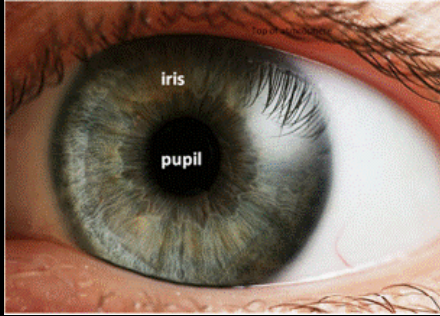
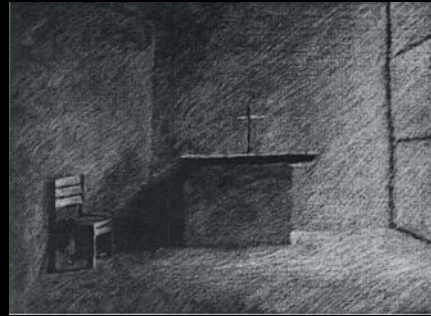


4.430 Daylighting



Human Eye



'HDR the old fashioned way' (Niemasz)

Christoph Reinhart
4.430 The Sensor



Happy Valentine's Day



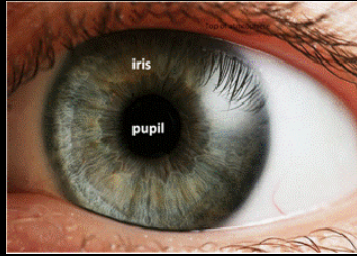
Happy Valentine's Day



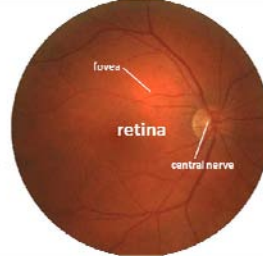
Light and Human Vision



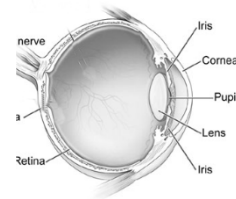
Human Eye



Outside view of a human eye



Opthalmogram of a human retina



Retina has three types of photoreceptors:
Cones, Rods and Ganglion Cells

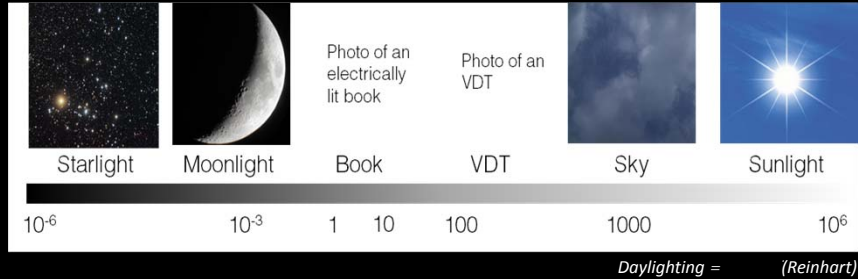


Day and Night Vision

- ❑ **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).



VisibleRange



- The human eye can see across twelve orders of magnitude.
- We can adapt to about 10 orders of magnitude at a time via the iris.
- Larger ranges take time and require 'neural adaptation'.

