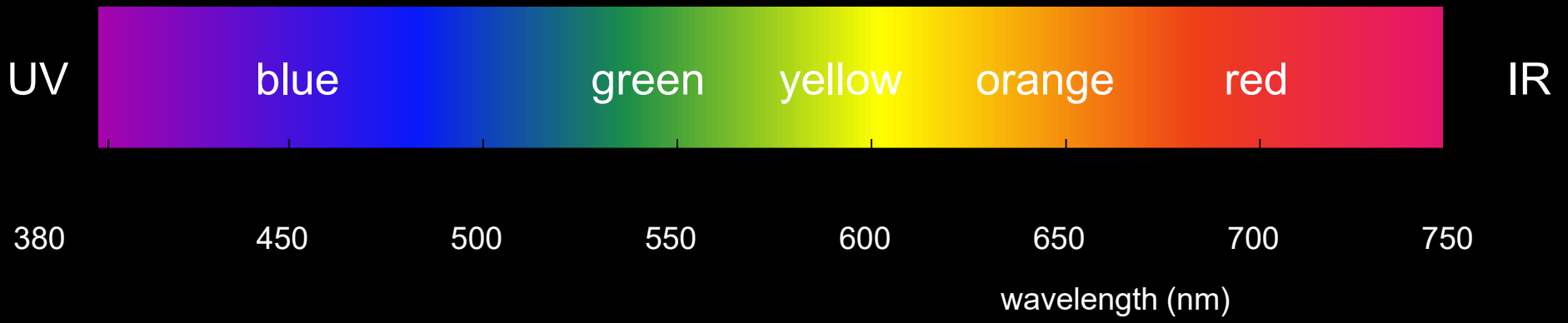
- ❑ Outside
- ❑ Atrium
- ❑ Circulation Area

Luminous Response Curve of the Human Eye

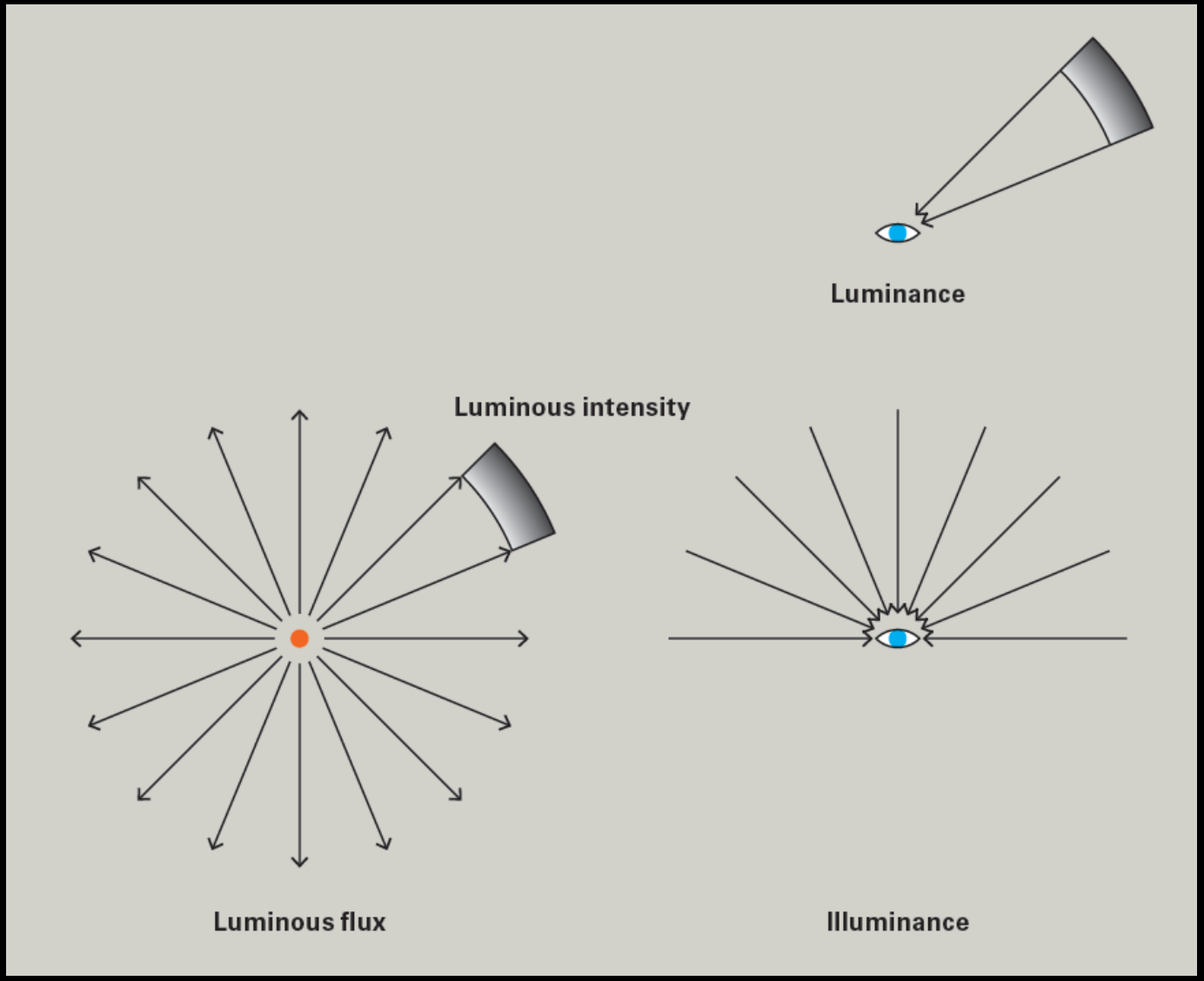


What is daylight?

Daylight is the visible part of the electromagnetic spectrum that lies between 380 and 780 nm.



Photometric Quantities



Characterize how a space is perceived.

Luminous Intensity

[Candela]

~ 1 candela

Luminous intensity: Power emitted by a light source in a particular direction

$$1\ candela = 1\ \frac{lumen}{steradiant}$$

Luminous Flux/Power

[Lumen = Candela* Steradiant]

~ 4 π lumen

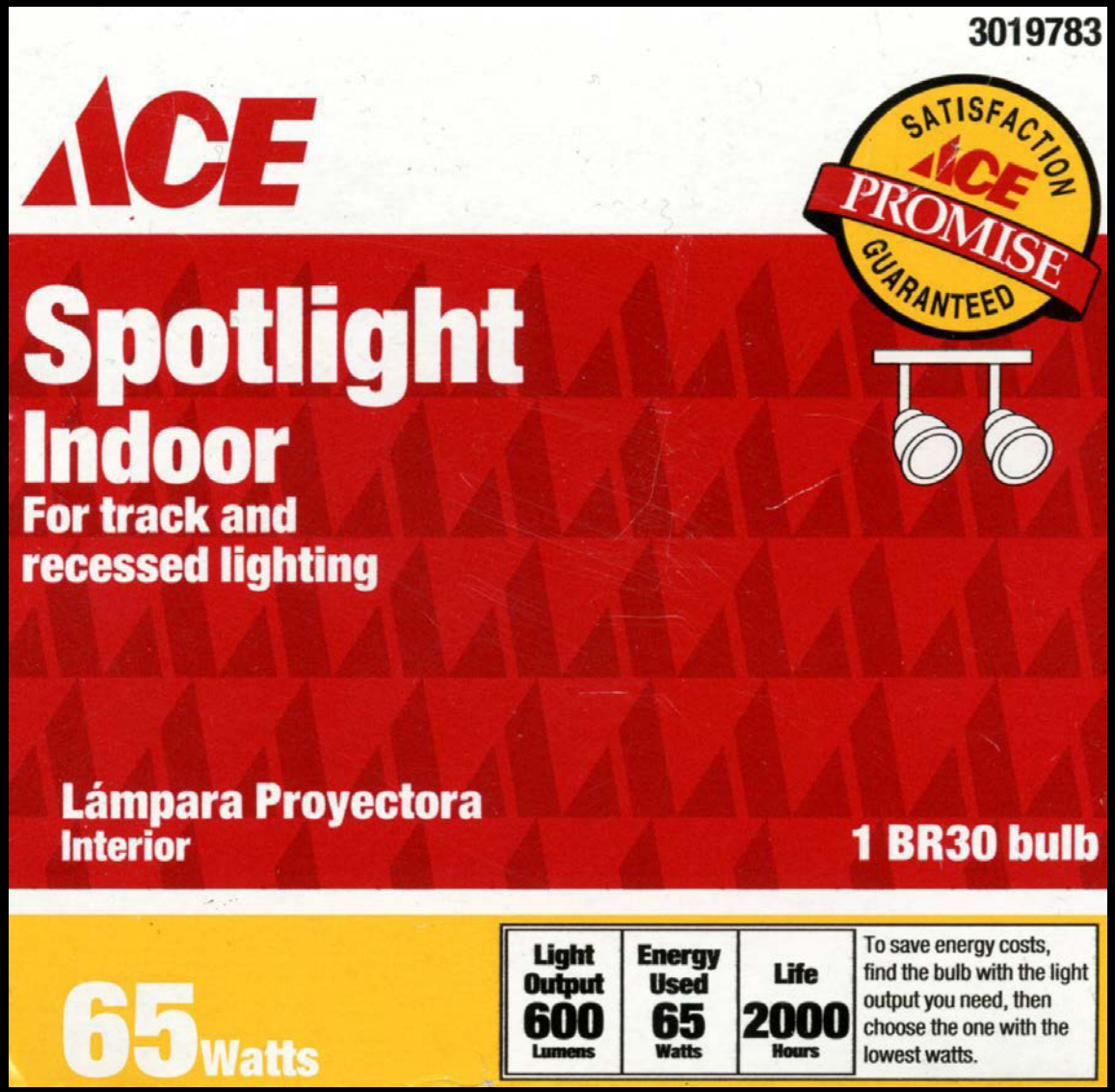
100 Watt , 1600 lumen

127 candles

13 Watt , 1600 lumen

Luminous flux: measure of the perceived power of a light source.

