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Designers Lighting Forum

Illuminating Illusions

Jonathan Clark, CEO / Innerscene

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Learning Objectives

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

1. **Depth Perception Mastery:** Understand the fundamental principles of human depth for creating realistic artificial windows.
2. **Color Perception Fundamentals:** Learn about human color perception and replicating the dynamic hues of the sky.
3. **Design Principles:** Understand the design principles that guide the creation of artificial windows.
4. **Future Trends:** Gain insights into the future potential and trends in the realm of artificial window and skylight creation

Why try to recreate windows and skylights?

- Impractical to add windows in the interior of large buildings
- Heating and cooling energy cost
- Modern society no longer follows the solar cycle
- Artificial lighting lacks important properties from windows

Recreating windows and skylights artificially

What does a window provide:

- Distant views and focal points.
- Visible light. Wide spectrum (high CRI).
- Non-visible light. ~490 nm blue light, UV, IR, etc.
- Variation in brightness, spectrum, and distribution (sunlight vs skylight)

Practical issues

- Construction considerations
- Cost & complexity

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Distant views and focal points.

- The “Corner office”
  - A corner office typically offers expansive views and abundant natural light due to windows on adjacent walls
- LEED: credit category called "Quality Views"
  - offer a view of natural elements, outdoor environments, and other pleasant sights to help reduce eye strain, increase mental relaxation, and enhance occupant well-being
- WELL v2
  - providing views to nature and the outdoors as a way to promote mental and emotional health
- Without access to distant focal points we have:
  - eye strain & headaches
  - vision development problems in children and adolescents
  - Feelings of claustrophobia

Human Depth Perception

Binocular Vision: Two eyes provide 3D depth perception.

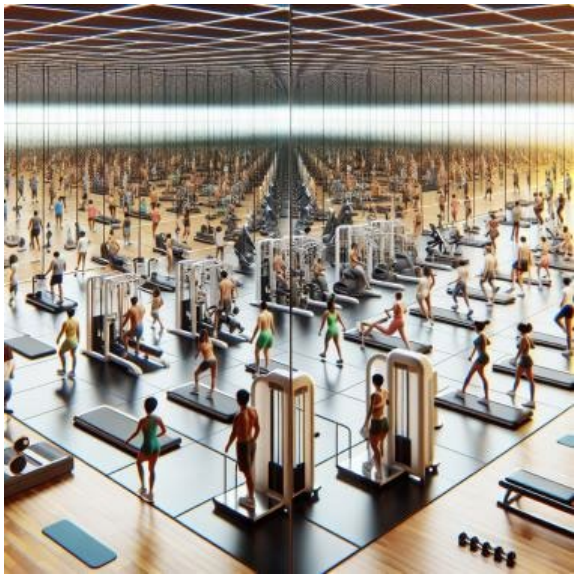
Monocular Cues: Size, texture, and shadows help gauge depth with one eye.

Motion Parallax: Objects move differently at various distances as we move.

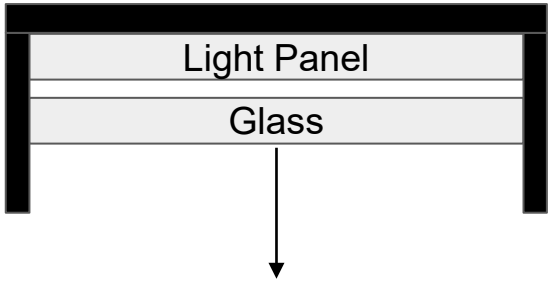
How can we create depth artificially?

- Mirrors create distant focal points
  - When placed adjacent to existing windows can create the illusion of additional windows
  - Doesn’t provide light output
  - Not appropriate for
    - Privacy sensitive areas such as healthcare, bedrooms, etc.
    - In workspaces, windows can lead to distractions

- Reflective surfaces such as glass and polished plastics
  - Lower reflectivity at normal angles which helps with privacy issues
  - When backlit, only objects brighter than the surface can be seen reflected enhancing privacy and reducing distractions



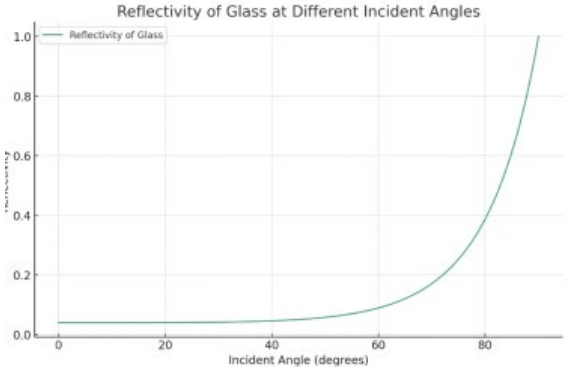
Backlit glass



- Reflects only light brighter than the surface
- Glass reflects 4% @ normal, 5% at 45 degrees, and 25% at 75 degrees
- Solves privacy issues
- Some backlit is also reflected, reducing fixture overall efficiency by ~10%

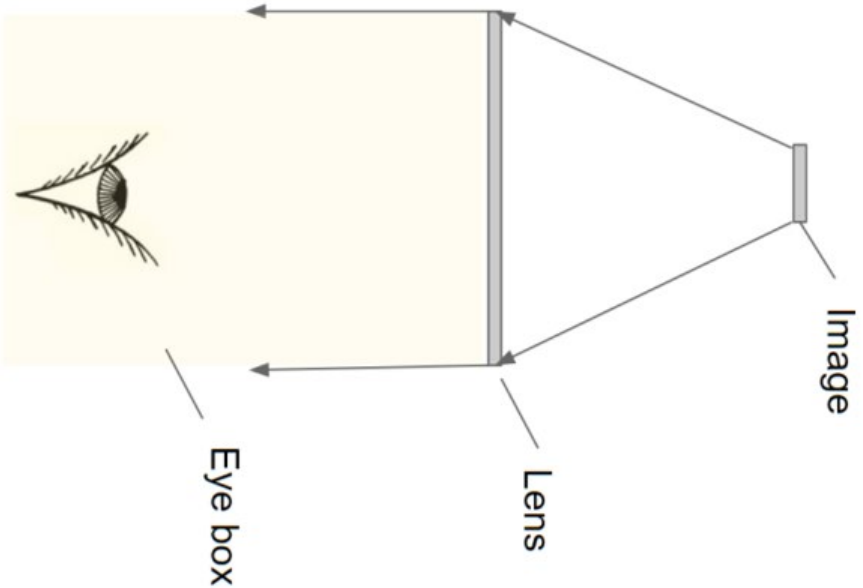
Design considerations - reflective surfaces

