101 Light and Human Perception

Presented by
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April 28 2020

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●2

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- More than 30 years in the lighting industry as an architectural lighting designer, instructor, daylighting and sustainability specialist, lighting control system consultant, and theatrical designer.
- Has taught and consulted on sustainability issues, lighting, and daylighting for the Lighting Design Lab and University of Washington Architecture Department

Selected Projects

- King Abdullah University of Science and Technology
- Masdar Headquarters
- Pearl River Tower
- Canyon Ranch Spa Club
- Amgen Helix Campus
- Reebok World Headquarters
- Reno Sparks Convention Center
- Pacific Place Retail Center
- Ala Moana Retail Center
- REI Denver Flagship Store
- Boeing Commercial Airplanes Offices
- Real Networks Headquarters
- Tommy Bahama Headquarters
- Microsoft B16/17
- San Francisco PUC Headquarters

Selected Awards

- Amgen Helix Campus
- Amgen Helix Pedestrian Bridge
- Canyon Ranch Spa Club
- Harvard University 60 Oxford
- King Street Station
- Lighting Design Lab
- Methodist Hospital Research Institute
- Microsoft B16/17
- One Cambridge Center
- Pacific Place Retail Center
- Reebok World Headquarters
- Reno Sparks Convention Center
- Real Networks Headquarters
- SFPUC Headquarters
- Tommy Bahama Headquarters
- University of Texas at Austin EER

AIA COTE Top 10

- REI Flagship Store Denver
- King Abdullah University of Science and Technology
- San Francisco PUC Headquarters
- Manitoba Hydro Place

●3

Pop Quiz

- Our first pop quiz of the day…..

  How would you best describe your role?

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Today's Learning Outcomes

- Describe fundamental light source metrics.
- Describe major physiological visual system elements and their function.
- Describe some basic non-visual circadian effects of light.
- Describe perception within the framework of source, modifier, encoder, and interpreter framework.
- Discuss practical application methods for targeted light delivery.

Amgen Helix Bridge
Johnson Architects

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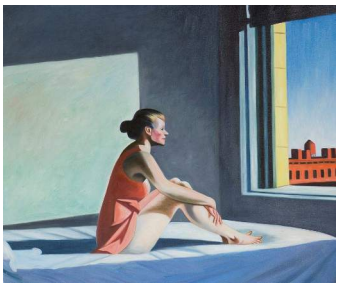
●5

We all respond in different ways to the effects of light.

Johannes Vermeer
Woman Writing A Letter



Edward Hopper
Morning Sun

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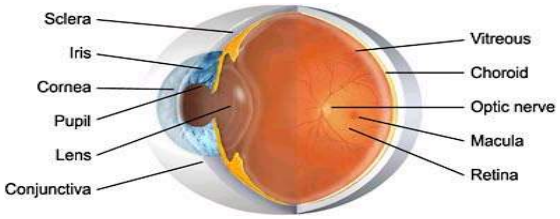
Why is this so critical?



As much as 80% of our environmental perception is visual.

Courtesy: IESNA

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●7

Biological Needs

Bill Lam identified eight important needs for biological information.

Location – with regard to water, heat, food, sunlight, escape routes, destination, etc

Time – and environmental conditions which relate to our innate biological clocks

Weather – as it relates to the need for clothing and heating or cooling, the need for shelter, opportunities to bask in the beneficial rays of the sun, etc

Enclosure – the safety of the structure, the location, and nature of environmental controls, protection from cold, heat, rain, etc.

Perception and Lighting as Formgivers for Architecture
William M C Lam

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Biological Needs

Other living things – the presence of plants, animals, and people

Territory – it's boundaries and the means available within a given environment for the personalization of space

Relaxation and stimulation – for the mind, body, and senses

Places of Refuge – shelter in times of perceived danger

King Abdullah University of Science and Technology
HOK

Perception and Lighting as Formgivers for Architecture
William M C Lam

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Health and Well Being

We need dynamic lighting cues and a connection to nature and the passage of time

...unvarying electric light can lead to low level sensory deprivation manifested by "impairment of organized thinking, oppression and depression, confusion, suggestibility, and general irritability."