Example of Manufacturer Information



Review Luminous Efficacy & Efficiency

Light Source	Efficacy	Efficiency
sunlight	93 lm/W	14%
daylight	120 lm/W	18%
monochromatic green light	683 lm/W	100%
100 W tungsten incandescent	18 lm/W	2.5%
T8 fluorescent tube with el. ballast	80-100 lm/W	12-15%
white organic LED	up to 65 -131 lm/W*	
high pressure sodium lamp	150 lm/W	22%

* lower range at room temperature and power levels above 1 W

200yr Evolution of Luminous Efficacy

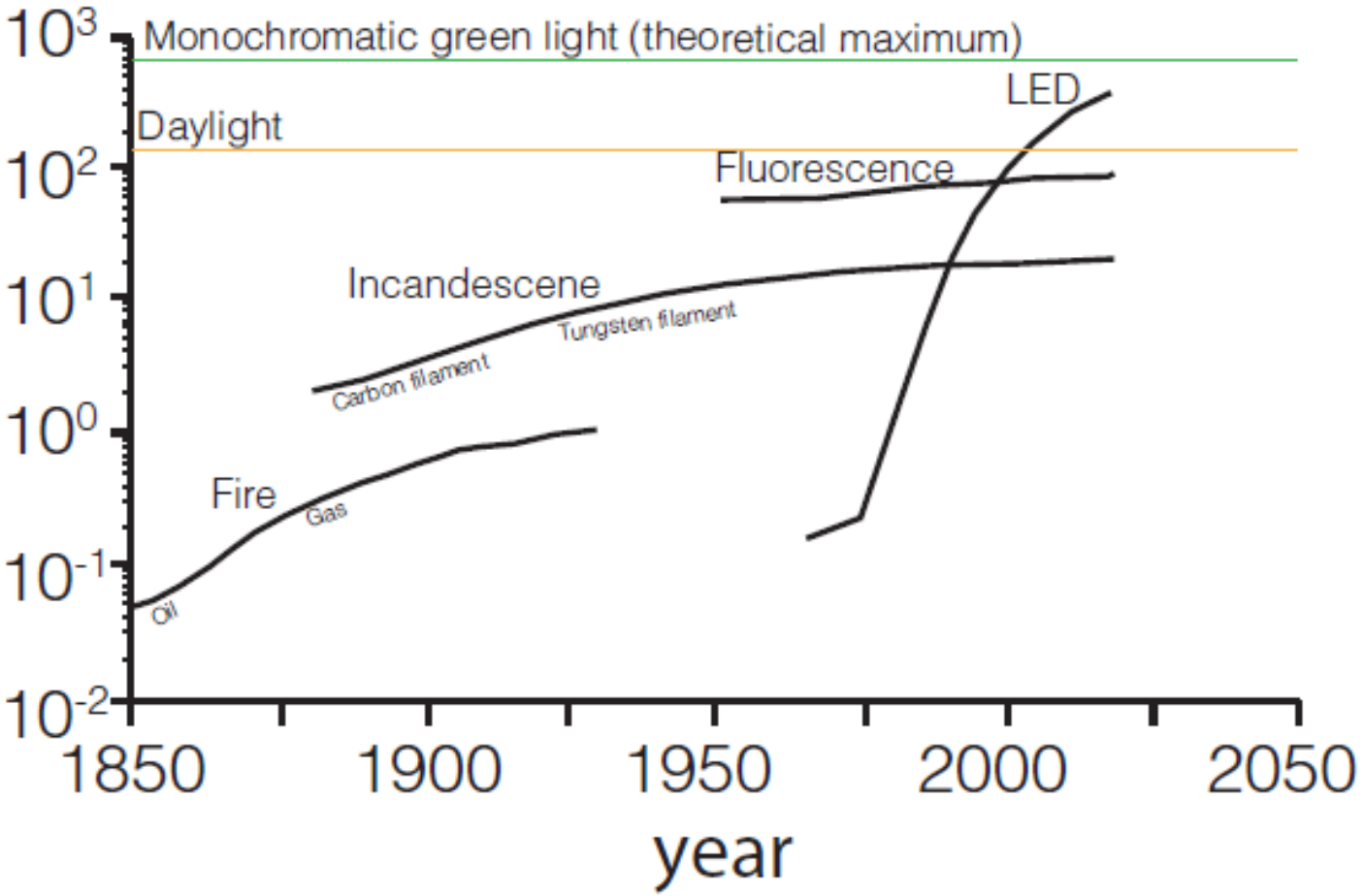
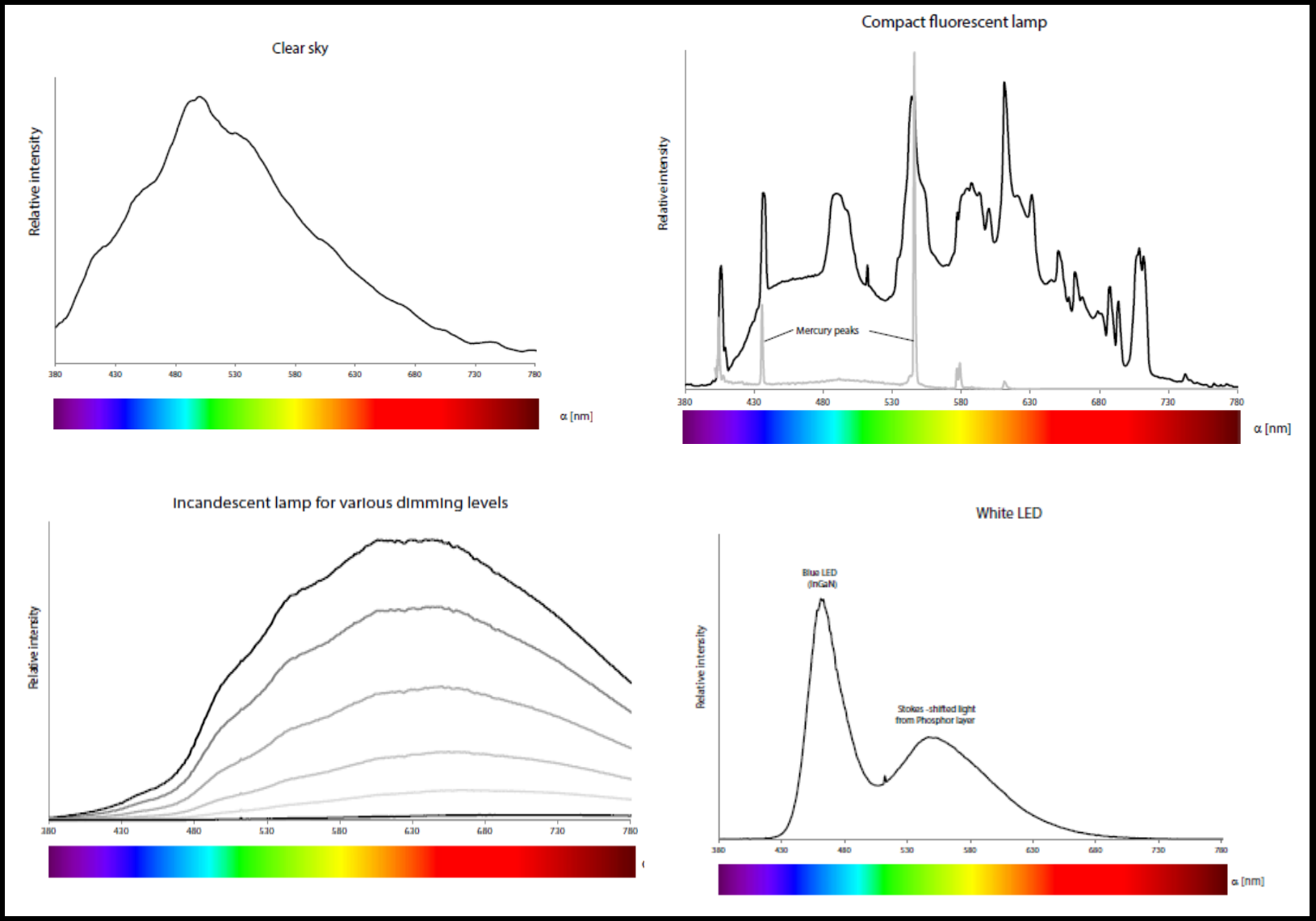
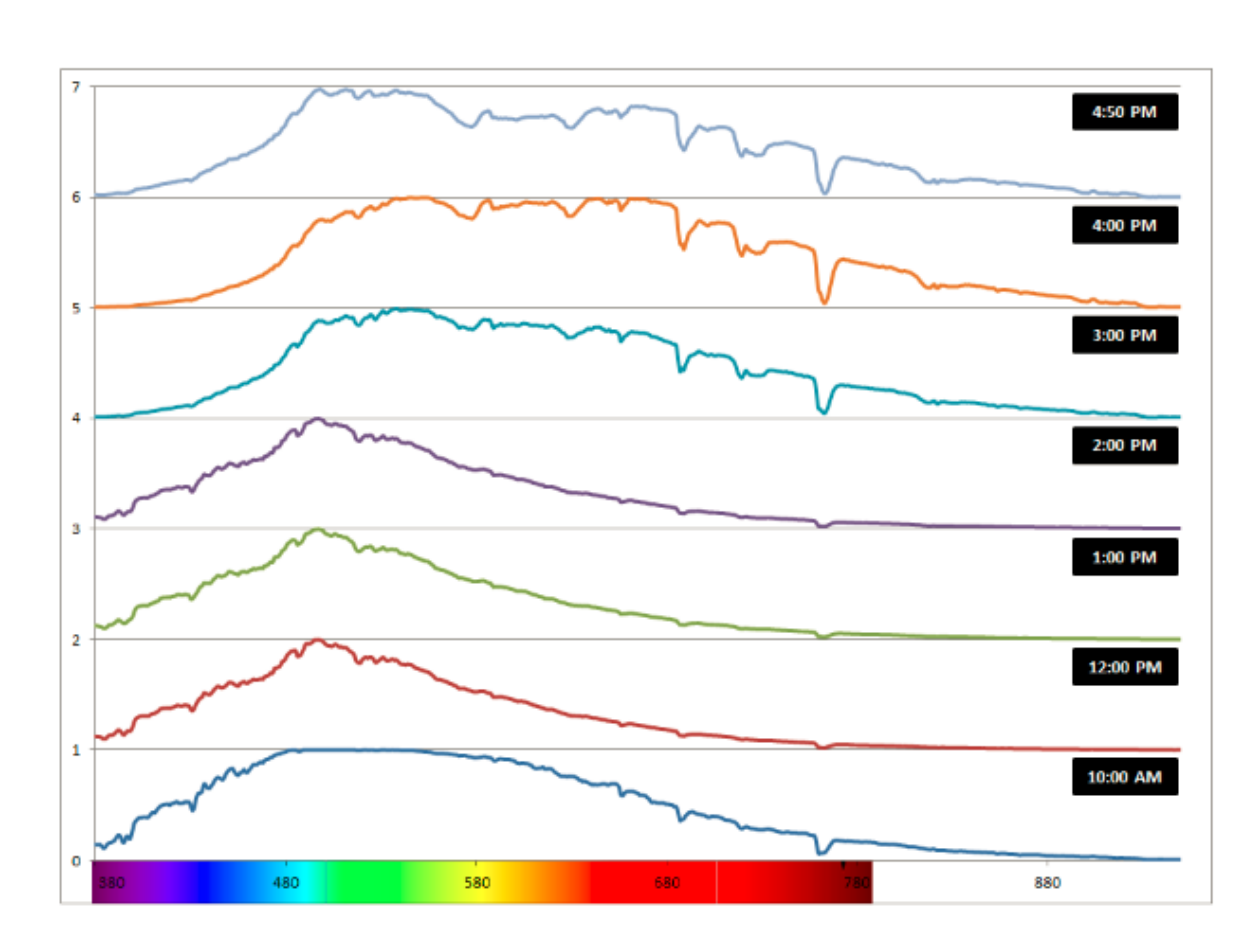