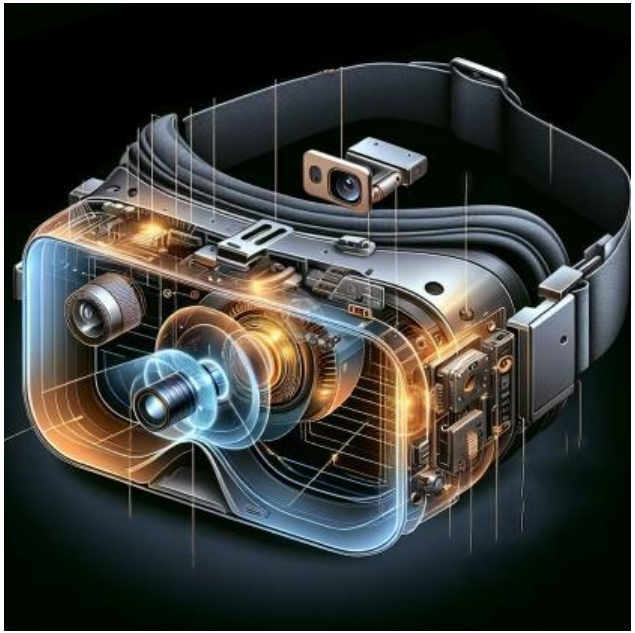
Reflective surfaces, single and double pane glass



How can we create depth artificially, part 2

- Optics!
- Techniques used in Virtual Reality





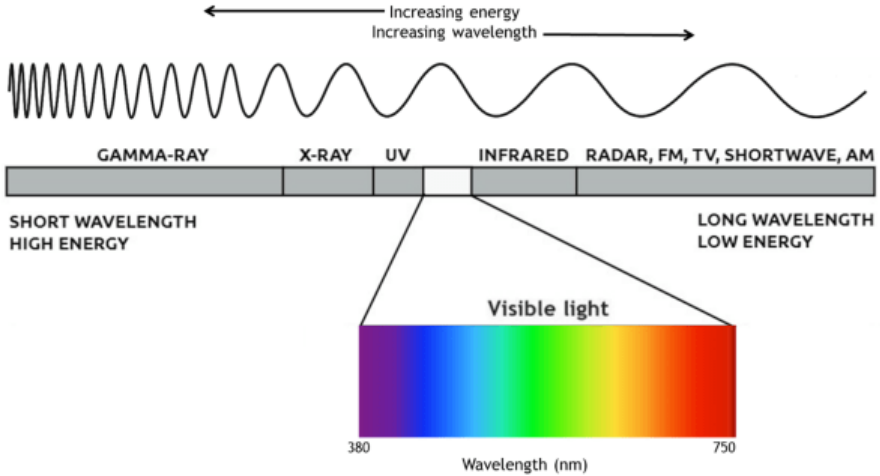
Effect achievable with optics

Design considerations - regressed

- Real windows and skylights are almost always regressed
  - Too little looks like a standard LED troffer
  - Too much loses visibility of the sky and reflection points
  - Maximum regress size depends on size of skylight/window
  - For a 2x4’ skylight, recommend 2-4”

Visible light

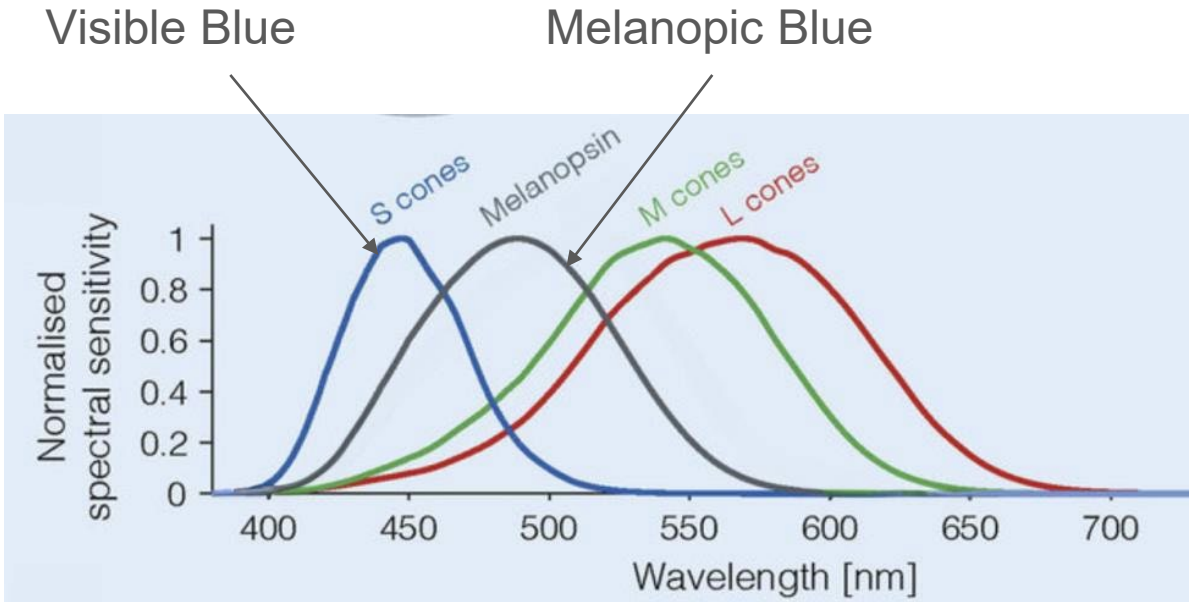
- Sunlight provides wide spectrum lighting
  - The “perfect” window/skylight would have the same spectrum & power density as sunlight
  - Sunlight is ~100W / sqft, sky is ~10W / sqft. **CA energy code allows 0.6W / sqft**
  - Regulation prevent us from emitting UV+ in most cases due to harmful effects



Energy efficient visible light

During the day, cones are responsible for sensing visible light

Using an output that more closely matches our visible system we can lower power requirements in ranges



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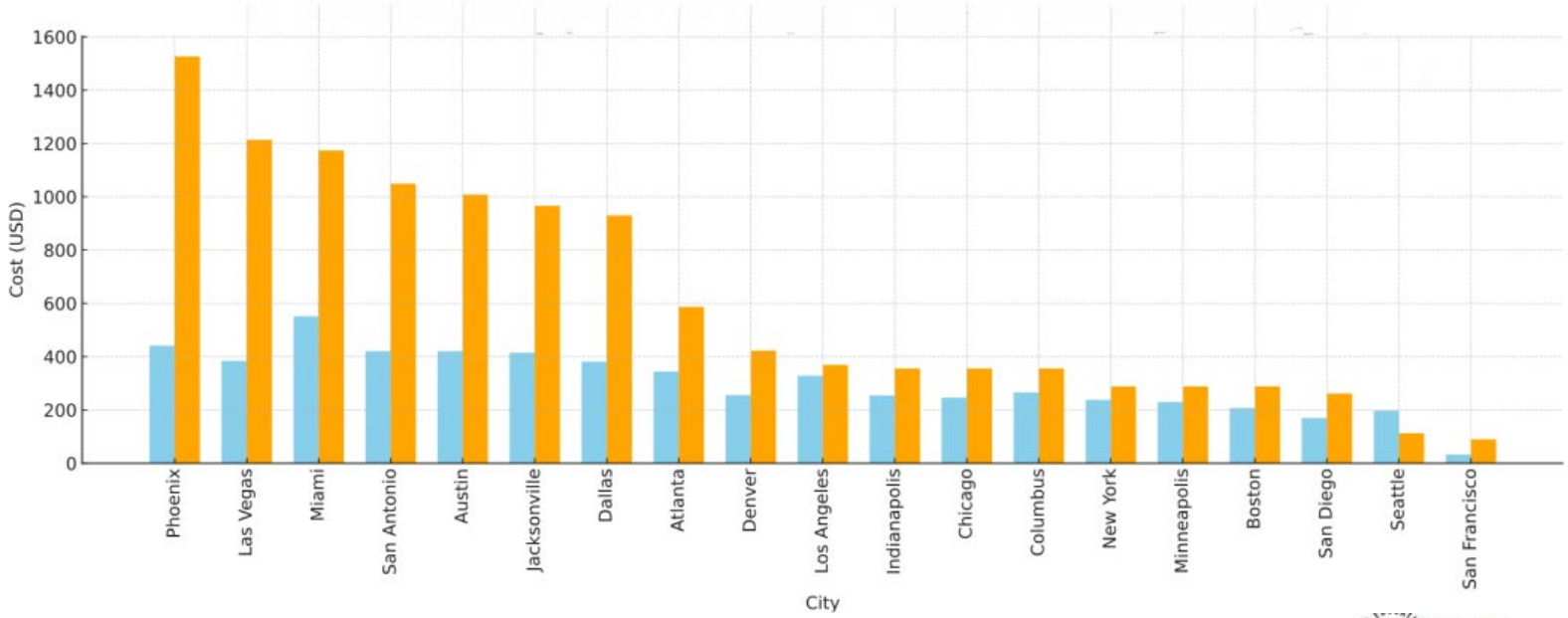
LED skylight vs real skylight Energy Efficiency compared