- Aldsworth and Bridgers (1971)

Provide daylight and unobstructed views to the outside

- Visual Fatigue
- Regulation of Chrono-biology
- Seasonal Affective Disorder
- Synthesis of Vitamin D
- Biophilia

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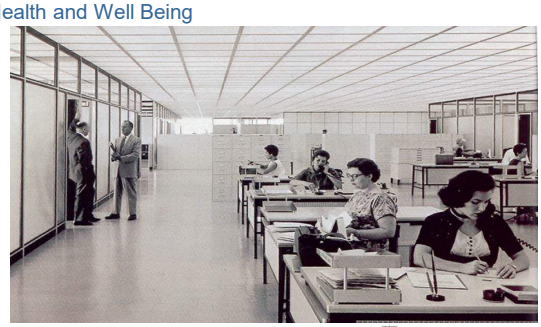
Health and Well Being



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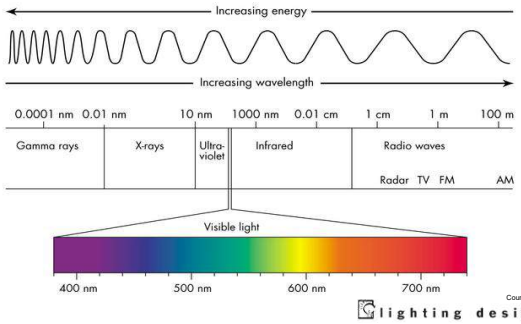
What is Light?



Courtesy: Cyberphysics

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Does it really matter what the light source is?

Courtesy: NASA, Candles.com, Xicato, Philips, Sylvania

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How do we begin to describe and quantify light?




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Quantity – how much light do we have?

Luminance : *The quotient of the luminous flux at an element of the surface surrounding the point, and propagated in directions defined by an elementary cone containing the given direction, by the product of the solid angle of the cone and the area of the orthogonal projection of the element of the surface on a plane perpendicular to the given direction. The luminous flux may be leaving, passing through, and/or arriving at the surface. Formerly, photometric brightness.*

Illuminance: *The areal density of the luminous flux incident at a point on a surface.*

IES RP-16-17 Nomenclature and Definitions for Illuminating Engineering:
https://www.ies.org/standards/definitions/

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●15

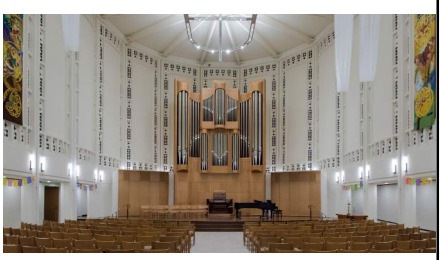
For our purposes these definitions will suffice…

Luminance – The light exiting a source or a surface.

Cd/M²

Illuminance – The light striking incident upon a surface.

Lux or Foot-candle



Plymouth Church
LMN

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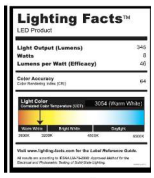
Quantity and Intensity

Lumen: Unit of Luminous Flux – a measure of the total light emitted by a light source.

Let's add a directional component and…

Candela: Luminous intensity per unit solid angle. One candela is one lumen per steradian (lm/sr).

Candlepower: Luminous intensity expressed in candelas (cd)



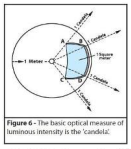


Figure 6 - The basic optical measure of luminous intensity is the 'candela.'

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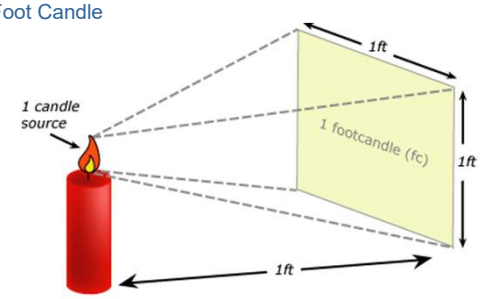
●17

The Foot Candle



Courtesy: Penn State

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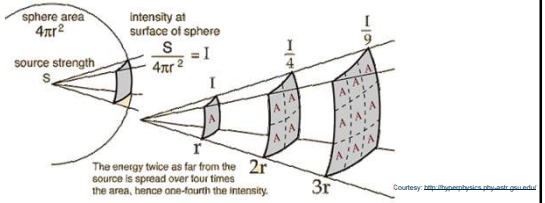
●18

What about distance?

Inverse Square Law:

The illuminance E at a point on a surface varies directly with the intensity I of a point source, and inversely as the square of the distance d between the source and the point. If the surface at the point is normal to the direction of the incident light: $E = I/d^2$



Courtesy: http://hyperphysics.phy-astr.gsu.edu/

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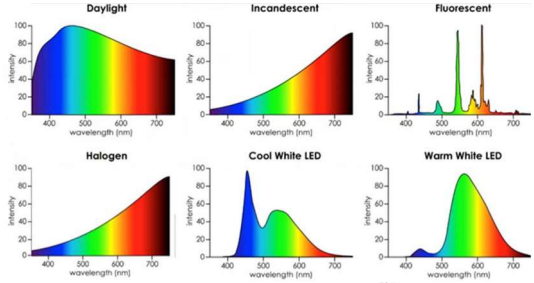
Spectral Distribution



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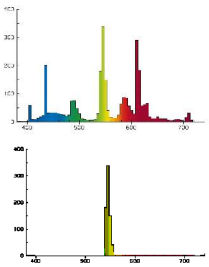
Color Spectrum

A red apple primarily reflects red wavelengths and absorbs other colors.



