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Designers Lighting Forum

# Creative and Practical Design Strategies for Delivering Visual and Non-visual Benefits of Lighting

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

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# Learning Objectives

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

1. Articulate the similarities and differences between various non-visual design metrics.
2. Define the elemental concepts underlying circadian-effective lighting and alertness and how they interact with traditional lighting design.
3. Apply new lighting design strategies that can address both circadian-effective lighting and alertness while meeting traditional lighting design standards.
4. Employ a non-visual effects vocabulary for discussing lighting design objectives with clients.

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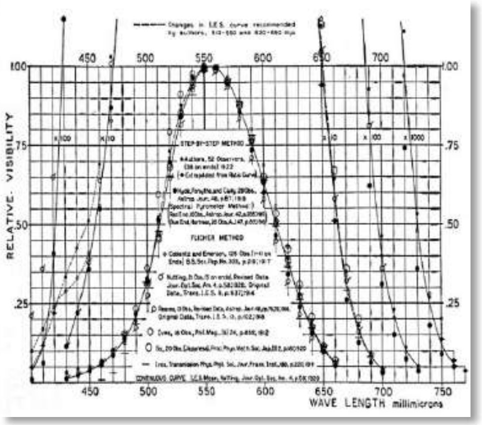
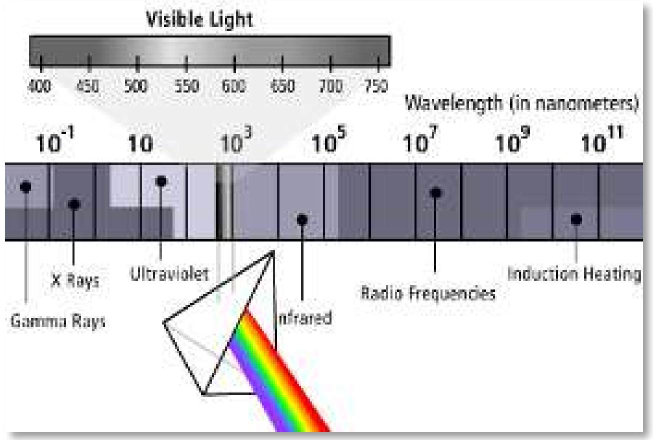
Mark S. Rea

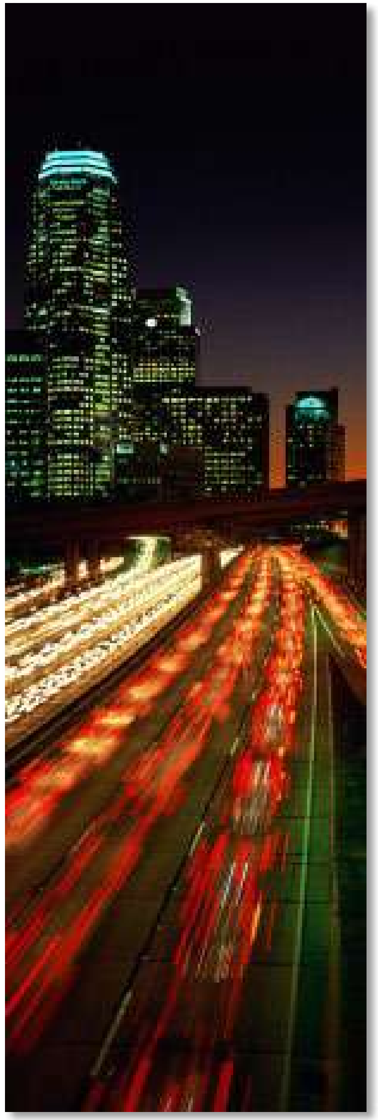
# THE BASICS

# What is light?

- Light, by definition, is optical radiation entering the eye that provides visual sensation
- Practical definition
  - Radiant power (P) weighted by the photopic luminous efficiency function, V(λ)