- Heating and cooling carry large annual energy cost for windows and skylights
- Artificial windows and skylights can lower this cost significantly



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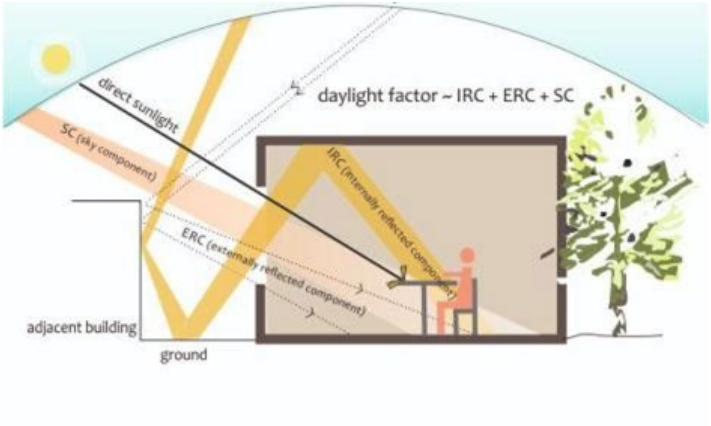
Color and CCT of the Sky

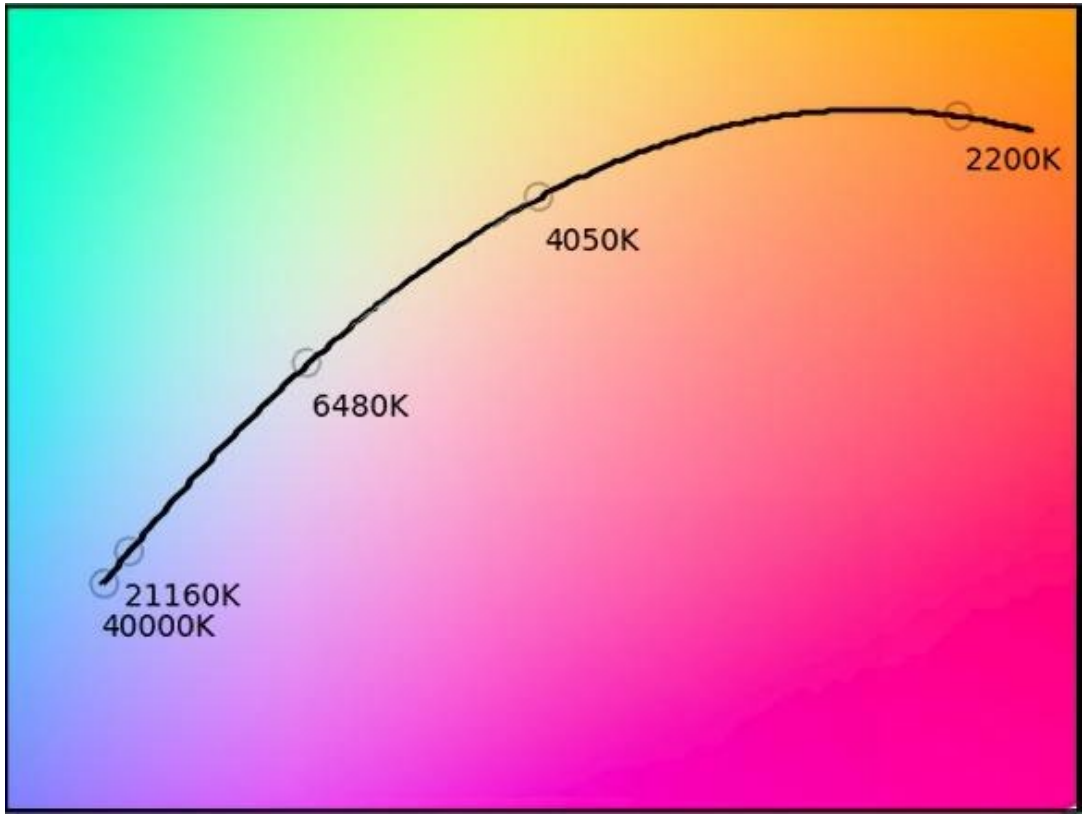


20,000-40,000K

6,000K-7,000K

2,000-3,000K

