LIGHT AND HEALTH RECIPES WITH RADIANCE

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I. Background: Light, Opsins and Health

II. Melanopsin in focus

III. Neuropsin in focus

IV. Myopia in focus

V. What about NIR?

VII. Measurements and Simulations

VI. Conclusion: Towards prescription of healthy lighting recipes

Integrative Lighting

- … integrate visual and nonvisual effects, producing physiological and psychological effects on humans that are reflected in scientific evidence. *CIE Position Statement on Integrative Lighting: Recommending Proper Light at the Proper Time, 2024.*

- replaces terminology such as “non-image-forming” (NIF), “non-visual” (NV), “human-centric lighting” (HCL), “circadian lighting”, “biodynamic lighting”, and so on…

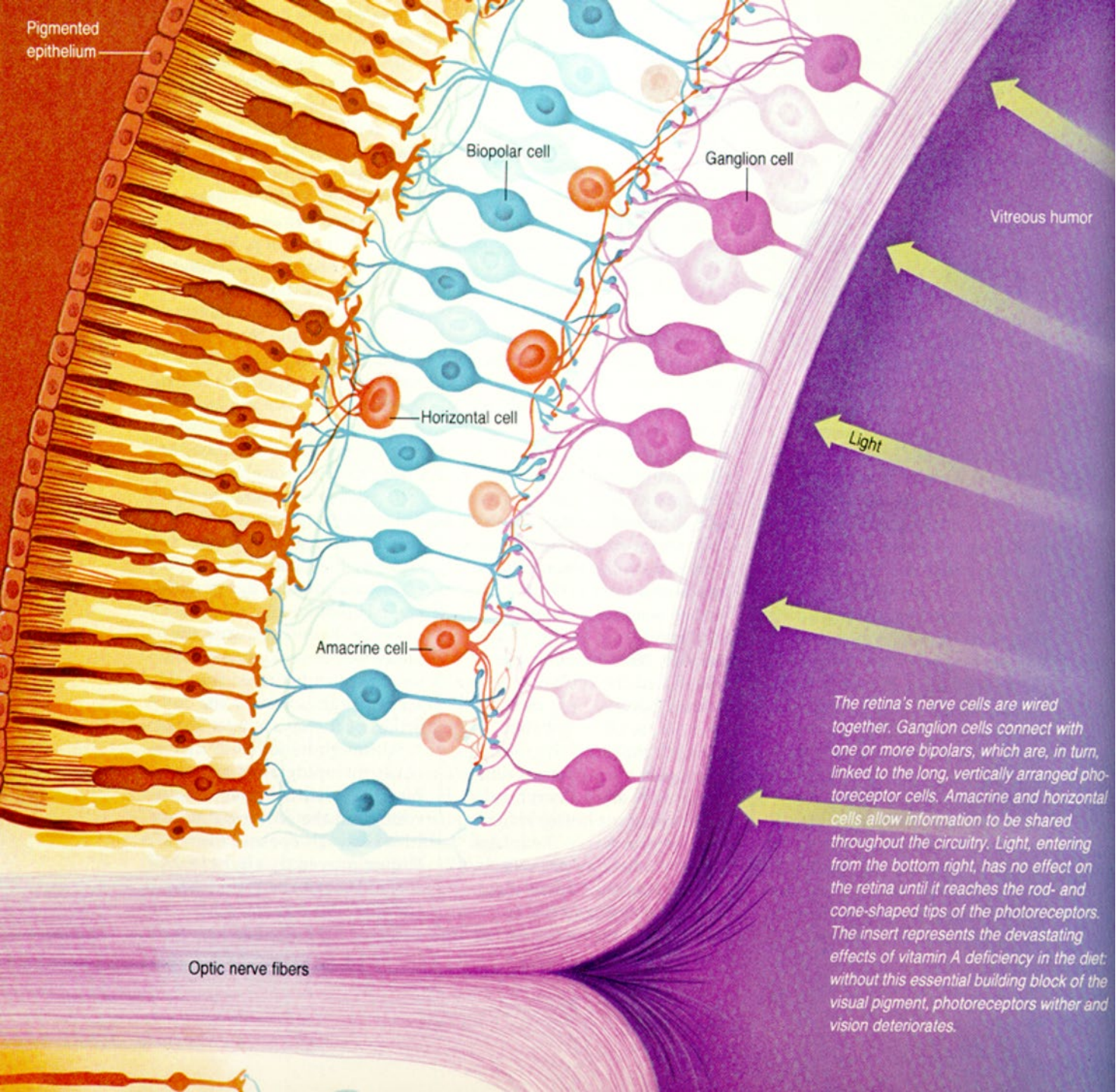
- “The SLL supports a daylight-first, electric-light-supported approach. Improve daytime vertical illuminance at the eye through room geometry, surface reflectance and task/location planning before increasing electric lighting power.” *Society of Light and Lighting Position Statement on Integrative Lighting, 2026.*



Nature

Adequate timing (Dark / light cycle)

Adequate dose (Dynamic spectra, intensity, exposure)



Intrinsically photosensitive retinal Ganglion Cells (iPrGCs)

Brainard GC, Hanifin JP, Greeson JM, Byrne B, Glickman G, Gerner E, Rollag MD; New Collective Author. Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. J Neurosci. 2001 Aug 15;21(16):6405-12. doi: 10.1523/JNEUROSCI.21-16-06405.2001.

Thapan K, Arendt J, Skene DJ. An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. J Physiol. 2001 Aug 15;535(Pt 1):261-7.

Hattar S, Liao HW, Takao M, Berson DM, Yau KW. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. Science. 2002 Feb 8;295(5557):1065-70.



opsins

Opsins are types of proteins
that interact with
light-sensitive chemicals to enable

- vision

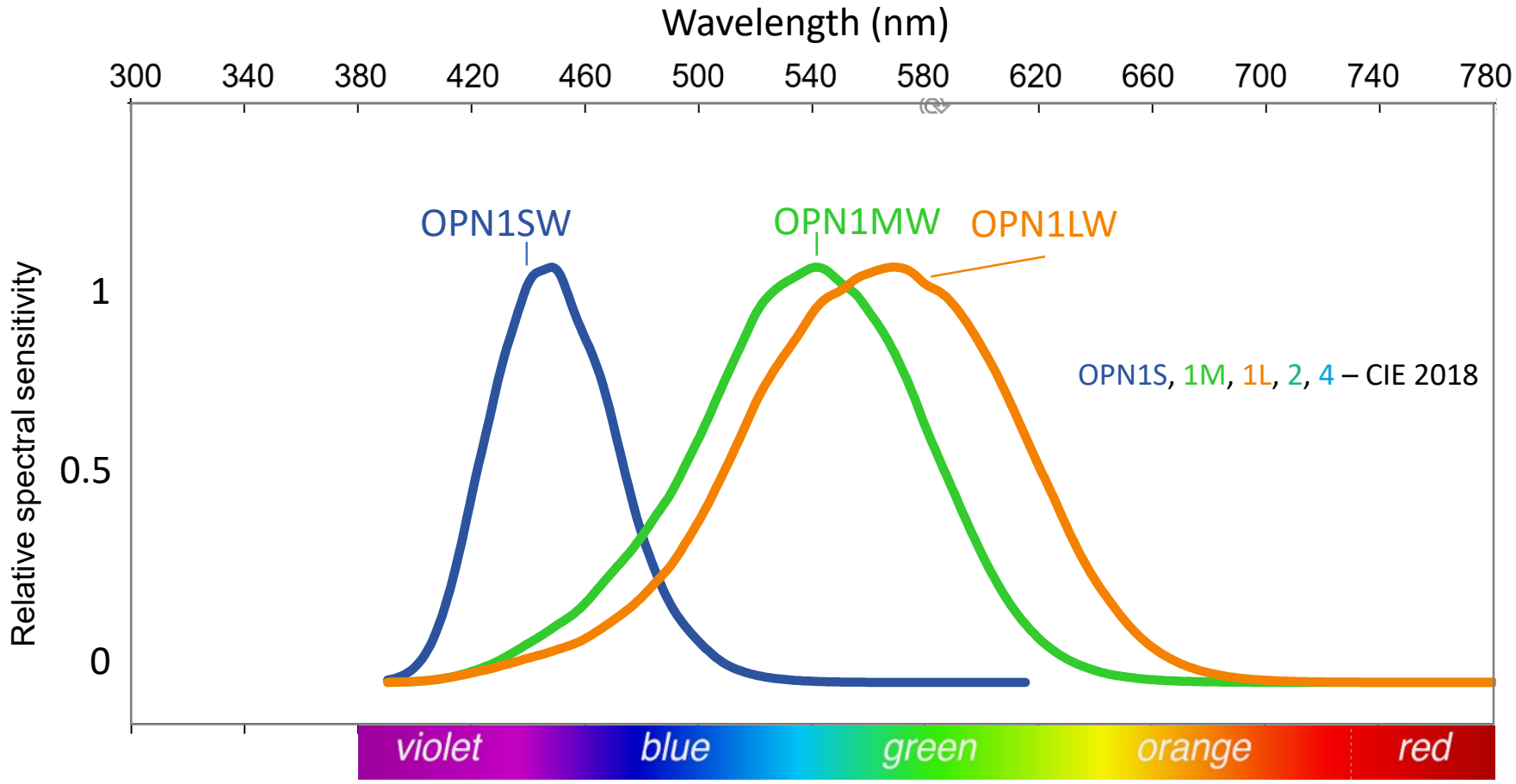
- circadian rhythms

-neuroendocrine, neurobehavioral, and other
light-induced reactions in living beings

Human Opsins

Vision:
OPN1SW (S cone)
OPN1MW (M cone)
OPN1LW (L cone)
OPN2 (Rhodopsin)

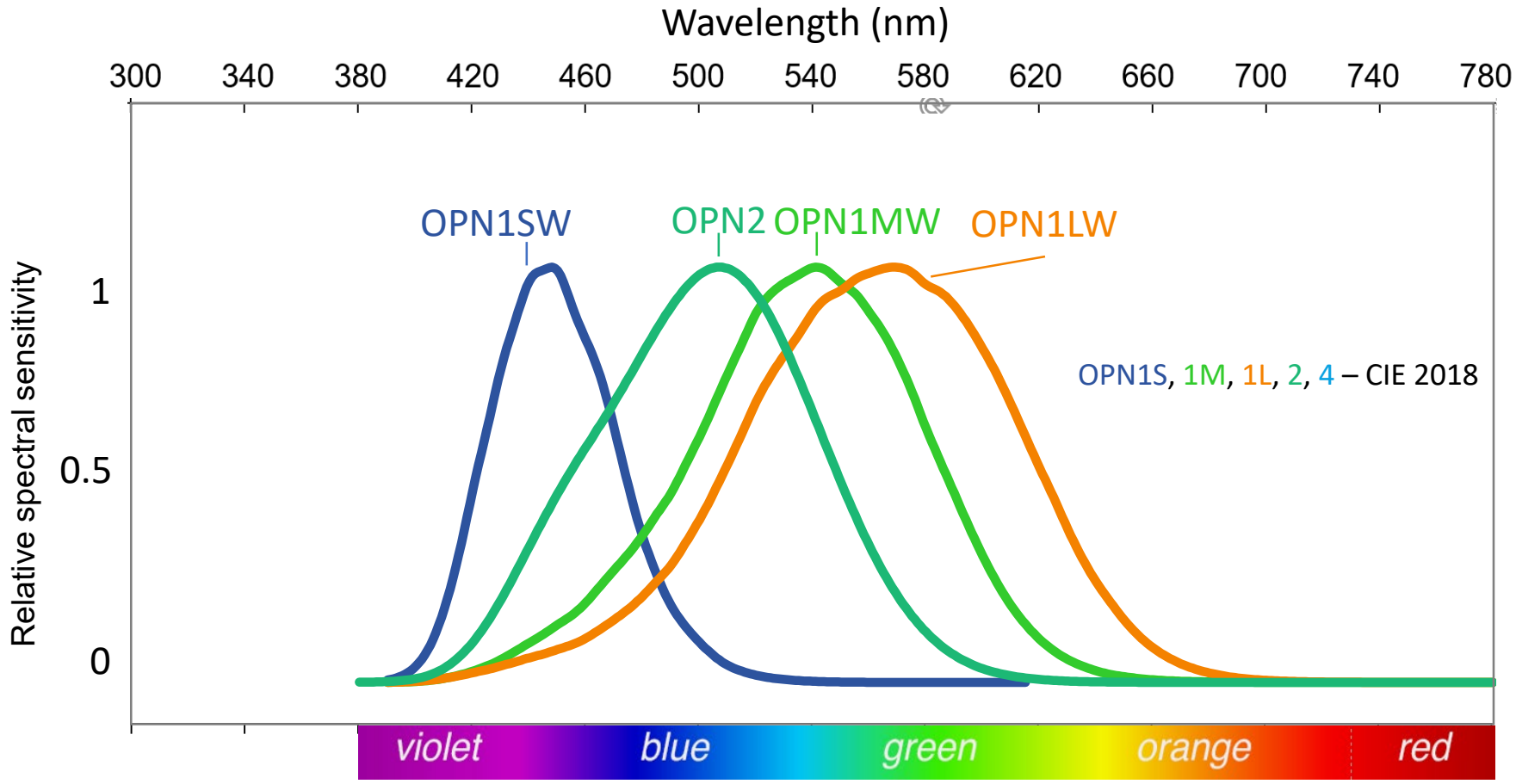
Non-visual:
OPN3 (Encephalopsin)
OPN4 (Melanopsin)
OPN5 (Neuropsin)



Human Opsins

Vision:
OPN1SW (S cone)
OPN1MW (M cone)
OPN1LW (L cone)
OPN2 (Rhodopsin)

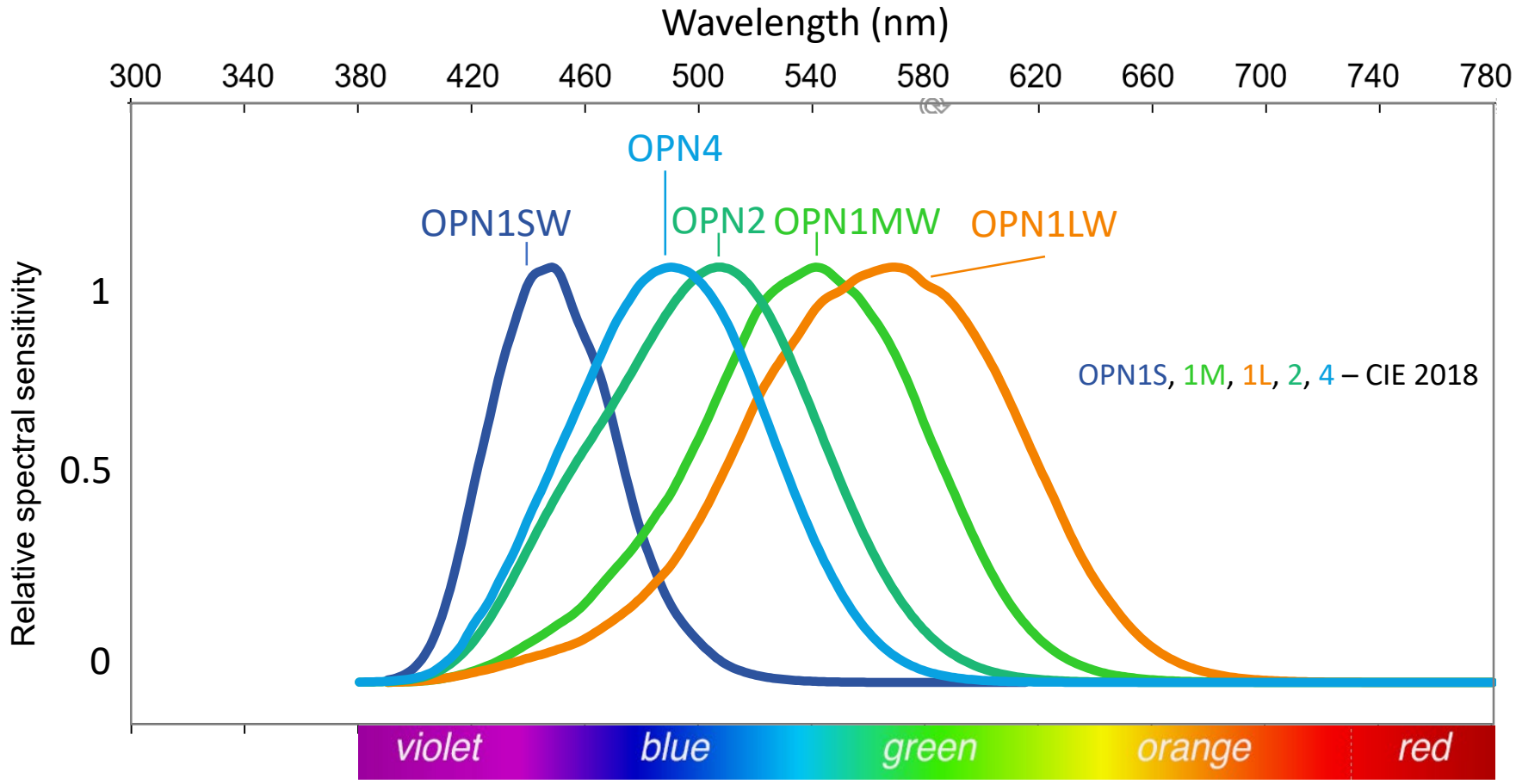
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Human Opsins

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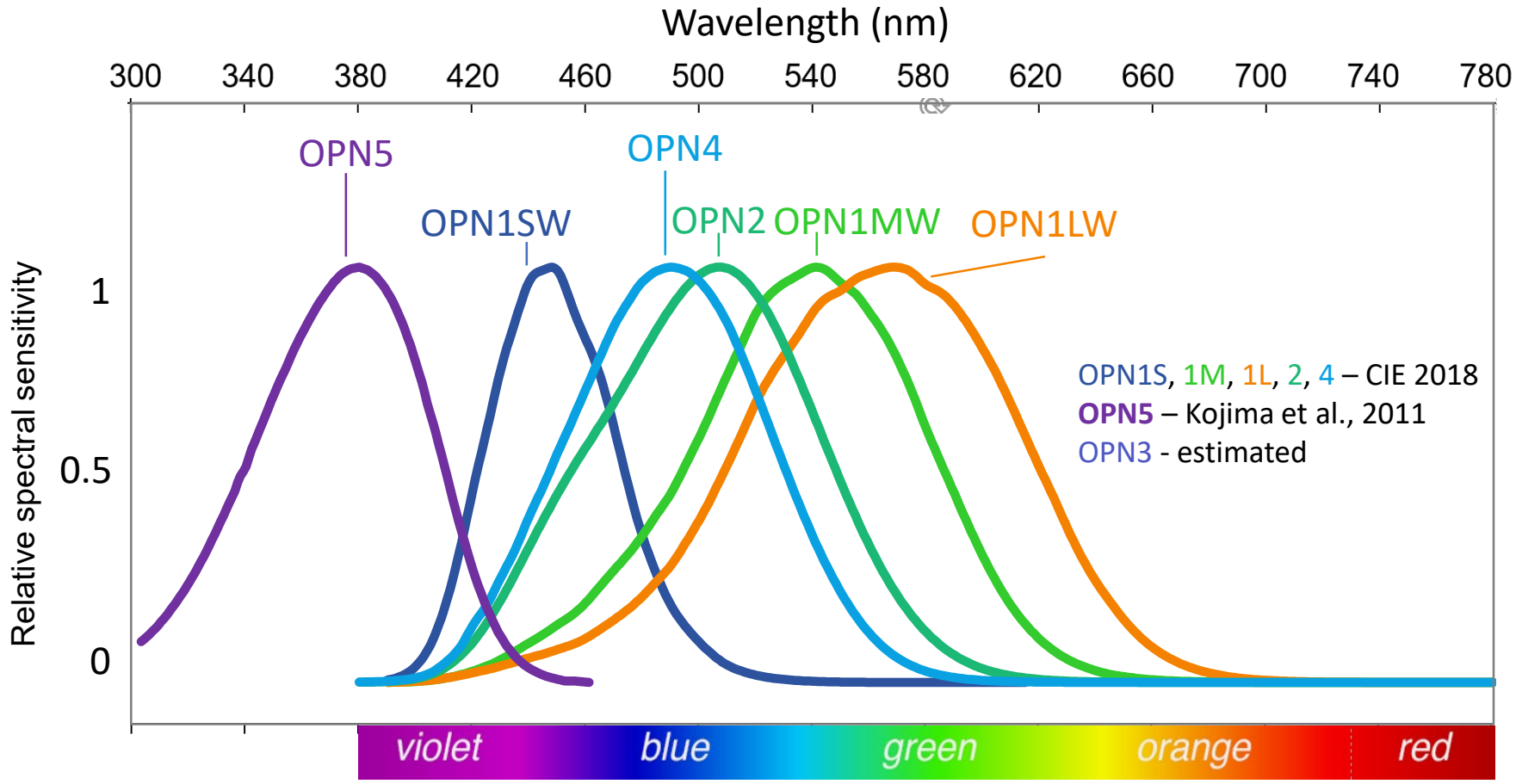


Opsin 4 curve: “Manchester Workshop I”, Lucas et al., 2014, CIE 2018

Human Opsins

Vision:
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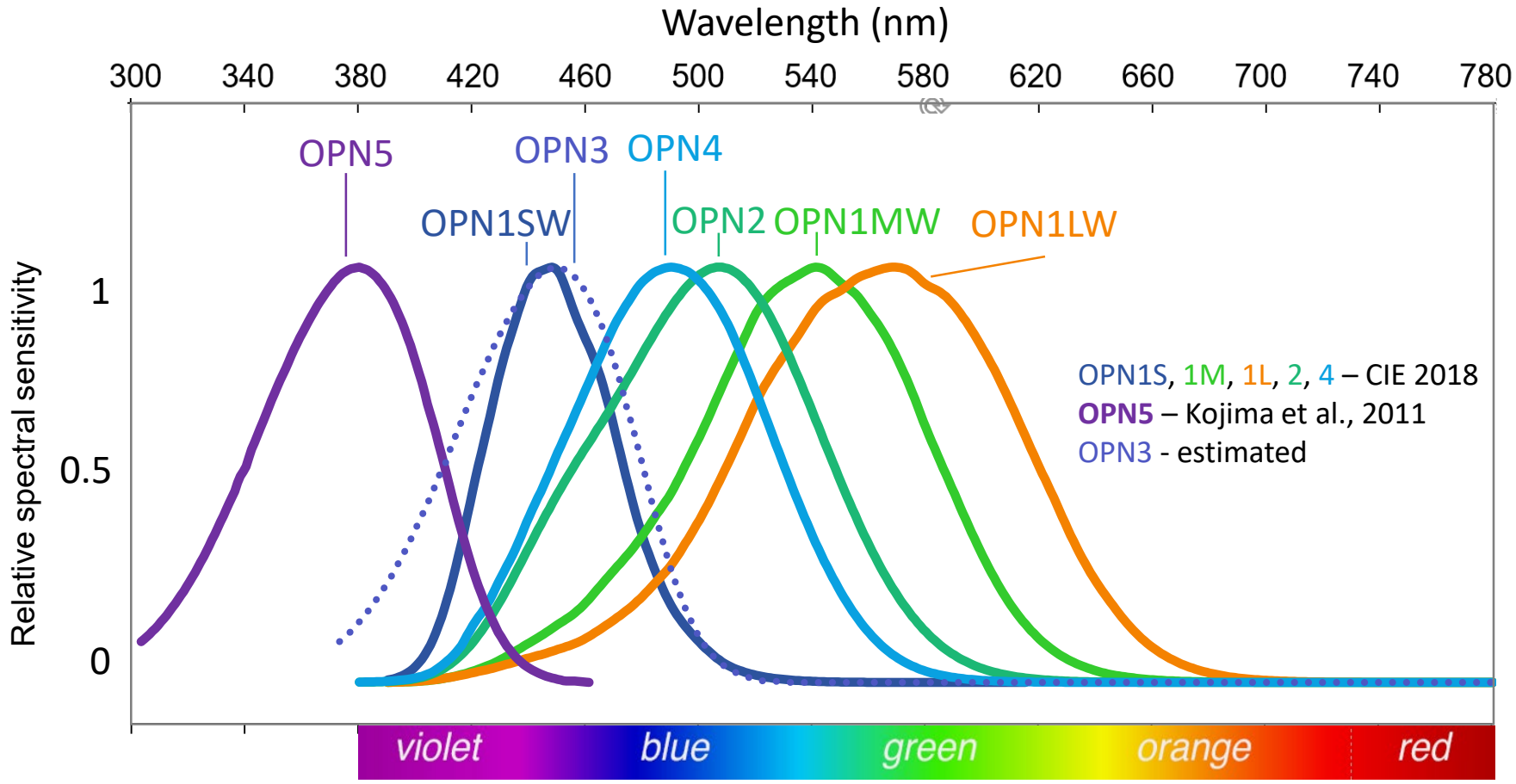
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Human Opsins

Vision:
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OPN1LW (L cone)
OPN2 (Rhodopsin)

Non-visual:
OPN3 (Encephalopsin)
OPN4 (Melanopsin)
OPN5 (Neuropsin)



OPN3, OPN4 and **OPN5** are responsive to short wavelengths

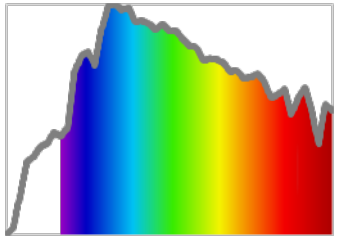
Melanopsin

- Our internal body clock is slightly longer than 24 hr (~24.3 hrs)
- Precise synchronization to a 24hr day requires environmental time signals
- The most important time signal is the light dark cycle and right spectra at the right time

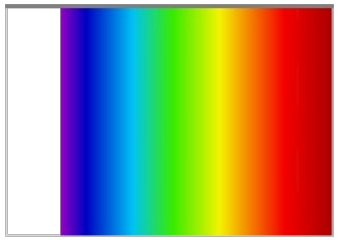
UNDERSTANDING PHOTOBIOLOGY IN BUILT ENVIRONMENTS

THE SOURCE	(Variable) Intensity and spectra in naturally occurring skies and electric light sources
THE MODIFIER	Incoming light interacts with natural and built materials
THE RECEIVER	Opsins trigger distinct neural pathways. Visual responses are processed in the visual cortex. Melanopic responses are mediated by the suprachiasmatic nucleus.

