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Designers Light Forum

Challenges of Connected Lighting and Sensor Integration

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CONTINUING EDUCATION AIA

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

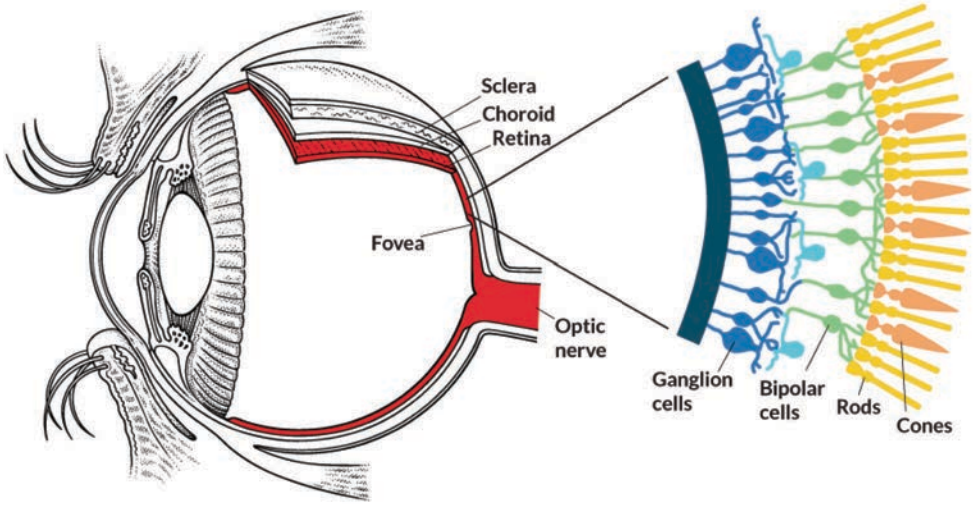
Learning Objectives

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

1. Proper equipment and measurement techniques to characterize LEDs in order to increase insight on the impact from lighting
2. Current and future trends of incorporating area and personal sensor arrays into building management systems
3. The state of interoperability of connected lighting systems
4. The security challenges involved in integrated smart lighting and building control systems

The Human Eye

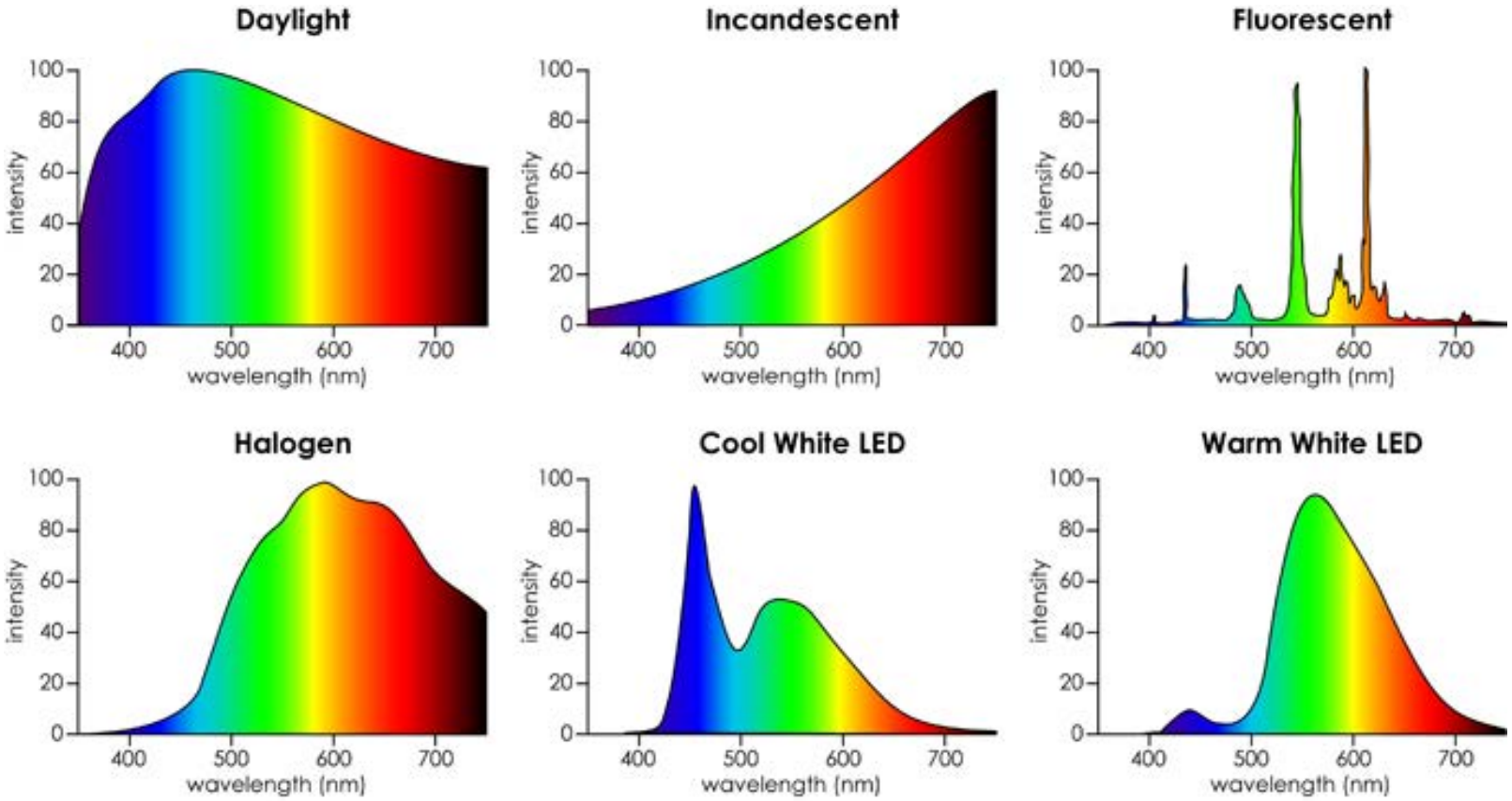
- Rods Blue/Green ~505nm
  - ~120 Million - All Over Retina
  - Peripheral Vision
  - Low Light Levels