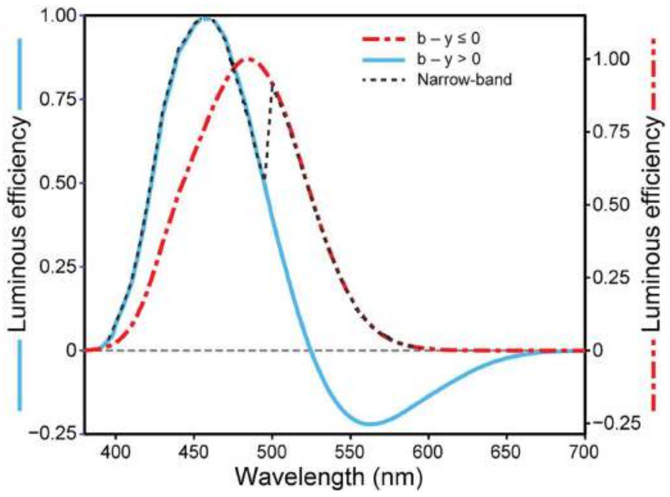


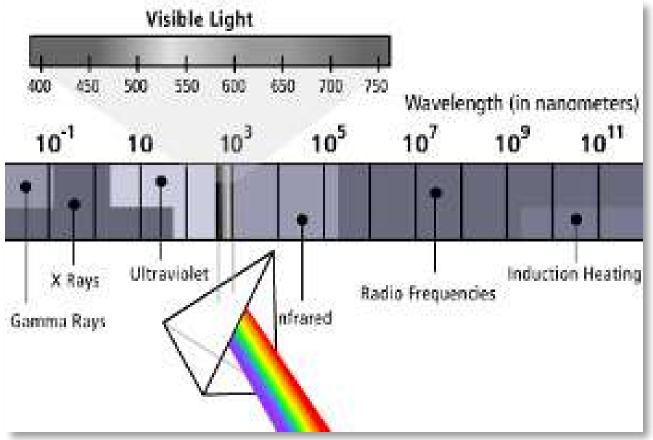



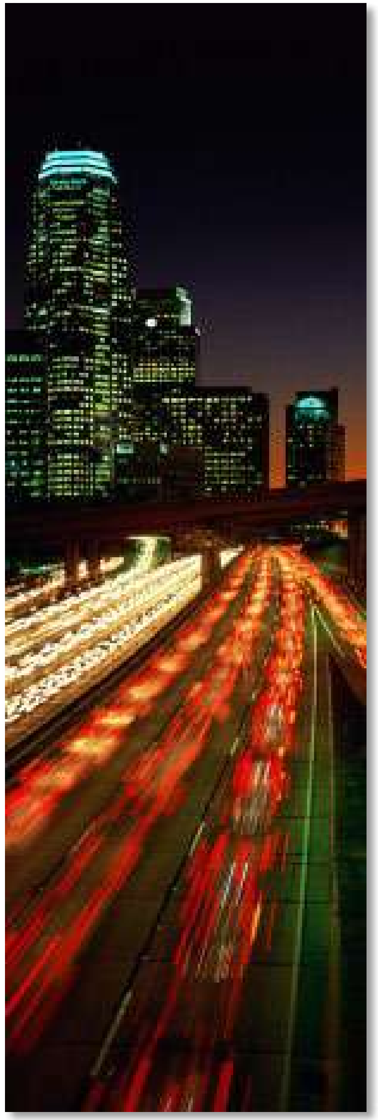



# What is light?

- Light, by definition, is optical radiation entering the eye that provides visual sensation
- But light isn't just for vision anymore!