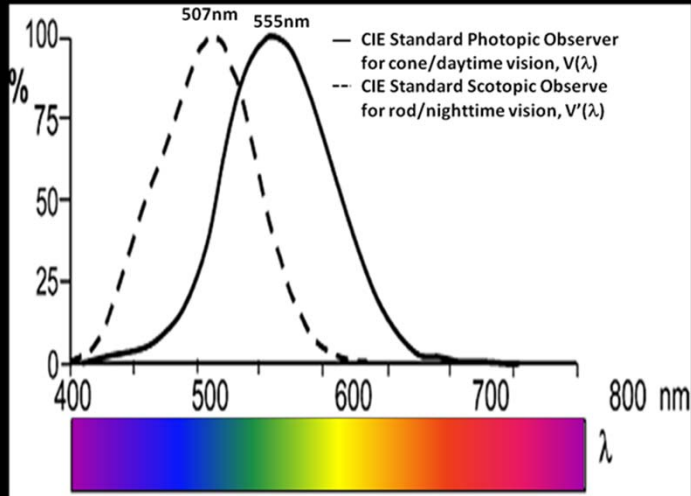


Transition Spaces

- Outside
- Atrium
- Circulation Area
- Final destination

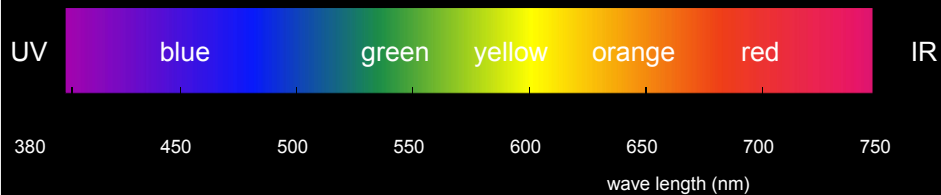


Luminous Response Curve of the Human Eye



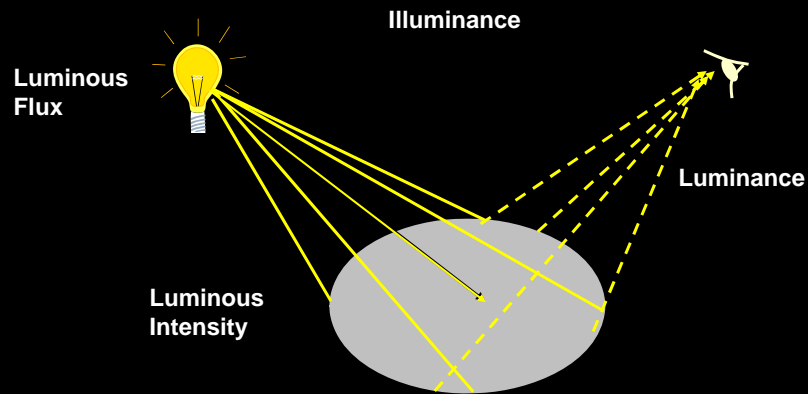
What is daylight?

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



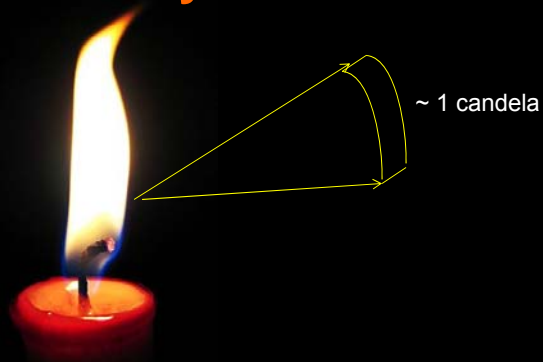
Photometric Quantities

Characterize how a space is perceived.



Luminous Intensity

[Candela]



Courtesy of Matthew Bowden at www.digitallyrefreshing.com. Used with permission.

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

$$1 \text{ candela} = 1 \frac{\text{lumen}}{\text{steradian}}$$



Luminous Flux/Power

[Lumen = Candela* Steradian]



~ 4π lumen



Image by MIT OpenCourseWare.

100 Watt , 1600 lumen

127 candles



Photo by Eric Beaulieu on Flickr.

13 Watt , 1600 lumen

Courtesy of Matthew Bowden at www.digitallyrefreshing.com.
Used with permission.

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



Example Manufacturer Information

Spotlight Indoor

For track and recessed lighting

65 watts	Light Output	Energy Used	Life	To save energy costs, find the bulb with the light output you need, then choose the one with the lowest watts
	600 Lumens	65 Watts	2000 Hours	

Image by MIT OpenCourseWare.