- Cones - Yellow/Green ~555nm
  - 8 Million - Predominantly in Fovea
  - 3 Types – L,M,S Wavelength
  - Visual Acuity
  - Higher Light Levels

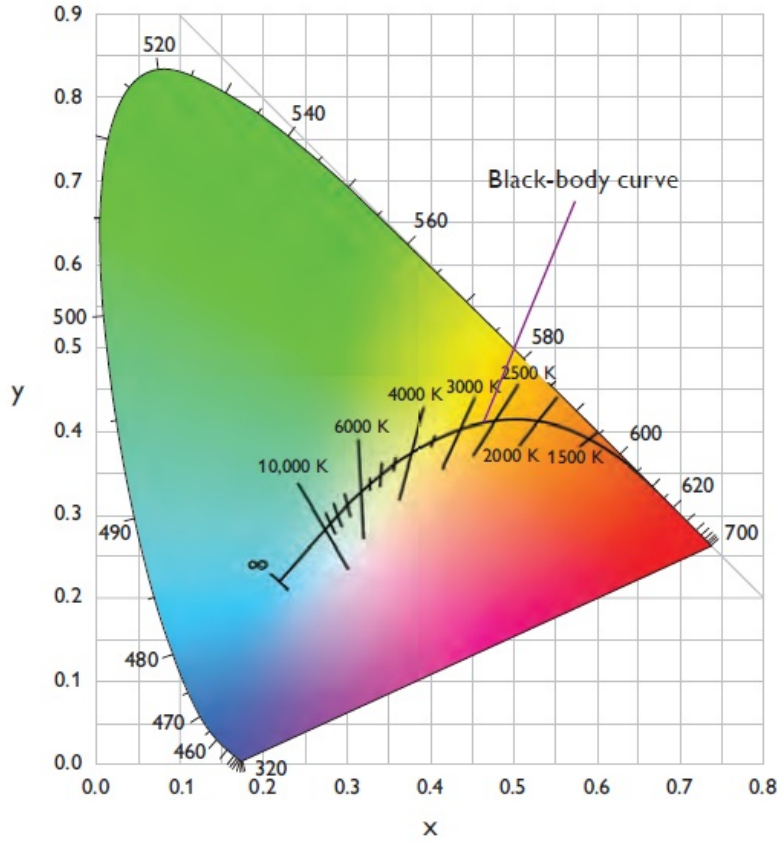
- Intrinsically Photosensitive Retinal Ganglion Cells (iPRGC) 484nm (Berson et al, 2002)
  - RGCs affect circadian rhythms (Foseter et al, 1991)
  - Influence on pupillary reflex, which influences light reaching the retina (McDougal and Gamlin, 2010)