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Correlated Color Temperature

The absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source.

Imagine heating a piece of iron that could not melt:

Heat it to ~2700^0 K it would glow the color of an incandescent lamp.

Heat it to ~5000^0 K and it's glow would approach the color of sunlight.

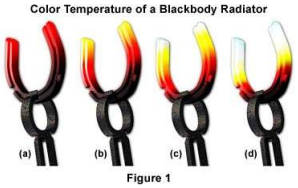

Figure 1

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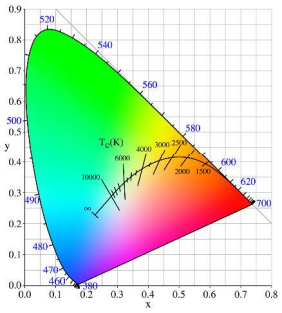
Black Body Curve

- Describes the chromaticity of a blackbody radiator at high temperatures
- Essentially describes what we would consider to be the range of white light
- Planckian Locus



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CCT in Kelvins

Cool

	6500	Daylight
Daylight	5000	Sunlight
Cool	4100	MH / CMH
Neutral	3500	
Warm	3000	Halogen / CMH
	2700	Incandescent
	2200	HPS
Warm	1500	Candle

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Correlated Color Temperature

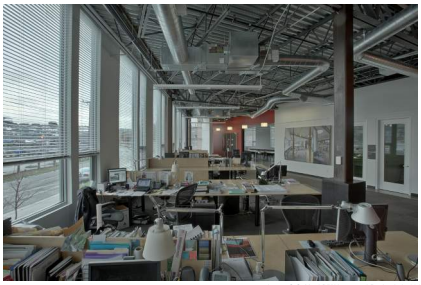

Image © C. Meek/UW Integrated Design Lab, 2017

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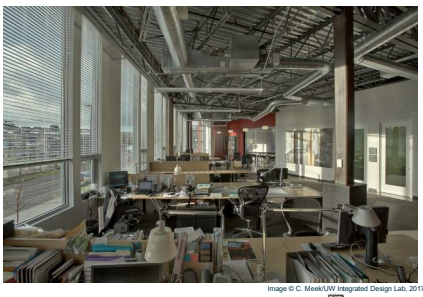
Correlated Color Temperature



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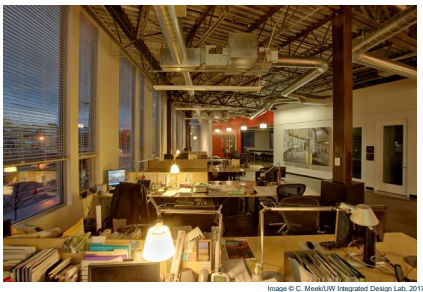
Correlated Color Temperature



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●27

Correlated Color Temperature

CCT	Very Warm	Warm	Neutral	Cool	Daylight
	2700K	3000K	3500K	4000K	5000K+
	Incandescent	Halogen	Non-Threatening	Clean	Bright
	Homey	Friendly		Efficient	Alert
	Intimate	Inviting		Bright	Color Match
	Personal	Personal			
Applications	Residential	Hospitality	Offices	Offices	Healthcare
	Hospitality	Retail	Classrooms	Big Box Retail	Jewelry retail
	Retail	Restaurants	Retail	Classrooms	Industrial
	Restaurants	Offices		Healthcare	
		Public Spaces		Industrial	
		Healthcare			
		Museums			

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●28

Color Rendering

Being able to perceive accurate colors is very important in certain settings

- Health care facilities
- Retail
- Industrial
- Scientific environments
- Architectural design

Tommy Bahama Headquarters
SNB Architects

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●29

Color Rendering

0-100 scale denoting how well a light source will render colors in a way that we find "normal."

- Daylight: 100
- Halogen: 100
- LED: Varies Widely

- Easy to game with LED…..

CRI 85

CRI 70

Courtesy: Philips

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●30

Pop Quiz

- What is a lumen?

Any questions so far?

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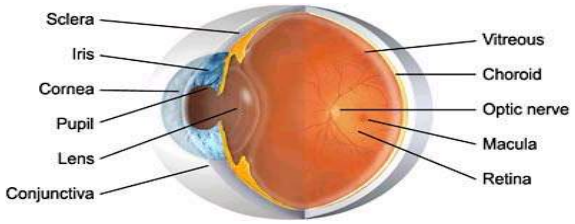
●31

Let's talk about the eye for a bit….



Courtesy: IESNA

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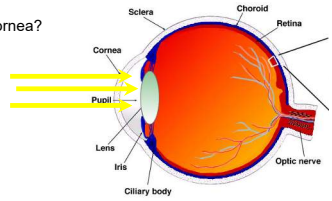
The Eye - Cornea

Light passes through the transparent protective layer of the cornea

What happens to the aging cornea?