CCTs are not linear in color space



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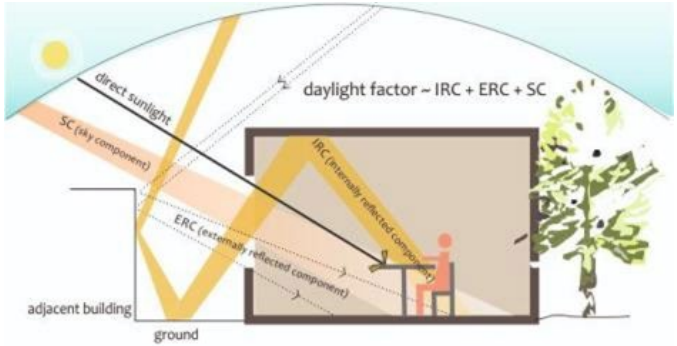
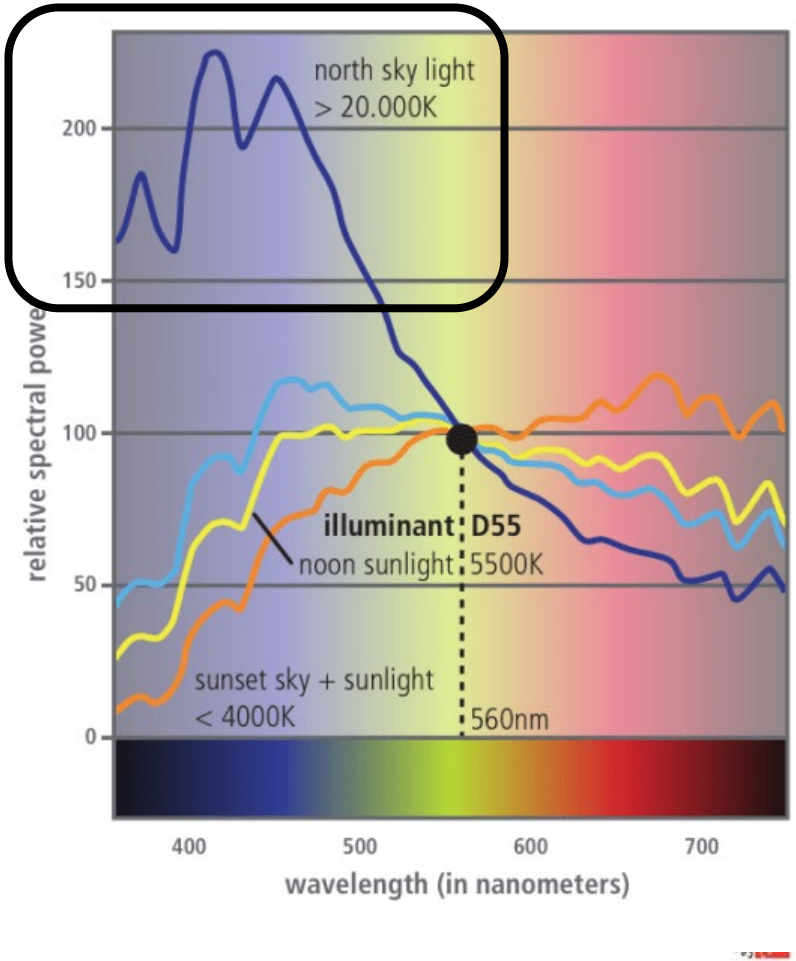
Spectrum of natural light

Without clouds and pollution,
the sky overhead is always blue

D55 = Average midday light

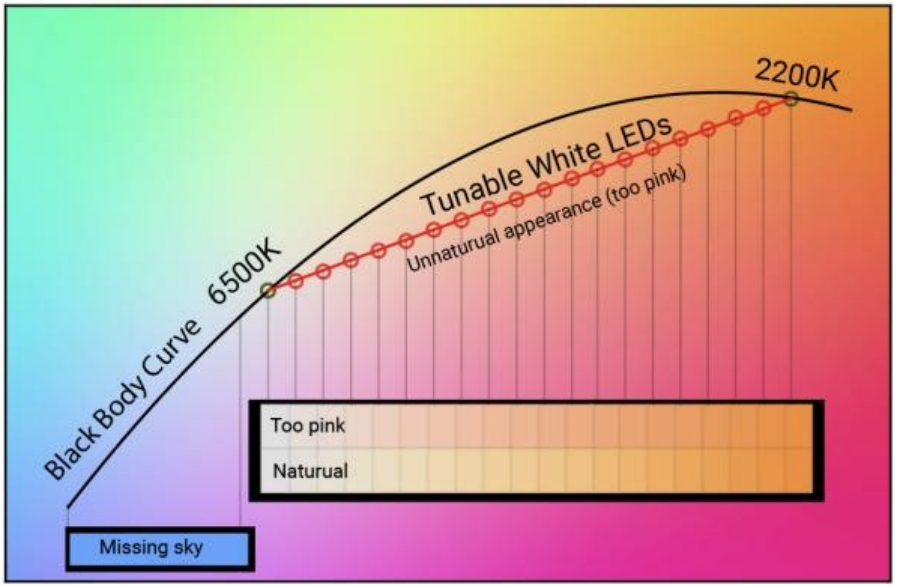


(show just skylight at 40,000k)