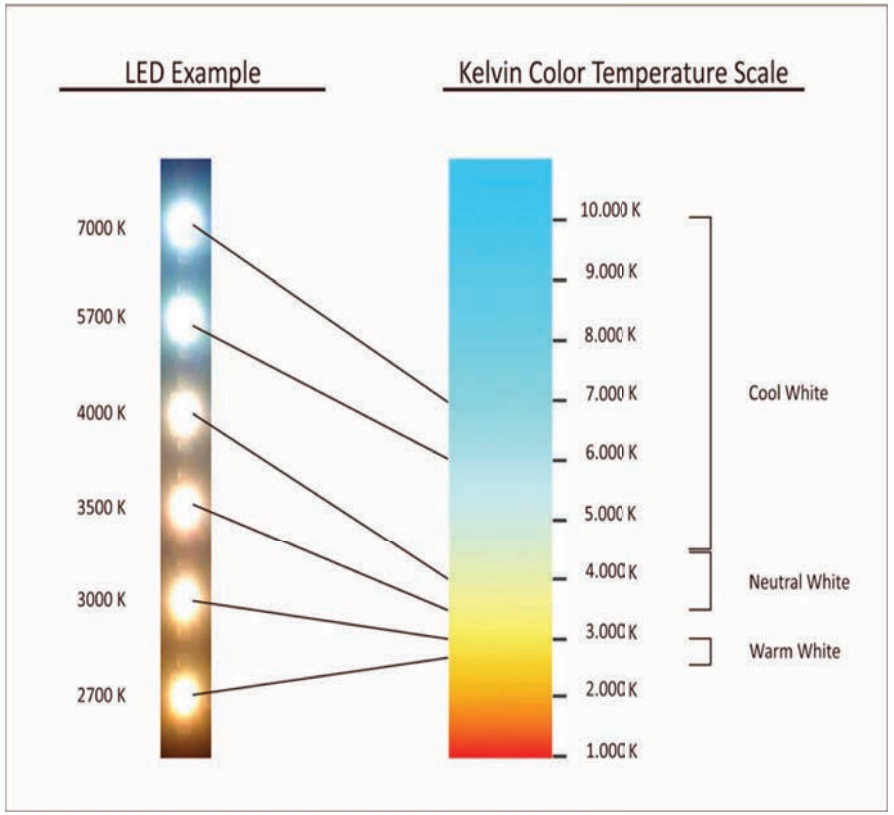
Example SPDs



CCT and SPD

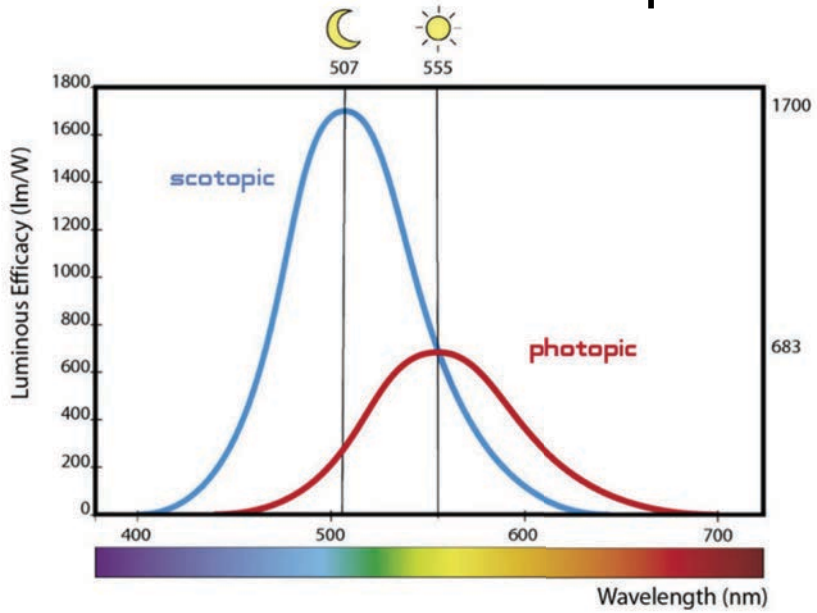
– Many spectral power distributions (SPD) can have same CCT





Luminous Efficiency Functions

- (V(λ)) Photopic (daylight)
  - CIE 2° field of view only take into account cones
- (V'(λ)) Scotopic (starlight)
  - Primarily takes into account rods
- Each neural channel weights the spectrum differently using different combinations of the same photoreceptors



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Ramifications from Photopic Only Specifications

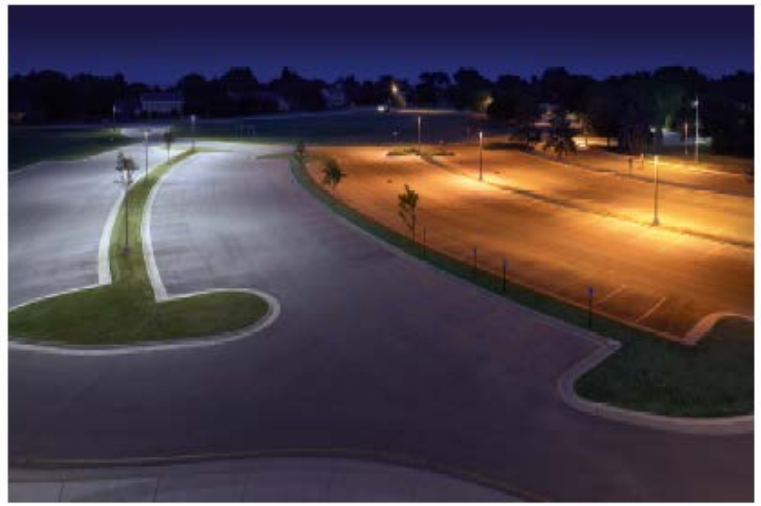
- V(λ) (Photopic vision)
  - Only takes into account L & M Cones
  - Ignores S Cones & Rods contribution to visual perception
  - Unable to quantify our perception of the physical environment if only one function is utilized

- Example Areas That Can Be Over Bright
  - Roadway lighting
  - Gathering spaces
  - Other low visual acuity task areas

- Why Do We Do Things This Way?
  - It's simplifies things
  - One definition is useful for commerce