Fig. 4.9 200-year evolution of luminous efficacy for different lighting technologies[6]

Spectral Intensity of Various Light Sources



Spectral Intensity Distribution of Daylight



SDLAB

Luminance

[candela/m²]

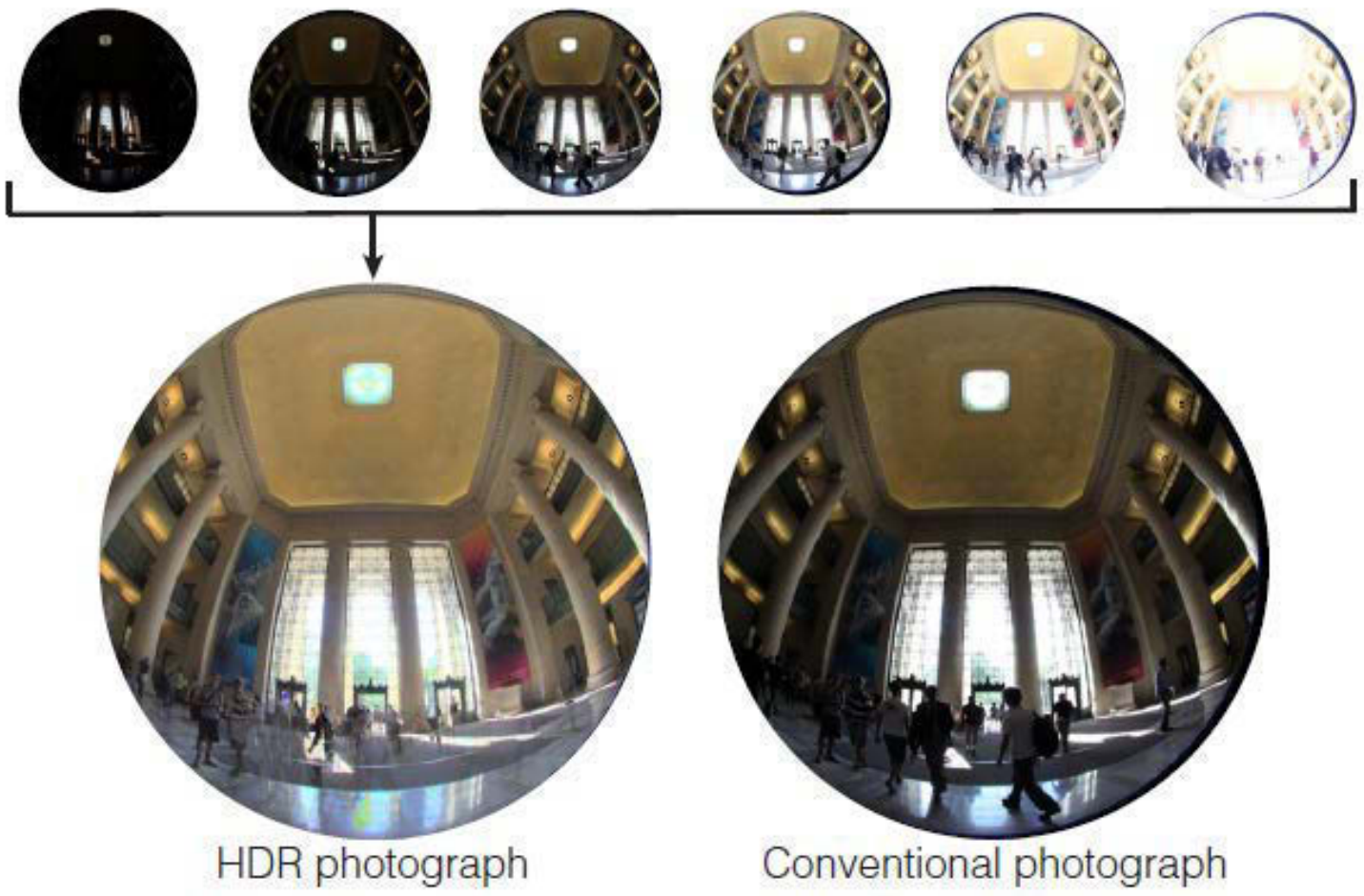
candela/m2

observer

Luminance: measure of the density of luminous intensity. It indicates how much luminous power reaches the eye of an observer looking at the surface from a particular viewpoint.

Luminance Measurement

High Dynamic Range Photography



HDR Photography

Exterior HDRI
(for representation)

Interior HDRI
(for glare analysis)

Sky Luminance Map
(for daylight simulations)