Courtesy: webvision.med.utah.edu

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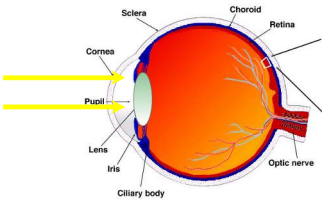
The Eye - Iris

The iris contracts or expands to control the amount of light entering the eye.



Courtesy: webvision.med.utah.edu

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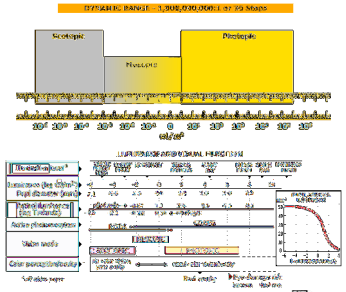
●34

Dynamic Range



Courtesy: Telescope Optics, Sareesh Sudhakaran

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●35

Adaptation

The Iris opens and closes to adjust to light levels from bright sunlight to dim moonlight.

This process is called “adaptation” and takes time.

- Several seconds for young eyes
- Up to a minute for older eyes
- Much longer from bright to dark

New York Theatre
Edward Hopper

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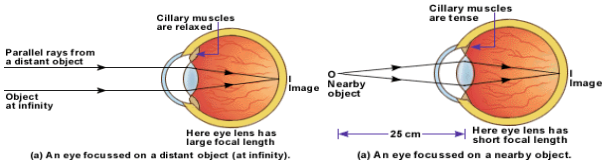
●36

The Eye - Lens

If our eyes are tracking movement, or are refocusing on different objects, the image will blur unless the lens curvature changes.

Ciliary muscles attached to the lens constantly change its curvature in a process called “accomodation.”



Courtesy: IESNA

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●37

Relax the Ciliary Muscles

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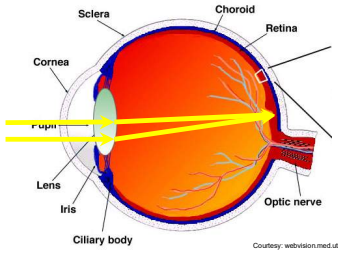
●38

The Eye - Retina & Fovea

A visual image is produced on the back of the retina creating neural impulses in response to the light's stimulus.



Courtesy: webvision.med.utah.edu

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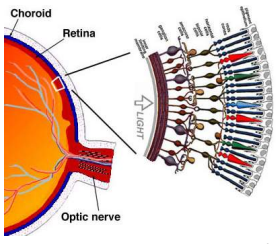
Rods and Cones

Rods are sensitive to blue-green light with a peak sensitivity around 500 nm.

Rods are highly sensitive and are used for scotopic vision (night vision).

Cones provide Red Green Blue color vision.

Cones are much less sensitive and require higher photopic light levels.



Courtesy: webvision.med.utah.edu

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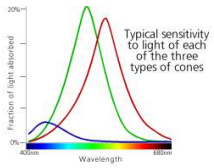
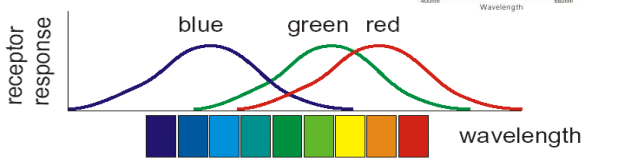
Color and Perception



Typical sensitivity to light of each of the three types of cones

3 cone types



Courtesy: IESNA

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Color and Perception

Courtesy:, UW Neuroscience for Kids

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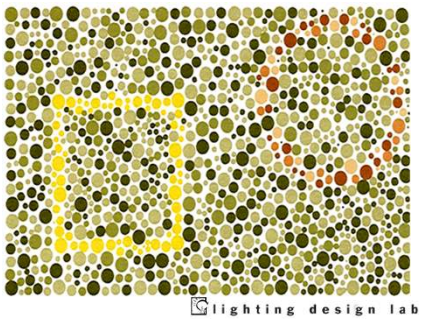
●42

Color Discrimination

Color blindness is a condition that occurs primarily in males

It affects the ability to discriminate between dissimilar colors (usually red and green)



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Let's do a brief demonstration

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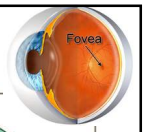
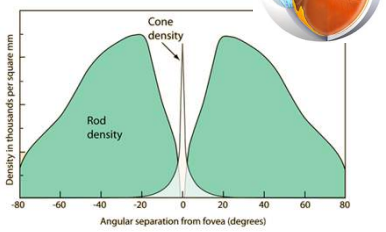
●44