Improved Methods

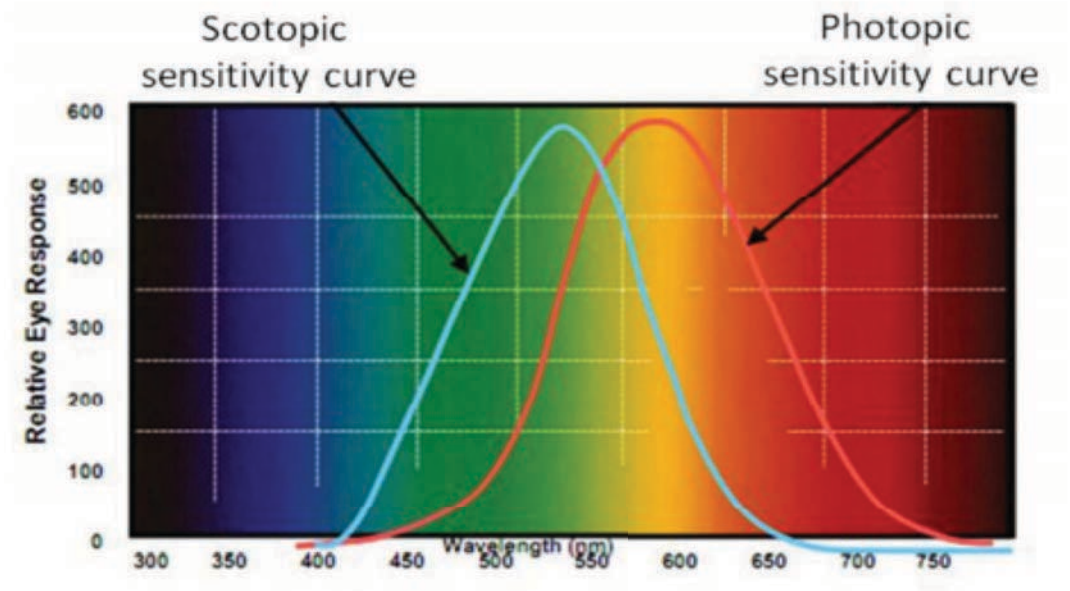
- Watts/ft$^{2\ illuminated}$ would allow manufacturers to utilize optics to provide better solutions
  - Luminous Efficacy (lumens/watt)
  - Directionality of lumens
- Spectral Power Distribution (SPD) of a specific light source is known to affect pupil size, visual acuity, and visual efficiency



Spectrally Enhanced Lighting

$$P_2 = P_1 \cdot \left[\frac{(S/P)_1}{(S/P)_2} \right]^{0.8}$$

P is photopic fc or lux



TM-24-13 IES Illuminance Categories P through Y

S/P of Common Luminaires

Light Source	Photopic Lum/Watt	S/P Ratio	Scotopic Lum/Watt
5000-6000k LED	90	2.00	180
4100k T5 Fluorescent	90	1.62	145
Clear Metal Halide	85	1.49	126
5000k Triphosphor Fluorescent	70	1.58	111
4000k Multi-Vapor Metal Halide	85	1.26	107
6500k Daylight Fluorescent	55	1.72	95
3500k Triphosphor Fluorescent	69	1.24	85
Vitalite Fluorescent	46	1.71	79
5000k 90 CRI Fluorescent	46	1.70	78
2900k Warm White Fluorescent	65	0.98	64
Low-Pressure Sodium	165	0.38	63
50watt High-Pressure Sodium	65	0.76	49
Deluxe Mercury Vapor	40	0.86	34
35watt High-Pressure Sodium	55	0.57	31
Tungsten Halogen	22	1.32	29
Standard Incandescent	15	1.26	19

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Space Type *	Lighting Level Range (fc)
Classroom	30 – 50
Science Lab	50 – 70
Library	30 – 50
Office	30 – 50
Computer Lab	3 – 30
Corridor / Common Space	10 – 20
Gym (recreational)**	30 – 50
Gym (competition)**	50 – 100
Gym (NCAA broadcasting)**	100 – 150
Cafeteria	10 – 20
Kitchen	30 – 50
Pool	5 – 50
Parking Garage	10 – 20
Restroom	5 – 15
Mechanical Room	20 – 50

* IESNA recommended lighting levels to be used for other space-types not listed above.
** "Gym" refers only to the lighting levels on the actual court, not the adjacent general circulation and seating.

1fc = 10.76lux

ASHRAE/ANSI Standard 90.1 - 2016

Building Type	Lighting Power Density (W/ft^2)
Automotive Facility	0.71
Convention Center	0.76
Court House	0.90
Dining: Bar Lounge/Leisure	0.90
Dining: Cafeteria/Fast Food	0.79
Dining: Family	0.78
Dormitory	0.61
Exercise Center	0.65

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How Do We Improve? Use Control

- ASHRAE 90.1 (2010/2013/2016)
  - Expanded control and daylighting requirements as well as increasing lower limits on interior and exterior lighting power densities
- International Energy Conservation Code (IECC) (2012/2015)
  - Expanded to include digital lighting control system that provides continuous dimming and individual addressability of the lamps and fixtures
- ASHRAE 189.1 (2014)
  - Expansion of 90.1 control requirements