Luminance Distribution

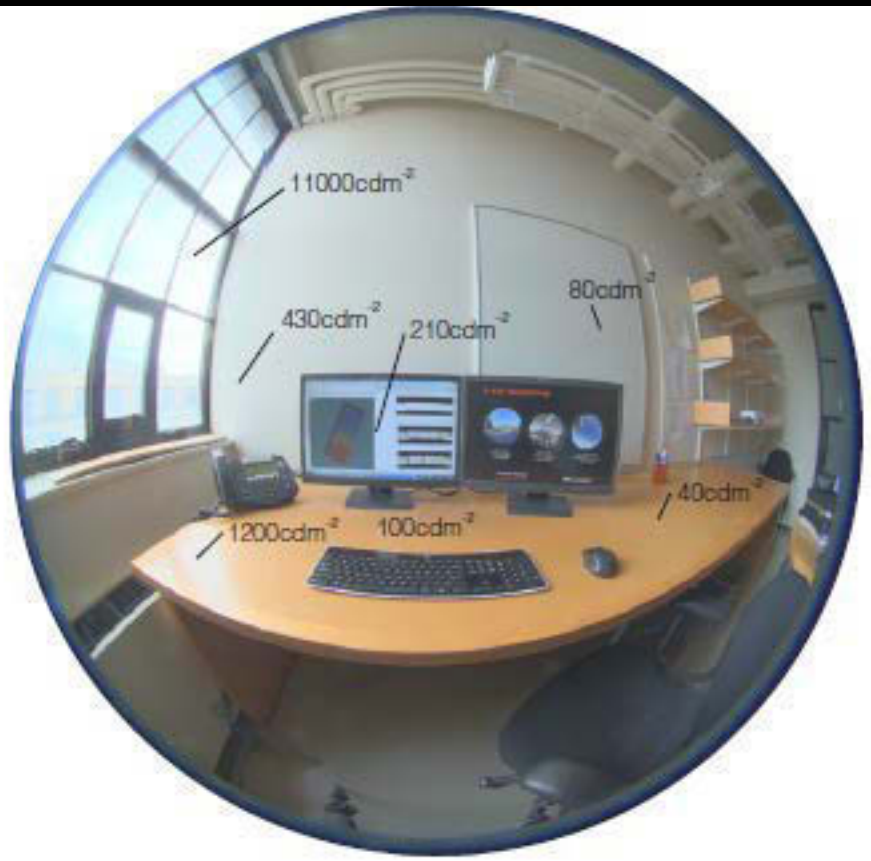


Fig. 4.15 Example analysis of a workspace with spot luminance measurements

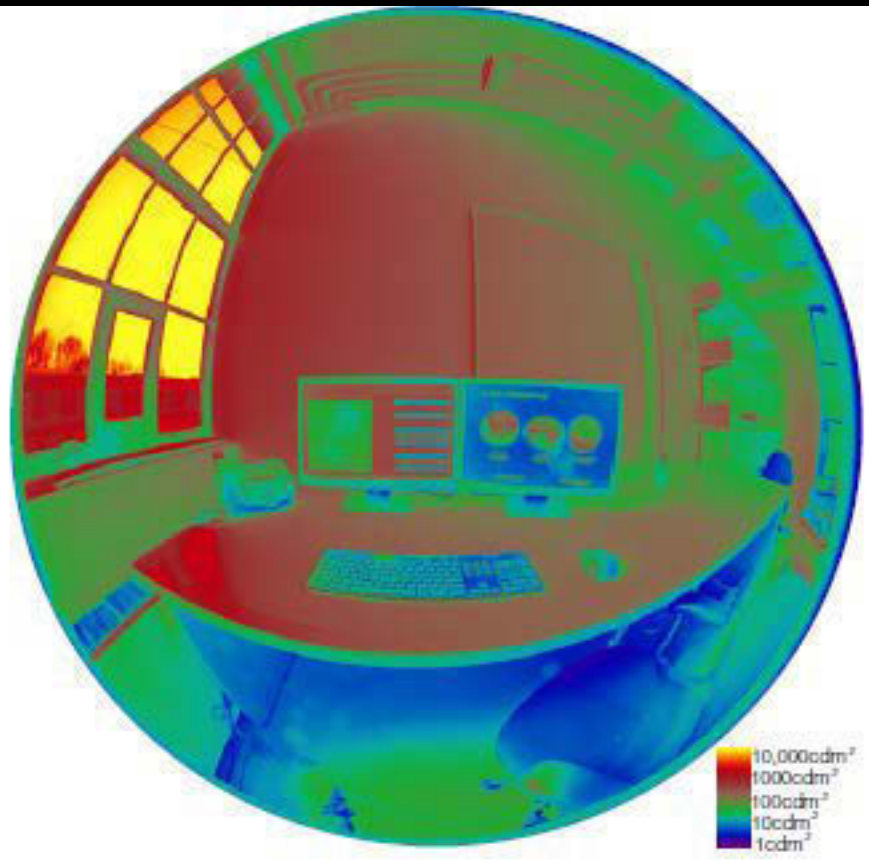


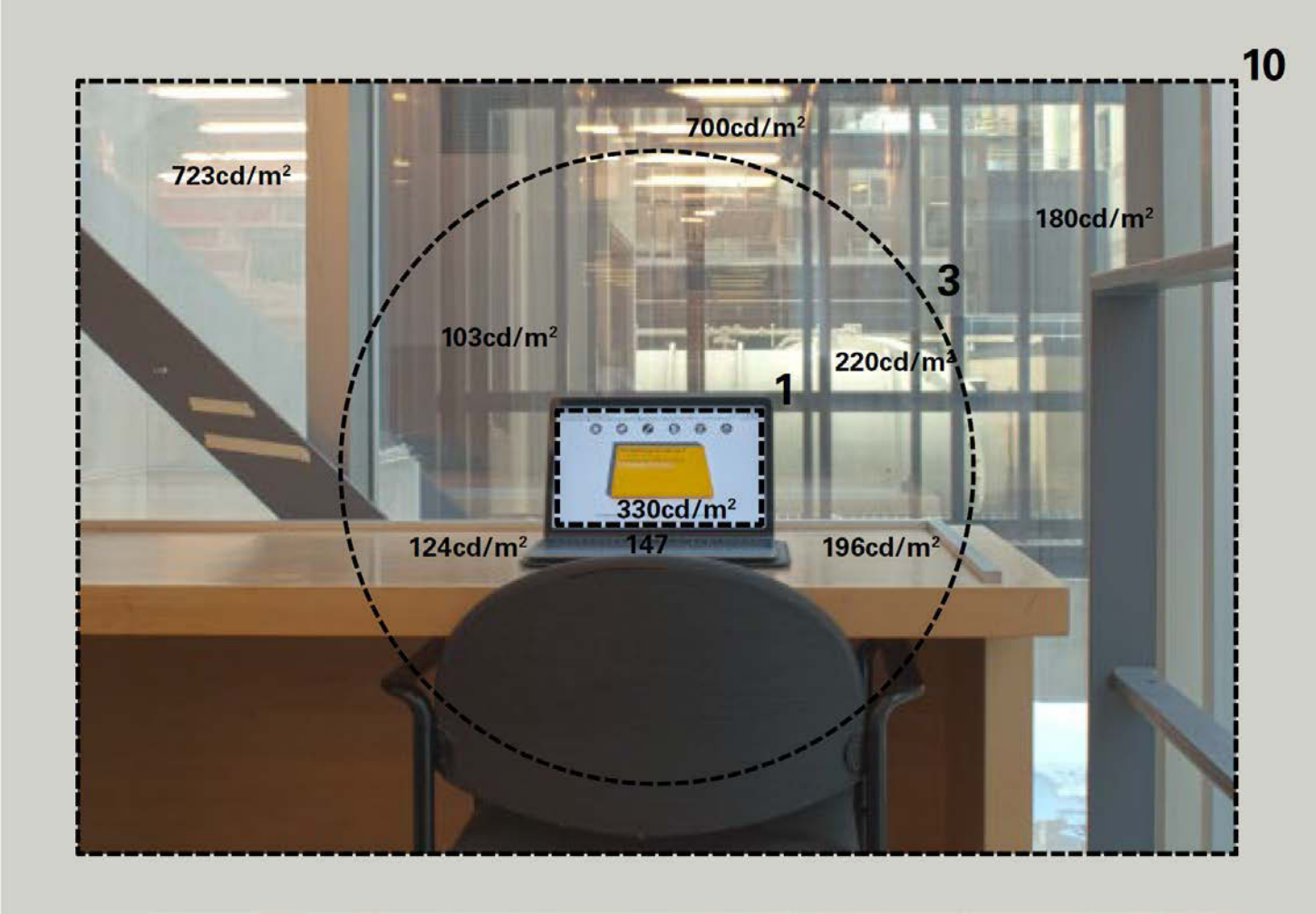
Fig. 4.16 This HDR photograph provides a falsecolor luminance map of the same workspace

Luminance Distribution

Demo: WXFalseColor: Exposure, falsecolor, human sensitivity, 10:3:1 ratio

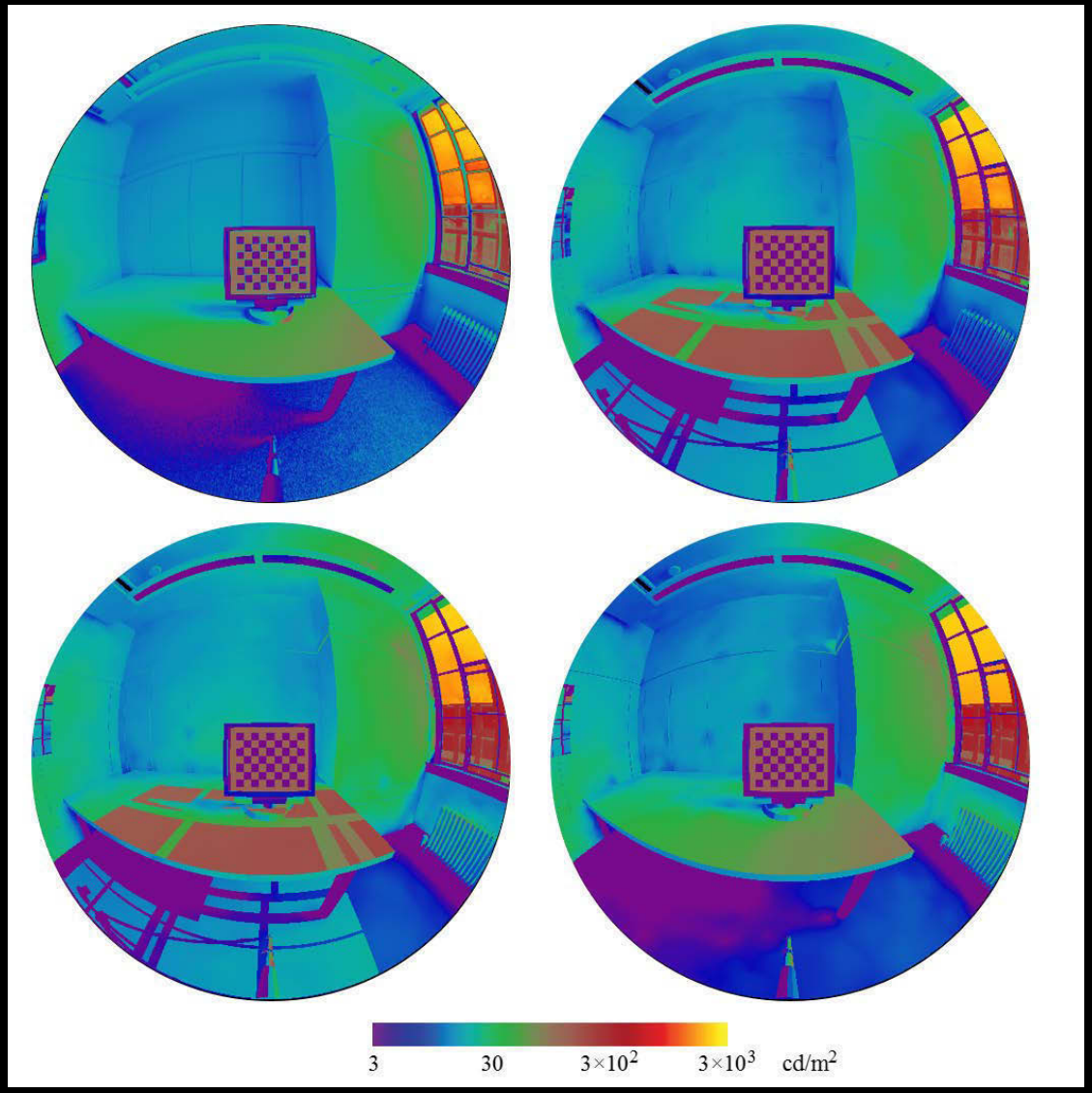
False color representation to display a larger range.

Preferred luminances in the field of view



- Keep luminance in the field of view within a factor of 3 / 10 within the near / far field vision.
- Rule widely used but not validated.
- Very difficult to maintain with daylight. Might not be necessary.
- Combine with an upper luminance level of 2500 to 3000 cdm^{-2} due to glare

HDR Photography vs Radiance



Paper: N. Jones and C F Reinhart, “Experimental validation of RADIANCE/Accelerad-based simulations as a means of image-based visual discomfort analysis,” submitted to *Building and Environment.*

Illuminance

[lux = lumen/m²]

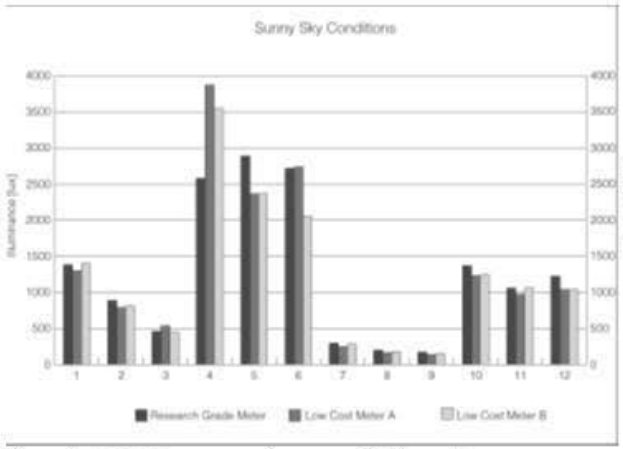
observer

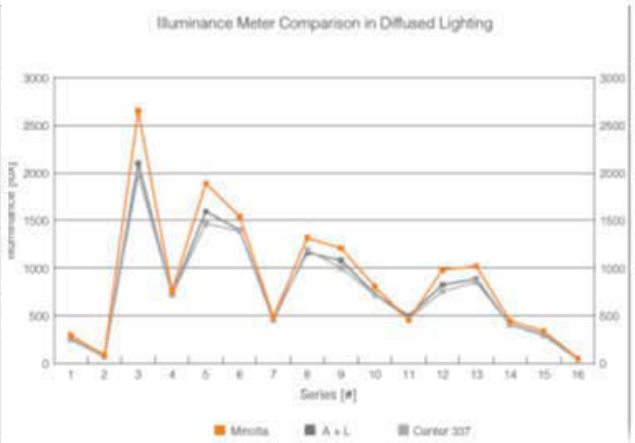
Illuminance is the most widely used photometric quantity to describe the light in spaces. It is defined as the total luminance flux incident on a surface and measured in lumen per unit area or lux[12]:

$$Illuinance = \frac{Luminous\ Flux}{Area} \quad ; \quad Unit\ [Illuminance] = \frac{lumen}{m^2} = lux$$

Foot-candle = non SI unit of illuminance 1 fc = 1 lumen/ft2 = 10.764 lux

Comparison of Illuminance Meters





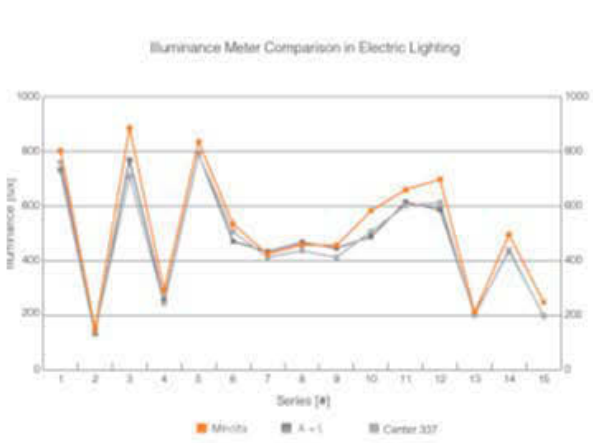
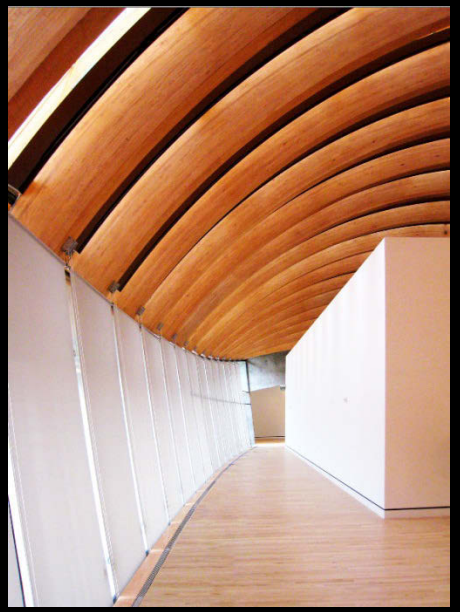