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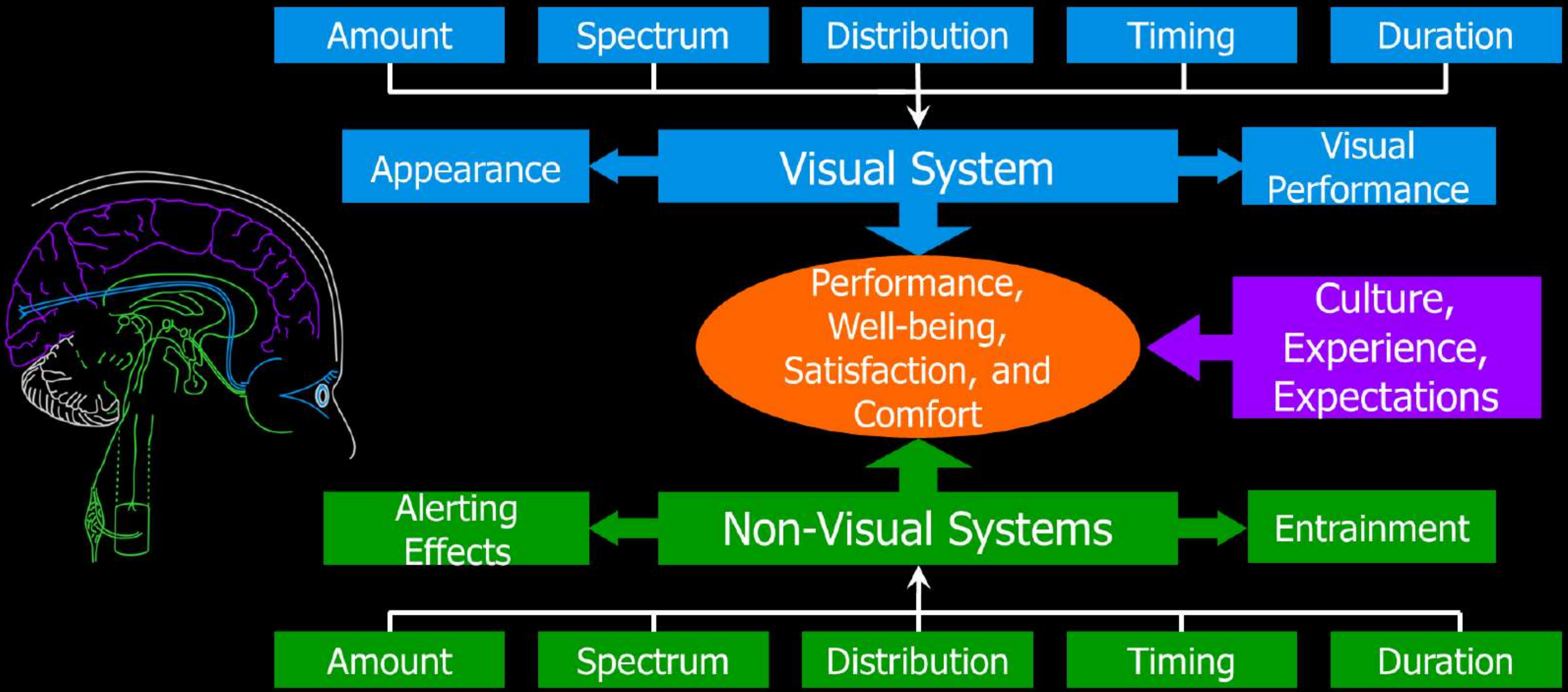
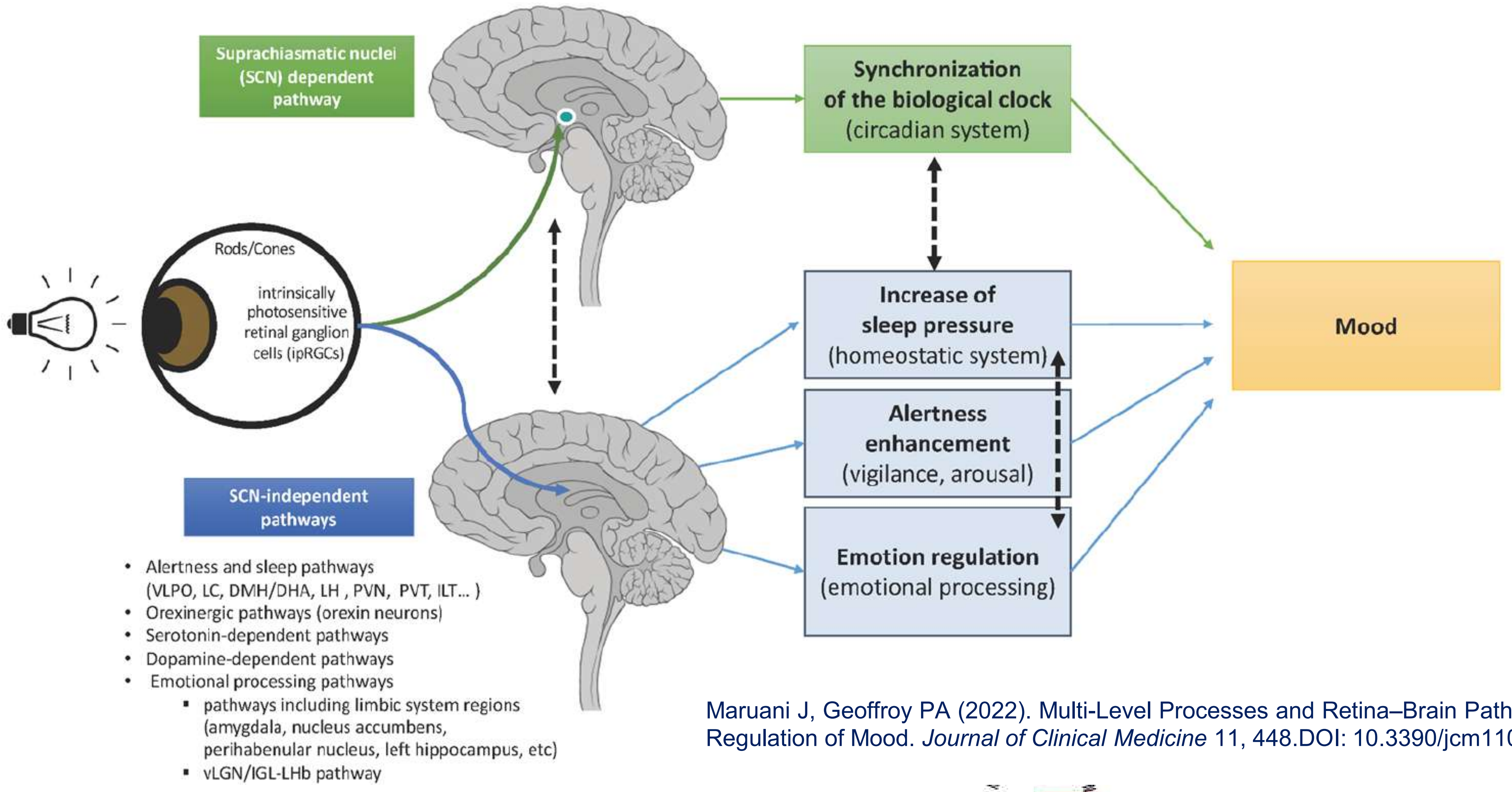
# Lighting affects three systems: Visual + Non-visual + Message