Color and Perception

- Fovea is dominated by red and green receptor cones
- What about blue?
- Rods distributed throughout





Courtesy: hyperphysics.phy-astr.gsu.edu/

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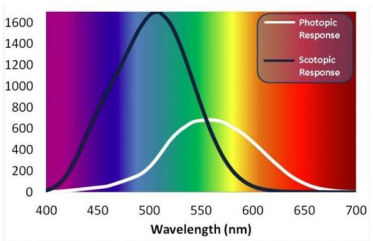
Luminosity Function

- V(λ) curve
- Spectral sensitivity of average human sensitivity to brightness
- Baseline for most of our lighting metrics
- Concentrated on Foveal Vision
- What about blue?
- Photopic: 555 nm
- Scotopic 507 nm



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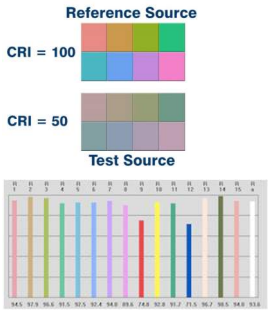
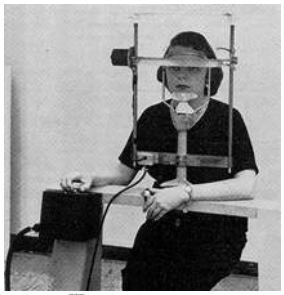
●46

Is CRI Good Enough?





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●47

Is CRI good enough?

- SSL offers extended options for spectral manipulation.
- SSL lighting may have “good” CRIs that may render materials in unexpected ways.
- For critical color installations, a mockup is always good practice.

Tommy Bahama Headquarters
SkB Architects

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●48

Is CRI good enough?

REI Mockup

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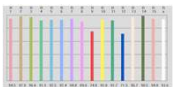
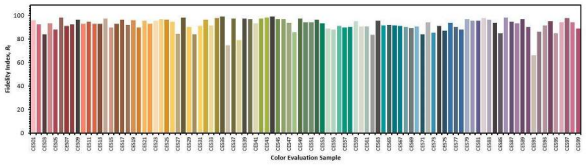
●49

TM-30 Method for Evaluating Light Source Color Rendition

- Fidelity
- Gamut
- Detailed Graphics





This chart displays the Fidelity Index for each of the 99 CES. The CES are arranged by their hue angle under the 5000 K reference source, which was also used to determine the color of each bar. The colors are approximate and depend on proper monitor calibration. Some colors may be outside of the gamut of the monitor, and will not be displayed accurately.

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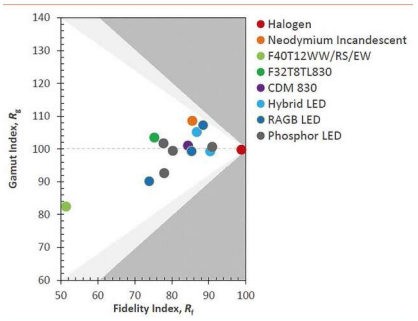
●50

Fidelity

- Fidelity Index (Rf)
- Similar to CRI



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●51

Gamut

Color variables

- Hue
- Saturation
- Lightness
- Gamut index (Rg)
- >100 Increasing saturation
- <100 Decreasing saturation
- Not specific to hue

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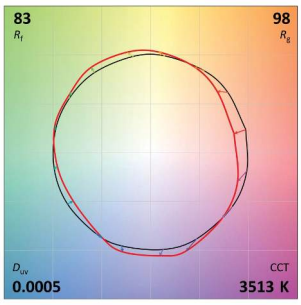
●52

Vector Graphics



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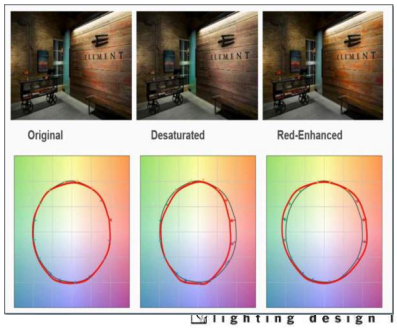
●53

Vector Graphics

Intentional Use of Gamut Information



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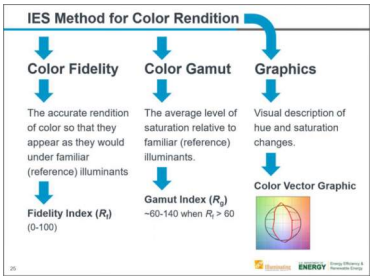
●54

Handy Reference

TM-30 Basics on Youtube:
https://youtu.be/CfxcbkM6ZHY



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●55

Pop Quiz

- What is the fovea?

Any questions at this point?

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●56

How Does It All Work Together?