Metrology



CIE Metrology
M-EDI: Melanopic –Equivalent Daylight Illuminance, Lux
With D65, 1 Photopic Lux = 1 M-EDI



EML – Equivalent Melanopic Lux
With an equal-energy white source, 1 Photopic Lux = 1 EML

Metrology: M-EDI, N-EDI vs EML, ENL

Response	α-opic efficacy	Photoreceptor [range]	Photo-pigment	α-opic action spec.	α-opic equivalent D65, $E_{v,\alpha}$(lx)	Eq. Melonopic/ Neuropic Lux
Melanopic	1,3262 $mW.lm^{-1}$	ipRGCs [380-780 nm]	Melanopsin	$s_{mel}(\lambda)$	$E_{v,mel}$ M-EDI	EML=M-EDI * 1.104 M-EDI= EML * 0.906

Melanopic Criteria: Proper Light @ Proper Time

>= 250 M-EDI during daytime

< = 10 lx melanopic EDI in the evening, starting 3 hours before bedtime

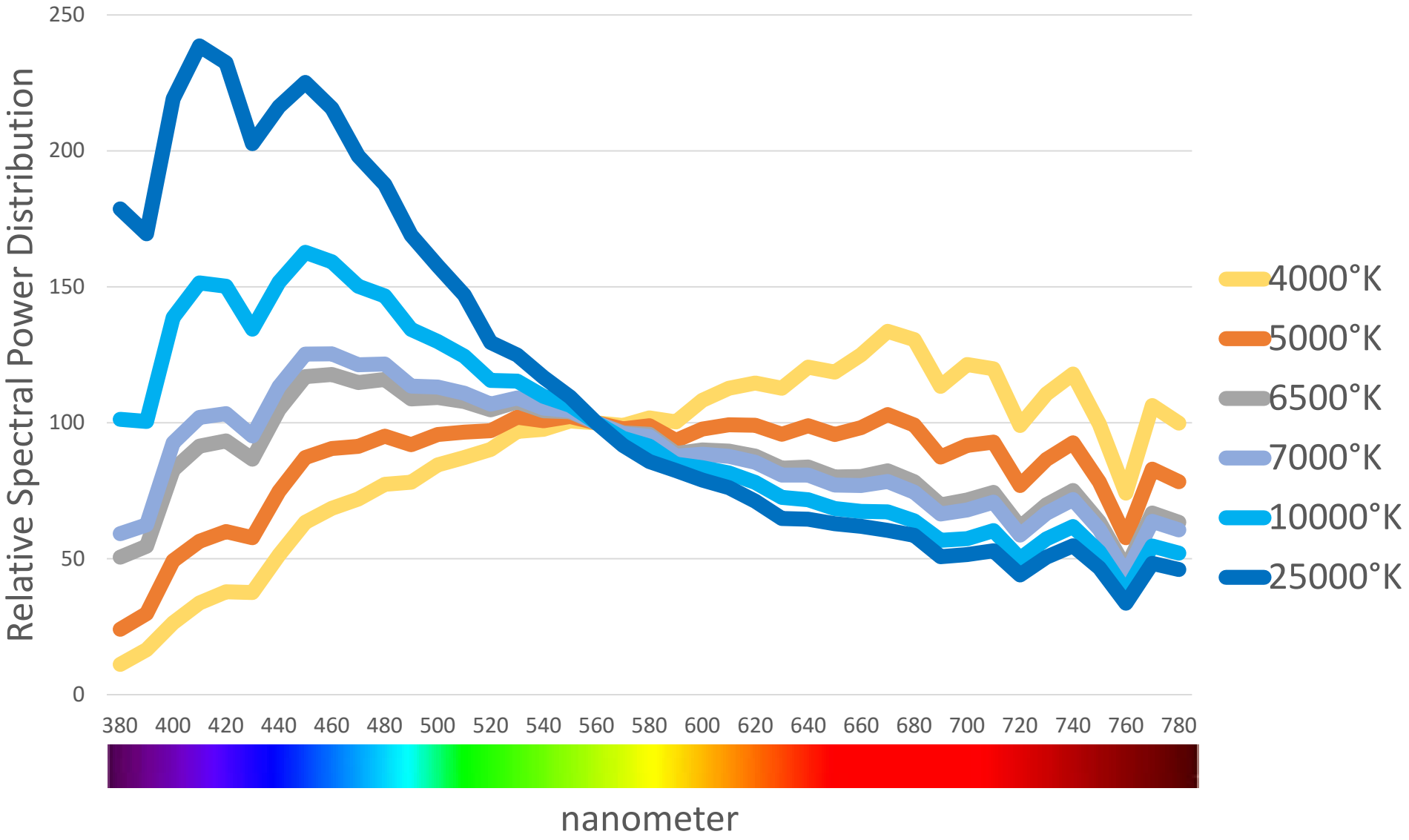
<=1 lx melanopic EDI overnight while sleeping

(Manchester Workshop II, Brown et. al., 2022, CIE 2024).

Well-Building: 275 EML for at least four hours (beginning by noon at the latest)

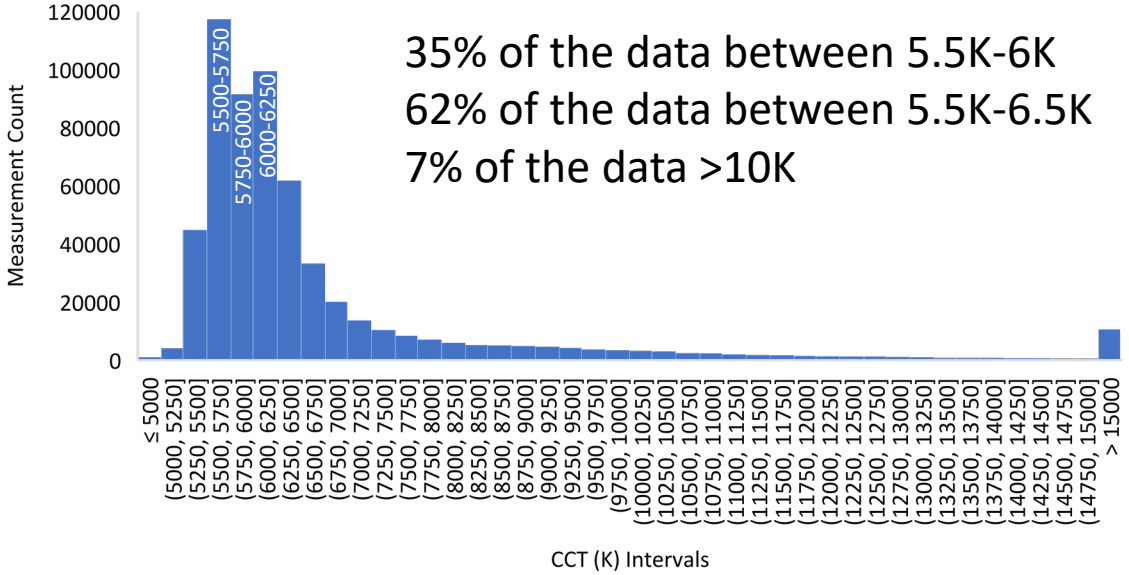
275 EML * 0.906 = 249.15 M-EDI

Daylight Spectra

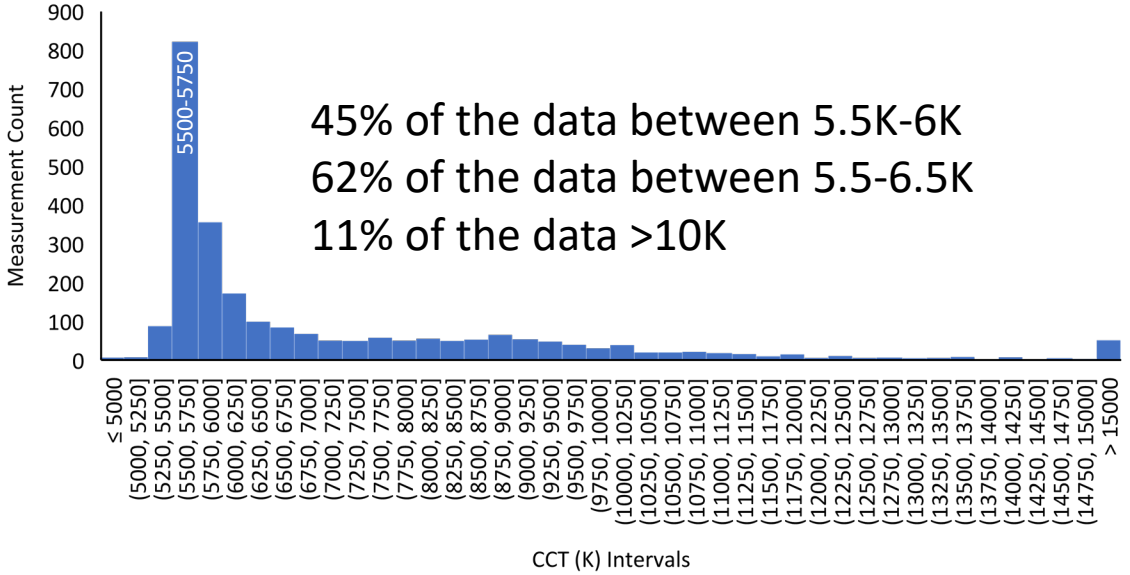


Calculated using the "Excel Daylight Series Calculator" from *RIT Munsell Color Science Laboratory*. Calculations are based on: Wyszecki G. and Stiles WS. *Color Science: Concepts and Methods, Quantitative Data and Formulae*. New York, John Wiley and Sons, Inc, 2000.

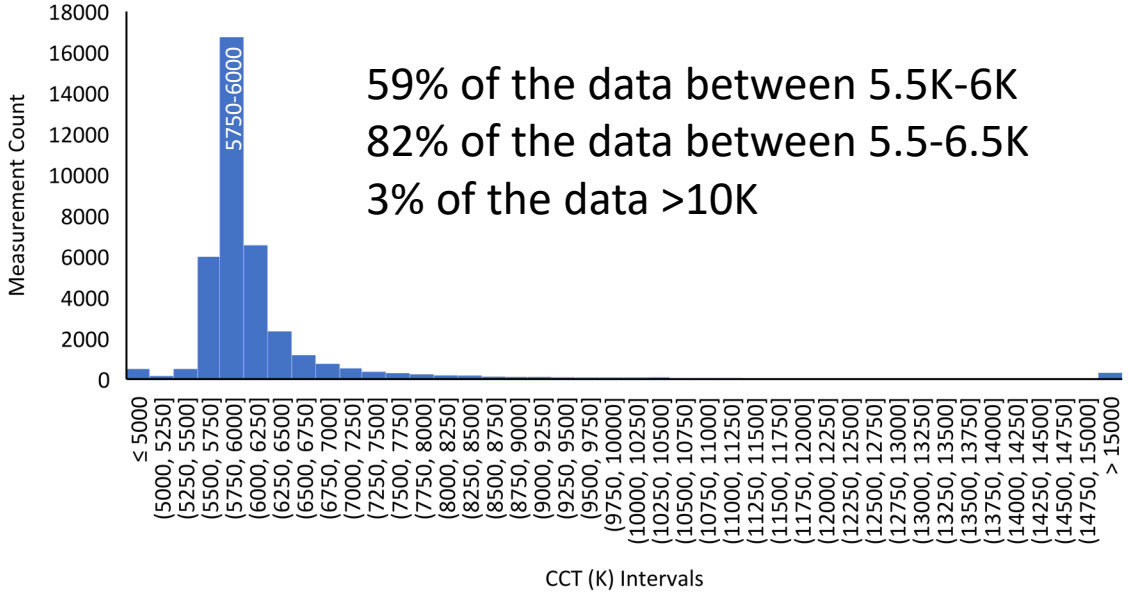
Seattle, WA (2021-2024)[1]



Granada, Spain (~2001)[4,5]



Golden, CO (2014)[2,3]



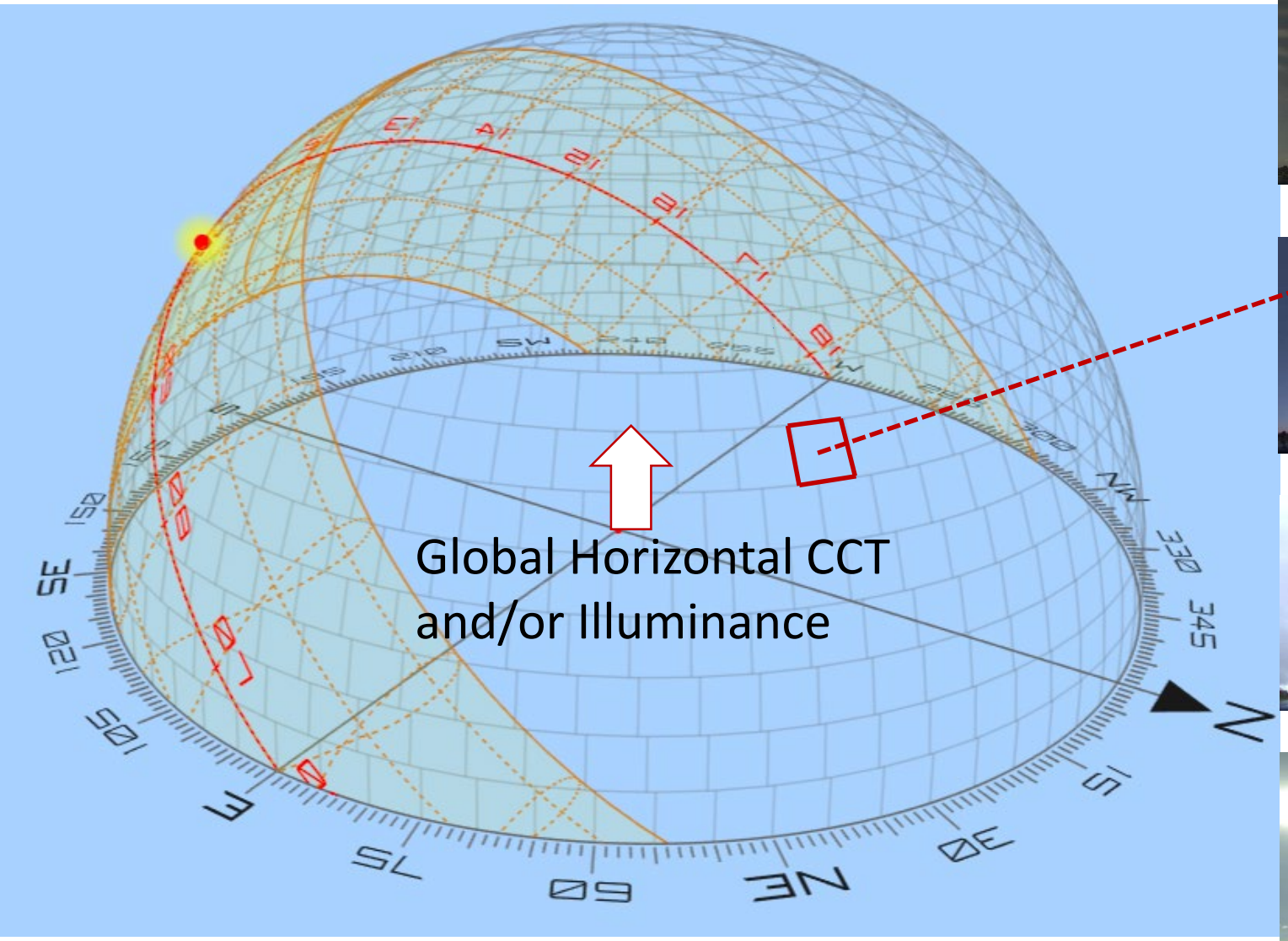
[1] Inanici M and ZGF LLC, 2024.

[2] Andreas A, Stoffel T. NREL Solar Radiation Research Laboratory (SRRL): Baseline Measurement System (BMS); Golden, Colorado (Data); 1981, NREL Report No. DA-5500-56488.

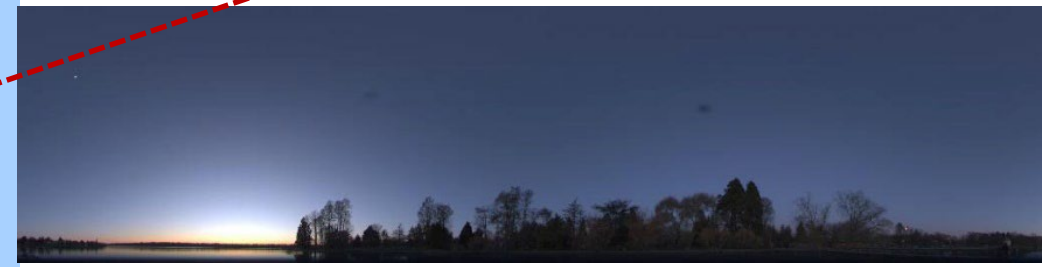
[3] https://www.nrel.gov/grid/solar-resource/spectral-solar.html

[4] Hernández-Andrés J, Romero J, Nieves JL, Lee, Jr. RL. Color and spectral analysis of daylight in southern Europe. *Journal of the Optical Society of America* A 2001, 18(6): 1325-1335

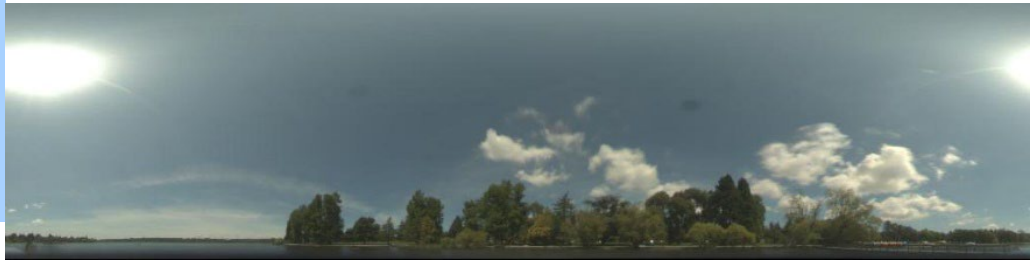
[5] University of Granada, Color Imaging Laboratory, Granada Daylight Spectral database, http://colorimaginglab.ugr.es/pages/Data#__doku_granada_daylight_spectral_database

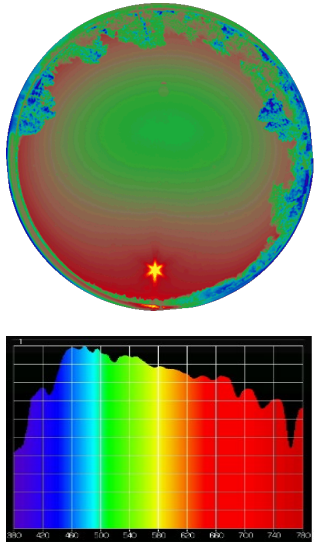
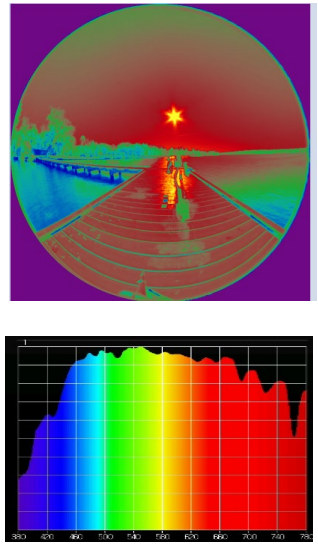
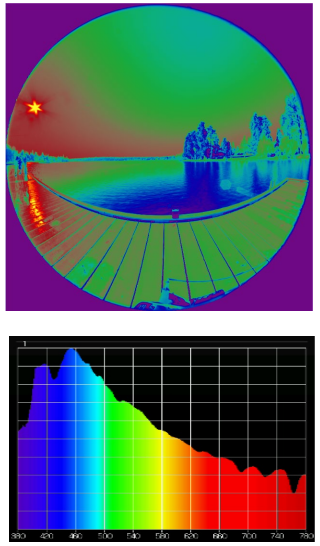
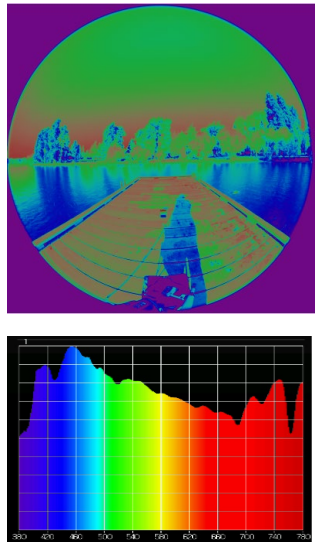
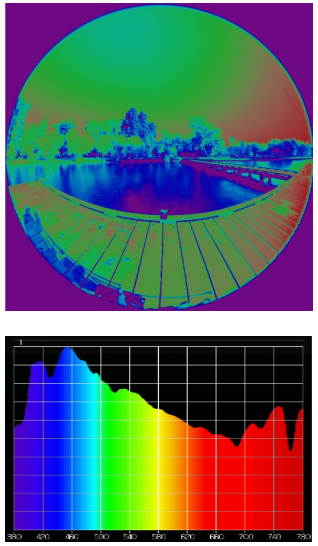