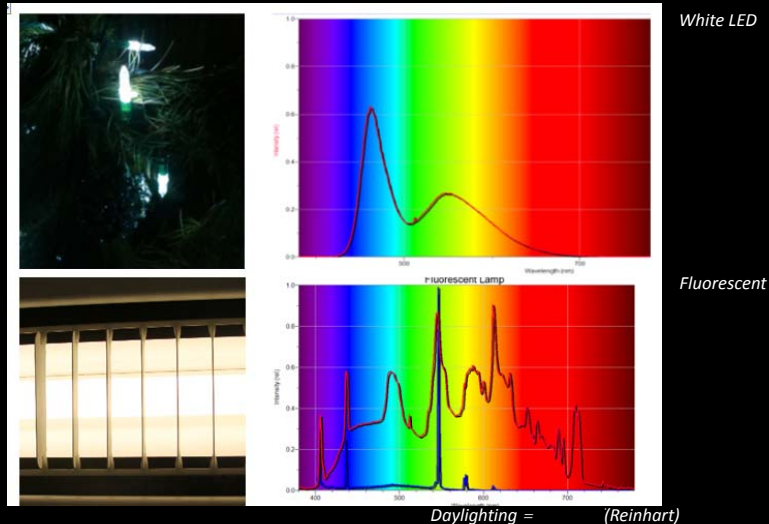
Review Luminous Efficacy & Efficiency

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%

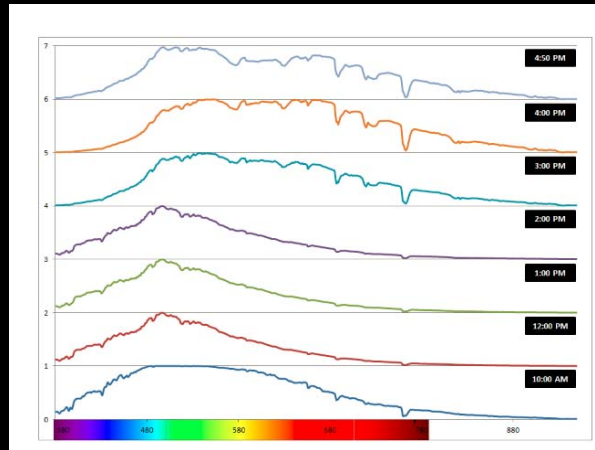
* lower range at room temperature and power levels above 1W



Spectral Intensity form Various Light Sources



Spectral Intensity Distribution of Daylight

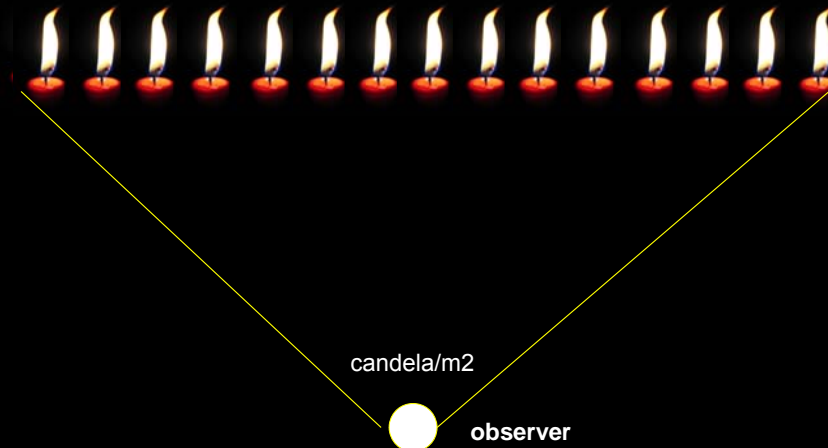


Measurement T Rakha, Figure 2

(Reinhart)
MIT

Luminance

[candela/m²]



Courtesy of Matthew Bowden at www.digitallyrefreshing.com. Used with permission.

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 view point.

MIT

Typical Luminance Values

Fig 4.25 Typical Luminance Values.

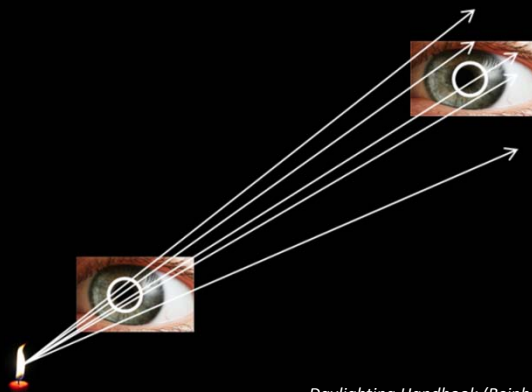
Light Source	Luminance [cd/m ²]
Starlight	10 ⁻⁶
Moonlight	10 ⁻³
Desk at Night	20
Computer Screen	200
Overcast Winter Sky	3000
Fluorescent Light	7000
Solar disc on a Clear Day	10 ⁸

Daylighting = (Reinhart)



Luminance

[candela/m²]



Daylighting Handbook (Reinhart)

The luminance caused by a point light source at a observer's eye falls with the observer's distance from the light source.