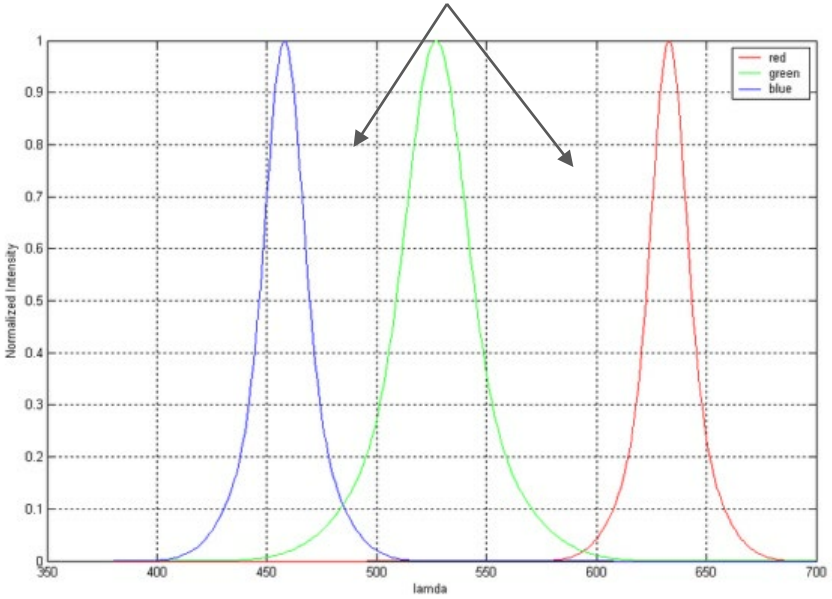


Tunable White lacks color, and RGBs lack spectrum

Tunable white = good CRI, bad color

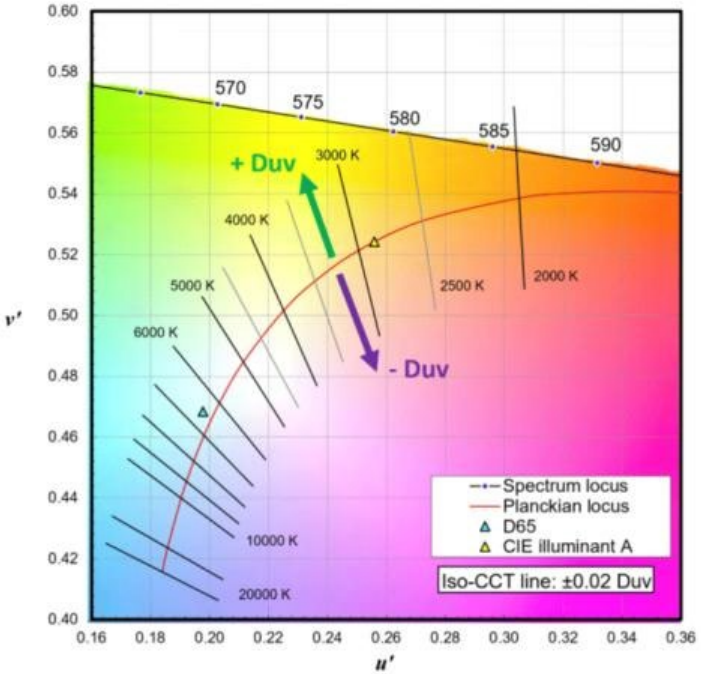


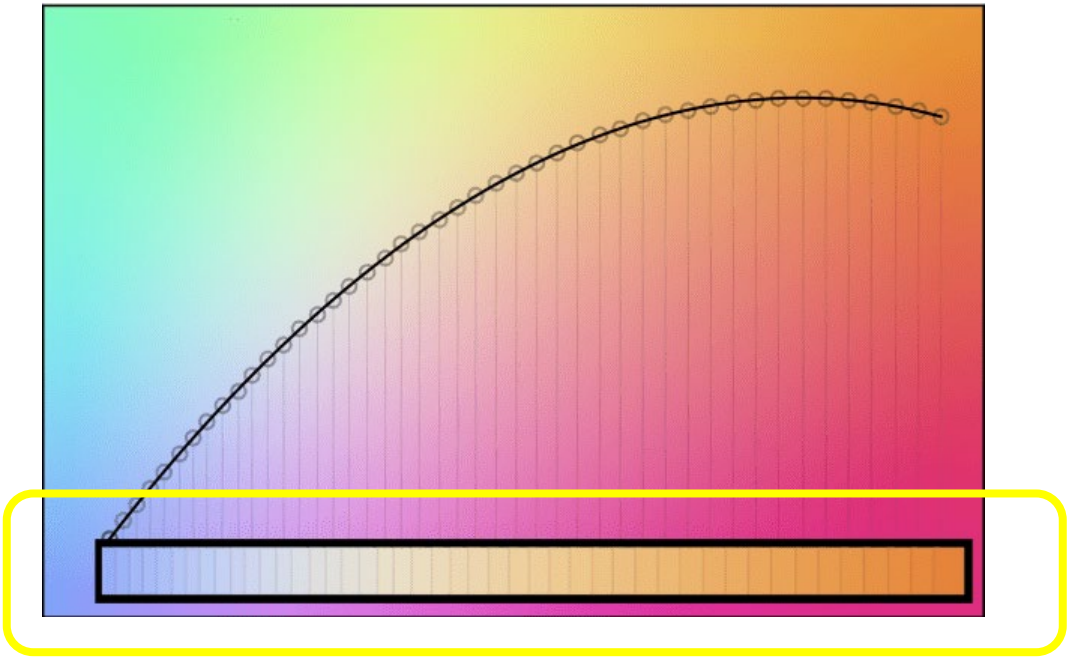
RGBs = good color, bad CRI



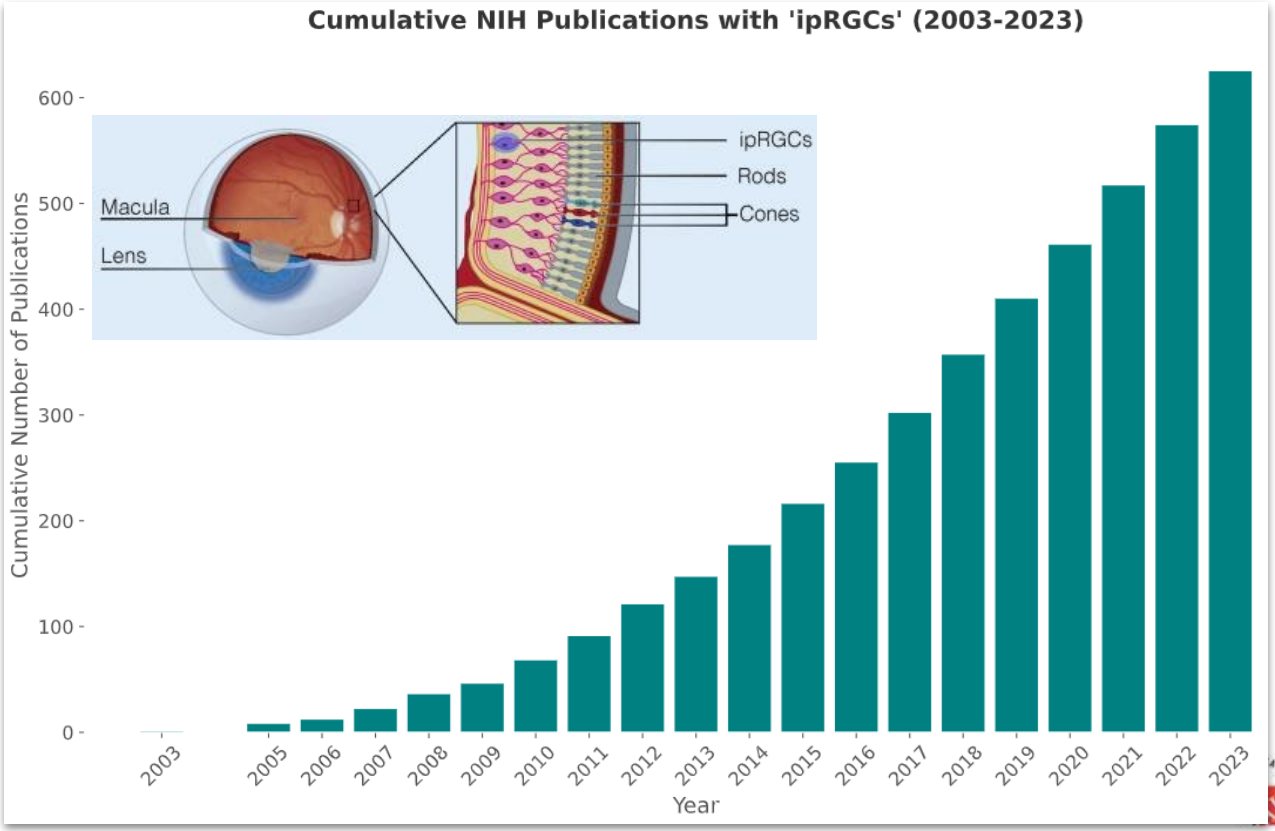
DUV measures how closely light color matches Planckian Locus