Global Horizontal CCT
and/or Illuminance









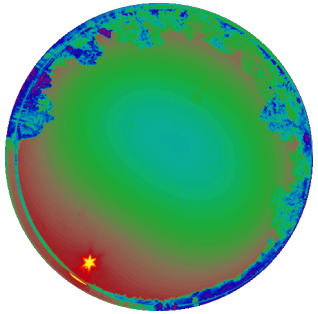
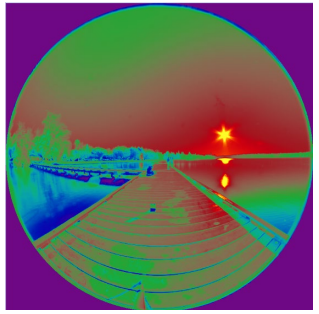
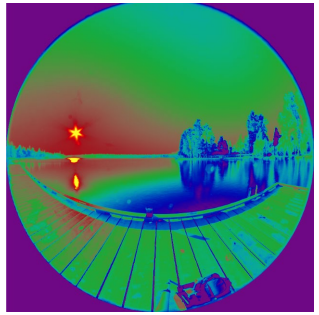
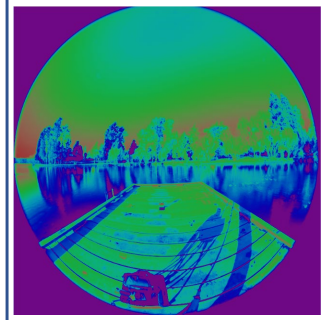
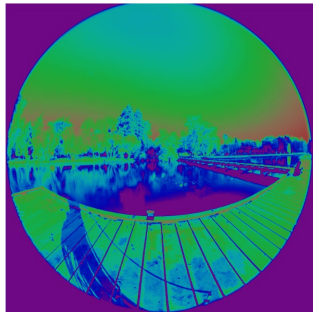
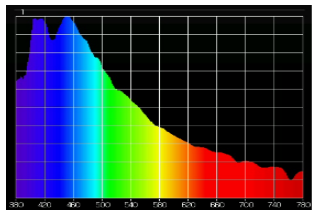
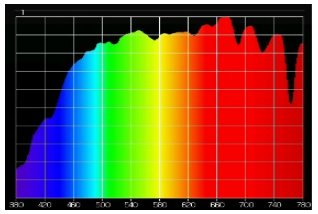
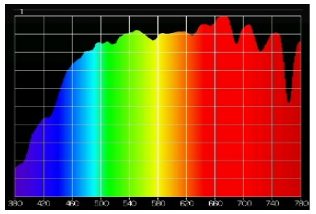
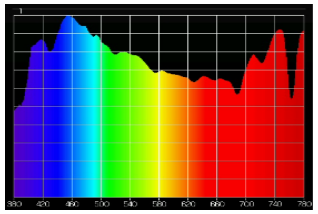
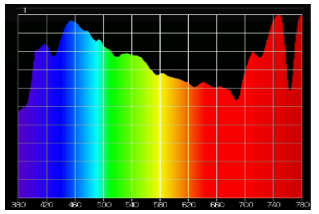
	HDR Sky	Vertical 1	Vertical 2	Vertical 3	Vertical 4
Nov 17, 12:02					
	CCT = 5,797 K	CCT = 5,140 K	CCT = 10,264 K	CCT = 6,859 K	CCT = 7,936 K
	Y = 27,481 Lx	Y = 96,323 Lx	Y = 5,993 Lx	Y = 4,617 Lx	Y = 3,746 Lx
	25,603 EM.Lx	86,896 EM.Lx	7,557 EM.Lx	5,955 EM.Lx	4,263 EM.Lx
	m:p = 0.93	**m:p = 0.90**	**m:p = 1.26**	**m:p = 1.29**	**m:p = 1.14**



Colors in normalized spectra graphs show actual color content [380-780 nm]

Inanici M. "Tri-stimulus Color Accuracy in Image-based Sky Models: Simulating the Impact of Color Distributions throughout the Sky Dome on Daylit Interiors with Different Orientations", *IBPSA 2019 Conference*, Rome, Italy, September 2-4, 2019.

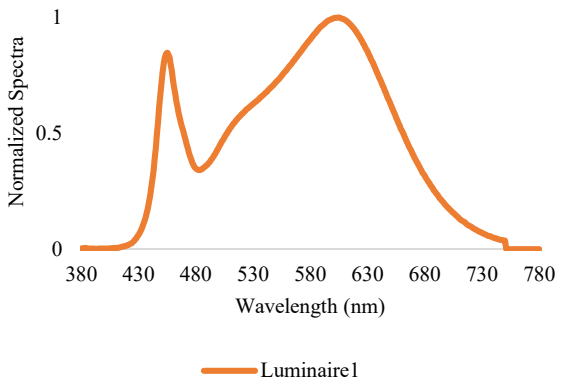
Inanici M, Abboushi B, and Safranek S. "Evaluation of Sky Spectra and Sky Models in Daylighting Simulations," *Journal of Lighting Research and Technology*, 55(6): 2023, 502-529.

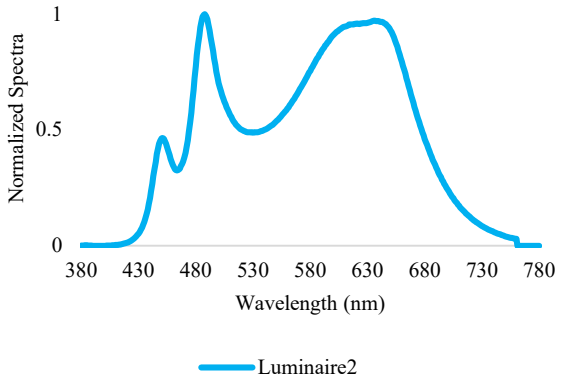
	HDR Sky	Vertical 1	Vertical 2	Vertical 3	Vertical 4
Dec 4, 14:20					
					
	CCT = 22,686 K	CCT = 4,623 K	CCT = 4,618 K	CCT = 7,172 K	CCT = 7,192 K
	3,725 Lx	72,481 Lx	62,183 Lx	3,100 Lx	2,806 Lx
	5,727 EM.Lx	54,862 EM.Lx	46,945 EM.Lx	3,359 EM.Lx	3,028 EM.Lx
	m:p = 1.53	**m:p = 0.76**	**m:p = 0.76**	**m:p = 1.08**	**m:p = 1.08**

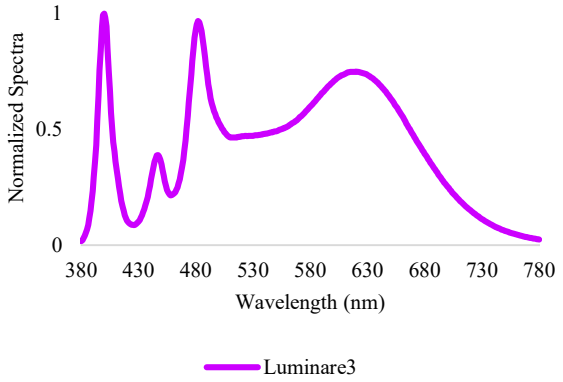


Colors in normalized spectra graphs show actual color content [380-780 nm]

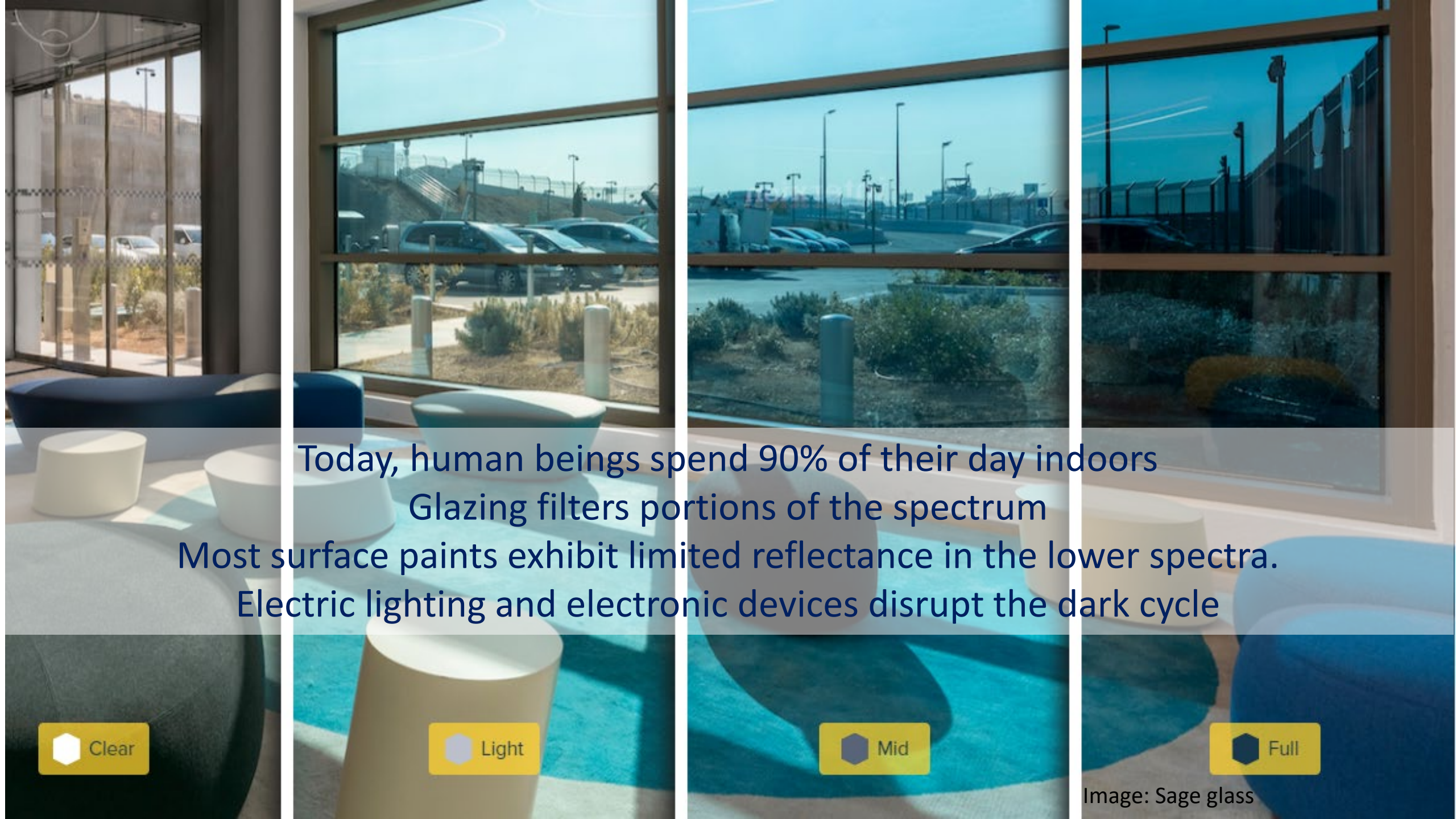
Electric Lighting







All have CCT of 3500 K!



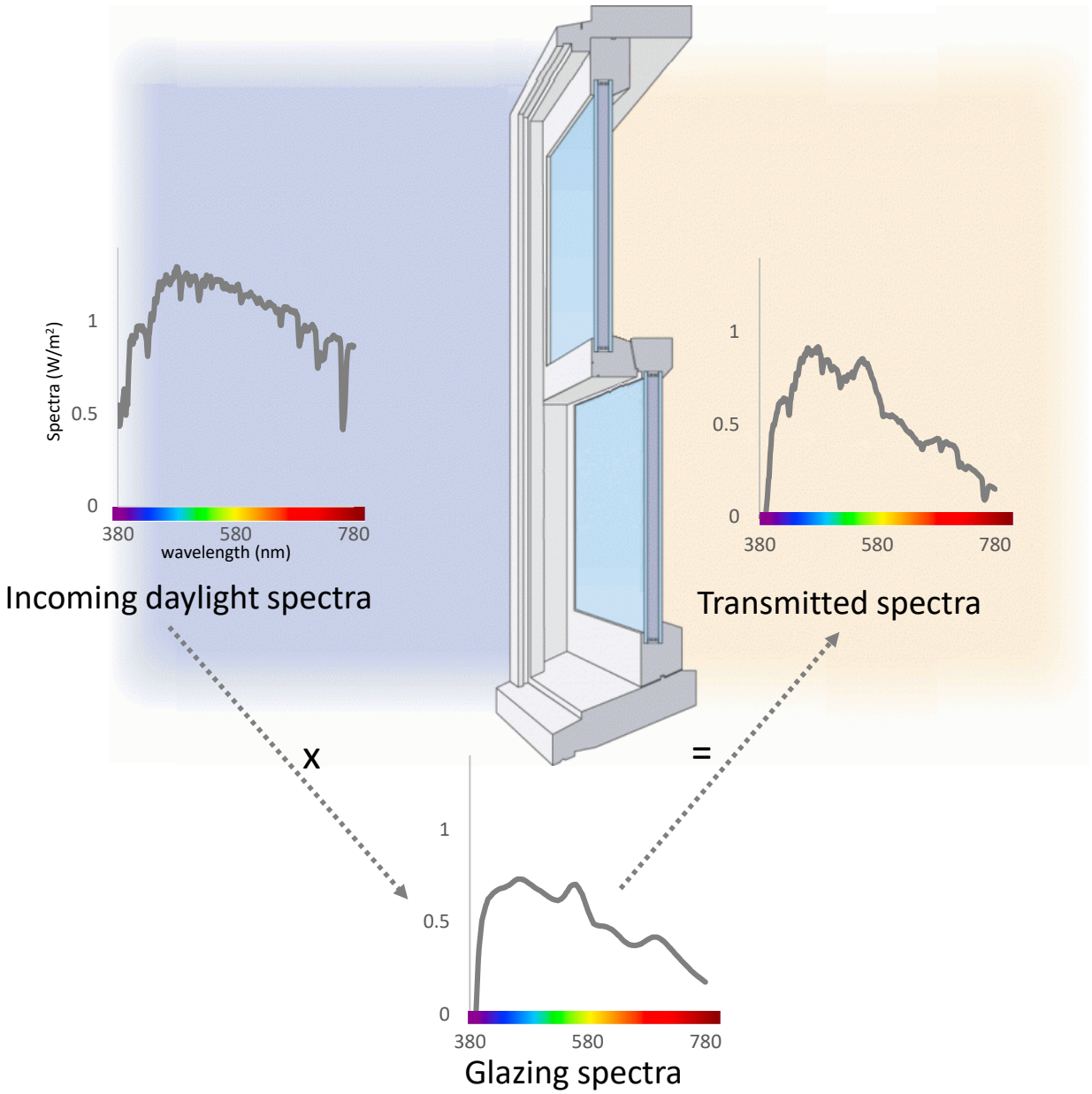
Today, human beings spend 90% of their day indoors

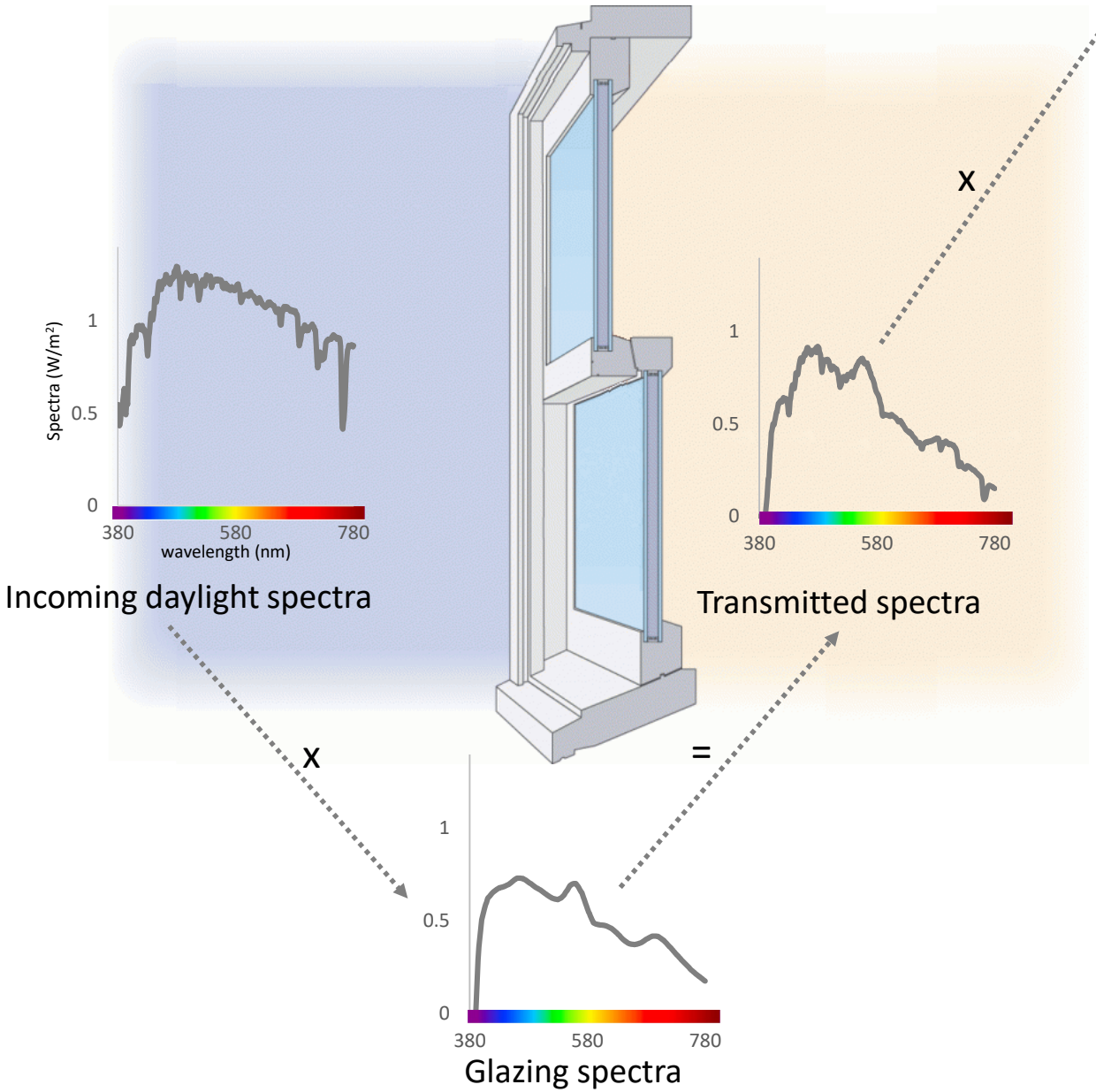
Glazing filters portions of the spectrum

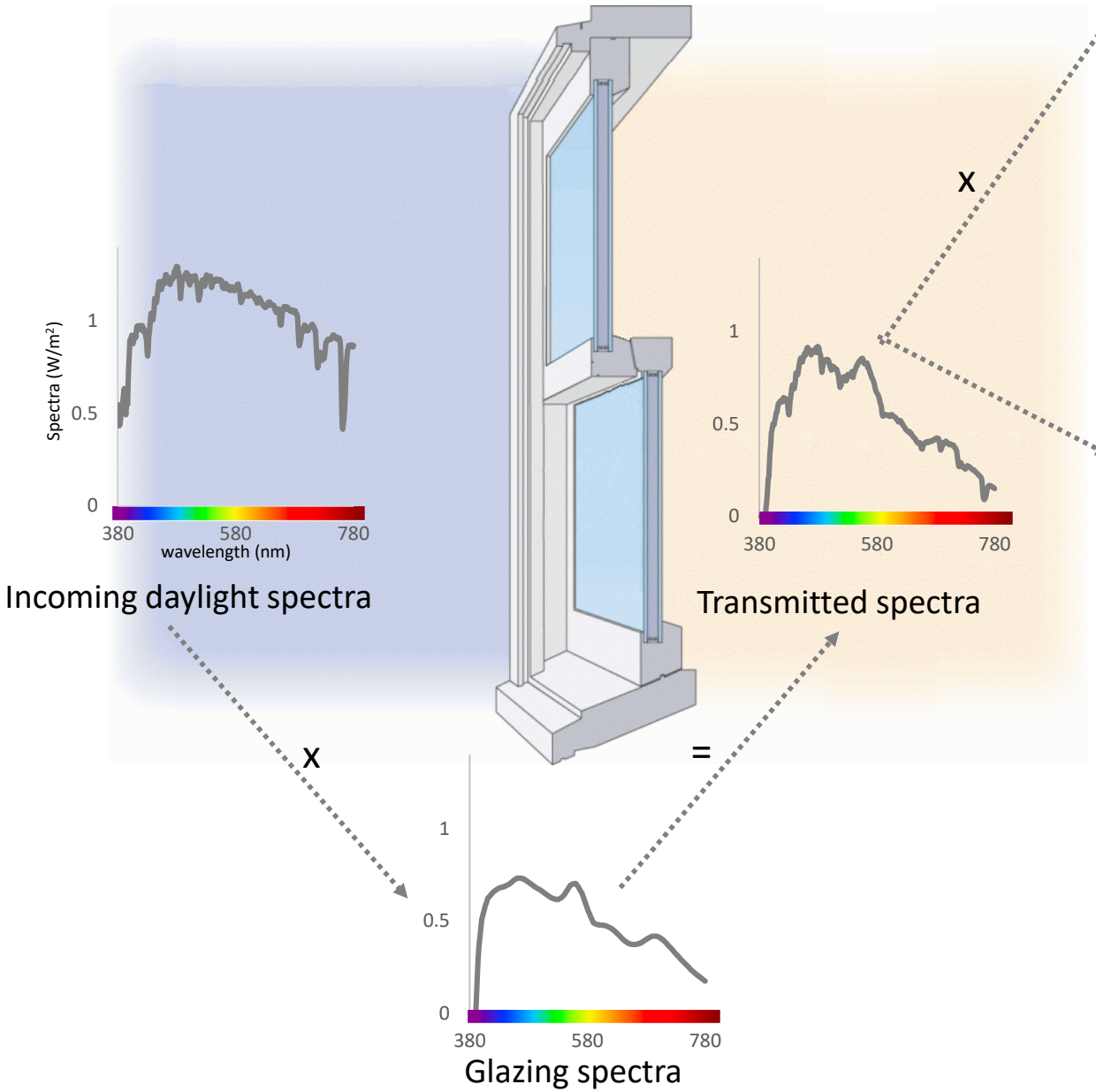
Most surface paints exhibit limited reflectance in the lower spectra.