Let's look at four simple elements:

- Generators
- Modifiers
- Encoders
- Interpreters

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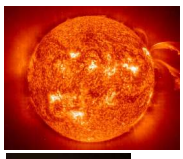
●57

Generators



Courtesy: NASA, Candles.com, Xicato, Philips, Sylvania

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●58

Modifiers

REI Denver Flagship
Mithun

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●59

Modifiers

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●60

Encoders

Courtesy: Health Magazine

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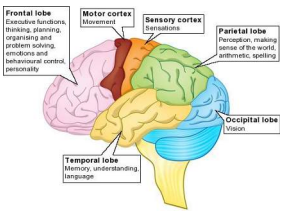
●61

Interpreters



Courtesy: Stanford University

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●62

Context and Meaning

Courtesy: Advanced Lighting Guidelines

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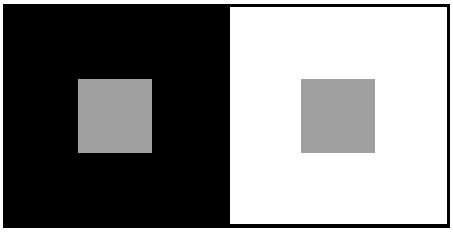
●63

Contrast of Lightness



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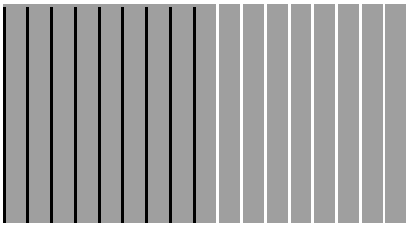
Assimilation of Lightness



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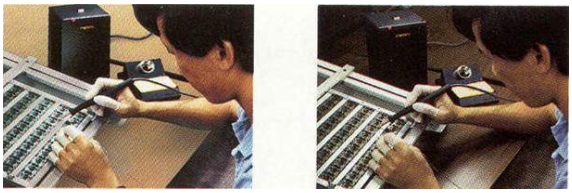
Brightness Contrast

Results from variations in the amount of light reflected or emitted from a surface, such as due to shadow patterns, changes in dark against light colors or surface shape and texture.



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Pattern Contrast

The perception of changes in a regular pattern, as when the pattern of stars and stripes on a flag changes perspective as the flag waves.

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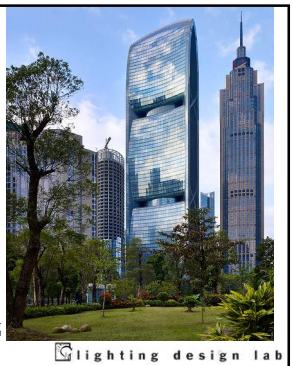
Pattern Contrast

Strong patterns and contrast are commonly used in architecture and interior design to shape and mold our impressions of space



Pearl River Tower
SOM

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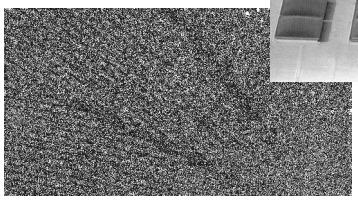
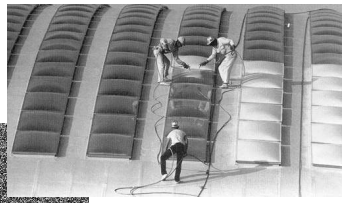
●68

Pattern Contrast





Courtesy: William Lam

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●69

Color Contrast

Based on the juxtaposition of different colors next to each other.

Complementary color pairs, such as red-green or blue-yellow, are likely to result in the greatest visual contrast.

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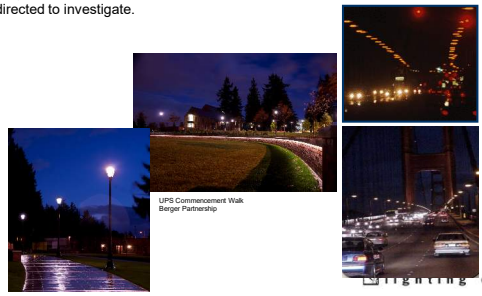
Motion in our field of view

Naturally attracts our visual attention, and our central vision is redirected to investigate.



UPS Commencement Walk
Berger Partnership

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●71

Pop Quiz

In the Generator to Interpreter Framework what is the Modifier?

Any questions so far?

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●72

Light and Health

There is a huge amount of research going on today with respect to light and human physiology / non visual effects of light.

- Circadian systems
- Sleep impacts
- Aging Populations
- Dementia
- Behavior Modification
- Alerting Functions
- Blue Light Hazard
- Flicker

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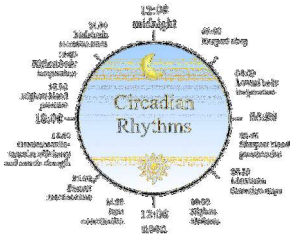
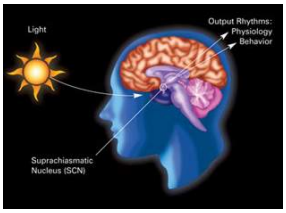
●73

Light has a role in circadian rhythm?