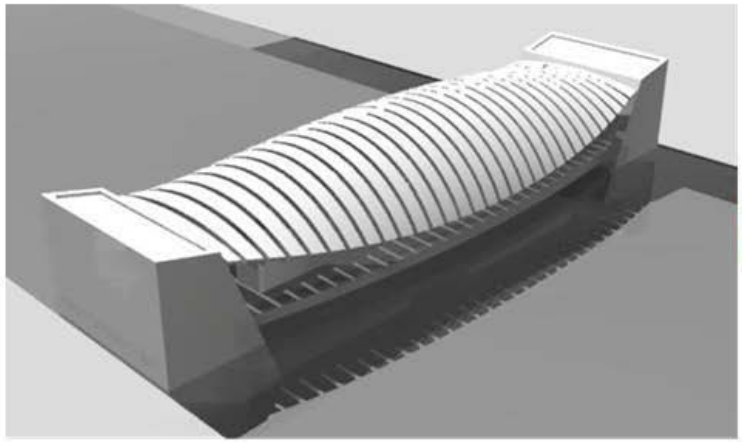
Fig 4.36 Comparison of illuminance measurements for three light meters[13].[

Illuminance Levels

- Clear summer sky 150,000 lux
- Overcast summer sky 16,000 lux
- Moonlight 1 lux
- Daylit office or classroom lighting requirement 300 lux
- Open plan office lighting requirement 500 lux – 800 lux
- Reading requirement 100 lux
- Conversation requirement 150 lux

Illuminance Distribution





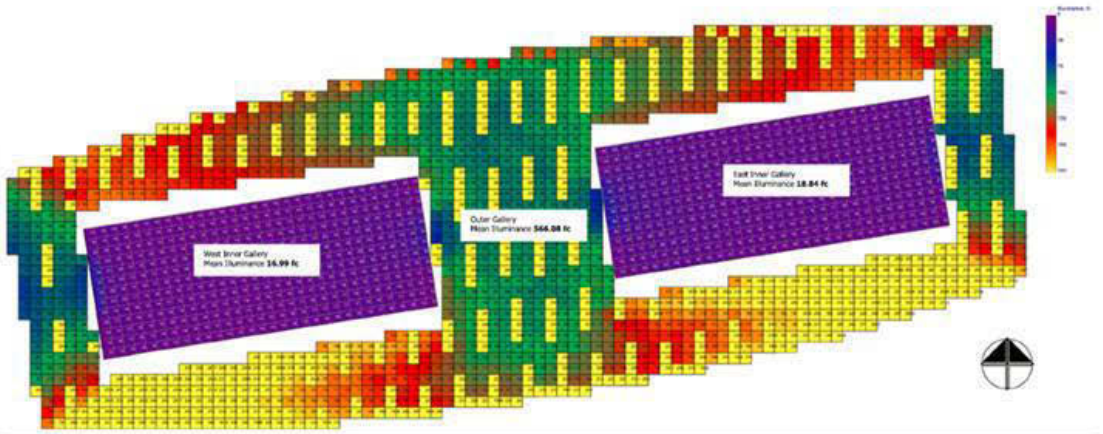
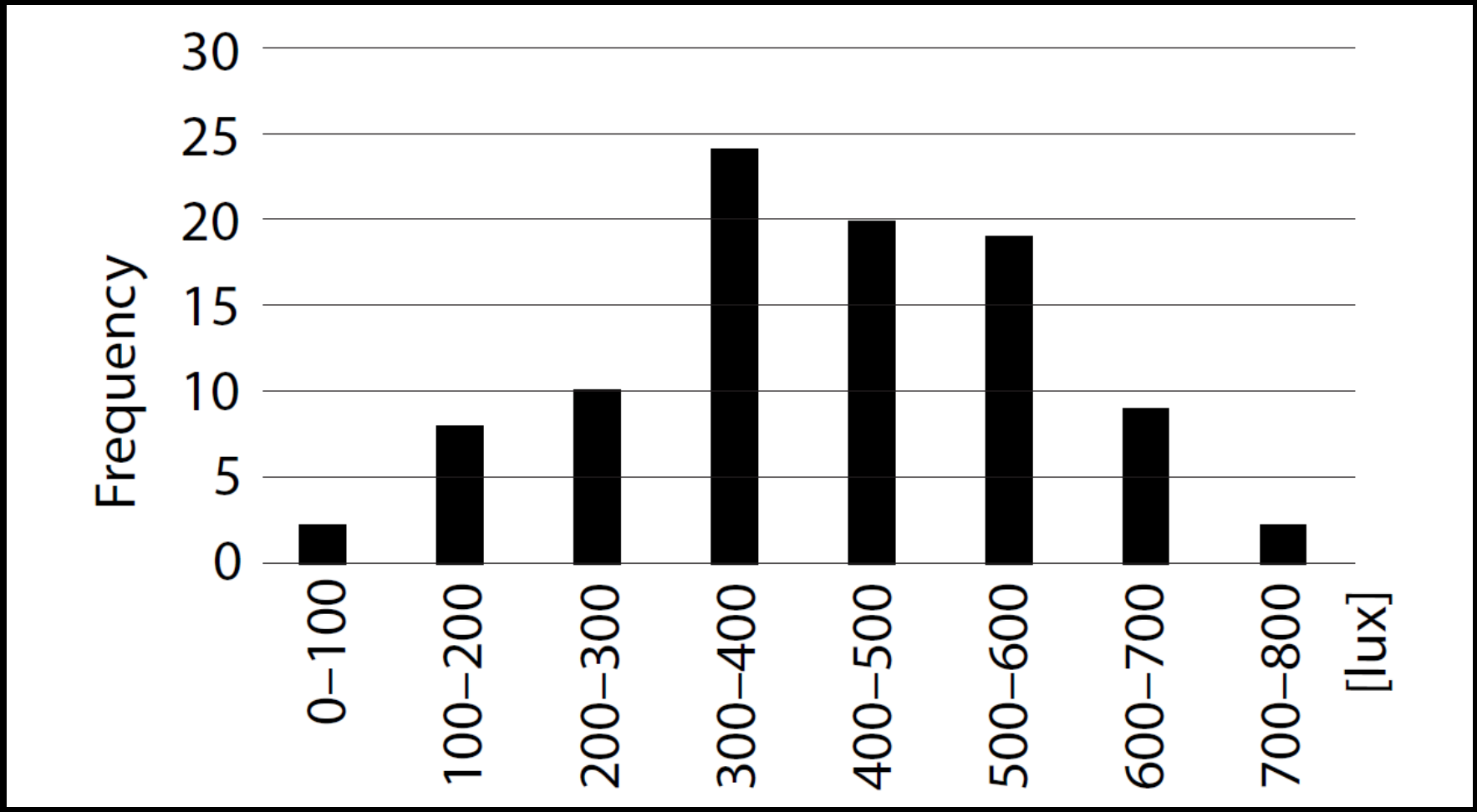


Fig 4.39 Simulated visualization (left) and illuminance distribution (right) on June 21 at noon in the Crystal Bridges museum in Arkansas, USA, 2011 (architecture Moshe Safdie, Lighting Lam Partners, Simulation Kera Lagios).

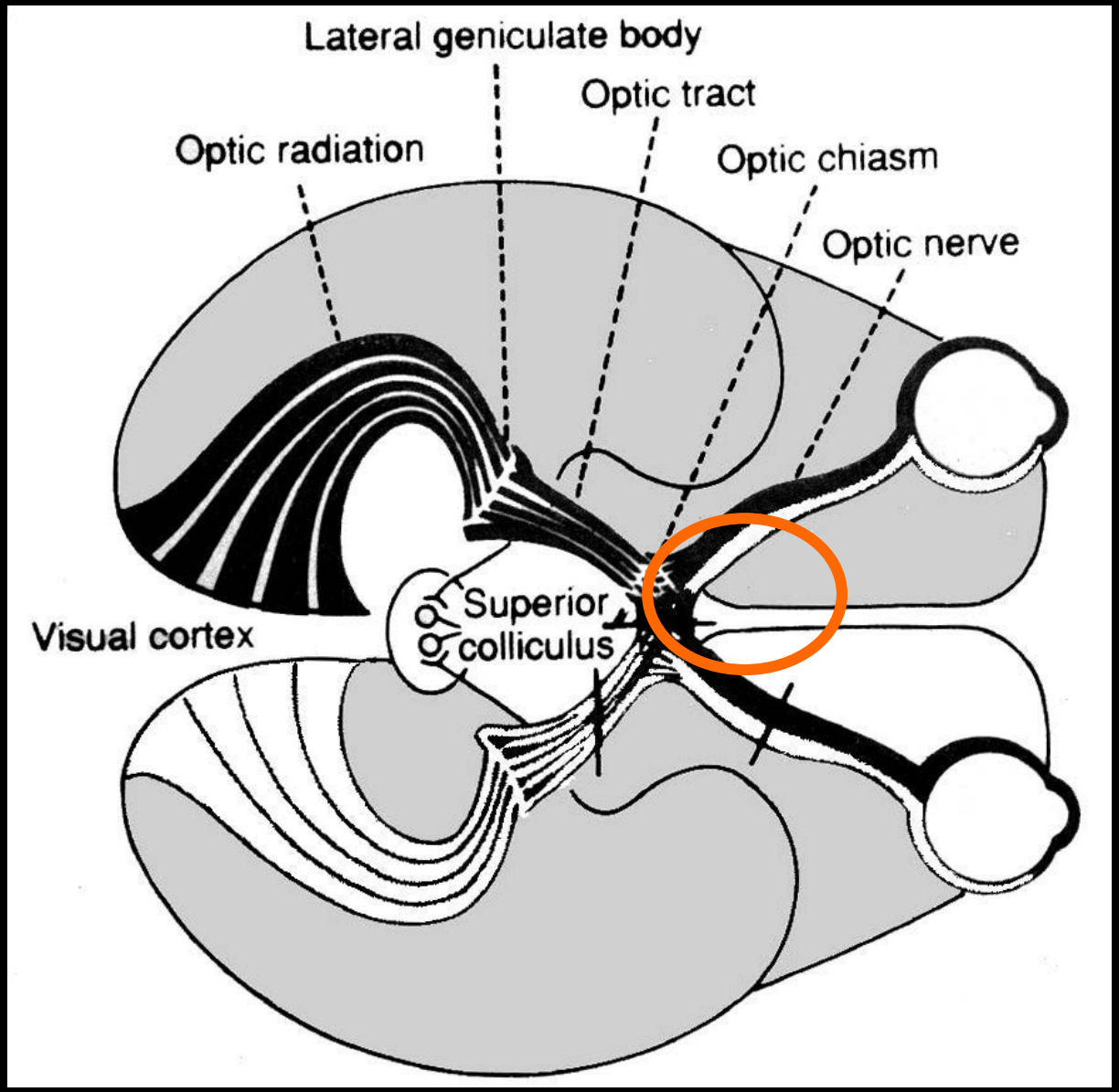
Simulation courtesy of Kera Lagios. Used by permission.