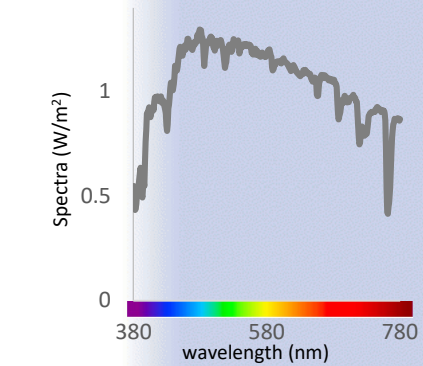
Electric lighting and electronic devices disrupt the dark cycle

Image: Sage glass


Spectra (W/m²)
1
0.5
0
380
580
780
wavelength (nm)
Incoming daylight spectra
1
0.5
0
380
580
780
Transmitted spectra
x
=
1
0.5
0
380
580
780
Glazing spectra

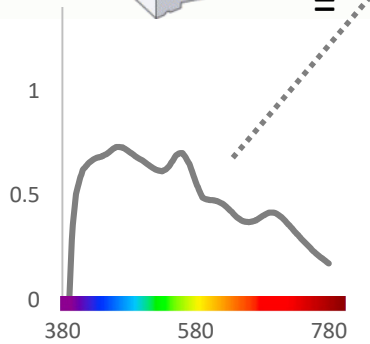

Spectra (W/m²)
1
0.5
0
380
580
780
wavelength (nm)
Incoming daylight spectra
x
Transmitted spectra
x
=
Glazing spectra
Cream wall
Reflected daylight from white wall
Second reflection from wall …


Spectra (W/m²)
1
0.5
0
380
580
780
wavelength (nm)
Incoming daylight spectra
x
Glazing spectra
=
Transmitted spectra
x
Cream wall
Reflected daylight from white wall
Second reflection from wall …
Oak table
Reflected daylight From oak table



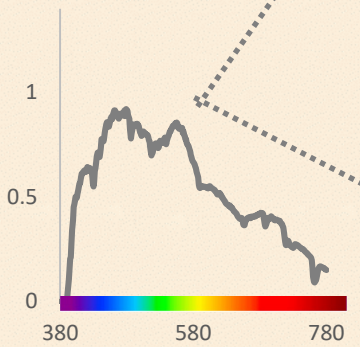
Incoming daylight spectra

x



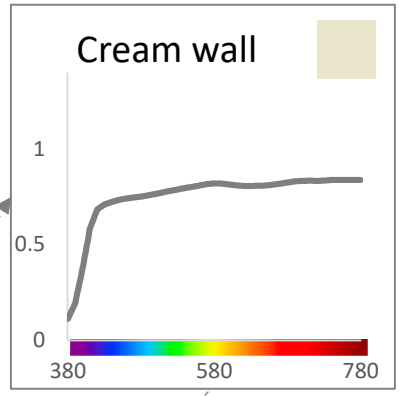
Glazing spectra

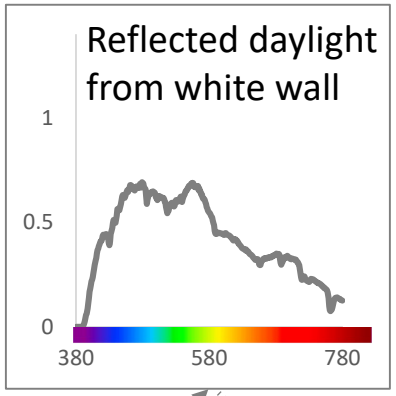
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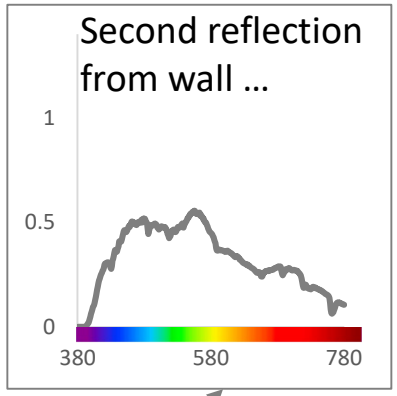


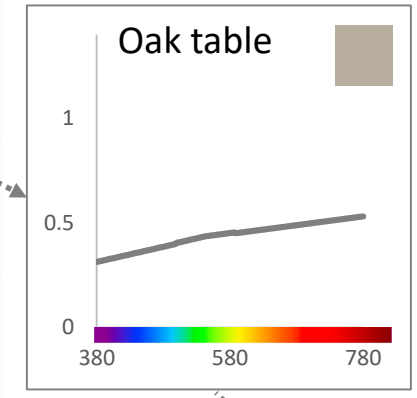
Transmitted spectra

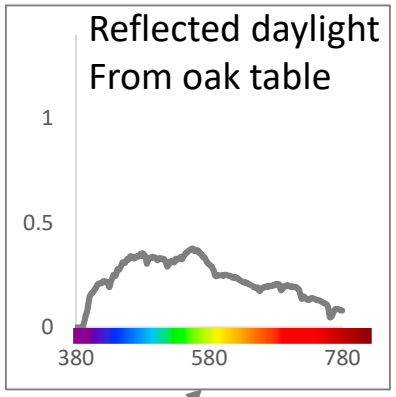
x

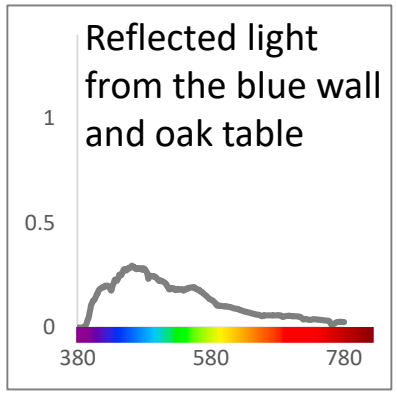


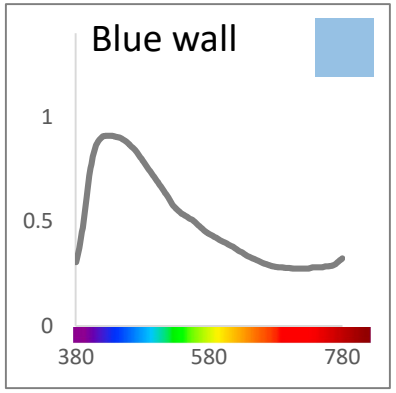


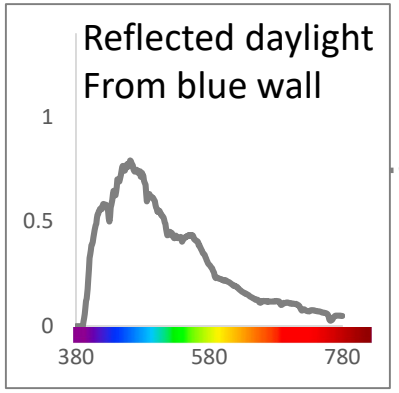




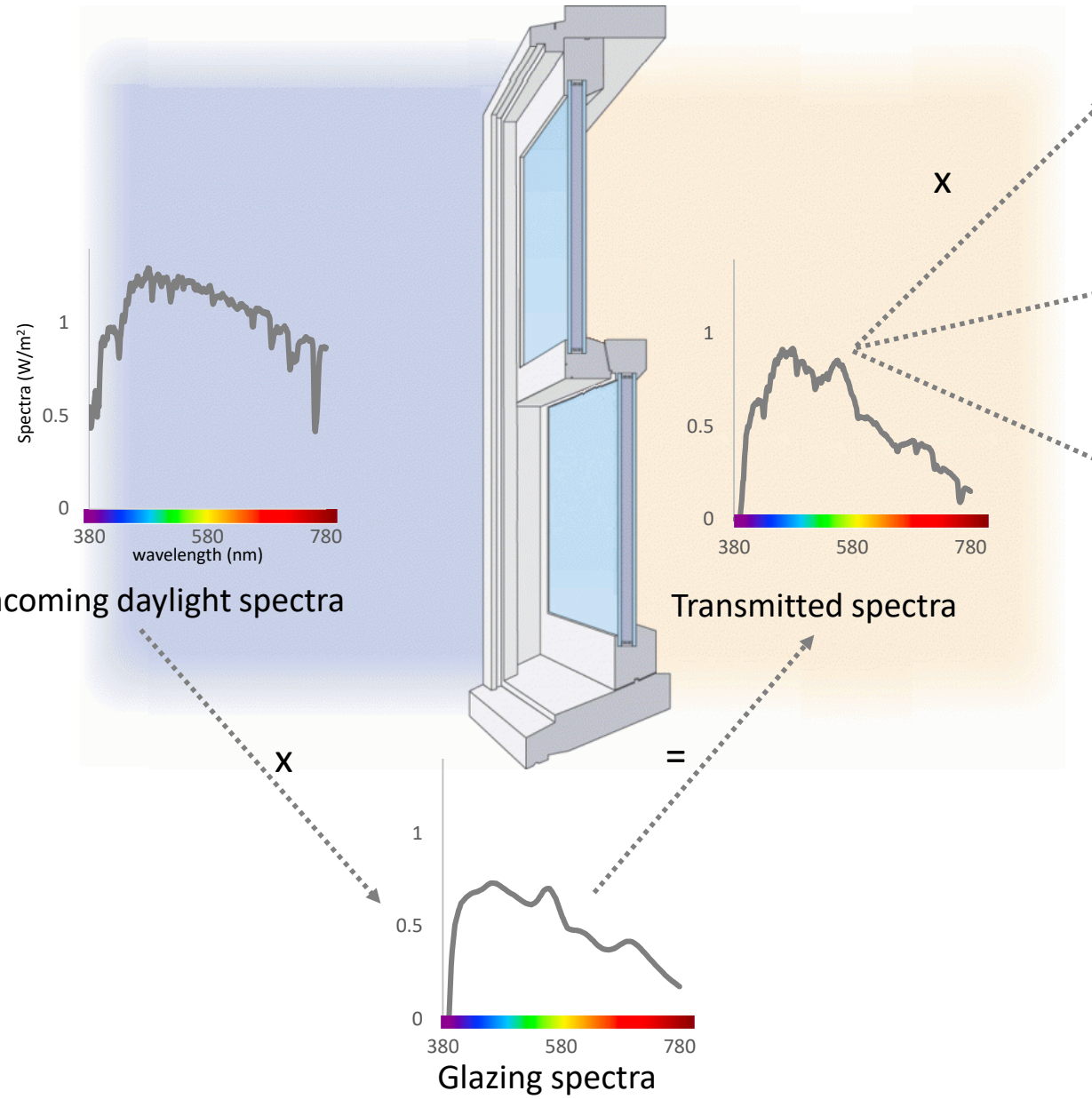








Building systems are routinely altered in response to occupant dissatisfaction.



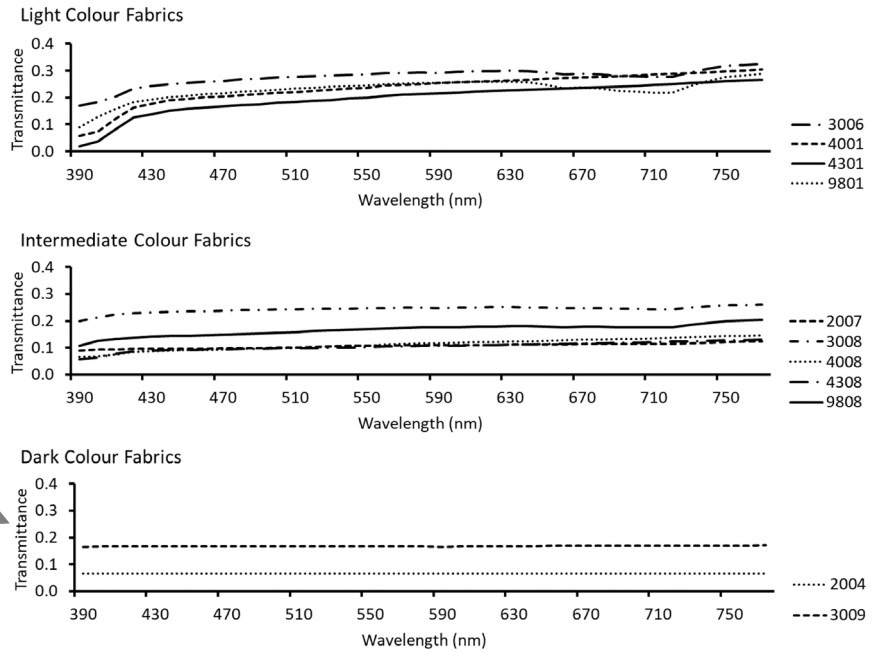
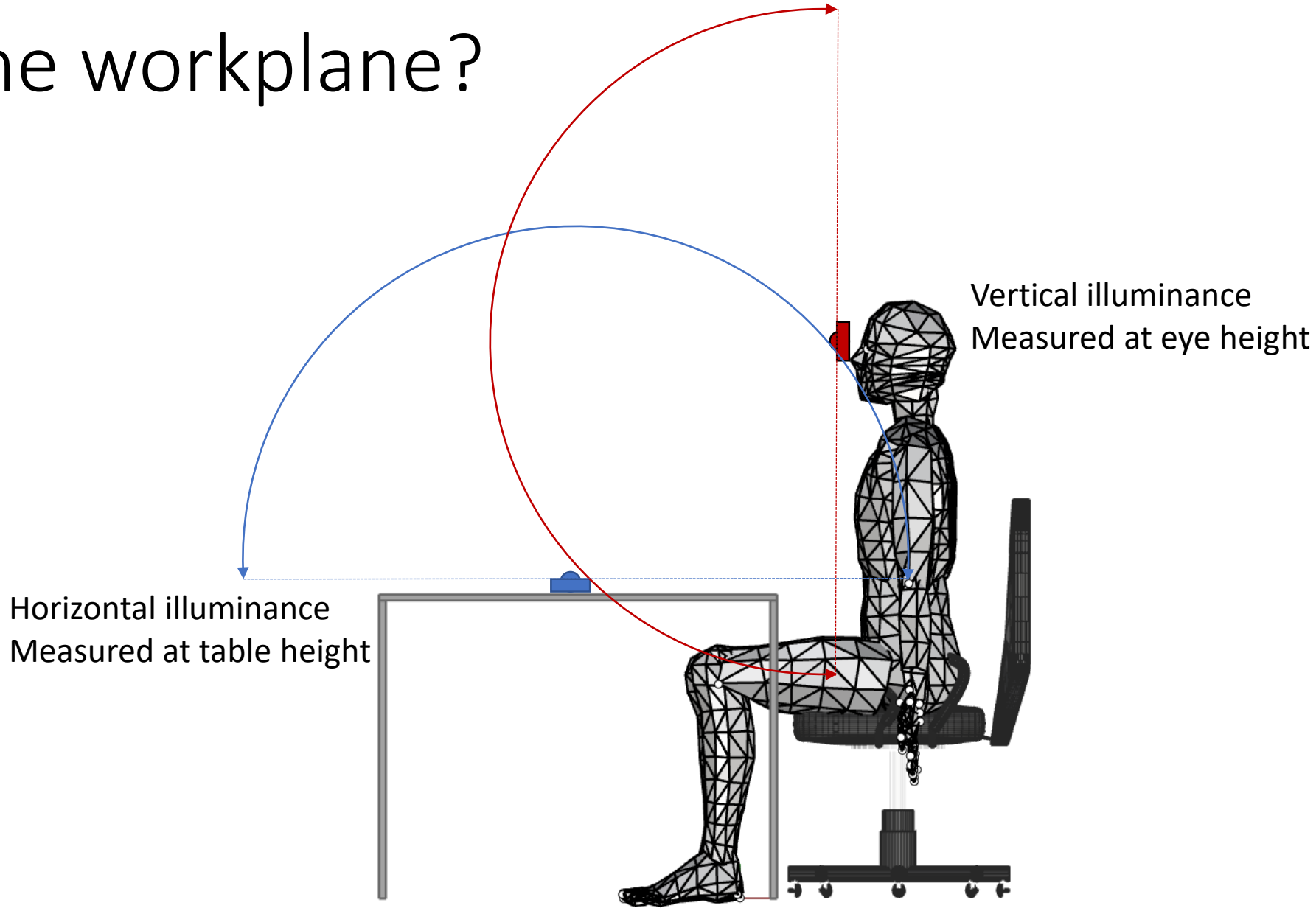
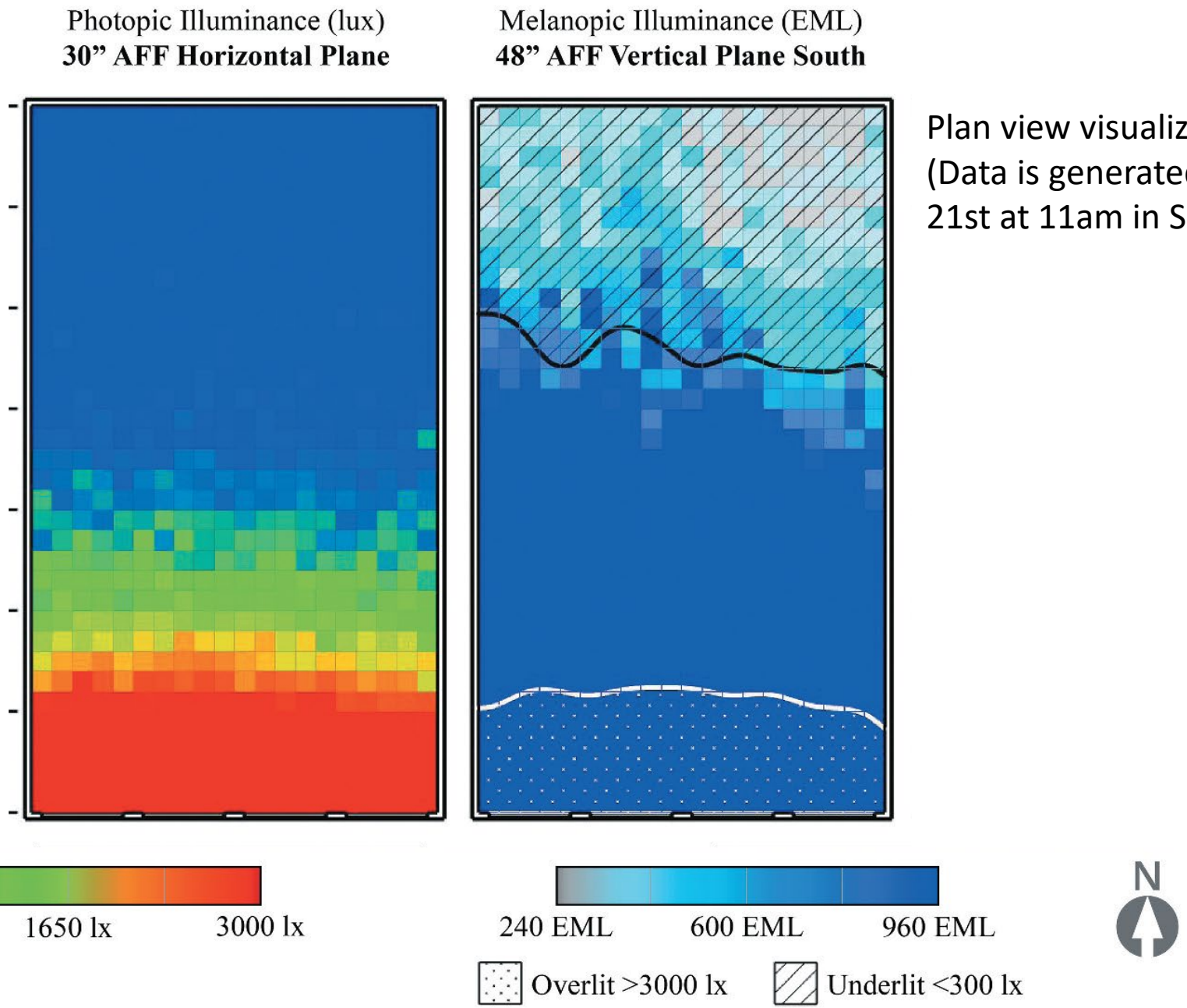


Image credit:Villalba, A., et al. (2022). The impact of woven shade fabrics on correlated colour temperature and illuminance with daylighting. Lighting Research & Technology, 55(6), 530–553

Where is the workplane?

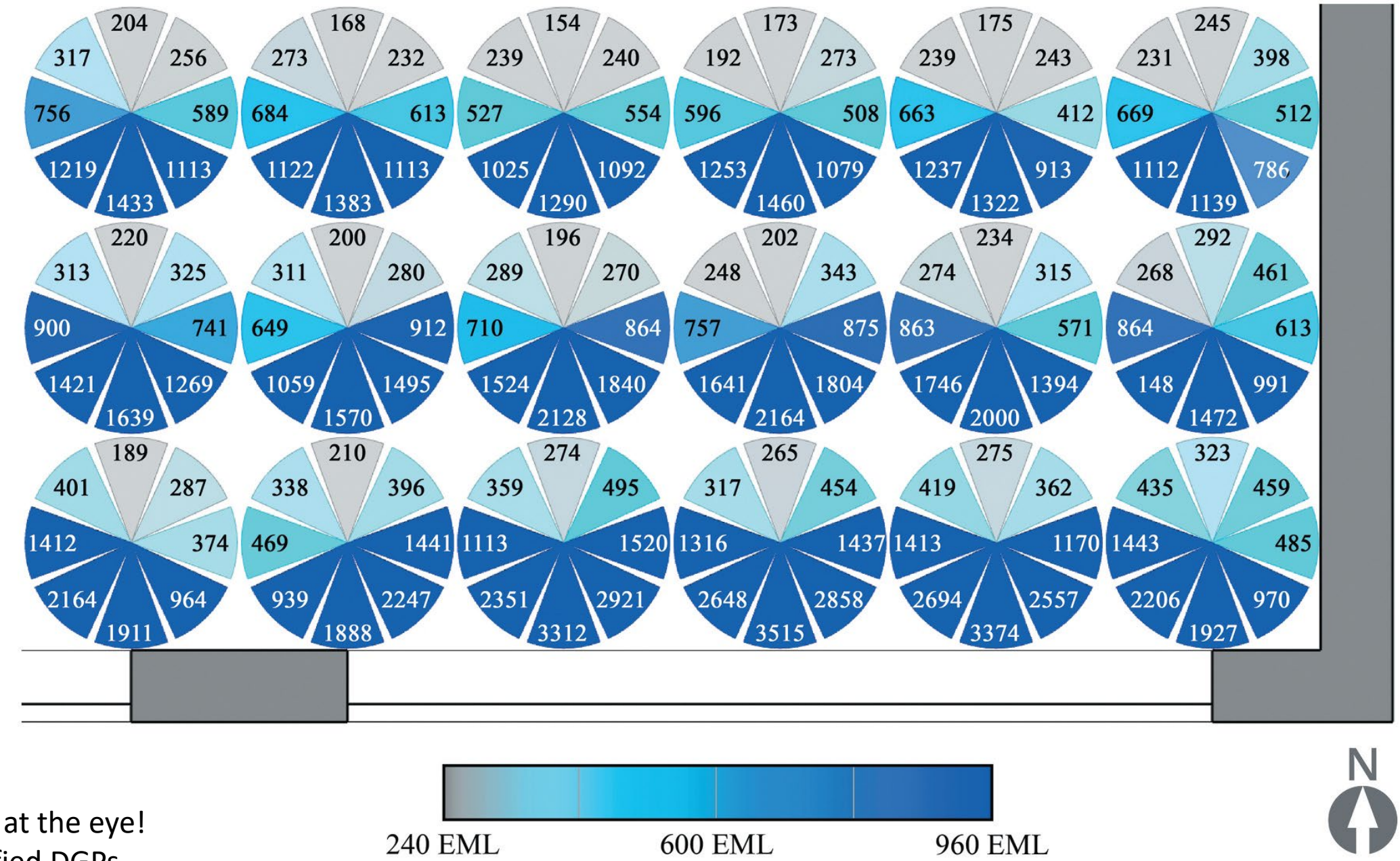




Plan view visualizations (Data is generated for Sept 21st at 11am in Seattle, WA).

Altenberg Vaz N and Inanici M. “Syncing with the Sky: Daylight-Driven Circadian Lighting Design,” *Leukos, the Journal of the Illuminating Engineering Society*, 17(3): 291-309, 2021.