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State of Lighting Control

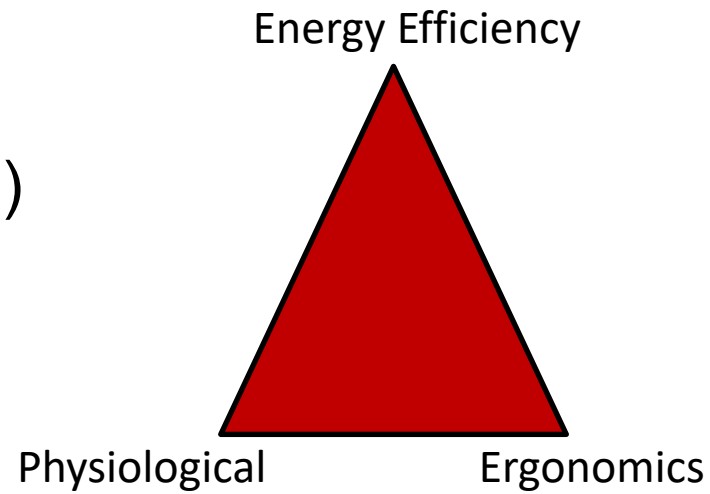
- Most are proprietary
- Open protocol commercial systems are growing
  - Early Example DALI
  - Cost of digital ballasts, limited choices and architect knowledge has led to reduced adoption in North America
  - Move toward addressable intelligence at the fixture level through an input/output (I/O) module
- Not designed for commercial/industrial building needs (DMX)
- Controls systems have to take into account quality of lighting for occupant satisfaction and comfort

Energy Efficiency and HF

- 54% of the energy consumption in commercial buildings is Heating, Ventilation and Air Conditioning (HVAC) and Lighting (U.S. Energy Information Administration 2016)
- Recent systems beginning to *integrate* separated networks such as HVAC and lighting
  - better control and efficiency
- *Room temperature* affects productivity
  - 72-77°F best (Tom 2008)
- CO_2 *concentrations* negatively affect cognitive function
  - 500 ppm → 1000 ppm, -8% decrease in cognitive function (World Green Building Council 2014)
- *Lighting conditions* can affect
  - concentration
  - alertness, headaches (Mills 2007)

Human Centric BMS Requirements

- Ergonomic/Human Factors
  - Task Lighting (productivity/alertness)
  - Circadian Rhythm Disruption (alertness/fatigue/performance)
- Physiological Issues
  - Wellbeing, comfort, mood
  - Flicker
- Safety (slips, trips, falls)
- Energy Efficiency (LEDs)
- Light Meters (S/P, spectrometers)



Circadian Rhythm

- High intensity light exposure mimics the effects of the sun
- Night shifts
  - Restlessness, fatigue, poorer waking life quality
- 2007, IARC -Shiftwork involving circadian disruption is “probably carcinogenic to humans” (Group 2A)
  - Observation of shifts in circadian rhythm and cancerous growth