Preferred Illuminance Levels



Energy saving potential through personal controls.

From the Eye to the Brain



Optical Illusions

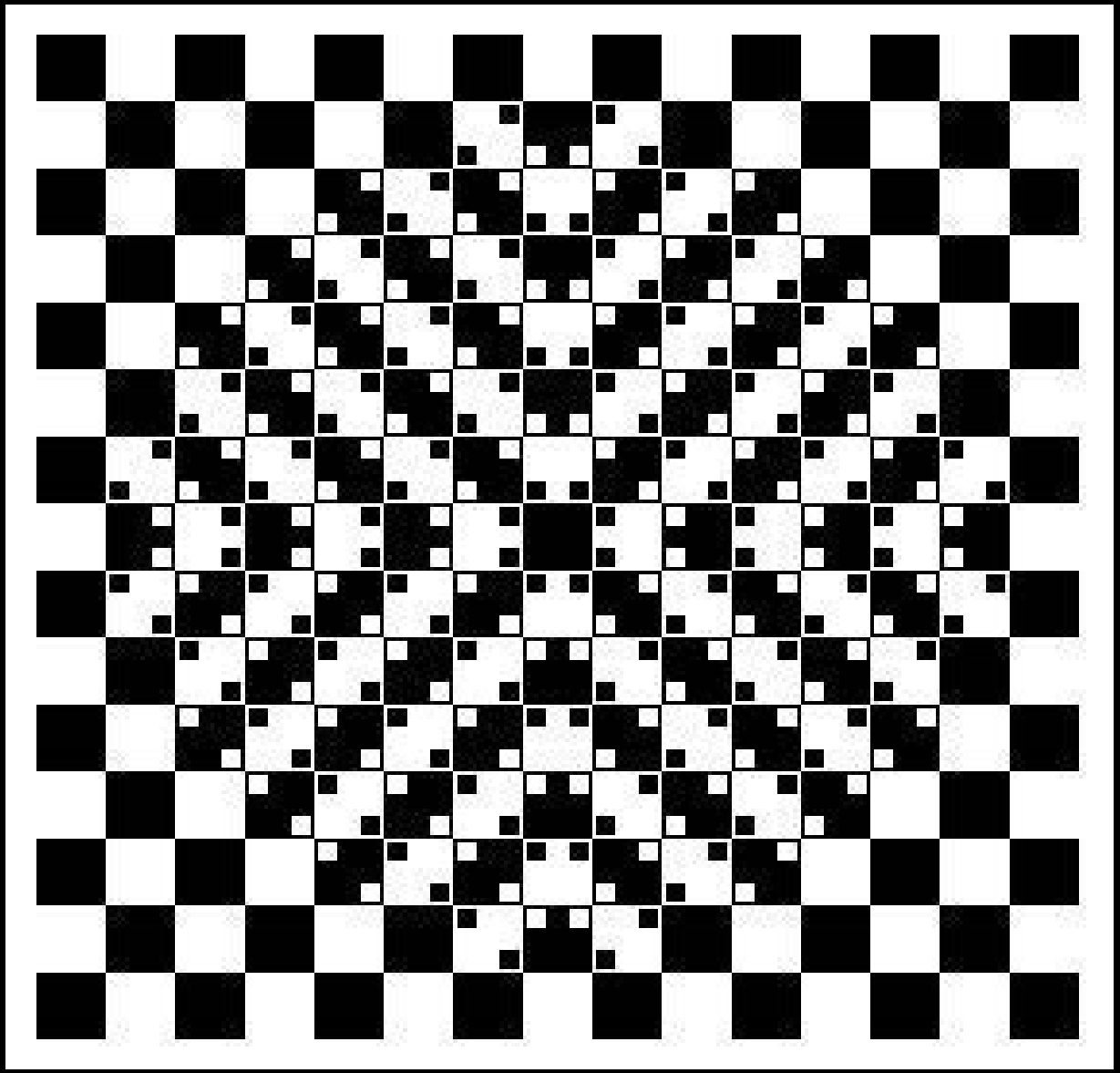


Image courtesy of Akiyoshi Kitaoka. Used with permission.

Optical Illusions

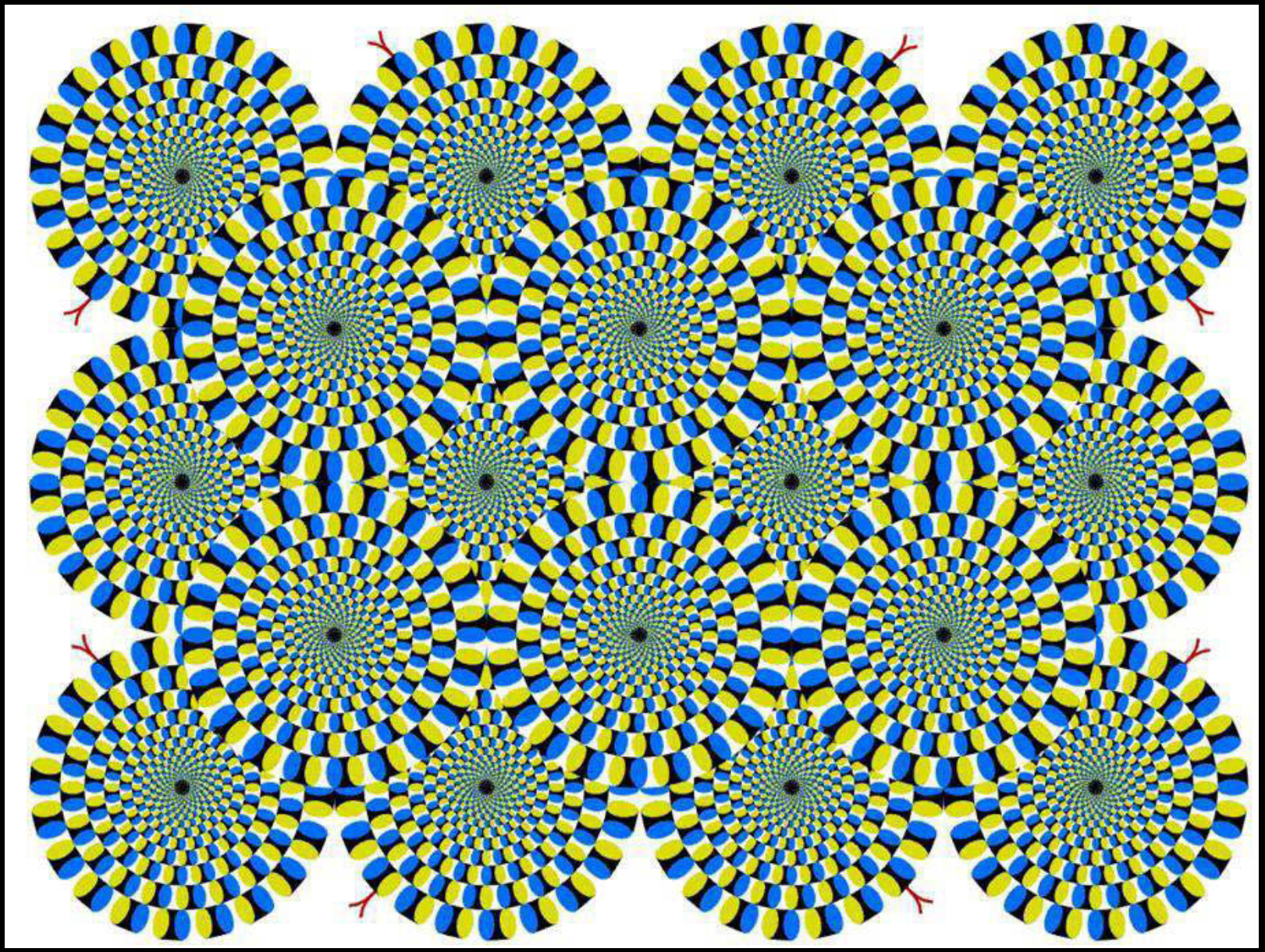
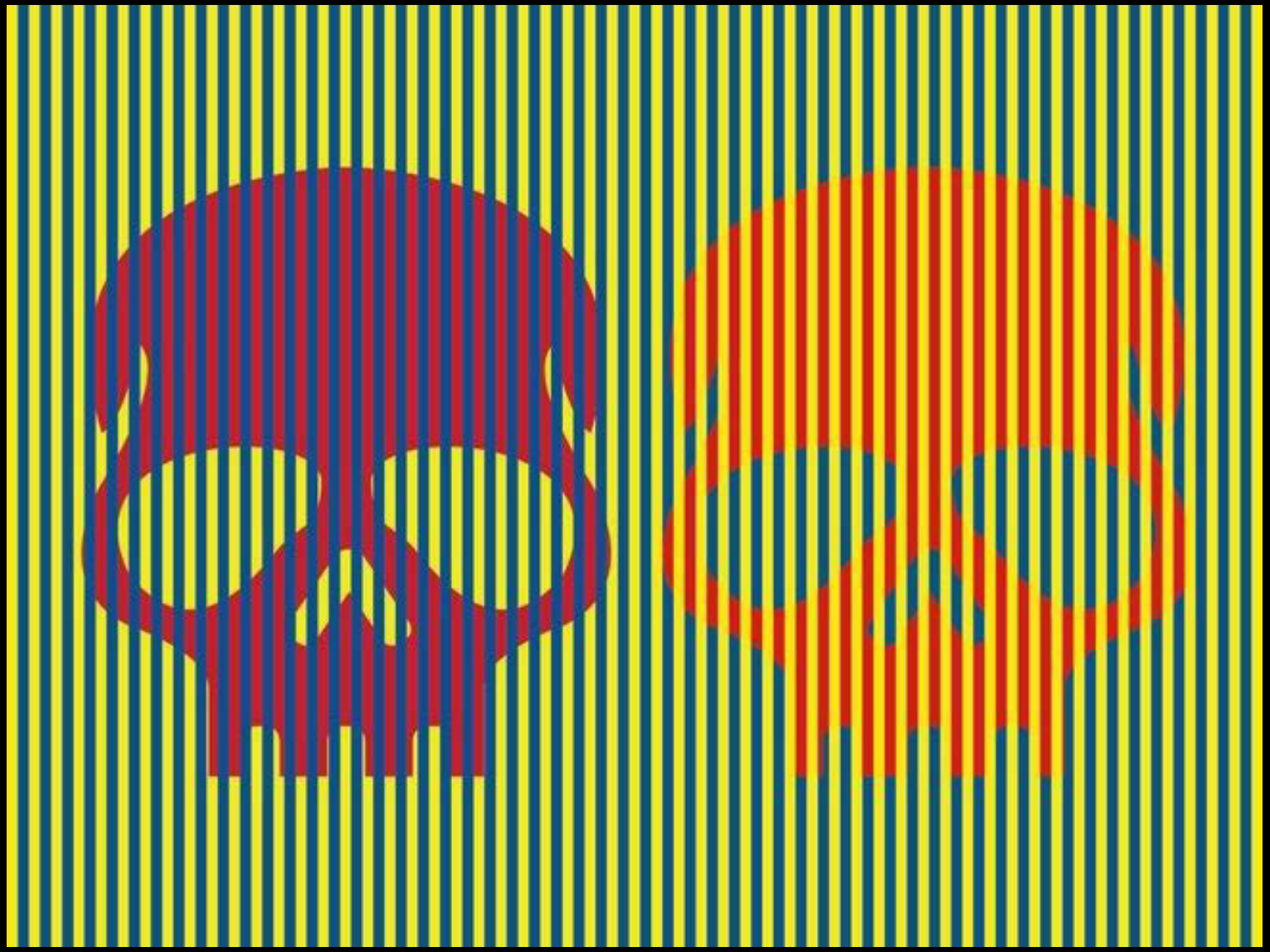


Image courtesy of Akiyoshi Kitaoka. Used with permission.