Colors that follow the Planckian Locus look natural



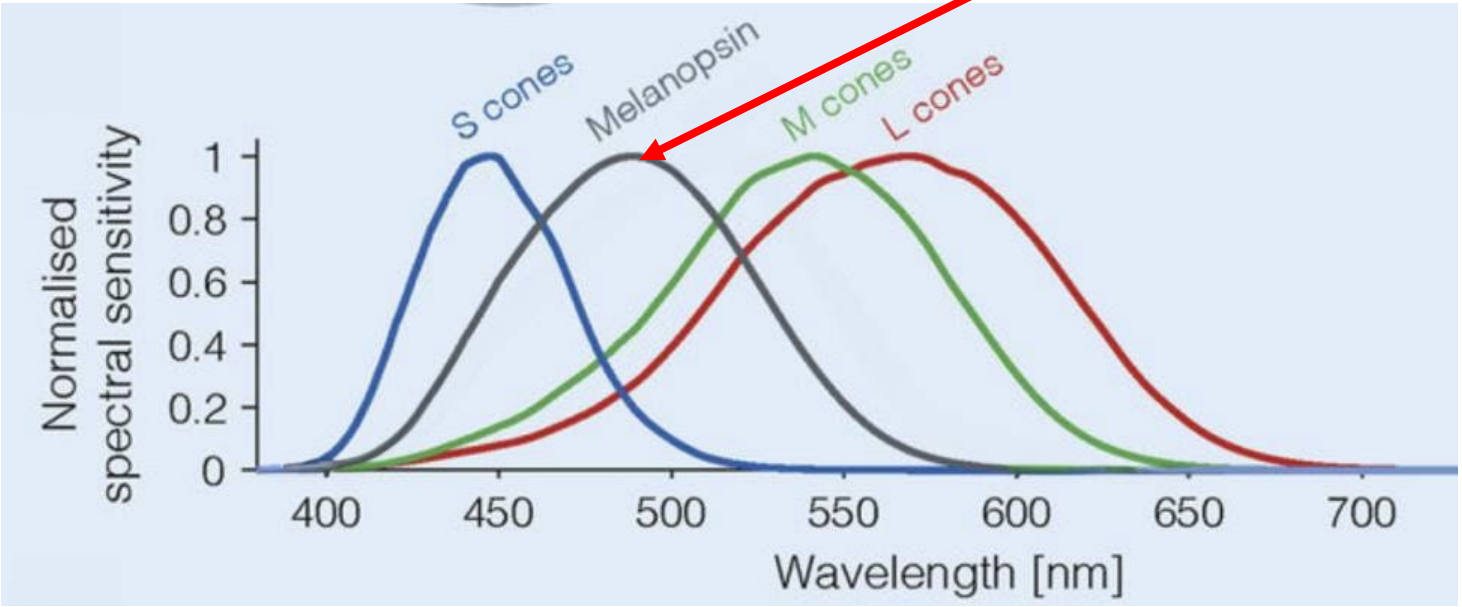


ipRGCs -Intrinsically photosensitive retinal ganglion cell



Importance of Blue Light, specifically ~490nm

ipRGCs cells are sensitive to blue light and control many body functions



Melanopic Lux = the new standard in lighting

WELL v2 specifies required light levels in Melanopic Lux (ML) not Lux

Lux = How bright lighting appears to our visual system

Melanopic Lux = How bright lighting appears to our Circadian System

- Specifically ML, is a measure of how much of the ~490nm blue spectrum is present

Many products will quote a Melanopic Ratio (MR) that can be used to calculate Melanopic Lux. ML = MR * Lux

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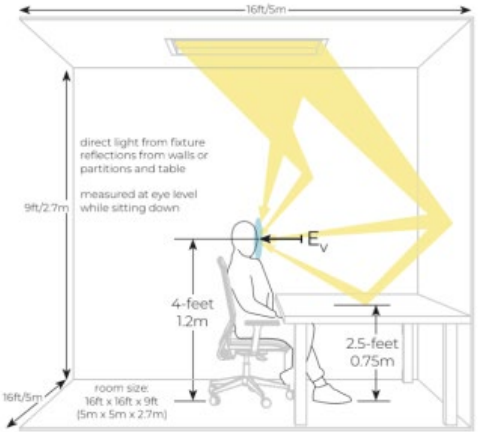
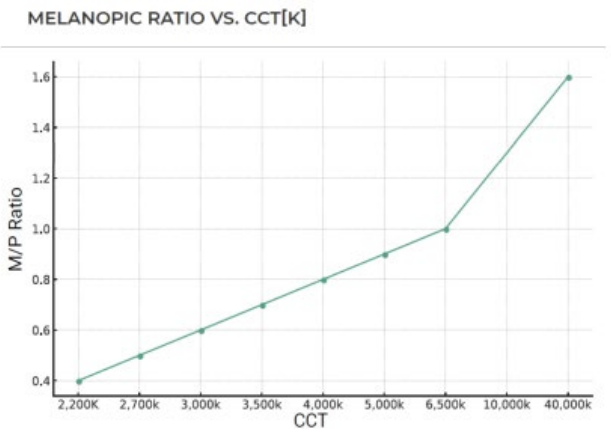
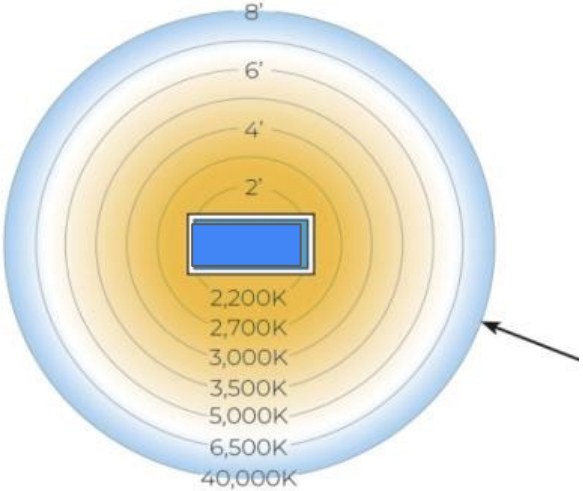
Generally, Higher CCTs = Higher Melanopic Lux







[add note about power & efficiency, and contrast lux/EML measurements]

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Health impacts of 490 nm Blue Light

Over 5000 research papers related to ipRGCs and 490 nm blue light

A few examples:

Performance, Alertness, Brain Responses Vandewalle, G., Maquet, P., & Dijk, D. J. (2009). "Light as a modulator of cognitive brain function." *Trends in Cognitive Sciences*, 13(10), 429-438.

Sleep, Mood, Circadian Rhythms. Lucas, R. J., Peirson, S. N., Berson, D. M., Brown, T. M., Cooper, H. M., Czeisler, C. A., ... & Brainard, G. C. (2014). "Measuring and using light in the melanopsin age." *Trends in Neurosciences*, 37(1), 1-9.

Stimulates Brain Activity in Visually Blind. Vandewalle, G., Collignon, O., Hull, J. T., Daneault, V., Albouy, G., Lepore, F., ... & Lockley, S. W. (2013). "Blue light stimulates cognitive brain activity in visually blind individuals." *Journal of Cognitive Neuroscience*, 25(12), 2072-2085.