Courtesy: NIGMS/NIH

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●74

What about non-visual light stimulus?

- 1923: Claude Keeler observed pupillary constriction in functionally blind mice
- These mice lacked traditional rod and cone receptors or had severely degenerated receptors.
- Well…that's interesting…

Courtesy: quanjing.com

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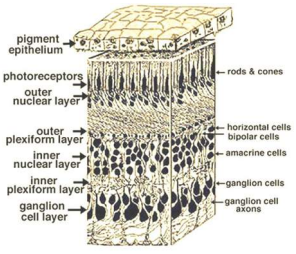
●75

What about non-visual light stimulus?

- A new photo-receptor was identified in 2002 in humans.
- Melanopsin-expressing, Intrinsically Photosensitive Retinal Ganglion Cells ipRGC
- Studies suggested that existing visual structures – rods and cones – were unrelated to light response and the circadian timing cycle.



Courtesy: webvision.med.utah.edu

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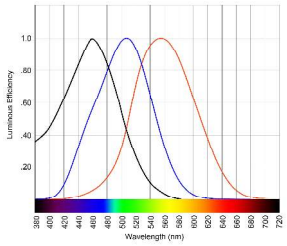
ipRGC

Intrinsically Photosensitive Retinal Ganglion Cells

- Non vision forming light receptors
- Slow response
- Melanopsin

- Circadian Rhythm
- Pupil Size
- Melatonin suppression



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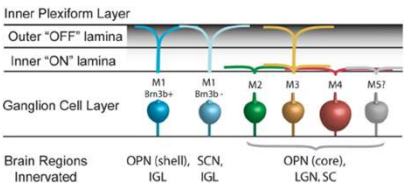
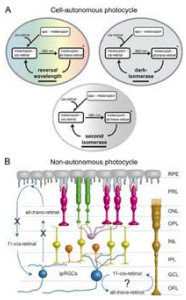
ipRGC

But wait, there's more…..





there are 5 types…what do they all do…

Courtesy: Sexton, et al

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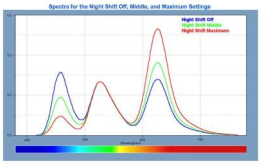
●78

Who is taking this seriously?

- NASA
- Google
- Apple
- Microsoft
- Schools
- Health Care
- Pro Sports
- Architects
- Engineers
- Owners



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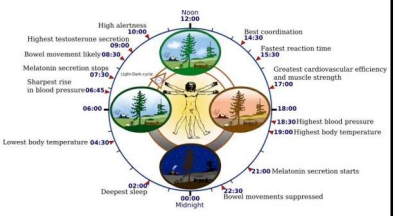
Circadian Entrainment

What do we know about the circadian system in humans?

- Needs to be reset
- Superchiasmatic nucleus
- Regulated in part by the endocrine system
- Affected by light exposure
- Melatonin suppression

- Chronotypes



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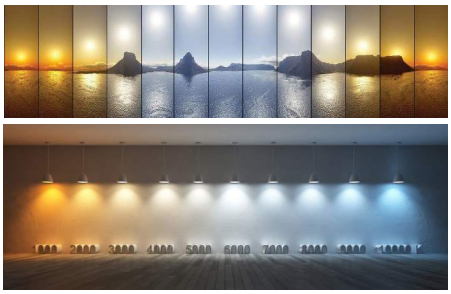
Circadian Rhythm and Light Spectrum



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Key Light Stimulus Variables

- Intensity
- Distribution
- Spectral Power Distribution
- Duration – Dose
- Timing
- Photobiological History

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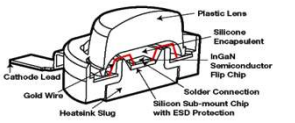
●82

LED – timing is everything…

- Solid state light source
- Extremely flexible
- Potentially long lamp life
- Dynamic color opportunities
- White light
- Poor to excellent color rendering
- Easily Controllable



Courtesy: Philips

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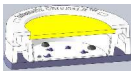
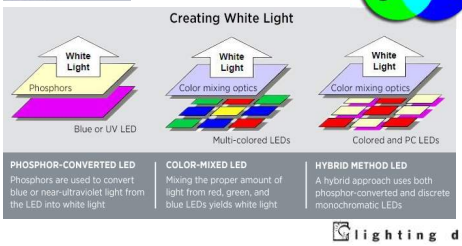
LED White Light



Creating White Light



PHOSPHOR-CONVERTED LED
Phosphors are used to convert blue or near-ultraviolet light from the LED into white light