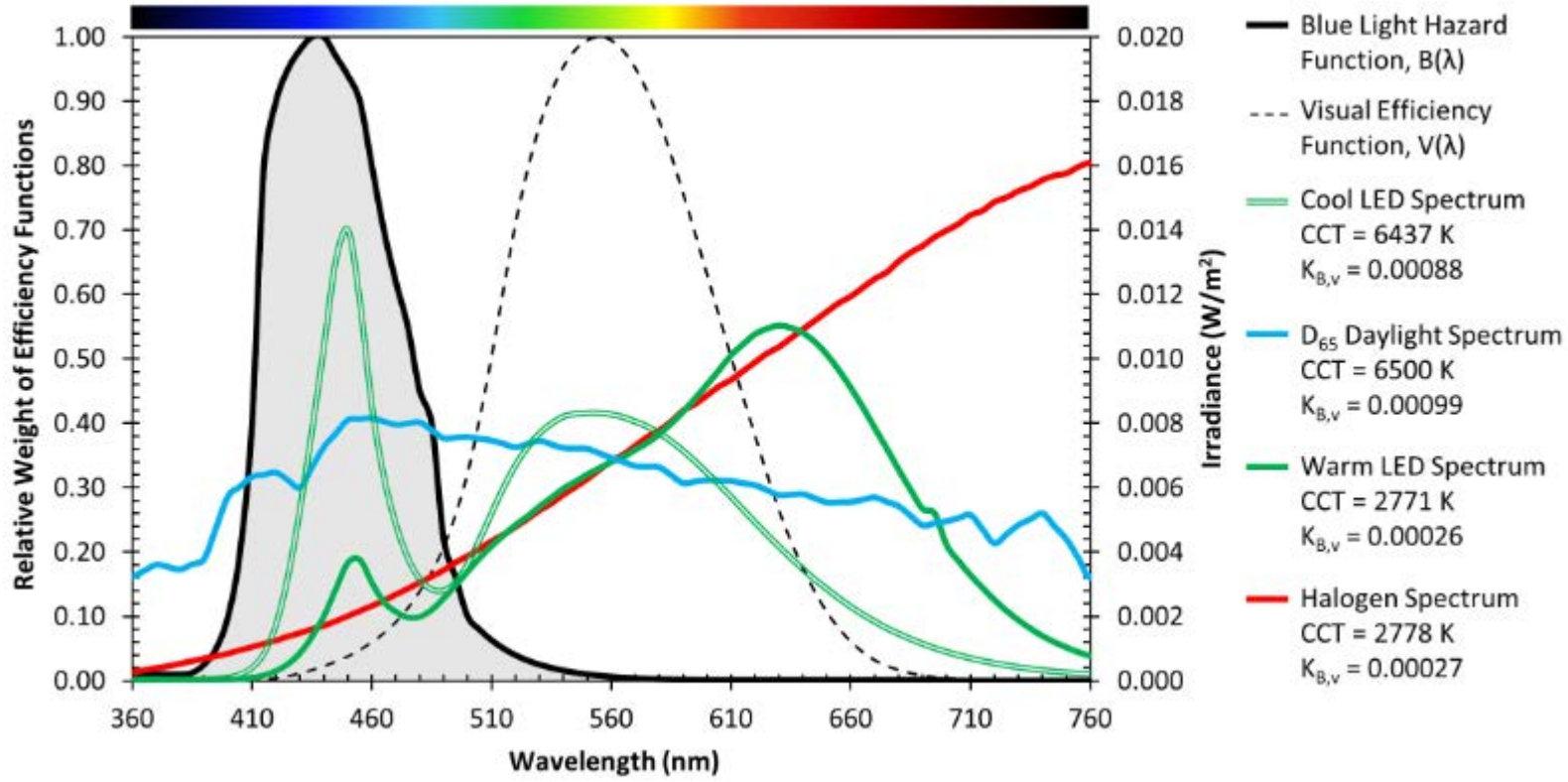
Circadian Rhythm

- All three photoreceptor types play a role in circadian rhythm
- Important Factors To Consider
  - Radiance of the light source (Intensity)
  - Spectral power distribution
  - Duration of focused exposure on the retina
  - Time of day (TOD)

See *Lighting Research Center , others.*

Blue Light Phototoxicity

- Short wavelength light (400-500 nm) is implicated in photochemical damage to retina ***blue light hazard***

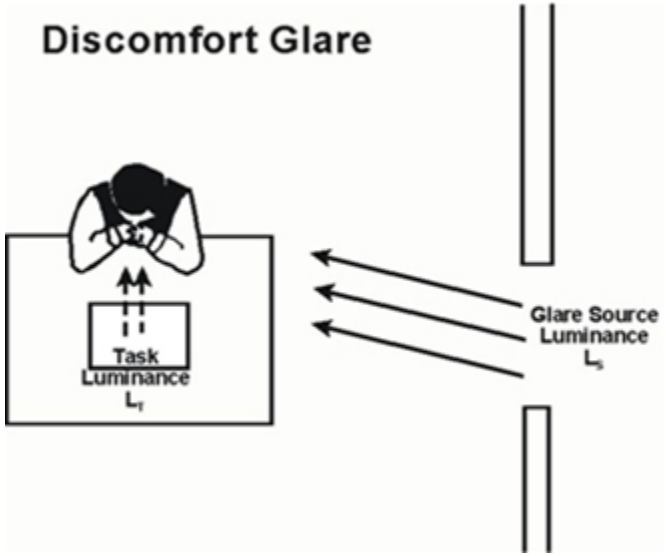


https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/opticalsafety_fact-sheet.pdf

Flicker

- Flicker refers to quick, repeated changes in light intensity
- Lamps running on AC power flicker at a frequency of 120Hz
- Typically, visually perceive the flicker up to about 50Hz
- Human sensory systems can still detect the flicker
  - Headaches, eye strain and general eye discomfort

Glare



Exceeds 3:1 Ratio Light Level Visual Field to Background

Reduced Contrast With Images Appearing Large Than Actual

Advances in Sensor Technology

- Computing power
- Power consumption
- Wireless communications
- Internet accessibility
- Size
- Costs
- Real Time Location Systems (RTLS)

Evolution in Sensor Size

- Movable
  - On wheels
- Portable
  - Straps, backpack, handles
- Wearable
  - Gen1
    - belt or vest
  - Gen 2
    - ***Lapel, wrist, etc.***

Where are Sensors Heading?

- ‘IoT Ready’ Alliance is striving to create a physical standard for intelligent sensors used in lighting control systems, but doesn’t appear to attempt to standardize on the data provided from those sensors.
- Beyond a common mechanical form factor of the socket, the alliance wants the standardization to apply to the electrical interfaces and connectors between the fixture and sensor.

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IoT Networking Considerations and Challenges

- Range
- Bandwidth
- Power usage
- Intermittent connectivity
- Interoperability
- Security
  - Denial of Service (What happens if the entire building shuts down?)
  - Audio/Video Surveillance
  - Local vs Cloud

Network Considerations

- Wired Systems
  - Typically utilizes the manufacturer's proprietary communication protocol
  - IEEE 802.3 Power over Ethernet (PoE)
  - 2018 standard to include 70W ➡ LED replacement for 4 lamp T8 Troffer
- Wireless Systems
  - Greatly reduce installation costs (interior coverage vs flexibility)
  - Open communication protocols like ZigBee and Bluetooth, among others. Ranges are typically (10-150m) or (2-300km)

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Network Protocols and Systems

- In lighting, look for a protocol that…
  - Forms an efficient mesh at large scale (1,000 + devices)
  - Supports line-powered and sleepy, battery powered devices
  - Has an application layer built for device interoperability
  - Is IPv6 based
- As far as the system…
  - You control the data generated
  - Operated locally if need be

NIU BEEEAM Research

- ***Building Energy Efficiency, Ergonomics, and Management (BEEEAM) Laboratory***
- ***Focus 1: Human Centric Intelligent Building Management Systems (BMS)***
- ***Focus 2: Reconfigurable Lighting Test Bed***
- ***Focus 3: Luminaire Design and Testing***

Overarching Theme:

Sensor selection, evaluation and integration

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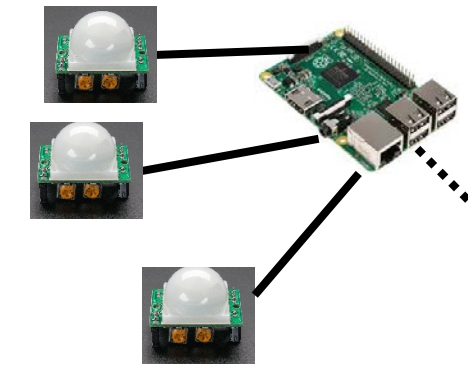


Occupancy Monitor

Master Controller

SmartThings

Lights

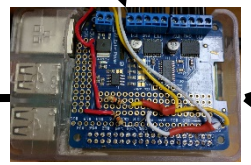
IAQM Controller

IR

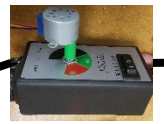
IAQM Unit

Spectrometer

Room Monitor



Air Controller



Indoor Duct Fan

Outdoor Duct Fan

Wired

Wireless

*All Pi communication through a router

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Outcome

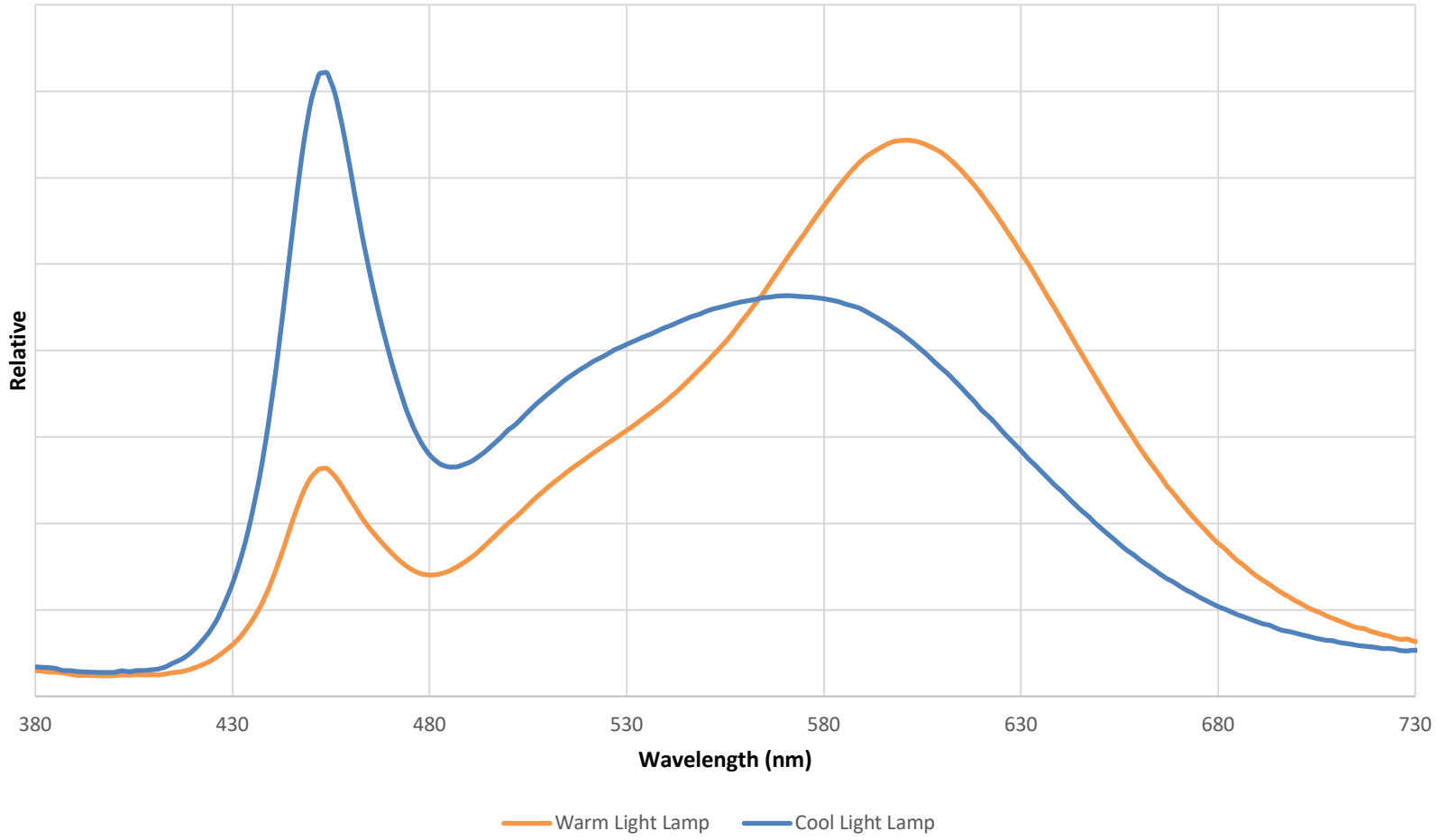
- 33% savings when VEL is considered
- 45% savings using P_{lux} with light harvesting
- 74% savings using VEL with light harvesting

	P (Watts)*NBC	VEL** (Watts)	% Savings
No Outside	6.9	4.6	**33%**
With Outside ***	3.8	1	**74%**
NBC % Savings	**45%**		