Glare when > 2657 Lux at the eye!
Calculated from Simplified DGPs



Photopic Illuminance (lux)
30” AFF Horizontal Sensors

Melanopic Illuminance (EML)
48” AFF Multi-Directional Sensors

Melanopic Illuminance (EML)
48” AFF South Sensors Only

70’
60’
50’
40’
30’
20’
10’
0’

300 lx 1650 lx 3000 lx

240 EML 600 EML 960 EML

N

Overlit >3000 lx

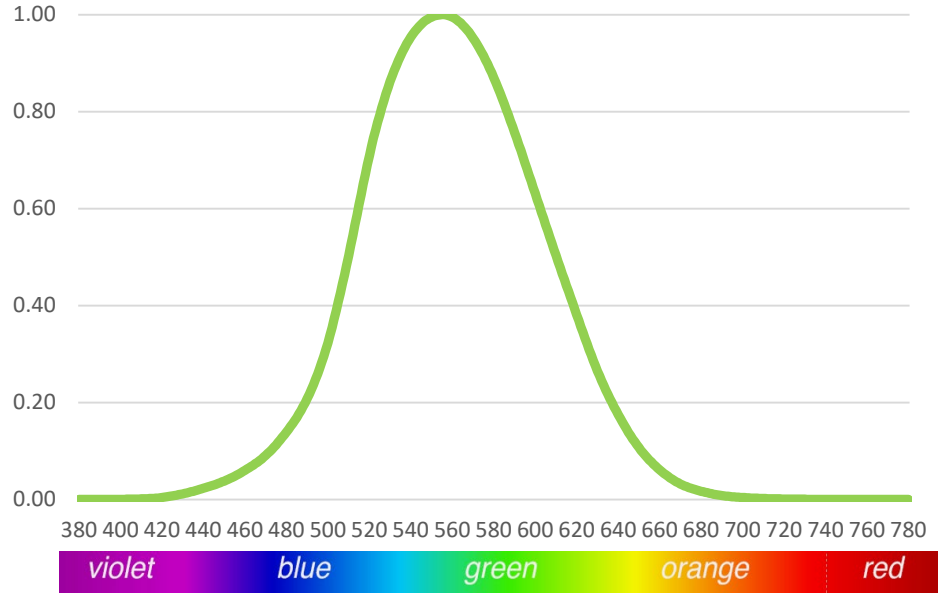
Underlit <300 lx

*Photopic overlit and underlit zones shown for reference

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NROWS=20
NCOLS=1
WAVELENGTH_SPLITS=780 588 480 380
FORMAT=ascii

RGB
0.265
0.67
0.065

Y
0.0000
0.0000
0.0001
0.0004
0.0015
0.0059
0.0192
0.0477
0.0909
0.1379
0.1751
0.1855
0.1627
0.1006
0.0431
0.0187
0.0079
0.0026
0.0004
0.0000



#?RADIANCE
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NROWS=20
NCOLS=1
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RGB

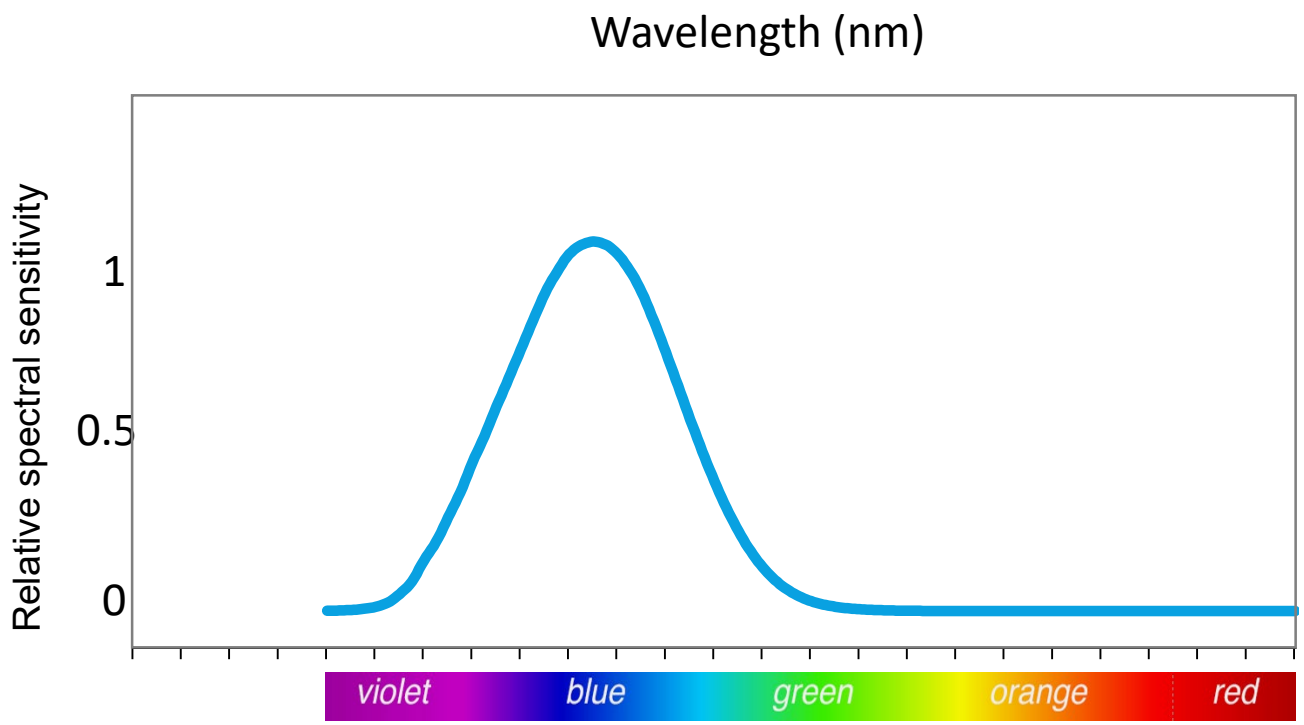


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0.3911
0.6066

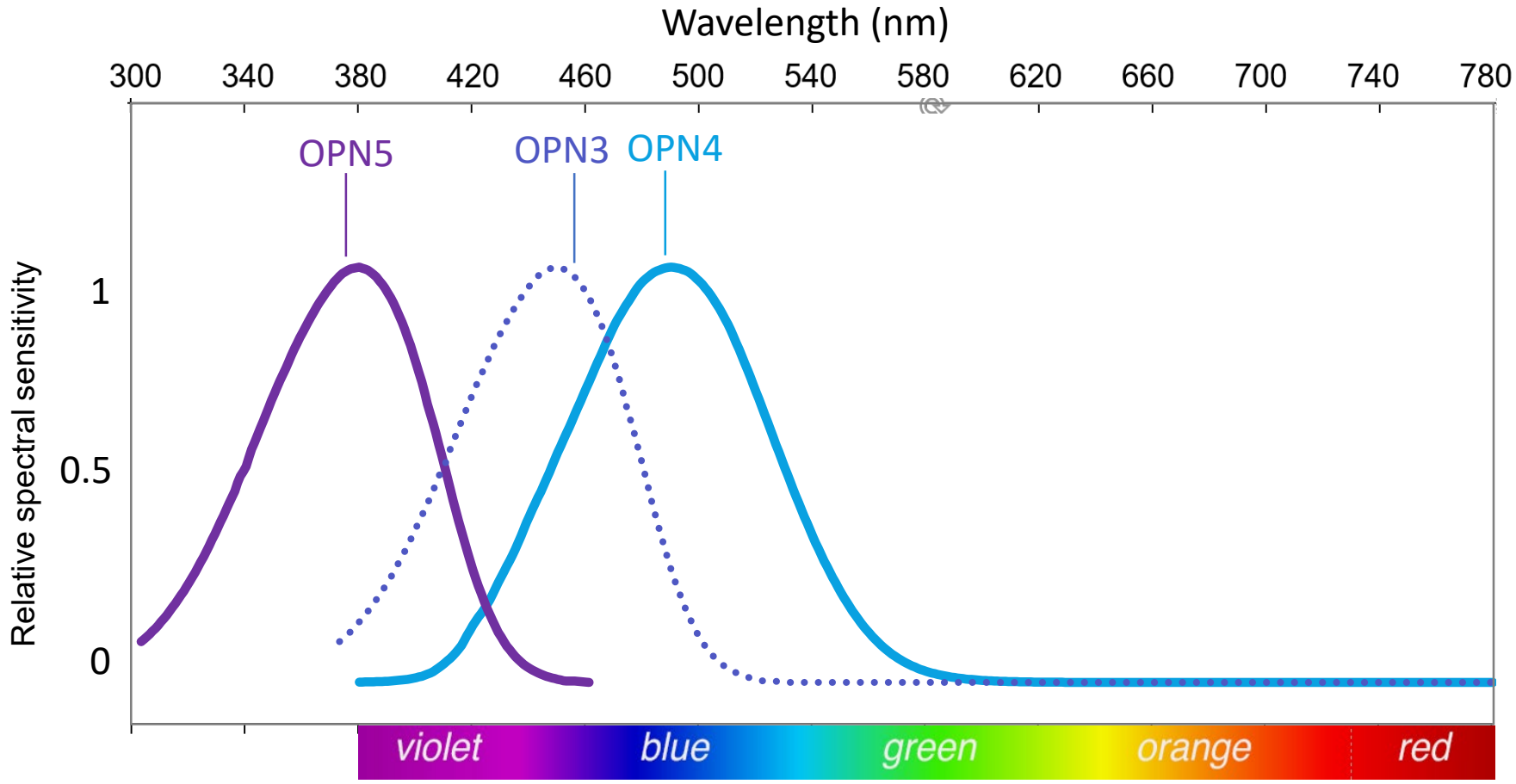
M



0.00000
0.00000
0.00000
0.00000
0.00000
0.00000
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0.00053
0.00288
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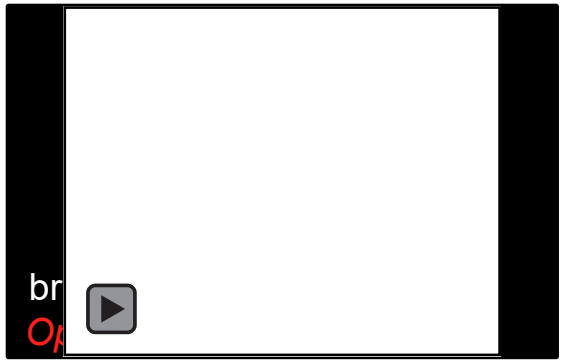


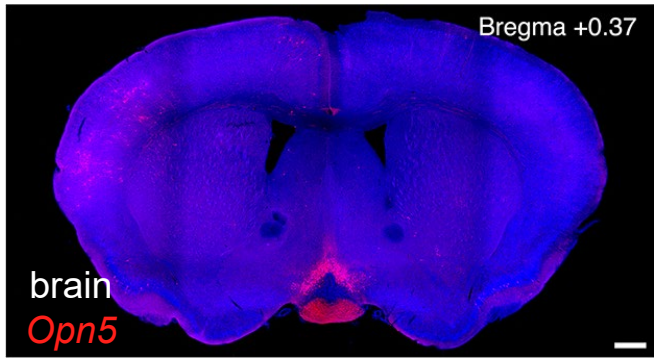
Human Opsins

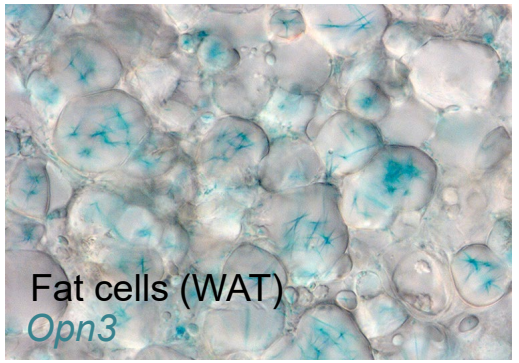


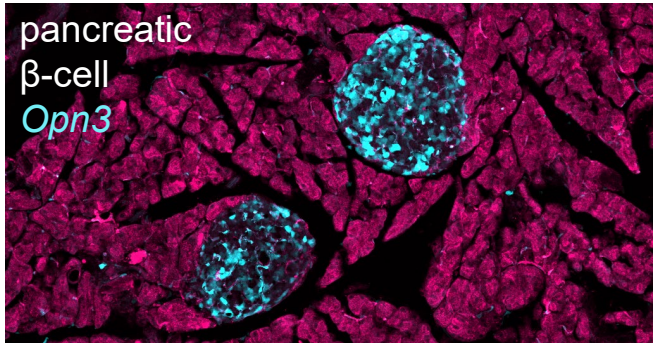
OPN3, OPN4 and **OPN5** are responsive to short wavelengths

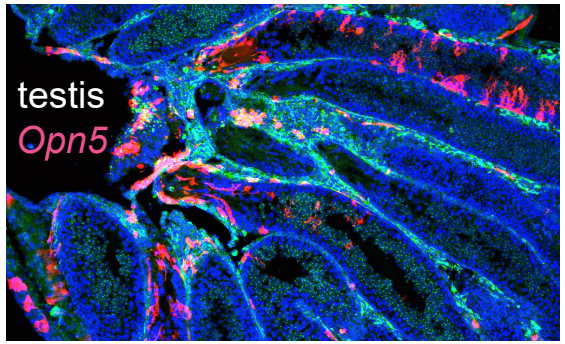
Kojima, D., Mori, S., Torii, M., Wada, A., Morishita, R., & Fukada, Y. (2011). UV-sensitive photoreceptor protein OPN5 in humans and mice. *PLoS ONE*, *6*(10), e26388. doi.org

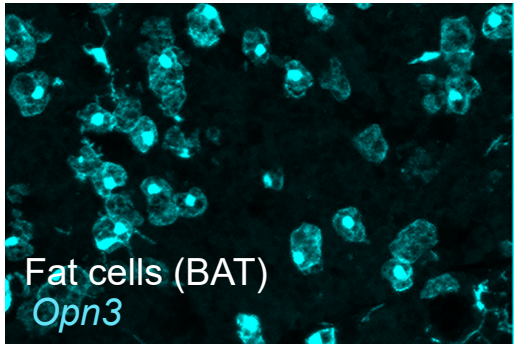


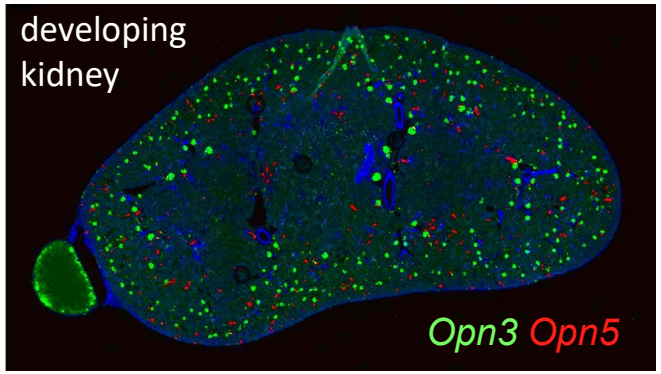


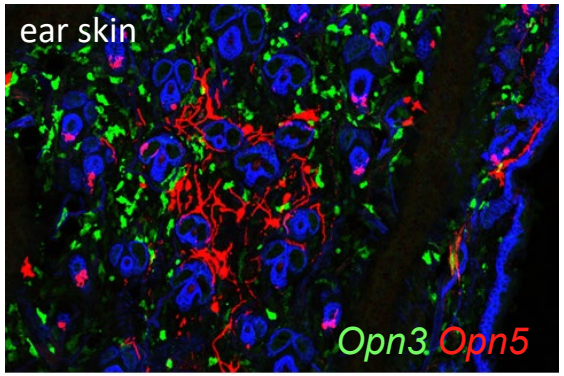


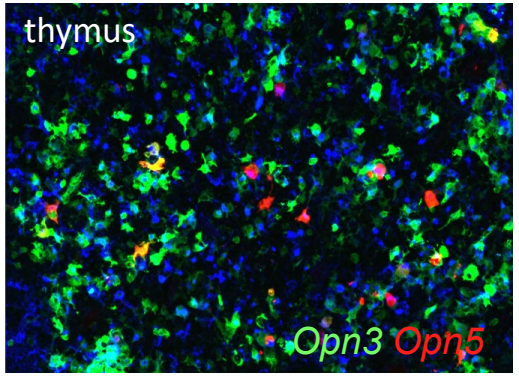




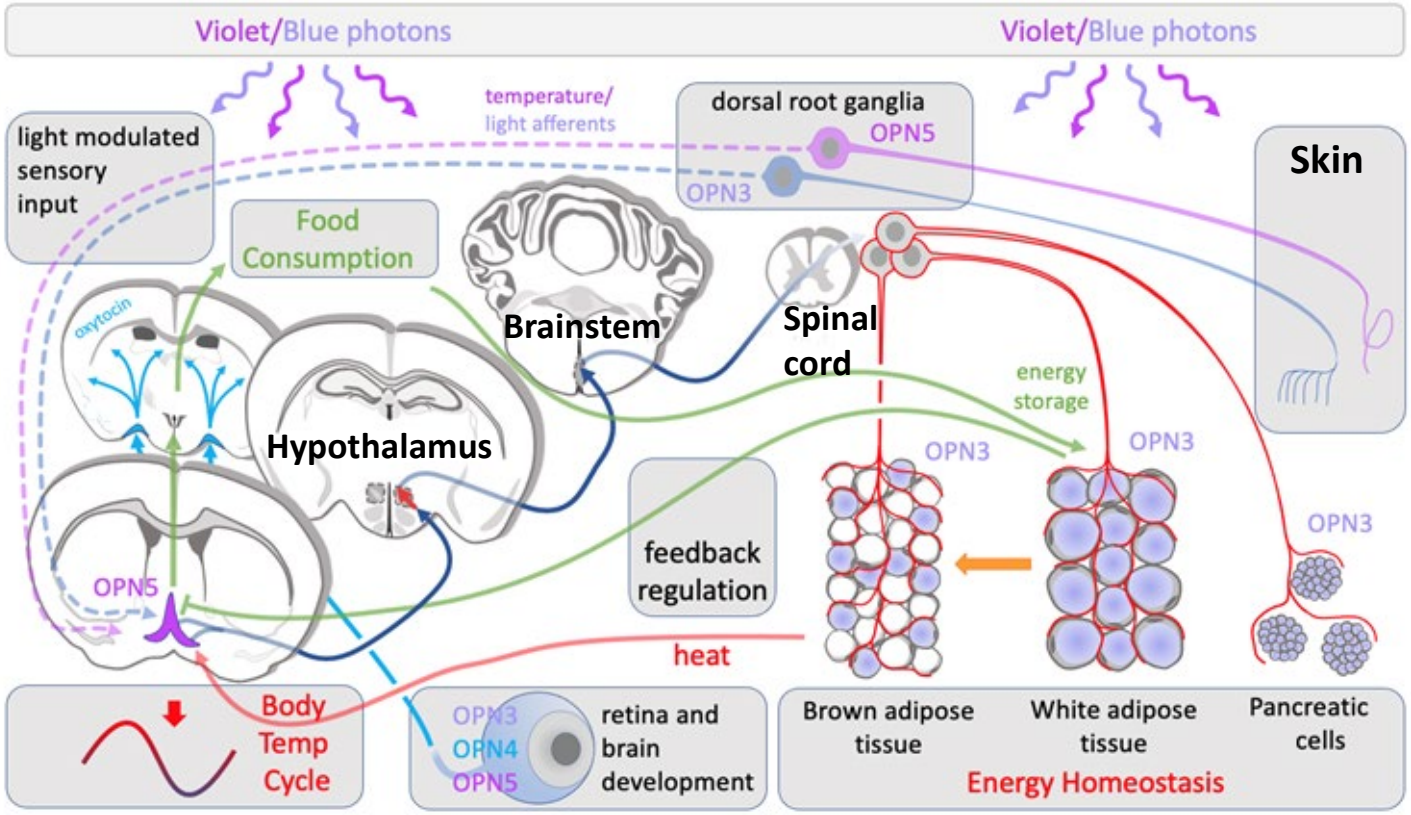








The OPN3 and **OPN5** light sensors are intra- and extraocular and mediate light responses in unexpected places



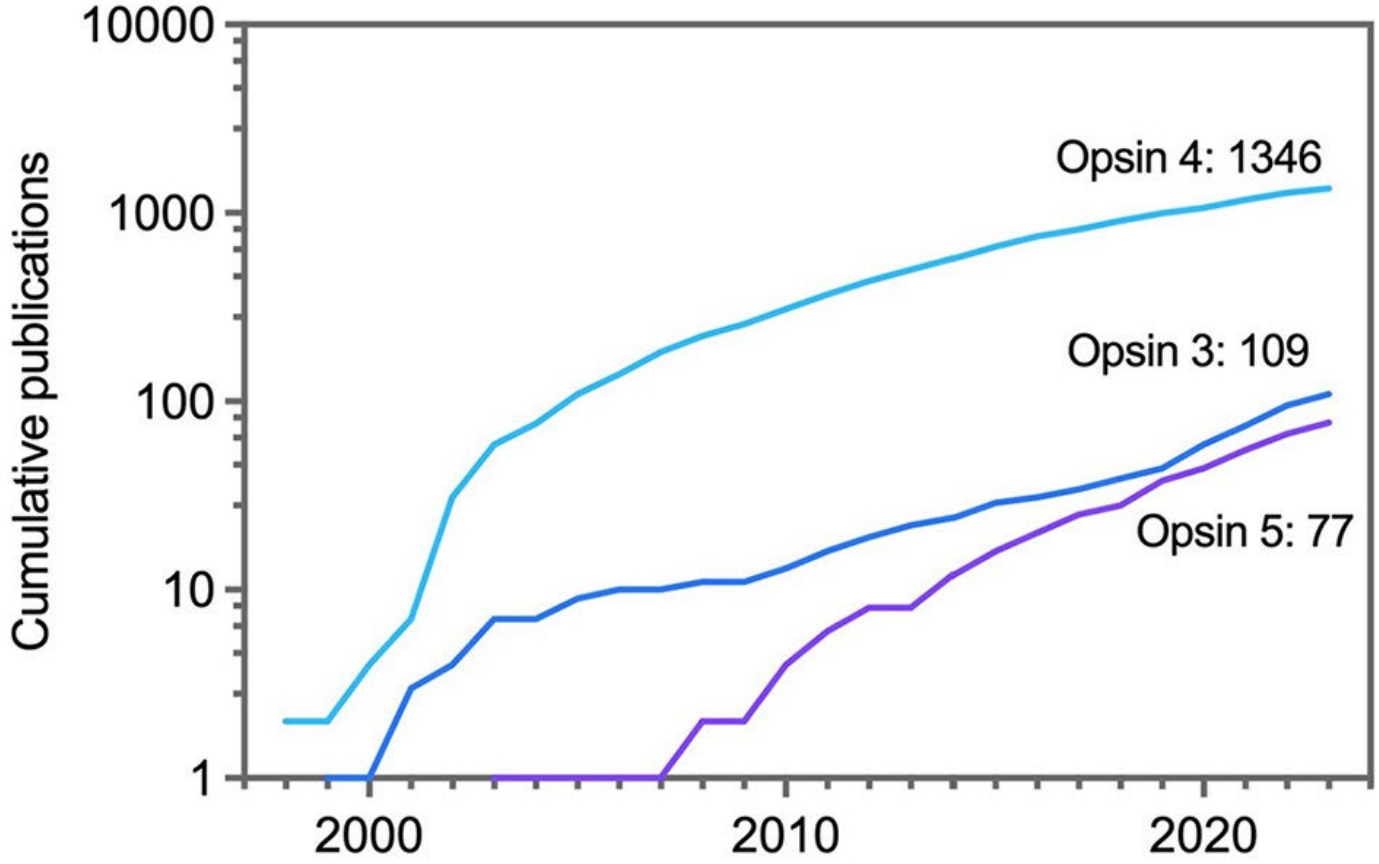
Skin is the largest organ in the human body, and the presence of OPN5 in the skin points to the importance of understanding the impact of extraocular sensing.

OPN3 and OPN5 are crucial light sensors for energy homeostasis and regulation of thermogenesis.

OPN3, OPN4, and OPN5 are implicated in light-dependent retina and brain development.

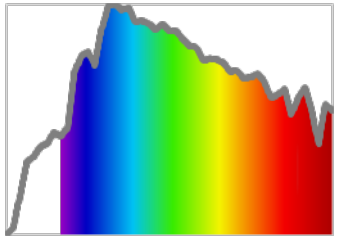
What's at stake?