COLOR-MIXED LED
Mixing the proper amount of light from red, green, and blue LEDs yields white light

HYBRID METHOD LED
A hybrid approach uses both phosphor-converted and discrete monochromatic LEDs

Courtesy: US DOE, Intermatix

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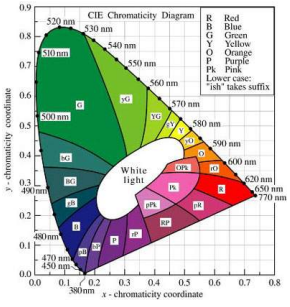
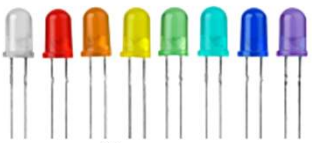
LED Color



A range of native colors are available with differing chip configuration.

Efficacy varies widely.



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Pop Quiz

- What are some characteristics of LED light sources that make them particularly useful for dynamic lighting systems?

Questions?

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Simple Steps to Better Lighting

- Start with Daylight
- View to Horizon
- Layer electric light as necessary.

SFPUC Headquarters
KMD Architects

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●87

Brightness Perception

Effective lighting design means putting light where it's needed.

Seatac Airport Renovation
Weinstein Copeland

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●88

Finishes

Scottsdale Fashion Square
Callison

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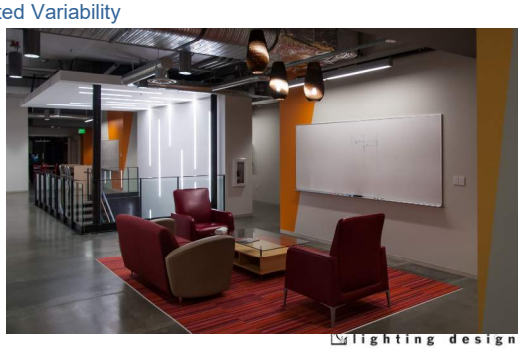
●89

Targetted Variability



RealNetworks
SkB

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Balanced Contrast

UW MEB
2GF

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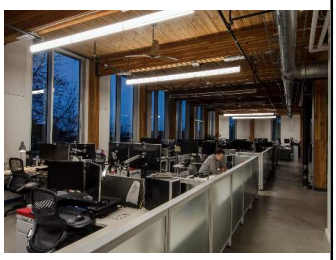
Daylight and Control



Bullitt Center PAE Offices
Miller Hull

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Setting a Mood

Canyon Ranch Spa
RTKL

Pan Pacific Yokohama
Hirsch Bednar Associates

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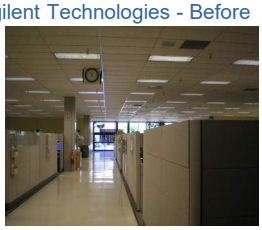
Agilent Technologies - Before



- High light level
- Low surface brightness
- Significant likelihood of direct glare.
- Forces users to accommodate light

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Agilent Technologies - After

- Lower overall light level
- Higher brightness perception with lighted surfaces
- Glare is eliminated.
- No more cubicle tents required.

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Lemieux Library

Pfeiffer Associates, Mithun

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Lemieux Library

Pfeiffer Associates, Mithun

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Lemieux Library

Pfeiffer Associates, Mithun

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Pop Quiz

- Is it better to light surfaces or volumes?

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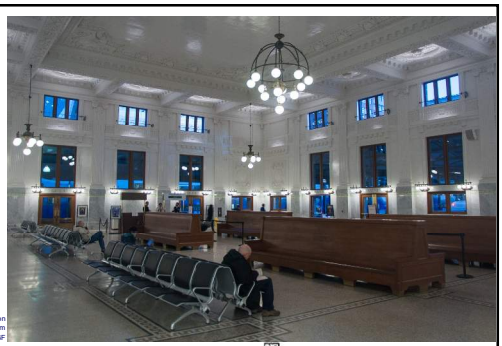
Well Done!

Questions?

Comments?



King Street Station
Reed and Stem
ZGF

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Key Services & Resources

- Lighting Classes (local & regional)
- Product Validation
- Mockups
  - Scaled and life-sized
- Consultations
- Online Resources
  - Publications
  - Energy Code Links
  - Event & Class Listings
- Speaking Engagements
- Lighting Demonstrations
- 500 sq ft Classroom Rental
  - Available for rent
- Facility Tours
- Networking Opportunities
  - Open House
  - Regional Meetings
  - Industry Assoc. Memberships

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Bonneville Power Administration

PSE Puget Sound Energy

Snohomish County PUD Public Utility District No. 1

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Tacoma Power Tacoma Public Utilities

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BC hydro For Generations

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Seattle, WA 98134

MISSION

Building business value through validation and education that drives adoption of energy-efficient lighting technologies and practices.

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