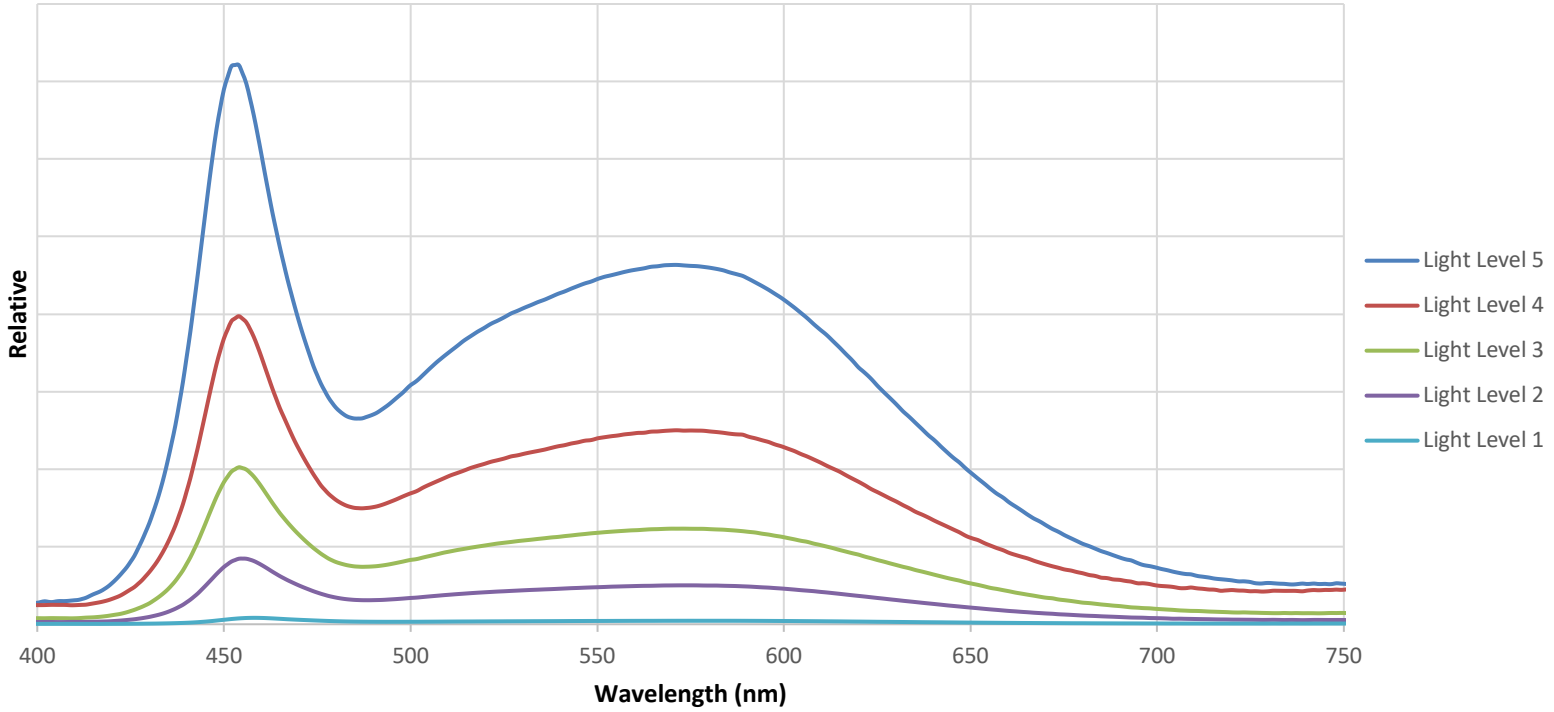
* National Building Code specifies usage of only P_{lux}
** P=525 lux, VEL = 536-542 lux, 5000K lamp
*** Outside 4100K

4 Programming Languages: Python, Android, C, Groovy,
8 Communication Protocols: Ethernet, WiFi, i2C, USB, GPIO, IR, Zigbee, BLE
3,000+ lines of code

Spectral Shifting Lamp



Scotopic 5900K CCT Lamp



SPD	S/P Ratio	Photopic Sum	Scotopic Sum	Wattage (W)
Light Level 5	2.14	14426	30914	8.1
Light Level 4	2.16	7946	17173	6.5
Light Level 3	2.17	4049	8800	4.9
Light Level 2	2.19	1693	3715	3.3
Light Level 1	2.29	165	379	1.7

Wearable sensor array for BMS

- Environmental parameters
  - Lighting
  - Temperature
  - eCO_2
  - VOC
  - Sound
  - Accelerometer
- Future
  - RTLS
  - BACnet compatibility
  - Improved Sensor Suite

Conclusions

- Future control systems need to include more parameters
  - ***Physical stimulus characteristics***
    - SPD
    - Amount
    - Duration
    - Spatial distribution (avoid double lighting, correct optical distribution)
    - Time of Day
    - Glare and Flicker
  - ***Biological response characteristics***
    - Spectral sensitivity
    - Temporal integration (timing of light)
    - Absolute threshold
- **Global Optimization based on HF, productivity, and power inputs**

For further info see: go.niu.edu/beeeam

This concludes The American Institute of Architects Continuing Education Systems Course

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