- Vision
- Eye Developmental processes
  - Rod number
  - Vascular growth
- Circadian rhythms are observed in all aspects of mammalian function, from gene expression to complex physiologic processes
- Metabolic Homeostasis
  - Energy mobilization
  - Temperature regulation
  - Food intake
- Mental health
- …



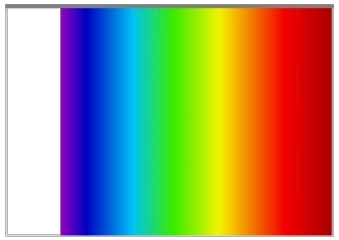
Heschong L, Lang RA, Vemaraju S. "New dimensions of daylight and health: How opsin biology may inform lighting standards in the near future," *Lighting Research and Technology*, 57(6-7), 636–648, 2025.

Metrology



CIE Metrology
M-EDI: Melanopic –Equivalent Daylight Illuminance, Lux

N-EDI: Neuropic - Equivalent Daylight Illuminance, Lux
i.e. with D65, Photopic Lux = Melanopic Lux, M-EDI = Neuropic Lux, N-EDI



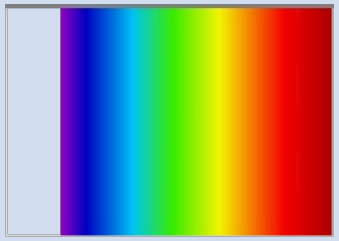
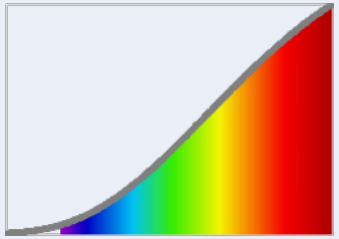
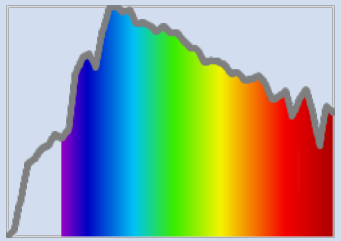
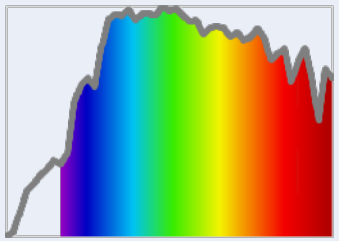
EML – Equivalent Melanopic Lux

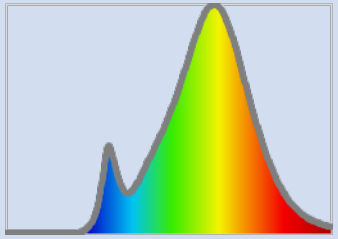
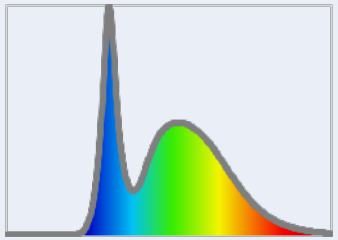
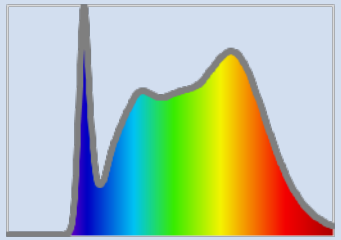
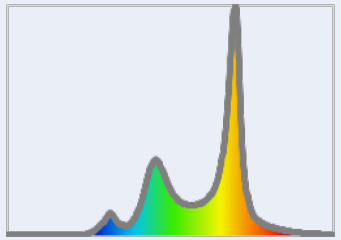
Kojima et al. 2011
ENL - Equivalent Neuropic Lux
i.e., with an Equal energy light source, Photopic = Melanopic Lux, EML = Neuropic Lux, ENL

Inanici M, Greenberg J, Lang RA, Struve J, Gruner KA. “Metrology for Neuropic response to light: A case study in a neonatal intensive care unit,” International Commission on Illumination (CIE) 2025 Conference, July 4-11, 2025 (CIE 2025 Best paper Award).

Metrology: M-EDI, N-EDI vs EML, ENL

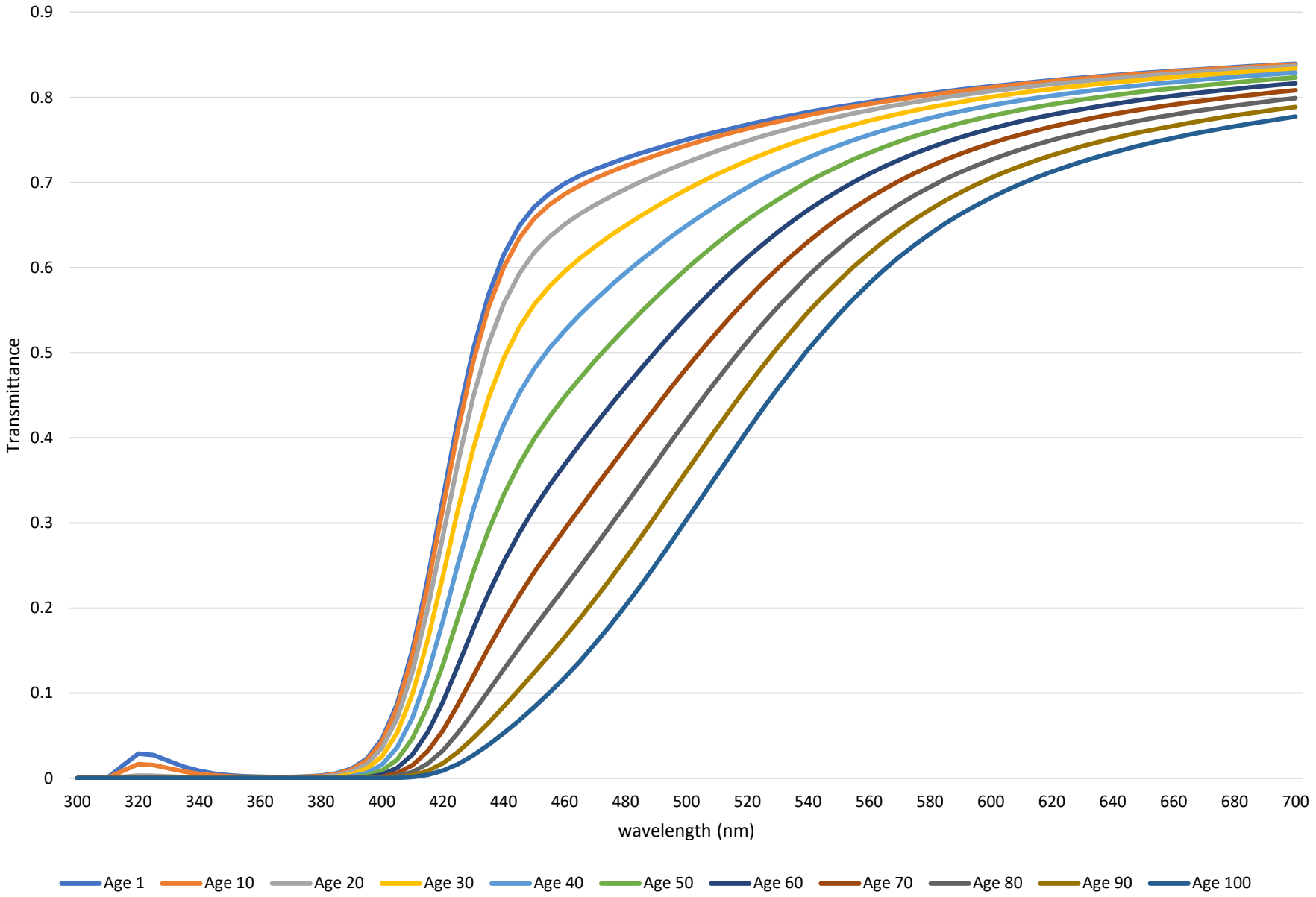
Response	α-opic efficacy	Photoreceptor [range]	Photo-pigment	α-opic action spec.	α-opic equivalent D65, $E_{v,\alpha}$(lx)	Eq. Melonopic/ Neuropic Lux
Melanopic	1,3262 $mW.lm^{-1}$	ipRGCs [380-780 nm]	Melanopsin	$s_{mel}(\lambda)$	$E_{v,mel}$ M-EDI	EML=M-EDI * 1.104 M-EDI= EML * 0.906
Neuropic	0,5716 $mW.lm^{-1}$	RGCs and extra-ocular [303-461 nm]	Neuropsin	$s_{nr}(\lambda)$	$E_{v,nr}$ N-EDI	ENL = N-EDI * 0.559 N-EDI = ENL * 1.786

	[300 - 780 nm]	**Illuminance** E_v **(lx)**	**Melanopic Irradiance** **(mW.m^{-2})**	**M-EDI** $E_{v,mel}^{D65}$ **(lx)**	**Neuropic Irradiance** **(nW.m^{-2})**	**N-EDI** $E_{v,nr}^{D65}$ **(lx)**
Equi-energy E		**100**	120	**91**	102	**179**
CIE Illuminant A		**100**	66	**50**	10	**17**
D65		**100**	133	**100**	57	**100**
D55		**100**	120	**91**	39	**69**

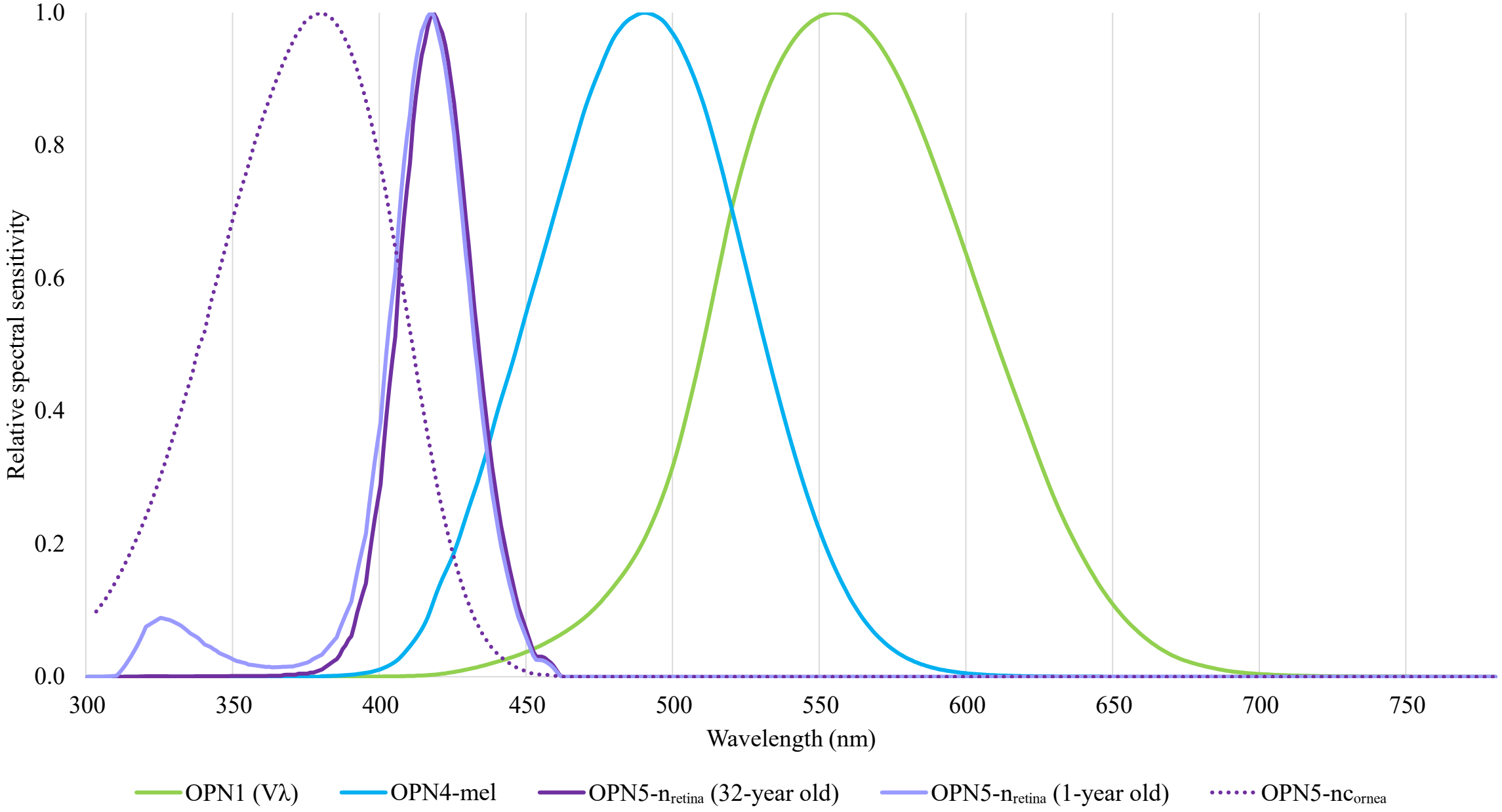
	[300 - 780 nm]	**Illuminance** E_v **(lx)**	**Melanopic Irradiance** **(mW.m^{-2})**	**M-EDI** $E_{v,mel}^{D65}$ **(lx)**	**Neuropic Irradiance** **(nW.m^{-2})**	**N-EDI** $E_{v,nr}^{D65}$ **(lx)**
CIE LED-B1		**100**	54	**41**	0,6	**1**
CIE LED-B5		**100**	113	**86**	2	**4**
CIE LED-V2		**100**	100	**75**	19	**33**
CIE LED-RGB1		**100**	77	**58**	0,6	**1**

Metrology

Total transmittance of the clear ocular media of the aging human eye



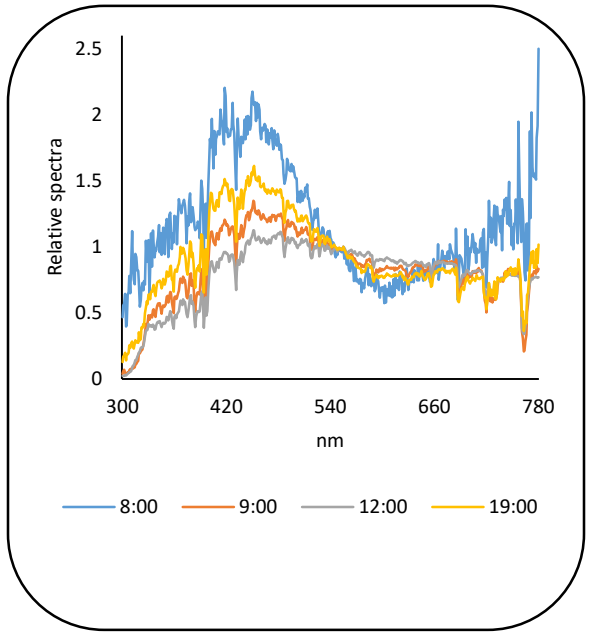
CIE-203-2012, A Computerized Approach to Transmission and Absorption Characteristics of the Human Eye



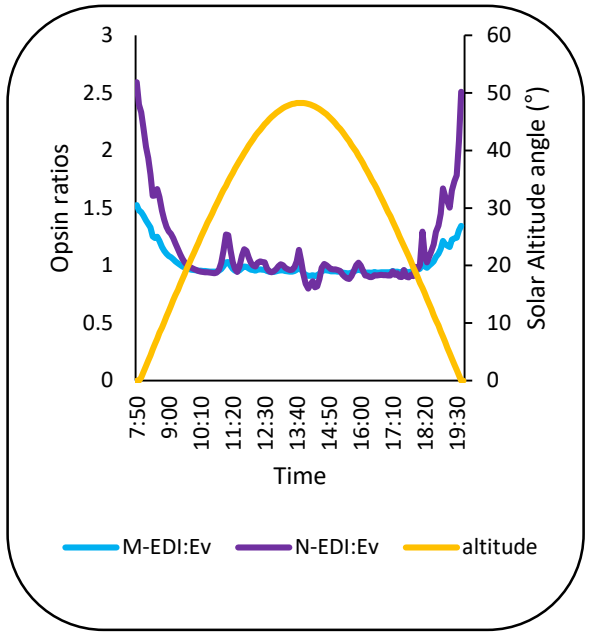
Inanici M, Greenberg JM, Struve J, Gruner KA, Lang RA. Neuropic Response to Light: Metrology and Applications in Built Environments. Preprint

	D65	D55	D75	A	E	LED-B1	LED-V2
Neuropic Irr., NI_{retina} (W/m^2)	0.0395	0.0305	0.0741	0.0089	0.043	0.0033	0.0367
N-EDI_{retina} efficacy of luminous radiation mW/lm	0.3945	0.3050	0.7406	0.0893	0.4297	0.0329	0.3667
N-EDI_{retina} (lx)	**100**	**77**	**120**	**23**	**109**	**8**	**93**
ENL_{retina} (lx)	92	71	110	21	100	8	85
Neuropic photon irr., NPI_{retina} /m^2.s	8.29 E+16	6.41 E+16	9.91 E+16	1.88 E+16	9.03 E+16	6.91 E+15	7.71 E+16
Log Neuropic photon irr., LogNPI_{retina} /m^2.s	16.919	16.807	16.996	16.273	16.956	15.839	16.87
Corneal - Neuropic Irr. NI_{cornea} (W/m^2)	0.0572	39.4	0.0471	0,096	0.1021	0.0006	0.0188
N-EDI_{cornea} efficacy of luminous radiation mW/lm	0.5716	3.942	0.4714	0.0961	10.2119	0.0064	0.1876
N-EDI_{cornea} (lx)	**100**	**69**	**130**	**17**	**179**	**1**	**33**
ENL_{cornea} (lx)	56	39	73	9	100	1	18
Neuropic photon irr., NPI_{cornea} /m^2.s	1.09 E+17	7.53 E+16	1.41 E+17	1.84 E+16	1.95 E+17	1.21 E+15	3.58 E+116
Log Neuropic photon irr., LogNPI_{cornea} /m^2.s	17.038	16.877	17.151	16.264	17.290	15.085	16.554

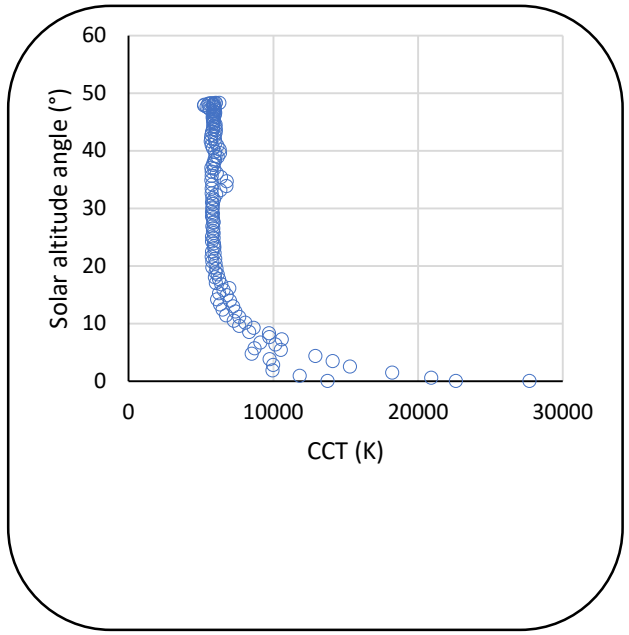
Towards establishing a criteria



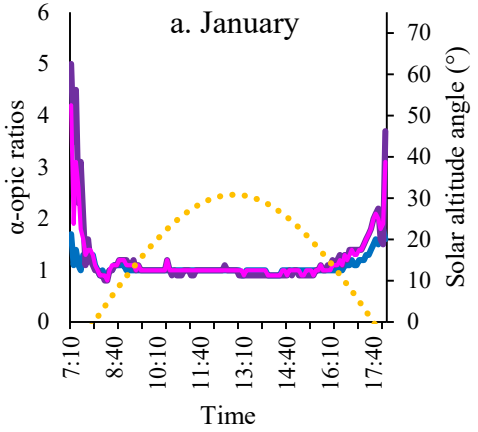
Relative horizontal global spectra for sunrise, noon, and sunset during one day in March

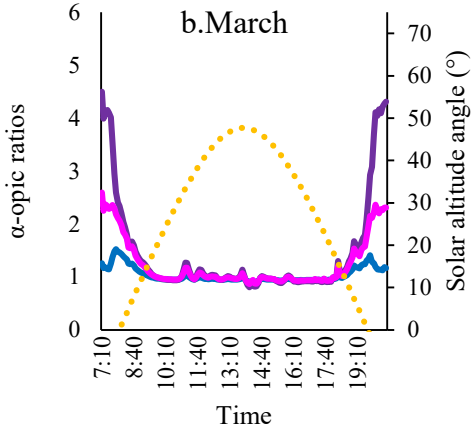


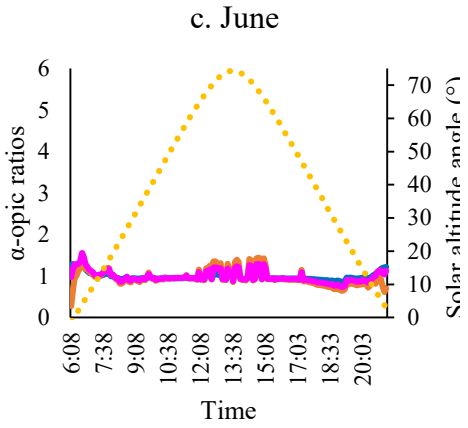
Melanopic-to-Photopic and Neuropic-to-Photopic ratios during one day in March

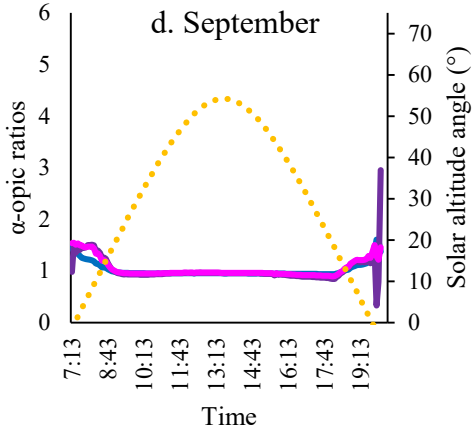


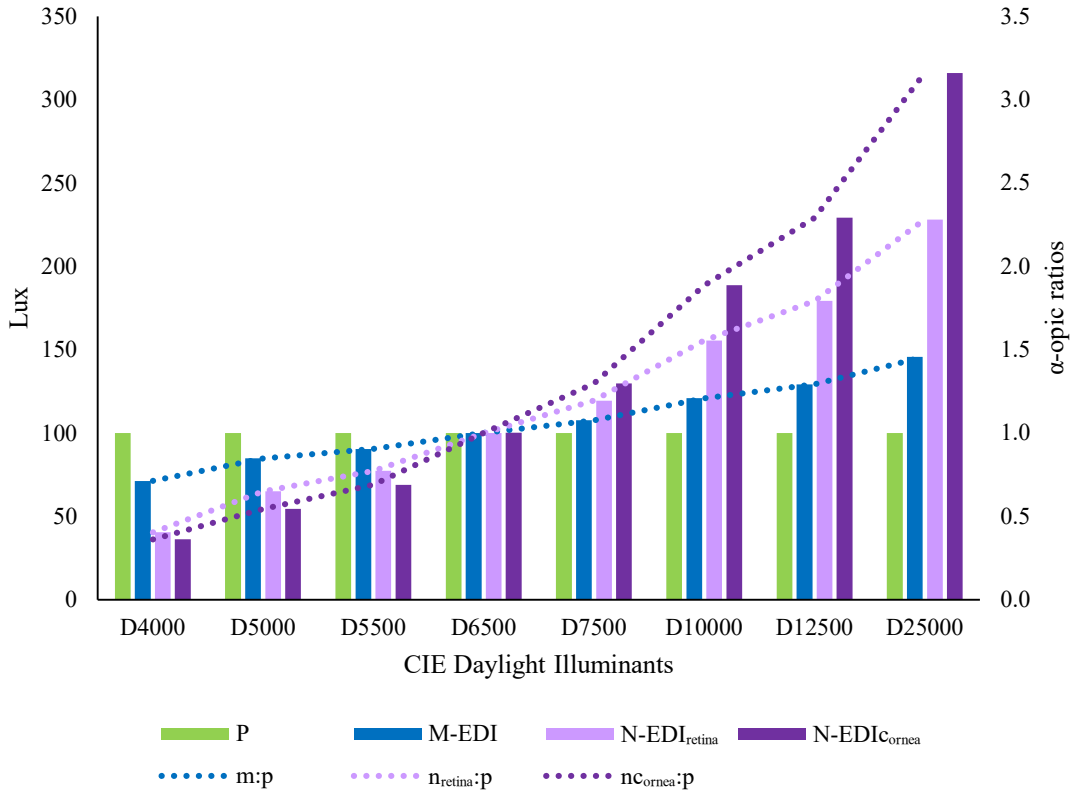
Daylight CCT variations as a function of solar altitude angle from sunrise to sunset during one day in March

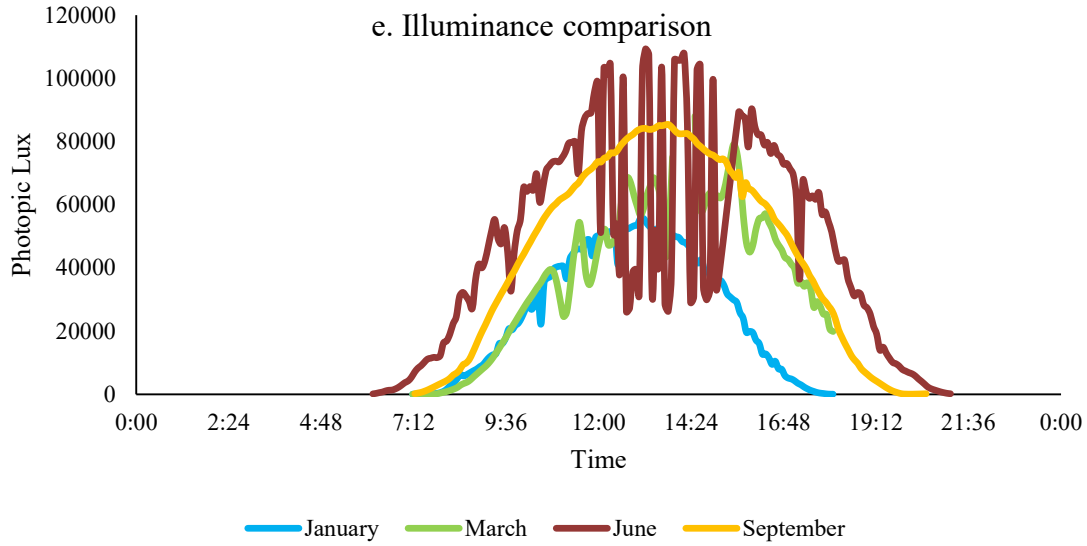












Inanici M, Greenberg JM, Struve J, Gruner KA, Lang RA. Neuropic Response to Light: Metrology and Applications in Built Environments. Preprint

Risks, benefits, time to rethink?