What are the colors of the skull?



From the Eye to the Brain

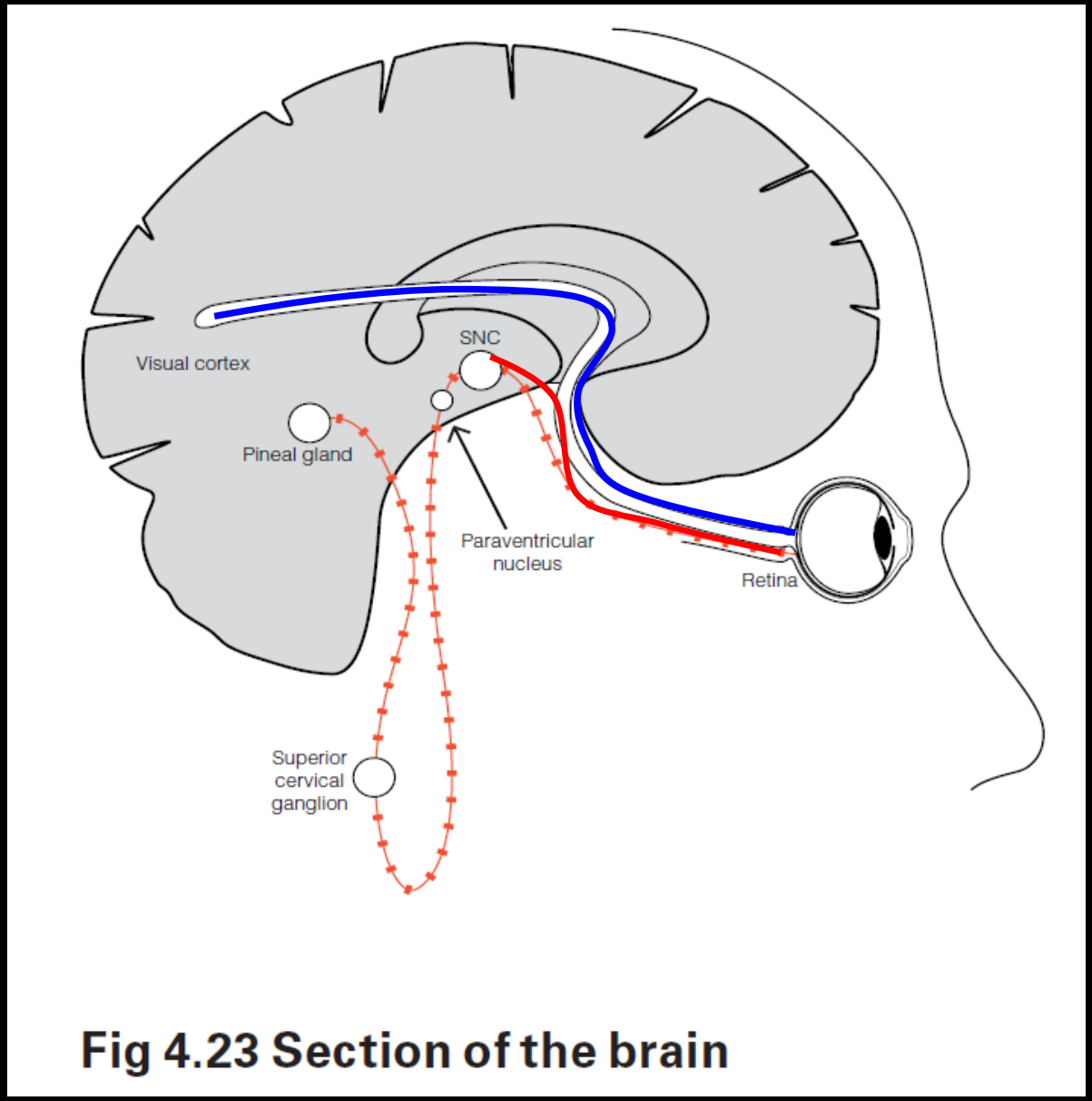


Fig 4.23 Section of the brain

Context Light and Health

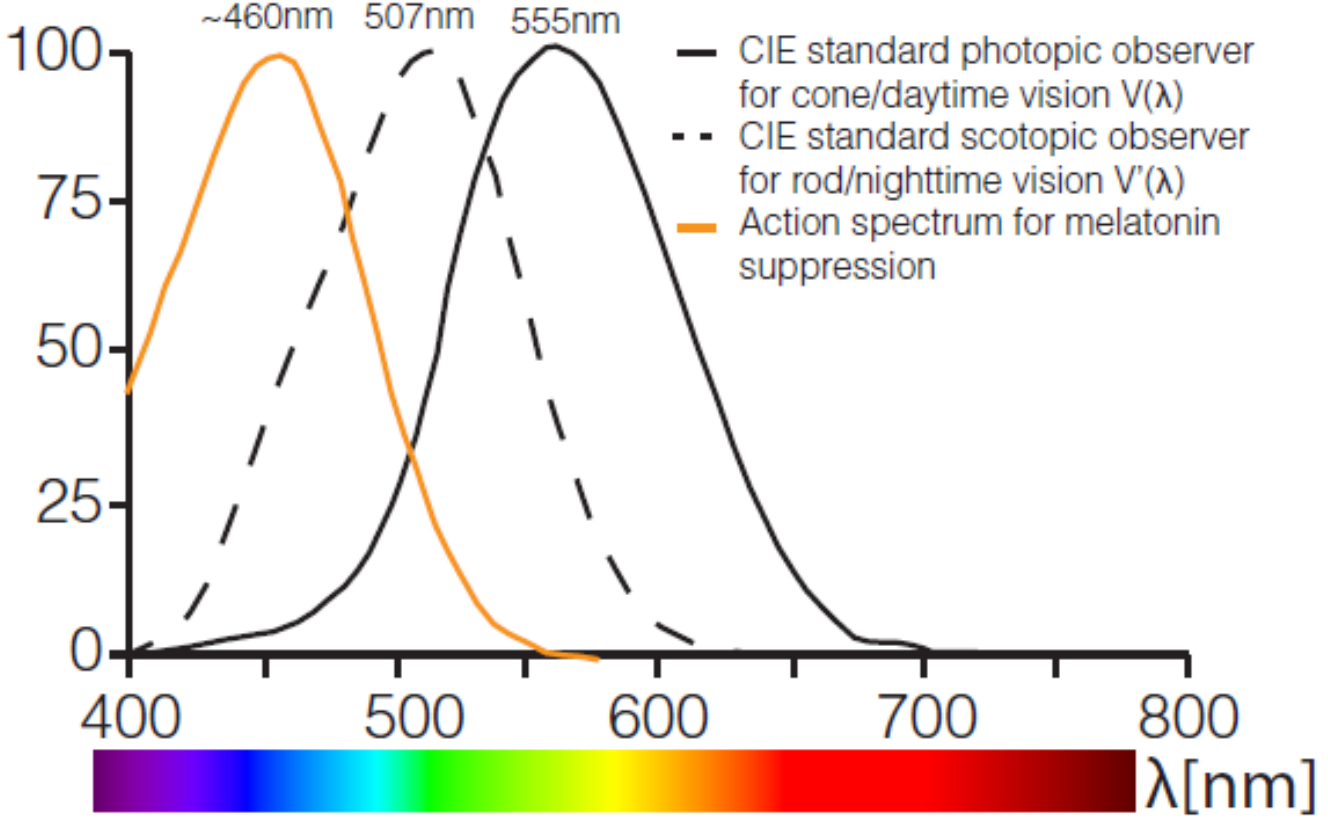
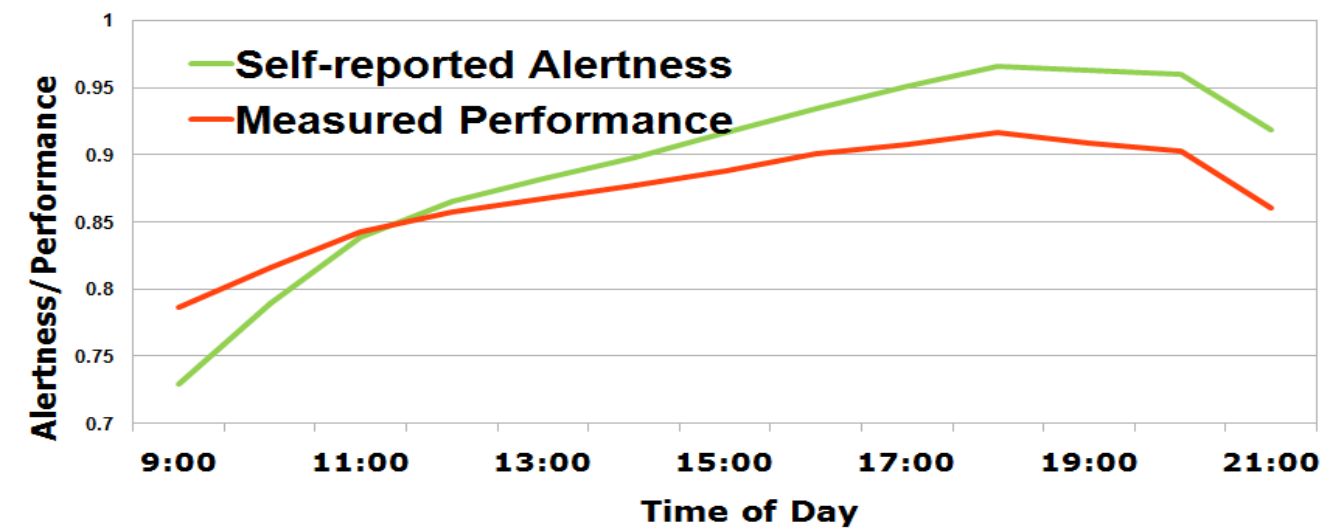