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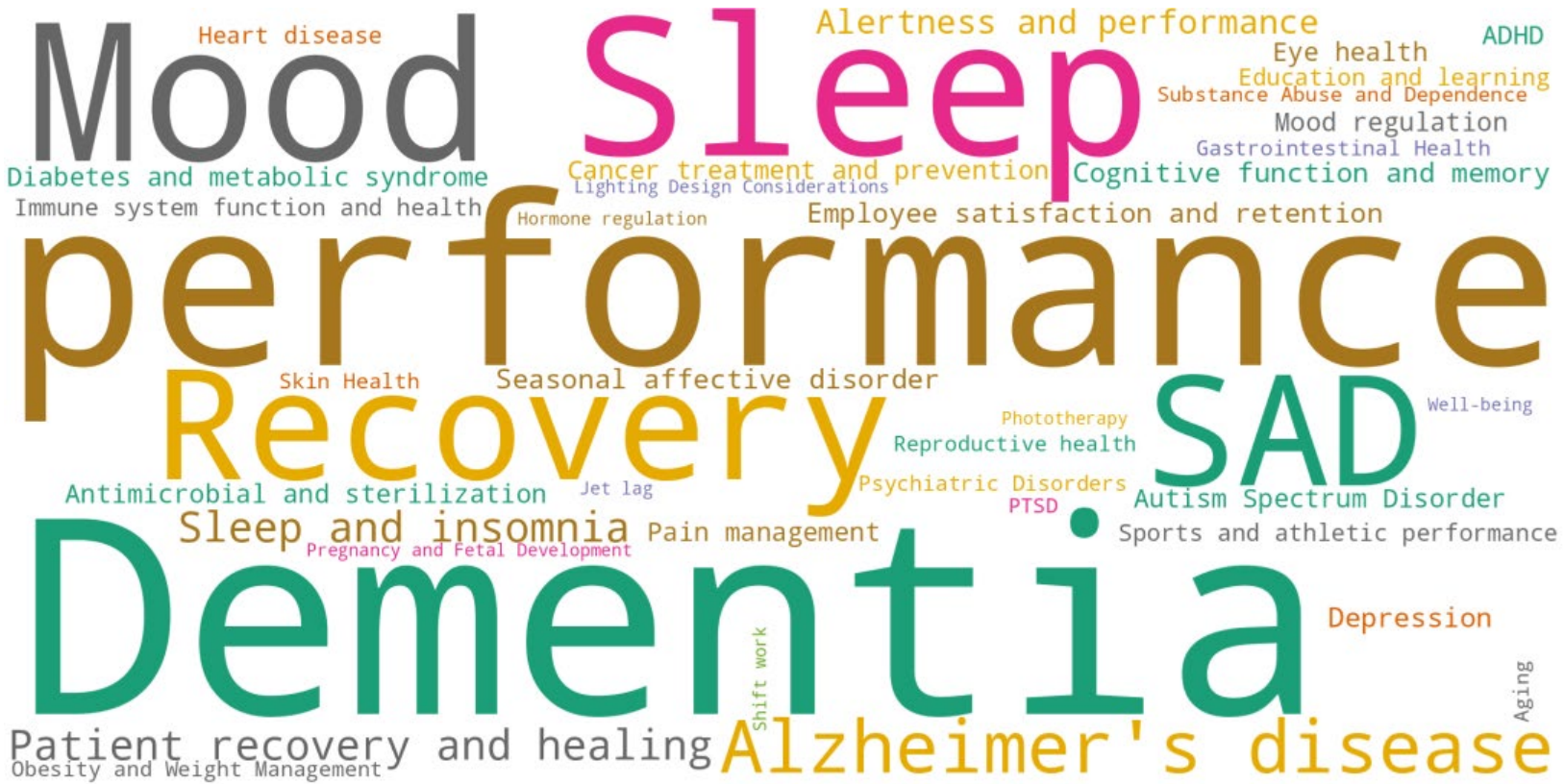

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Design and research recommendations on Melanopic Lux

WELL v2 requirements (living spaces)

- >= 250 EML during the day
- <= 50 EML for evening lighting

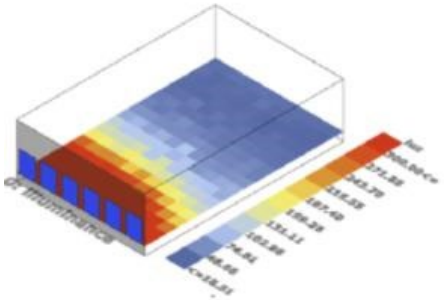
Natural Light: Sunny summer's day

- **130,000 EML** - Outside on clear sunny day
- **24,000 EML** - Outside on clear sunny day (shade)
- **16,000 EML** - 1' from a double pane window
- **160 EML** - 10' from a double pane window

Natural Light: Cloudy winter day

- **2,500 EML** - Outside
- **1,750 EML** - 1' from double pane window
- **17 EML** - 10' from a double pane window

(assumes people are facing



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Example of light drop off

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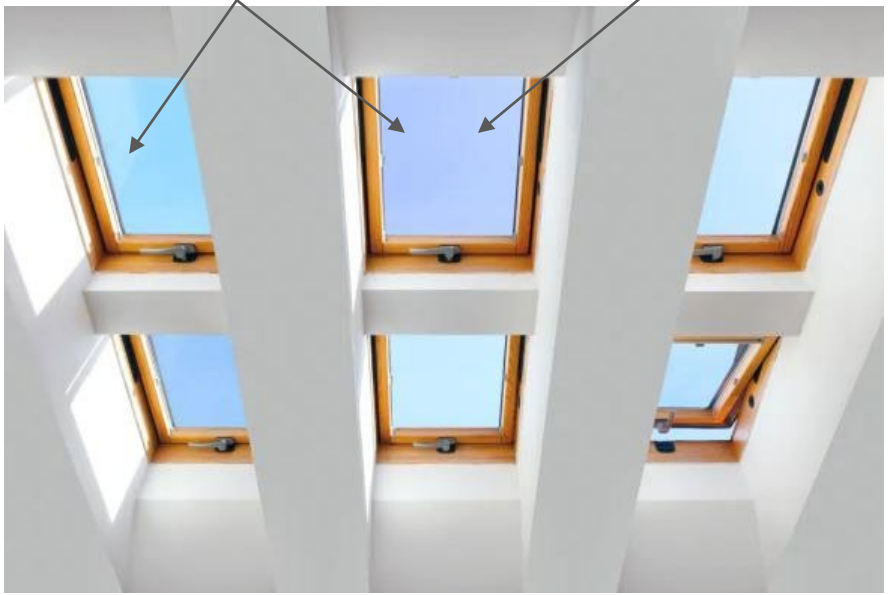
Variation in brightness, spectrum, and distribution

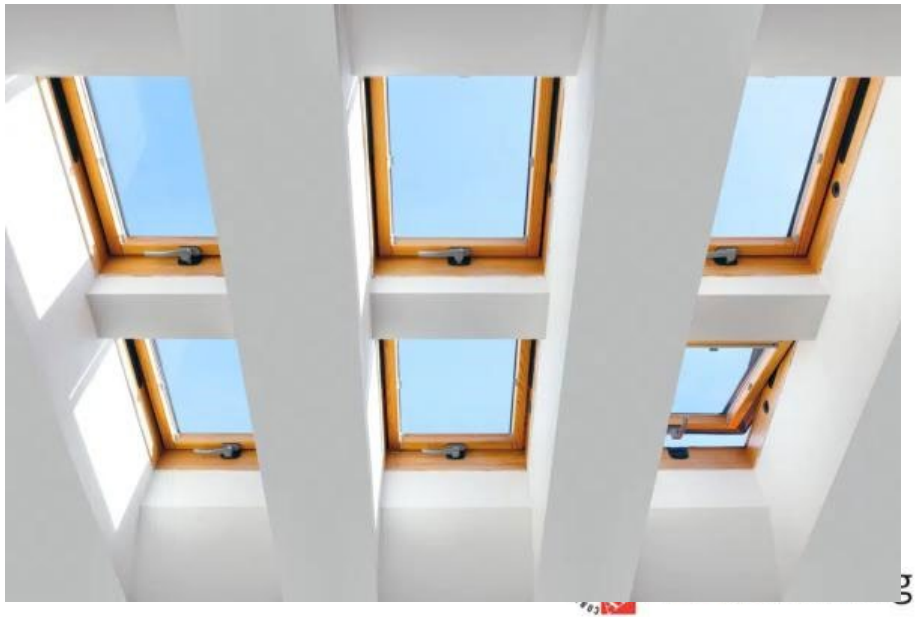
- Most artificial lighting has constant color, intensity, and distribution all day
- Natural lighting has large variations in CCT and intensity based on:
  - Position of the sun (more or less direct light)
  - Time of day and location on earth
  - Weather conditions
  - Nearby buildings