Luminance

[candela/m²]



Daylighting Handbook (Reinhart)

Collimated light source.



Luminance Distribution

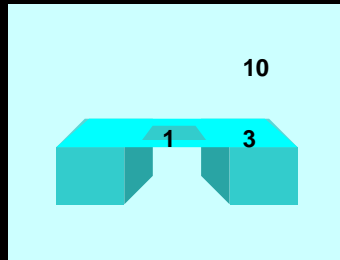


Daylighting Handbook (Reinhart)

Demo: Radiance Image Viewer: Exposure, falsecolor, human sensitivity, 10:3:1 ratio
False color representation to display a larger range.



Preferred Luminances in the field of view (1:3:10 rule of thumb)



Note:

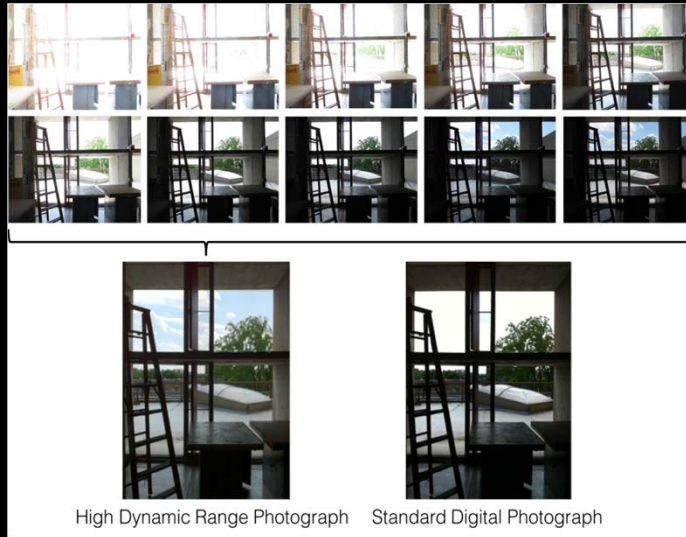
Rule widely used but not validated.

Very difficult to maintain with daylight. Might not be necessary.

Upper luminance level of 2500 to 3000 cdm^{-2} due to glare.



High Dynamic Range Photography



Daylighting Handbook (Reinhart)



Illuminance

[lux = lumen/m²]



Courtesy of Matthew Bowden at www.digitallyrefreshing.com. Used with permission.



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 lux¹²:

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

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



Typical Illuminance Levels

Fig 4.37 Typical outside illuminance levels.

Light Source	Horizontal Illuminance [lux]
Clear summer sky (temperate)	150,000
Overcast summer sky (temperate)	16,000
Busy urban street at night	XX
Sidestreet at night	XX
Moonlight	1

Fig 4.38 Program specific target illuminances.

Space Type	Horizontal Illuminance
Office work or teaching	300 lux (mostly daylight)
	500 lux (mostly electrically lit)
	800 lux (open plan)
Reading	100 lux
Conversation	150 lux

Daylighting Handbook (Reinhart)



Comparison of Illuminance Meters

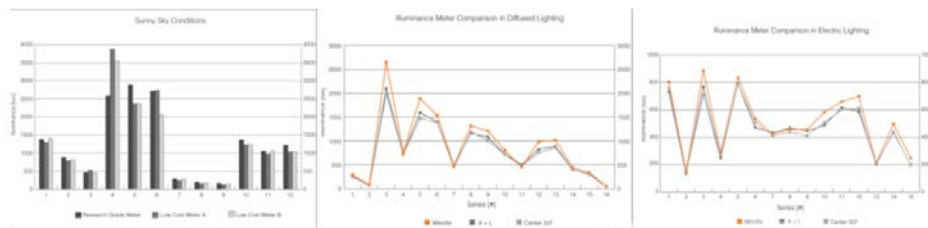


Fig 4.36 Comparison of illuminance measurements for three light meters¹⁵.

Daylighting Handbook (Reinhart)

Illuminance Distribution

Photograph of Safdie's Crystal Bridges Museum removed due to copyright restrictions.