“UVR is a skin carcinogen, yet no studies link sun exposure to increased all-cause mortality. Epidemiological studies from the United Kingdom and Sweden link sun exposure with reduced all-cause, cardiovascular, and cancer mortality…

Dermatologists and skin researchers have made great progress in understanding some aspects of the interaction between UV and our skin, but we need to stand back and take a more holistic view of UV exposure and human health. The United Nations Environmental Effects Assessment panel (Neale et al, 2023) and an Australian panel endorsed by the Cancer Council of Australia and Australasian College of Dermatologists (Neale et al, 2024) have both just produced position statements recognizing that sunlight has beneficial effects that should be considered in formulating policy on sunlight exposure and highlighting the necessity of carrying out further research into these beneficial effects. We should take note.”

Weller R. **Sunlight: Time for a Rethink?** Journal of Investigative Dermatology, 2024; 144, 1724-1732



The NICU

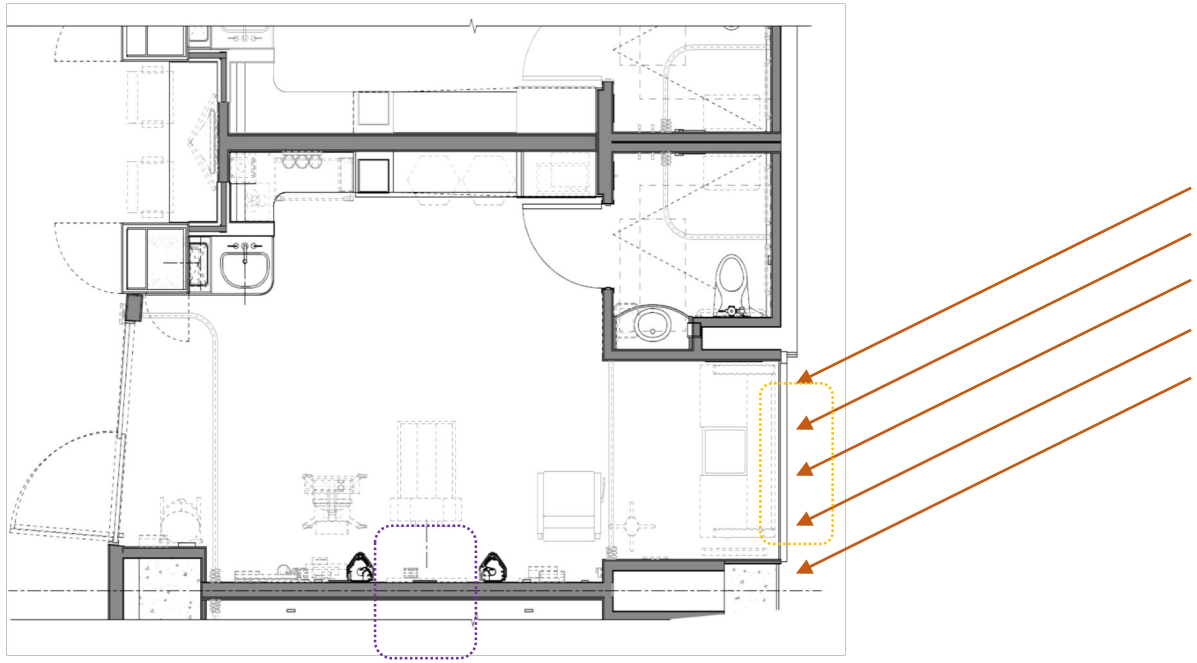
- The preterm infant transitions from an intrauterine environment that provides circadian and other environmental cues from the mother.
- Clinical care in the NICU had often prioritized 'dark and quiet' environments.
- Emerging research suggests that low lit environment approach may not provide the most supportive environment for the developing infant.
- Neuropsin and melanopsin activation support circadian alignment and development in neonates.

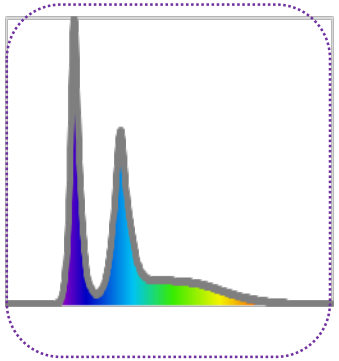
Setting



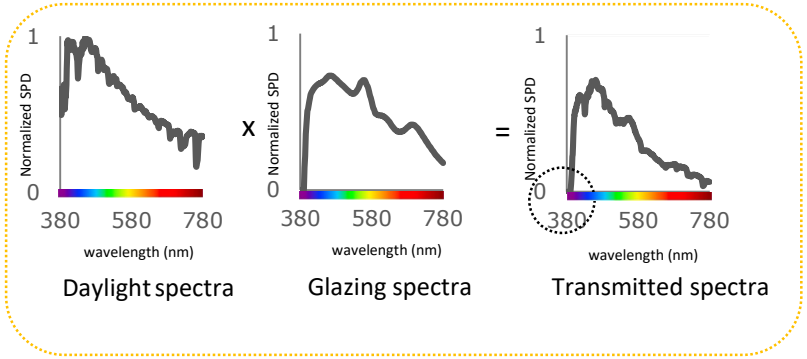


The new NICU at Cincinnati Children's Hospital

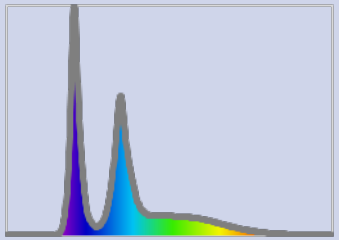
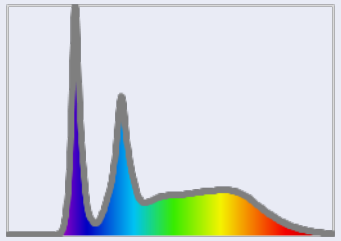
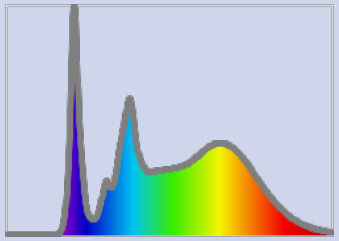
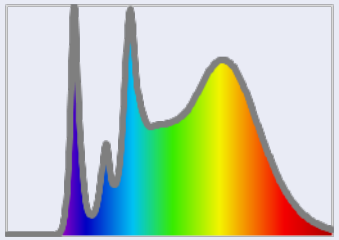




Violet and blue light supplement

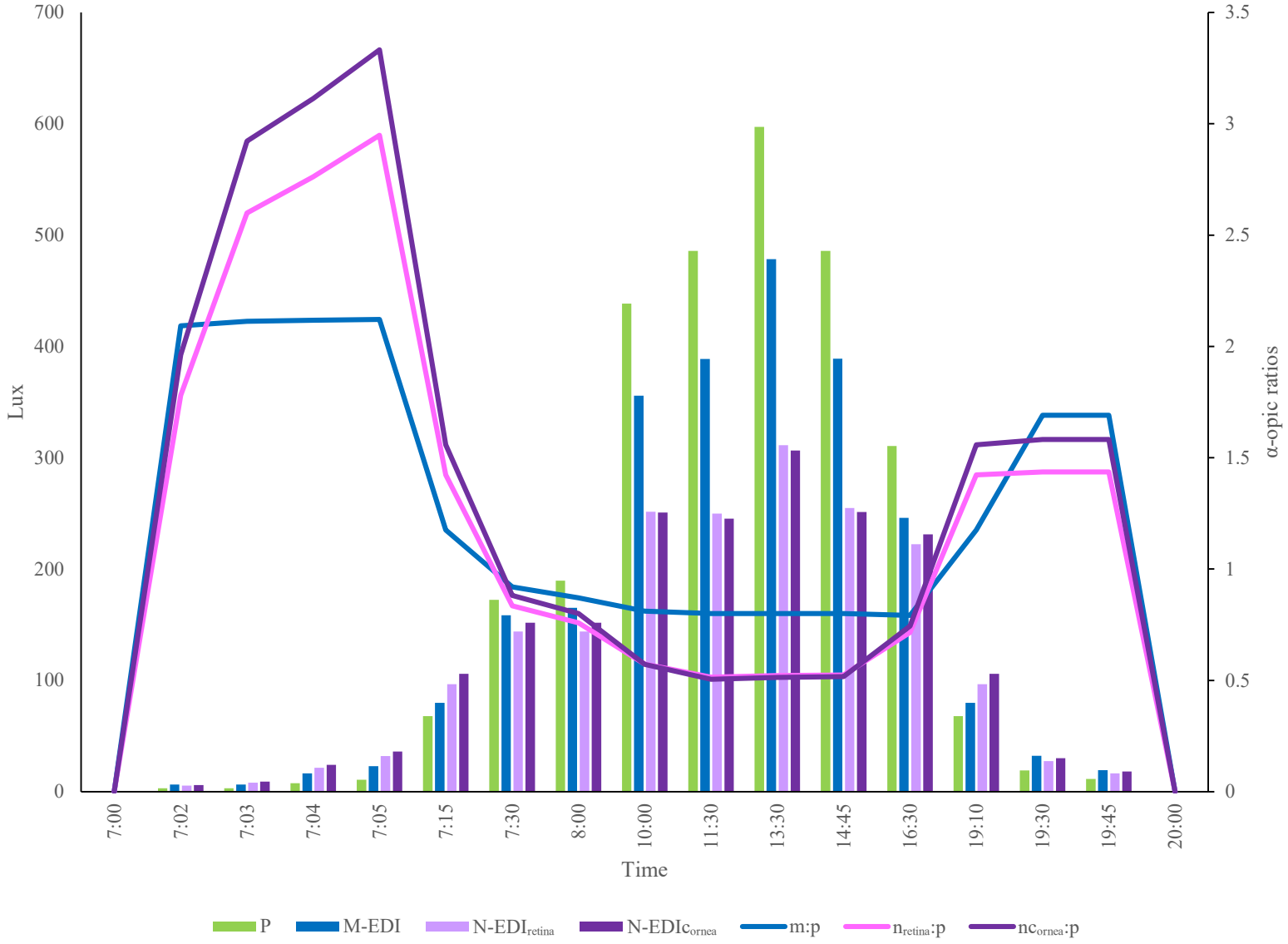


Transmitted daylight

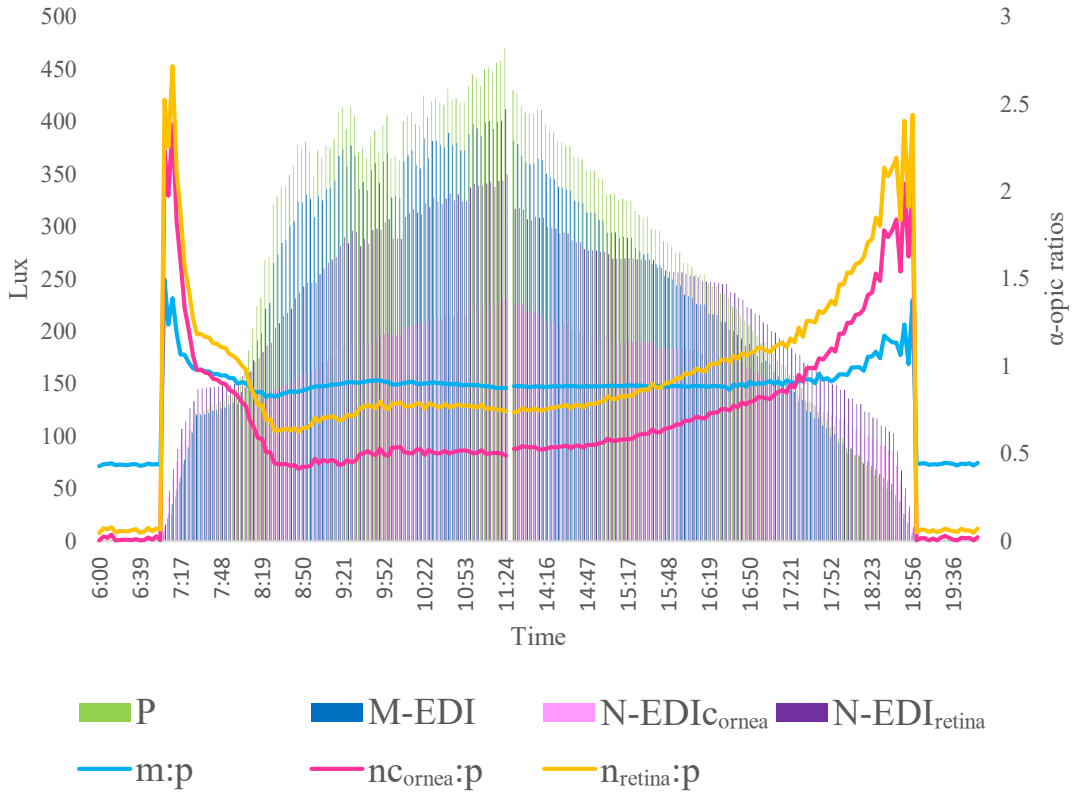
	[300 - 780 nm]	**Illuminance** E_v **(lx)**	**Melanopic Irradiance** **(mW.m^{-2})**	**M-EDI** $E_{v,mel}^{D65}$ **(lx)**	**Neuropic Irradiance** **(nW.m^{-2})**	**N-EDI** $E_{v,nr}^{D65}$ **(lx)**
NICU LED-s1 (7:05)		**100**	281	**212**	191	**333**
NICU LED-s2 (7:15)		**100**	156	**118**	89	**156**
NICU LED-s3 (7:30)		**100**	122	**92**	50	**88**
NICU LED-s4 (11:30)		**100**	106	**80**	29	**51**

Metrology

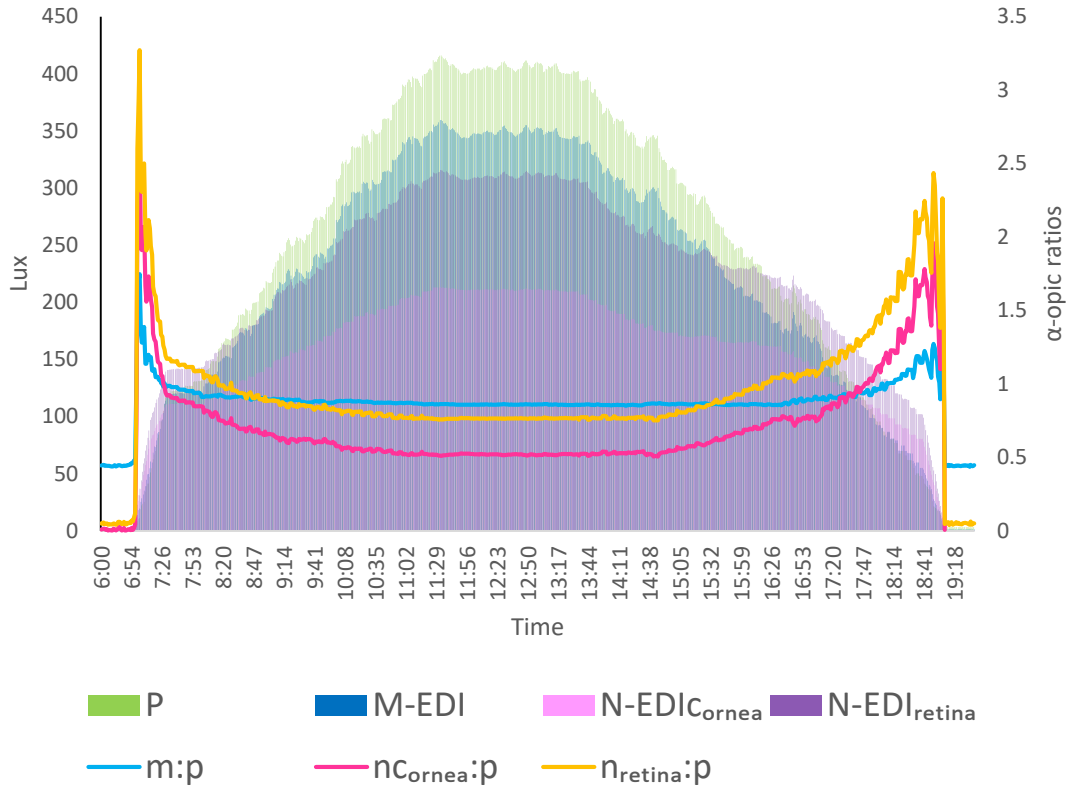
17 cycles of electric lighting in a day



One-day measurements on a patient's bed



January 22 (mostly sunny day)



March 4 (cloudy day).

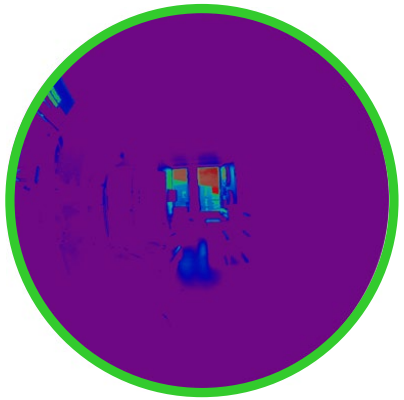
Inanici M, Greenberg JM, Struve J, Gruner KA, Lang RA. **Neuropic Response to Light: Metrology and Applications in Built Environments.** Preprint



Color calibrated
HDR photography
(3 channel)
+
Spectrophotometry



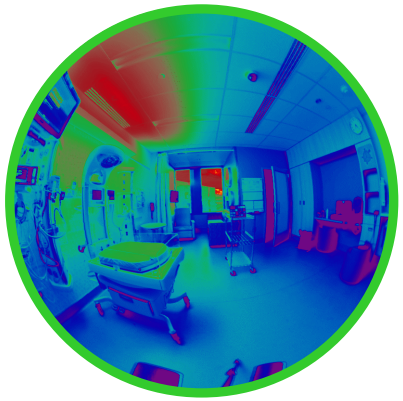
Time: 7:20 am
Ev: 11 Lx
M-EDI: 9 Lx
N-EDI: 1 Lx



Photopic false-color
Ev: 11 Lx
M-EDI: Ev (0.9:1)
N-EDI: Ev (0.1:1)

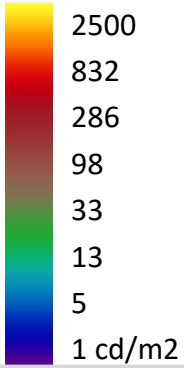


Time: 7:23 am
Ev: 71 Lx
M-EDI: 66 Lx
N-EDI:57 Lx

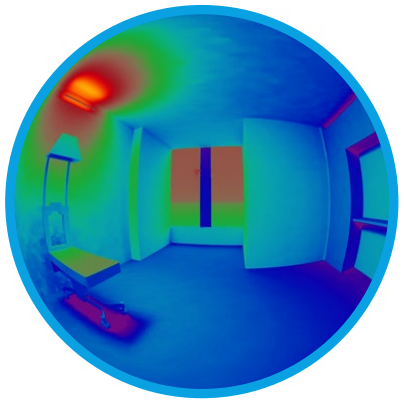


Photopic false-color
Ev: 71 Lx
M-EDI: Ev (0.9:1)
N-EDI: Ev: (0.8:1)

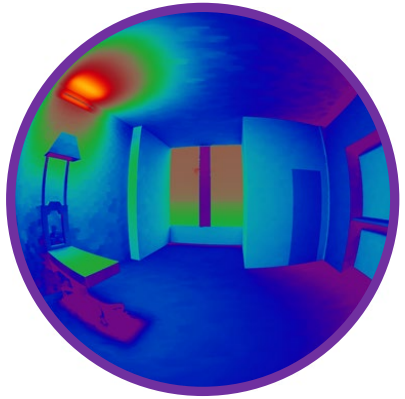
Simulation



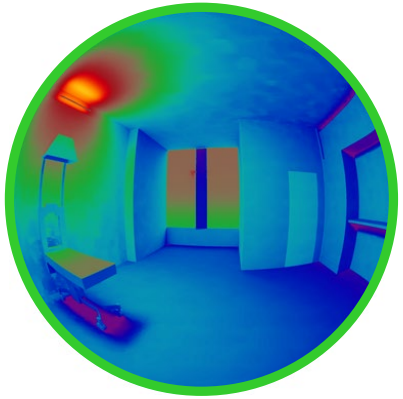
Luminance maps
Photopic
Melanopic
Neuropic cd/m2