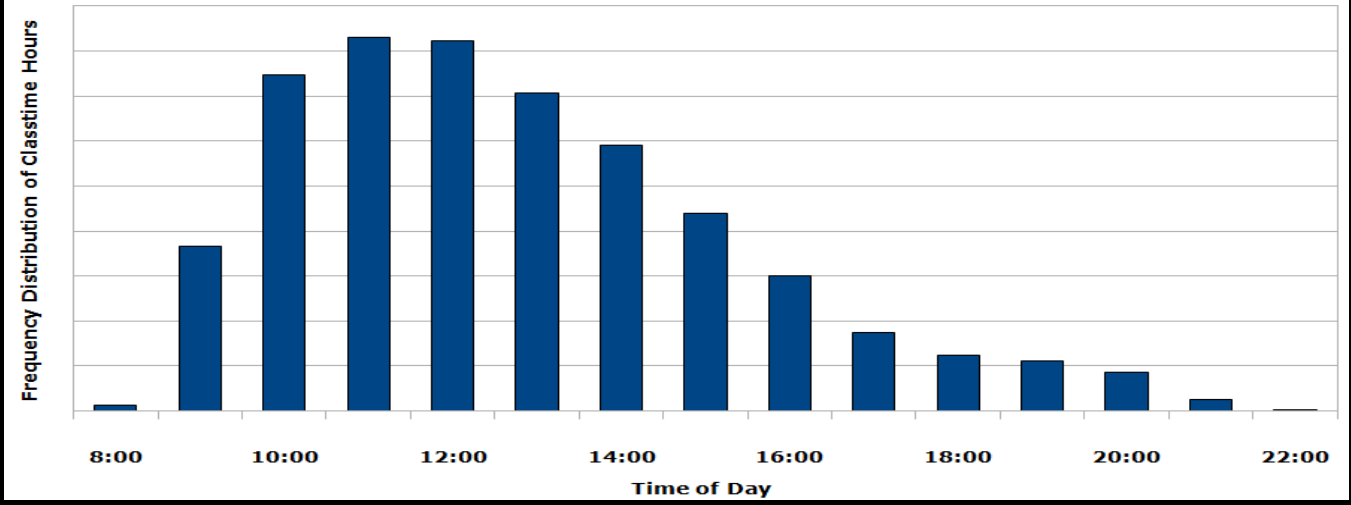
Fig 4.26 Action spectrum of ganglion cells versus a CIE standard Photopic and Scotopic Observer

Context Light and Health

Student Performance in the Classroom

Collaboration with Harvard Medical School, Division of Sleep Medicine

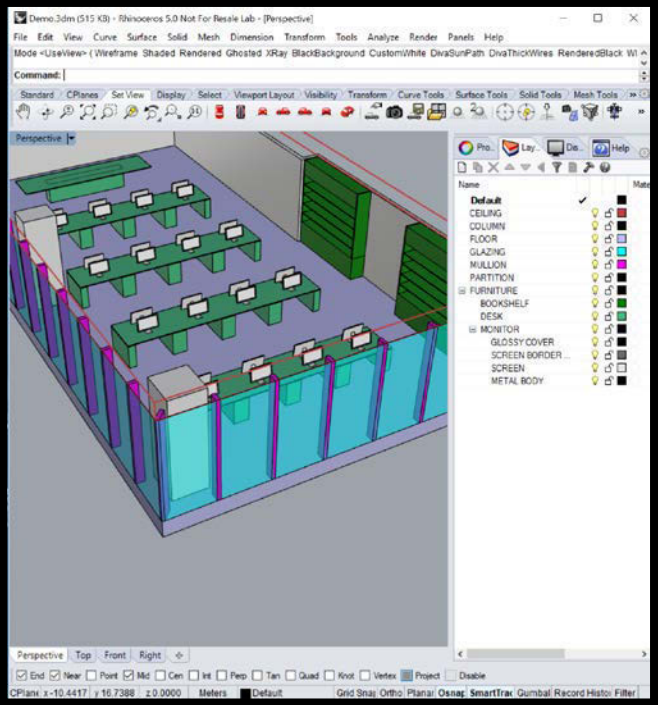


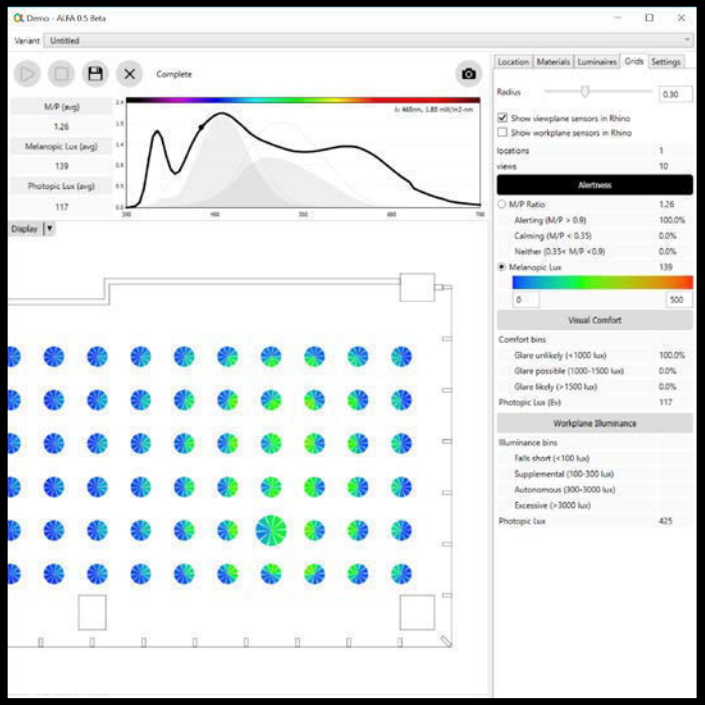


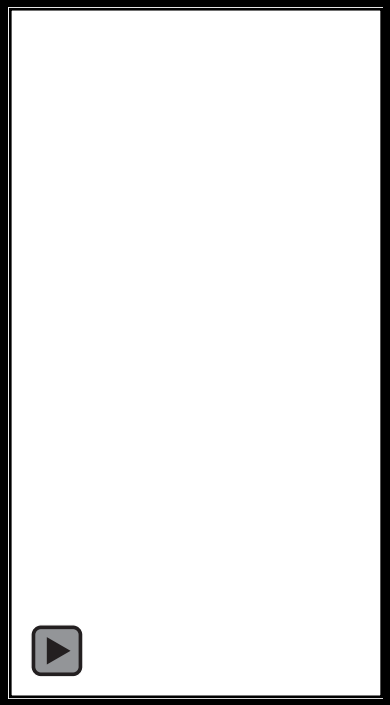
Preliminary Results (!)

SDLAB

Adaptive Lighting For Alertness)





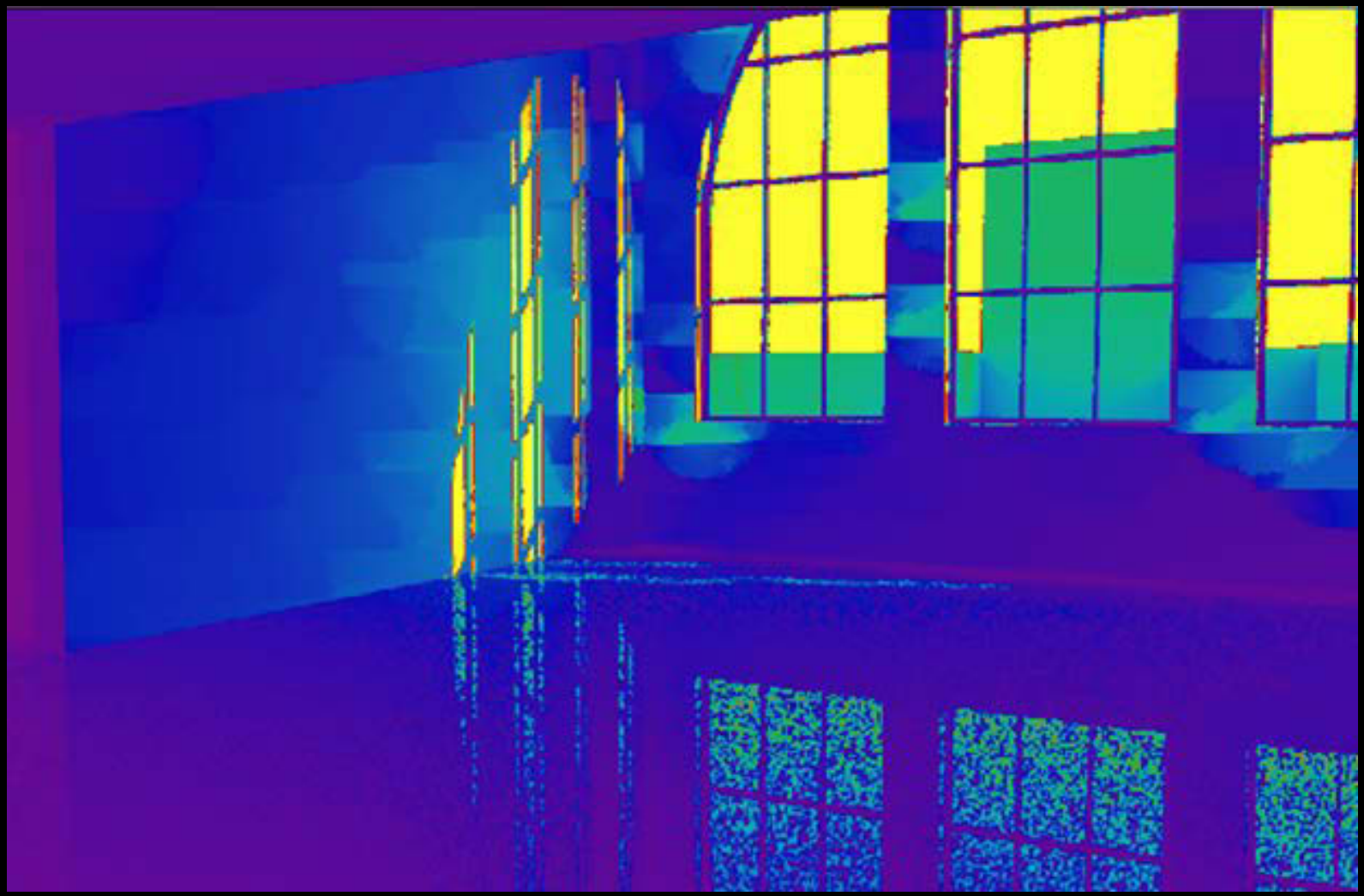


https://www.solemma.com/Alfa.html

- ALFA features a spectral sky model, spectral opaque and glazing material descriptions, and a path-tracing like approach based on Radiance.

SOLEMMA

Questions?



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