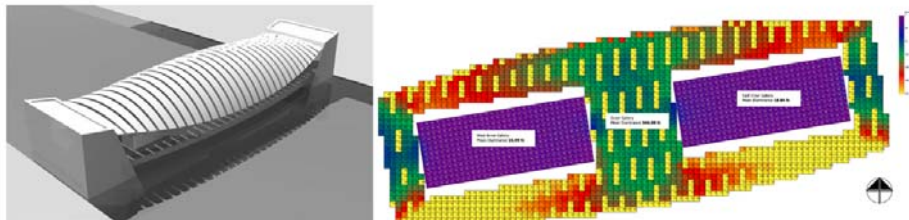
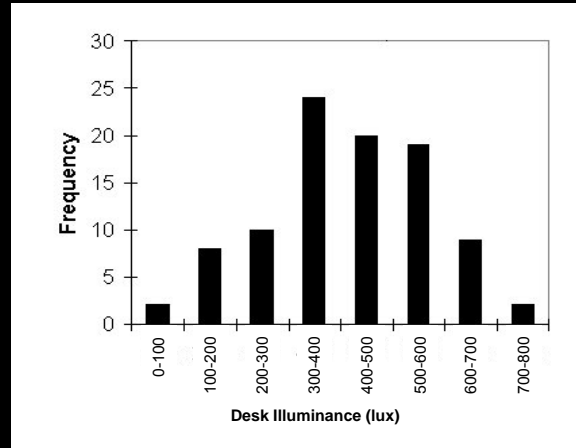


Fig 4.39 Simulated visualization (left) and illuminance distribution (right) on June 21 at noon in the Crystal Bridges museum in Arkansas, USA, 2011 (architecture Moshe Safdie, Lighting Lam Partners, Simulation Kera Lagios).

Daylighting Handbook Reinhart



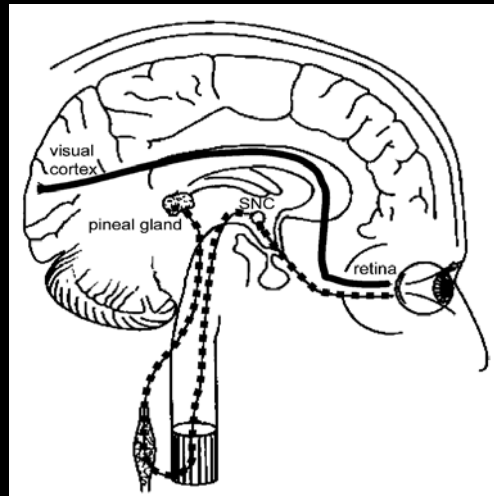
Preferred Illuminance Levels



Energy saving potential through personal controls.



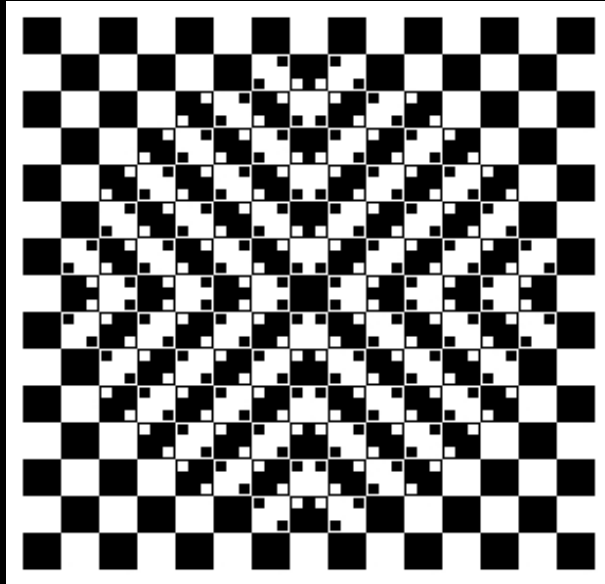
From the eye to the brain



Daylighting Handbook (Reinhart)



Optical Illusions



Courtesy of Akiyoshi Kitaoka. Used with permission.

Kitaoka, "The Bulge" (<http://www.ritsumei.ac.jp/~akitaoka/cushione.html>)



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4.430 Daylighting
Spring 2012

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