Arrays and color accuracy

Color mismatch destroys illusion

Color with high DUV values look unnatural





Color accuracy

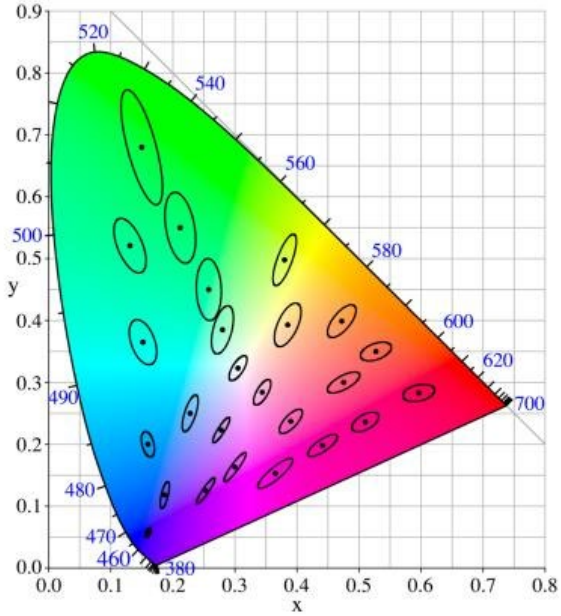
- Most LED fixtures use a 3-5 Macadams Ellipse standard
- Color matching is achieved by color binning by manufacturer (~3 steps)
- Modern approach is to mix LEDs and use microprocessors to calibrate colors (<1 step)

1 step : visible to 5-10% of population

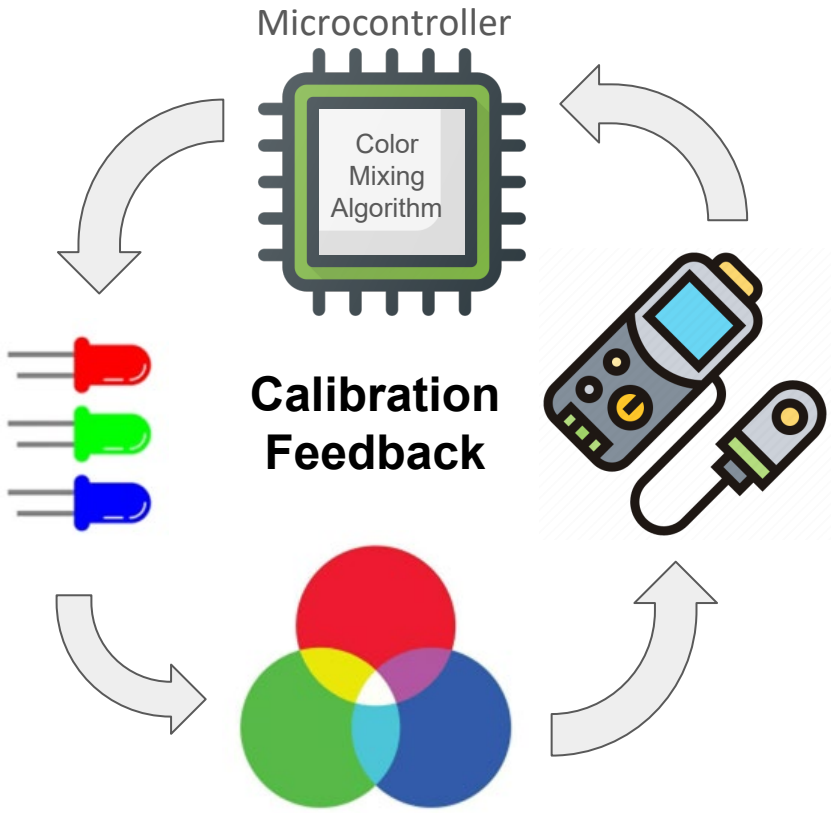
2-3 steps: visible to ~60% of the population

4 steps: visible to ~90% of the population

The eye is more sensitive to blue and less to green



Color accuracy through Mixing



LEDs Mixed to Create Uniform Color

Photometric Sensor

Glare considerations

- Too much contrast between min/max can cause glare issues
- WELL v2 requires <6000 cd/m^2 or UGR <16
  - <6000 cd/m^2
    - For a 4” circular downlight, max lumens = **48 lumens** (@ 6000 cd/m^2)
    - For a 1” x 4’ linear light, max lumens = **185 lumens**
    - For a 2’ x 4’ linear light, max lumens = **4459 lumens**
  - Larger emission areas produce less glare

Less Glare = larger lights and/or more lights

Practical considerations

Construction considerations

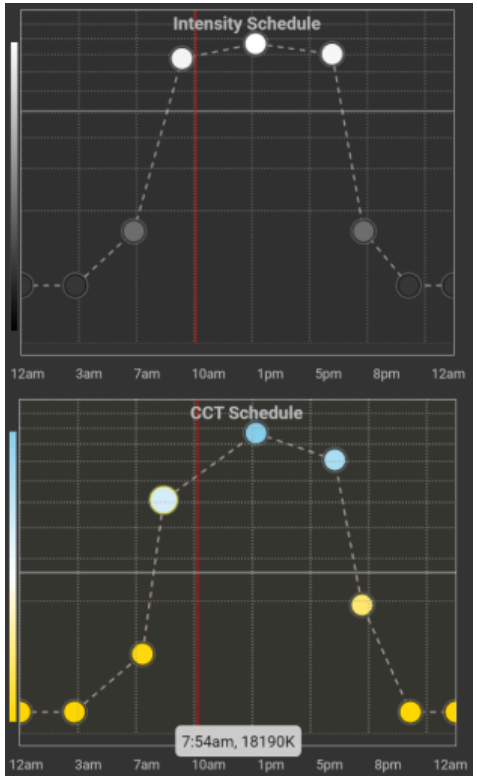
- Plenum and wall space
- User controls

Cost

- Design
- Installation
- Provisioning
- Maintenance
- Replacement

Automation : What schedule to use?

- Clock based time or sunrise / sunset based time?
- Type of environment
  - Shift workers: High CCT lighting for performance & alertness
  - Patient rooms: Low CCTs for sleep, high CCT for treatments
  - Retail: High CCT creates bright vibrant environment, encourages shopping
  - Fast Food : High CCT promotes lively atmosphere and fast turnover.
  - Classroom: High CCTs for morning & early afternoon, warmer CCTs in the late afternoon for wind down.
  - Evening Classes & Study areas. High CCTs to offset drowsiness supporting concentration and learning



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Future Trends

Higher demand for energy for cooling buildings due to climate change

Increasing building density worldwide

Work from home
Commercial property redevelopment

Research on ipRGCs leads shift from Photopic Lux to Melanopic lux for lighting

Find more information

https://innerscene.com/Research

Illuminating Illusions

Jonathan Clark / CEO Innerscene

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This concludes The American Institute of Architects Continuing Education Systems Course

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