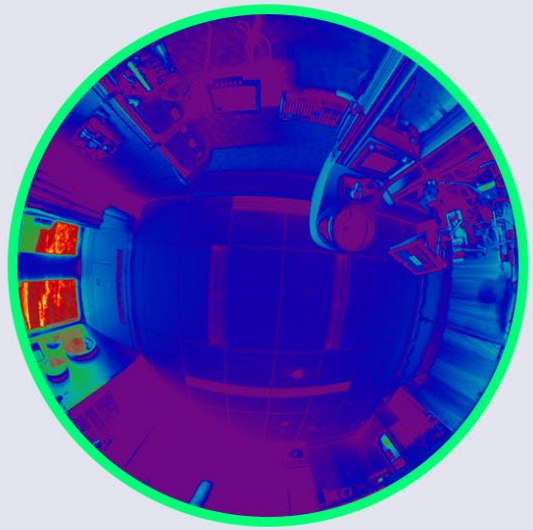
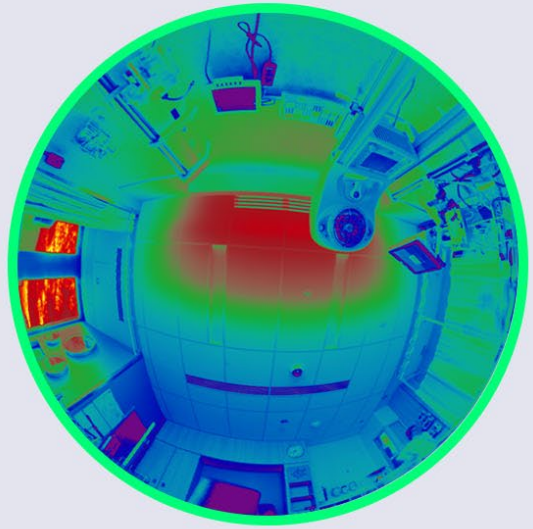
Melanopic false-color
Time: 7:23
M-EDI: 67 Lx
M-EDI: Ev: (0.9:1)



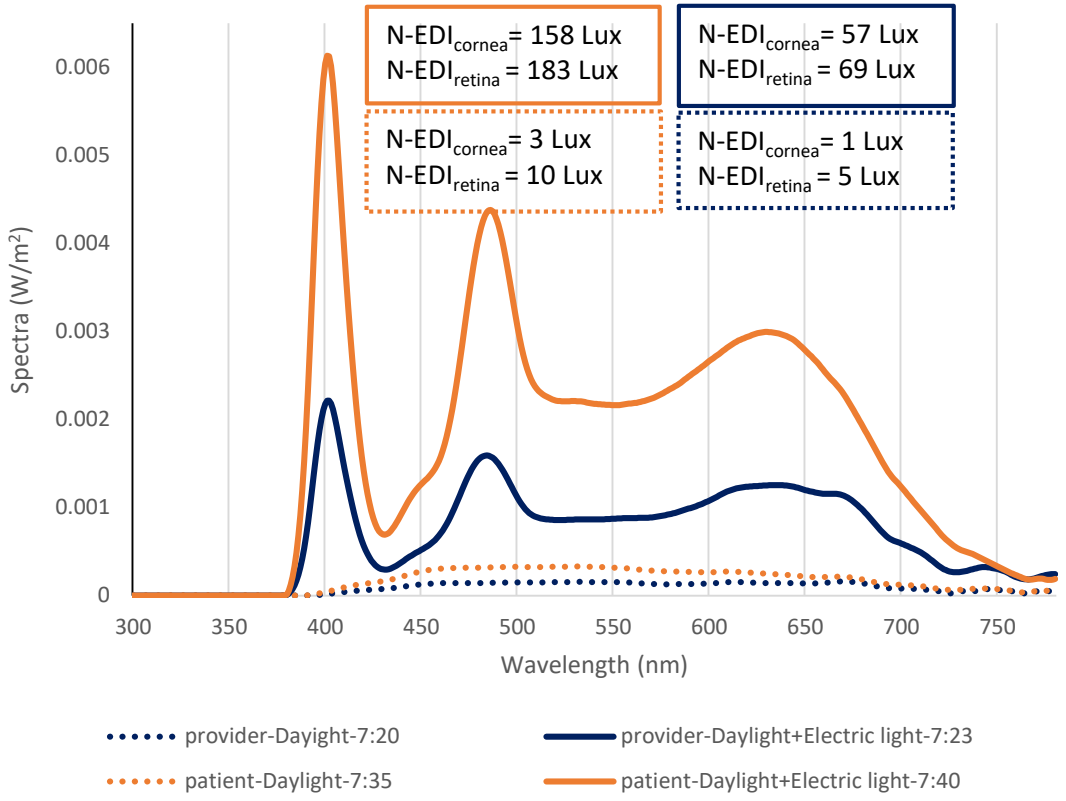
Neuropic false-color
Time: 7:23
N-EDI: 57 Lx
N-EDI: Ev: (0.8:1)



Photopic false-color
Time: 7:23 am
Ev: 73 Lx

	HDR Photograph		Luminance falsecolor map
Daylight only		7:35 am p = 22 Lx M-EDI = 20 Lx **$N\text{-}EDI_{cornea}$ = 3 Lx** **$N\text{-}EDI_{retina}$ = 10 Lx** m : p = 0.9:1 n_{cornea}: p = 0.1:1 n_{retina}: p = 0.5:1	
Daylight and electric lighting		7:40 am p = 178 Lx M-EDI = 171 Lx **$N\text{-}EDI_{cornea}$ = 158 Lx** **$N\text{-}EDI_{retina}$ = 183 Lx** m : p = 1:1 n_{cornea}: p = 0.9:1 n_{retina}: p = 1:1	




N-EDI$_{cornea}$= 158 Lux
N-EDI$_{retina}$ = 183 Lux
N-EDI$_{cornea}$= 57 Lux
N-EDI$_{retina}$ = 69 Lux
N-EDI$_{cornea}$= 3 Lux
N-EDI$_{retina}$ = 10 Lux
N-EDI$_{cornea}$= 1 Lux
N-EDI$_{retina}$ = 5 Lux
Spectra (W/m^2)
0.006
0.005
0.004
0.003
0.002
0.001
0
300
350
400
450
500
550
600
650
700
750
Wavelength (nm)
provider-Dayight-7:20
provider-Daylight+Electric light-7:23
patient-Daylight-7:35
patient-Daylight+Electric light-7:40

Myopia (Nearsightedness) boom





Grytz R, El Hamdaoui M, Yamashita T, D'Souza SP, KhalafAllah MT, Inanici M, Lang RA. "Prevention of myopia in a near-primate by supplemental indigo light suggests a hypothesis for the myopia boom," *Cell Reports Medicine*, 2026.

Myopia: Eyeball grows too long, light focuses in front of the retina.
School-age children (5-10 years of age)

Prevalence:
2010: 28 % of the global population
2030: 40% (estimated)
2050: 50% (estimated) ~5 billion
Exhibit geographic variation

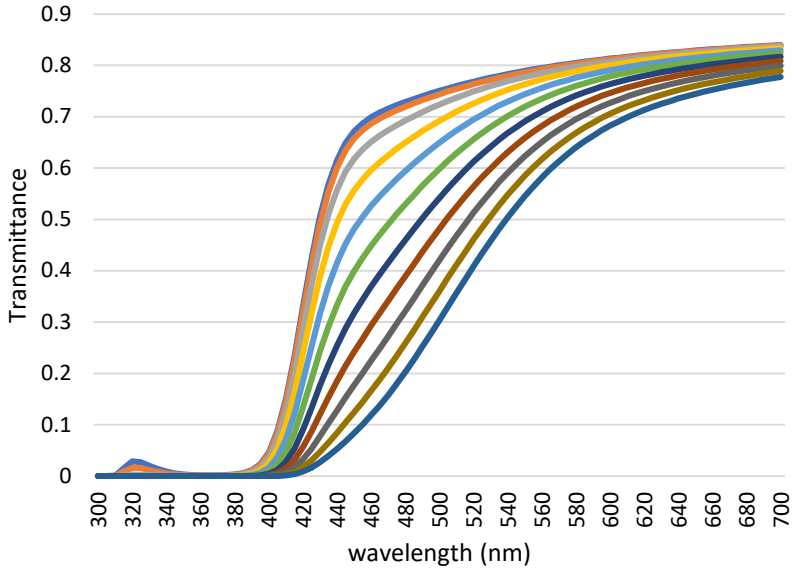
Protection: spending time outdoors
Increased risk: increased time indoors

- Multiple opsin pathways regulate eye health. Although the cause of myopia may be multifactorial, the absence of indigo light in the built environment is likely to be a crucial factor.
- The most protective wavelength range is 419–446 nm (430nm)
- Built environments typically lack protective indigo wavelengths

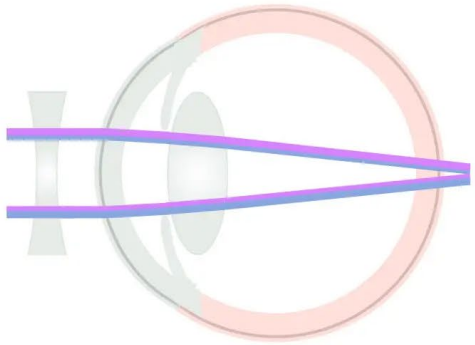
Tree-shrew experiments



Near primate Eyes similar to humans: do not transmit UV light…

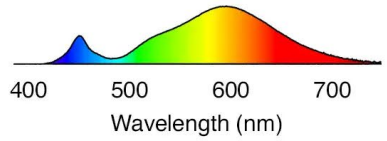


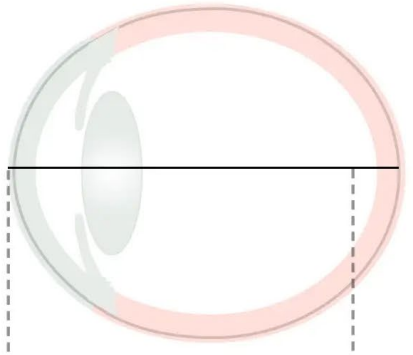
Myopia prevention with indigo light supplementation



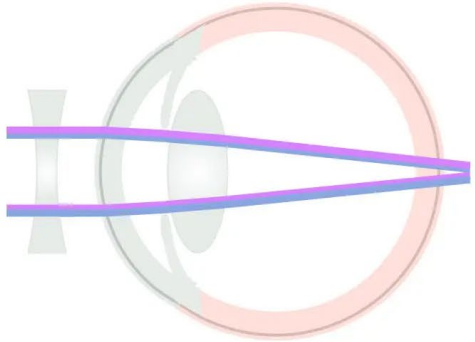
Minus lens myopiagenic stimulus

Warm white LED



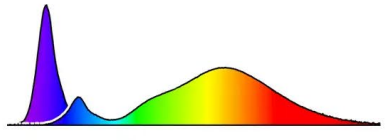


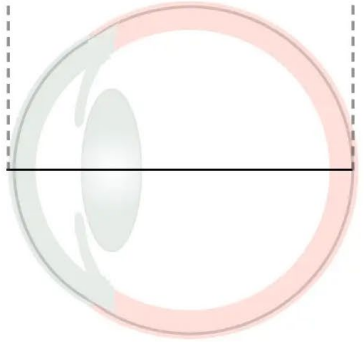
Warm white LED permits induced myopia



Minus lens myopiagenic stimulus

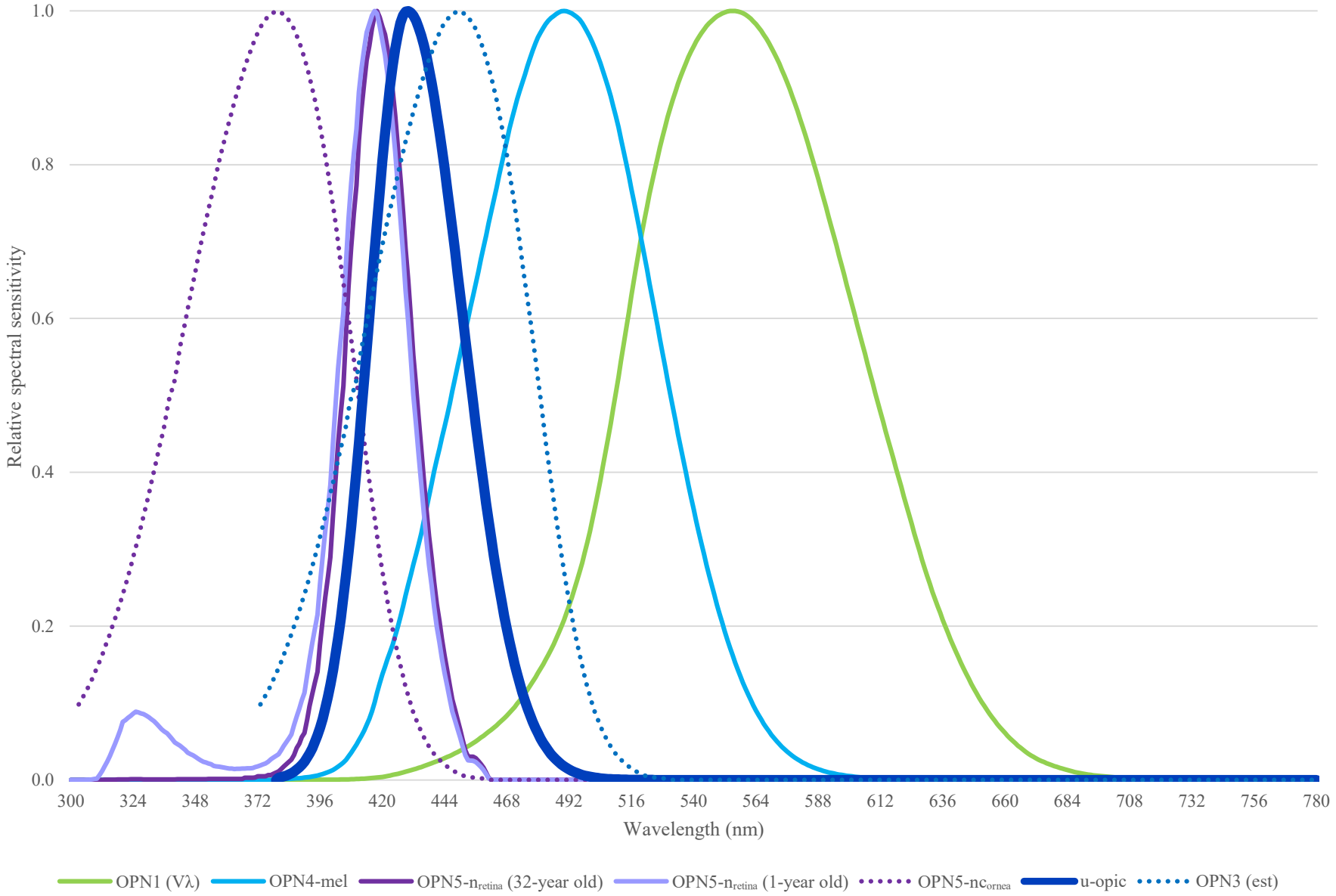
Warm white LED
+ Indigo LED supplement

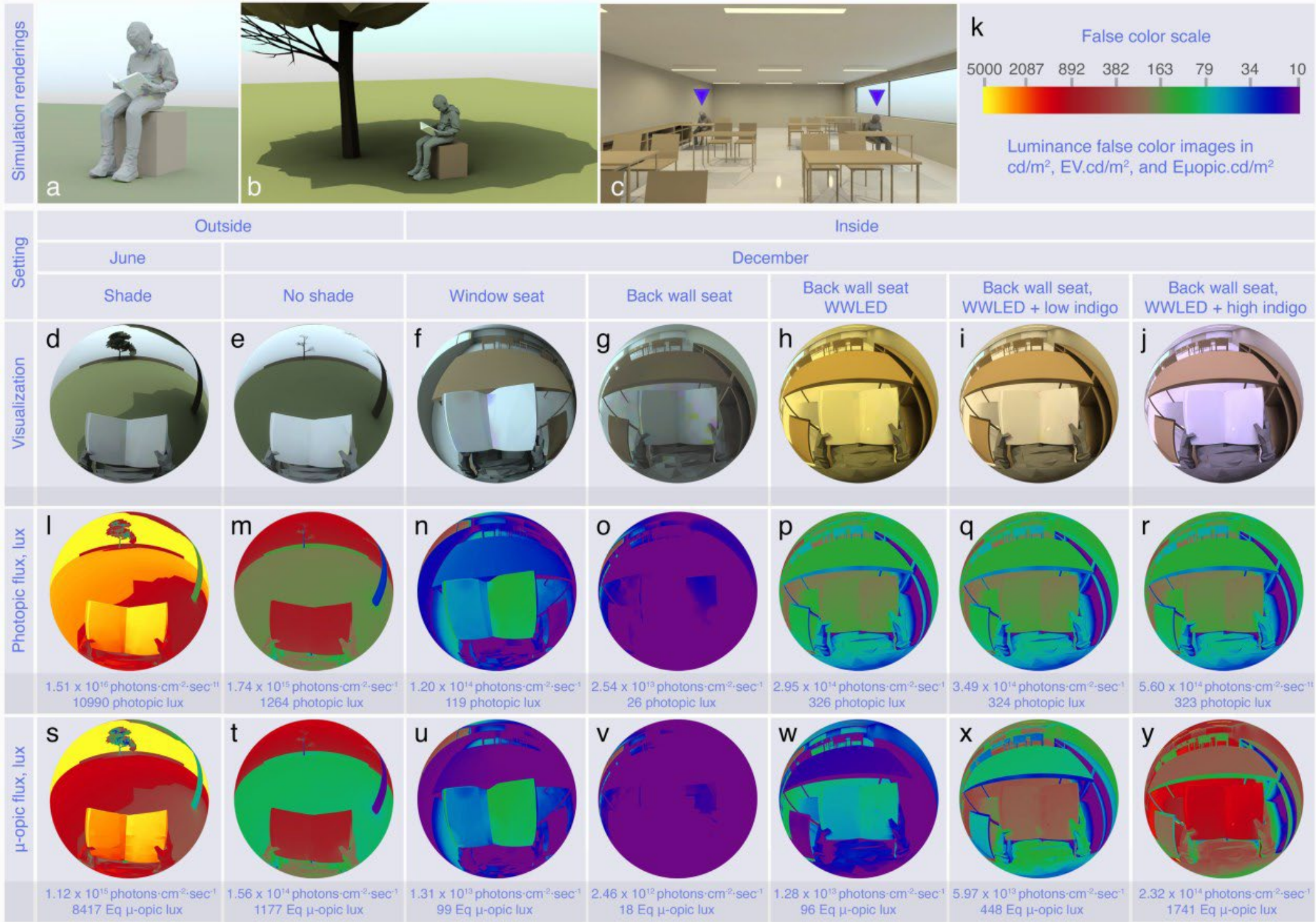




Indigo light supplementation prevents induced myopia

µ-opic curve

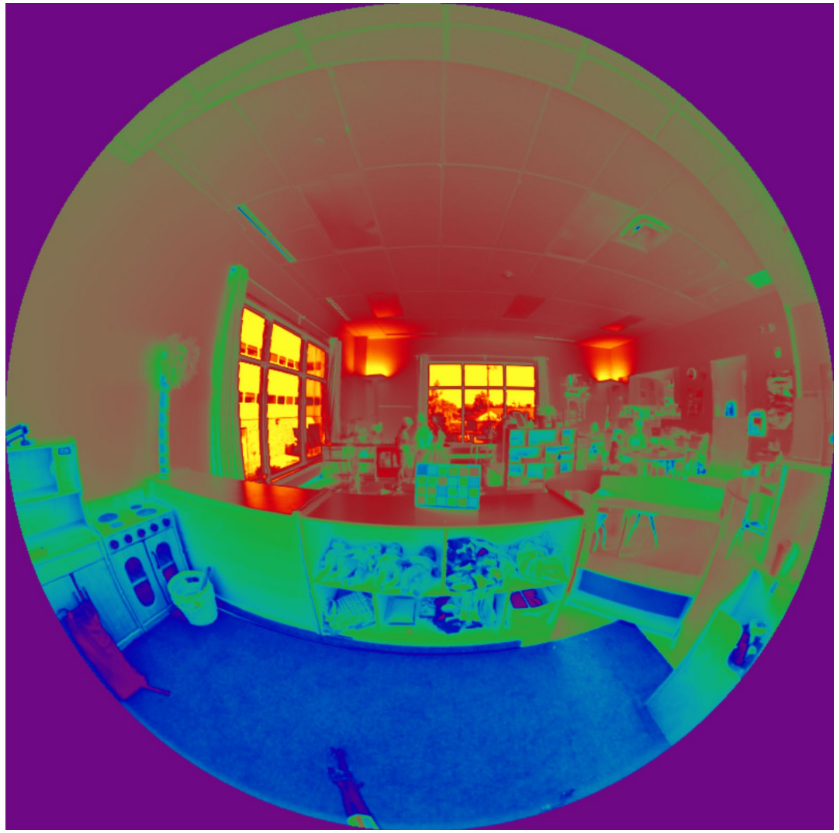

1.0
0.8
0.6
0.4
0.2
0.0
Relative spectral sensitivity
300
324
348
372
396
420
444
468
492
516
540
564
588
612
636
660
684
708
732
756
780
Wavelength (nm)
OPN1 (Vλ)
OPN4-mel
OPN5-n$_{retina}$ (32-year old)
OPN5-n$_{retina}$ (1-year old)
OPN5-nc$_{ornea}$
u-opic
OPN3 (est)


Simulation renderings
a
b
c
k
False color scale
5000 2087 892 382 163 79 34 10
Luminance false color images in cd/m², EV.cd/m², and Eμopic.cd/m²
Setting
Outside
Inside
June
December
Shade
No shade
Window seat
Back wall seat
Back wall seat WWLED
Back wall seat, WWLED + low indigo
Back wall seat, WWLED + high indigo
Visualization
d
e
f
g
h
i
j
Photopic flux, lux
l
m
n
o
p
q
r
1.51 x 10^16 photons·cm^-2·sec^-1
10990 photopic lux
1.74 x 10^15 photons·cm^-2·sec^-1
1264 photopic lux
1.20 x 10^14 photons·cm^-2·sec^-1
119 photopic lux
2.54 x 10^13 photons·cm^-2·sec^-1
26 photopic lux
2.95 x 10^14 photons·cm^-2·sec^-1
326 photopic lux
3.49 x 10^14 photons·cm^-2·sec^-1
324 photopic lux
5.60 x 10^14 photons·cm^-2·sec^-1
323 photopic lux
μ-opic flux, lux
s
t
u
v
w
x
y
1.12 x 10^15 photons·cm^-2·sec^-1
8417 Eq μ-opic lux
1.56 x 10^14 photons·cm^-2·sec^-1
1177 Eq μ-opic lux
1.31 x 10^13 photons·cm^-2·sec^-1
99 Eq μ-opic lux
2.46 x 10^12 photons·cm^-2·sec^-1
18 Eq μ-opic lux
1.28 x 10^13 photons·cm^-2·sec^-1
96 Eq μ-opic lux
5.97 x 10^13 photons·cm^-2·sec^-1
448 Eq μ-opic lux
2.32 x 10^14 photons·cm^-2·sec^-1
1741 Eq μ-opic lux

Daycare Center







Photopic L: 1-3000 cd/m^2





How about NIR?

- Powner, M. B., & Jeffery, G. (2024). Light stimulation of mitochondria reduces blood glucose levels. *Journal of Biophotonics*, 17(5), e202300521. doi.org

M-EDI has advanced our understanding of melanopsin.

The development of **all opsins** metrology provides the framework to interrogate

- Design decisions,
- Health Outcomes (vision and eye development, Metabolic homeostasis, mental health),
- Timing,
- Dosage, and
- Seasonality;

and paves the path for

expanding the integrative lighting standards beyond intraocular opsins.

Collaborators

Greenberg J.M., MD.

Lang, R.A., Ph.D.

Struve, J.

Gruner K.A.

Science of Light Center, Department of Pediatrics, Department of Ophthalmology, Cincinnati Children's Hospital, University of Cincinnati College of Medicine.

Raffael Grytz, Ph.D.

Department of Ophthalmology and Visual Sciences, Heersink School of Medicine, University of Alabama.

Marty Brennan

ZGF Architects

LIGHT AND HEALTH RECIPES WITH RADIANCE

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