# Multi-level processes and retina
# Brain pathways of photic regulation of mood




Maruani J, Geoffroy PA (2022). Multi-Level Processes and Retina–Brain Pathways of Photic Regulation of Mood. *Journal of Clinical Medicine* 11, 448.DOI: 10.3390/jcm11020448



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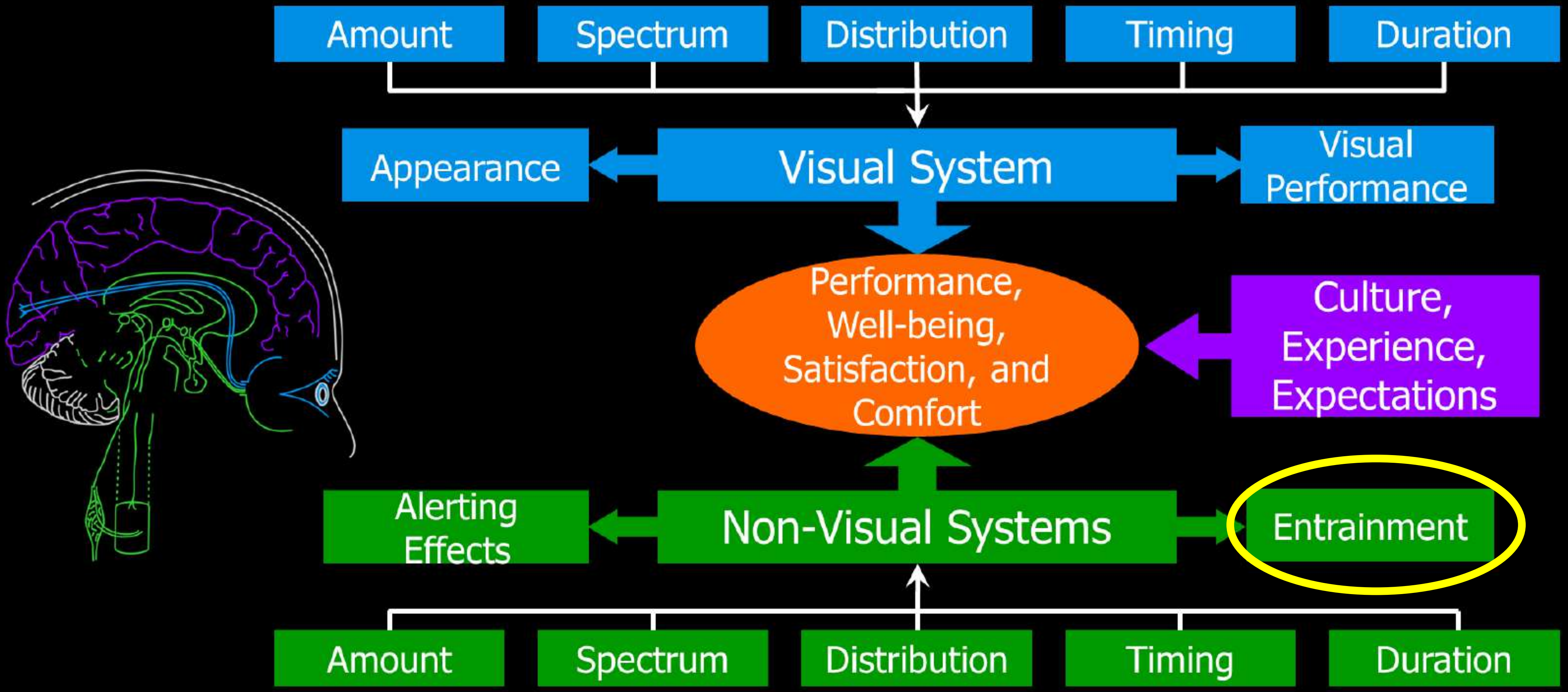
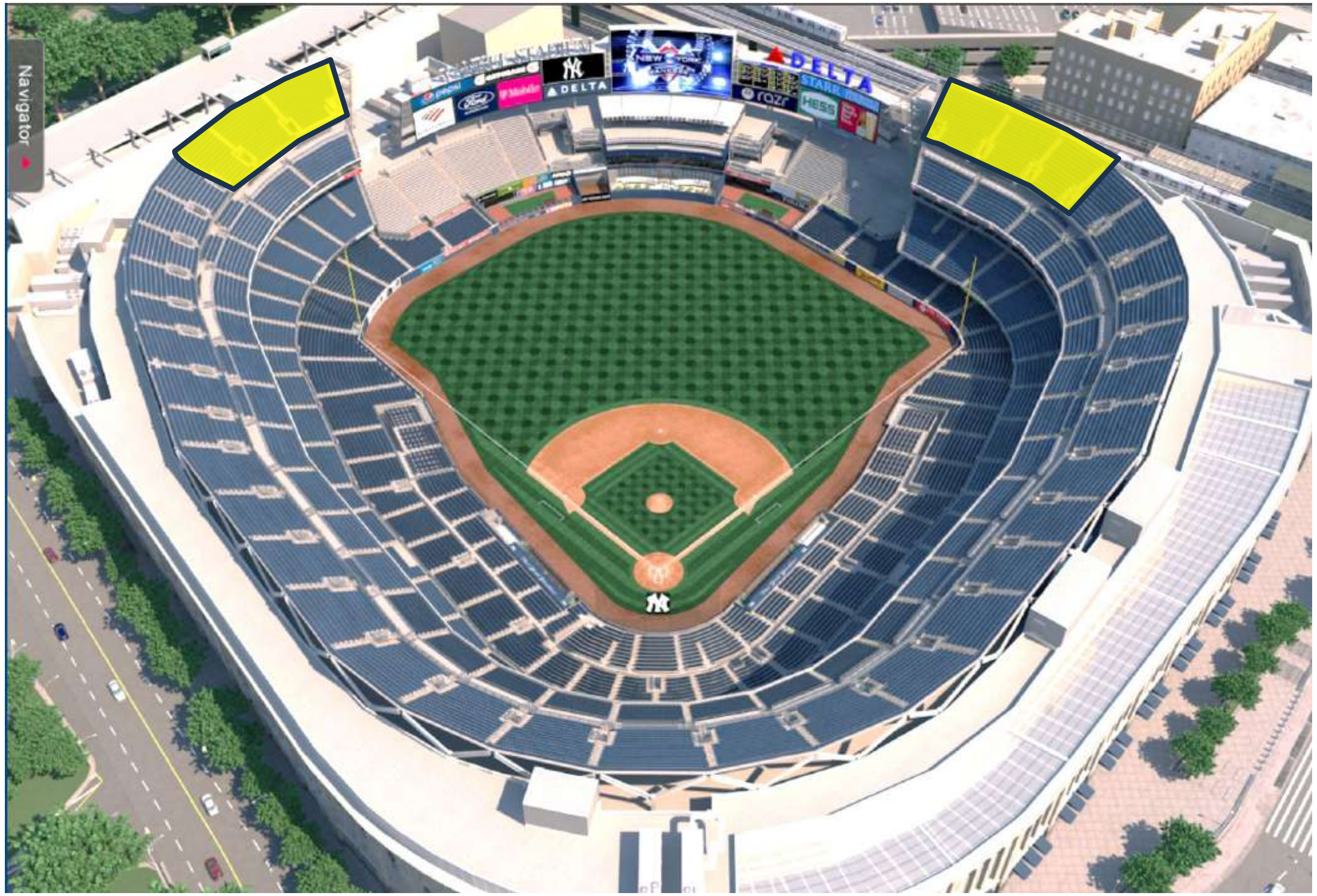
# Entrainment



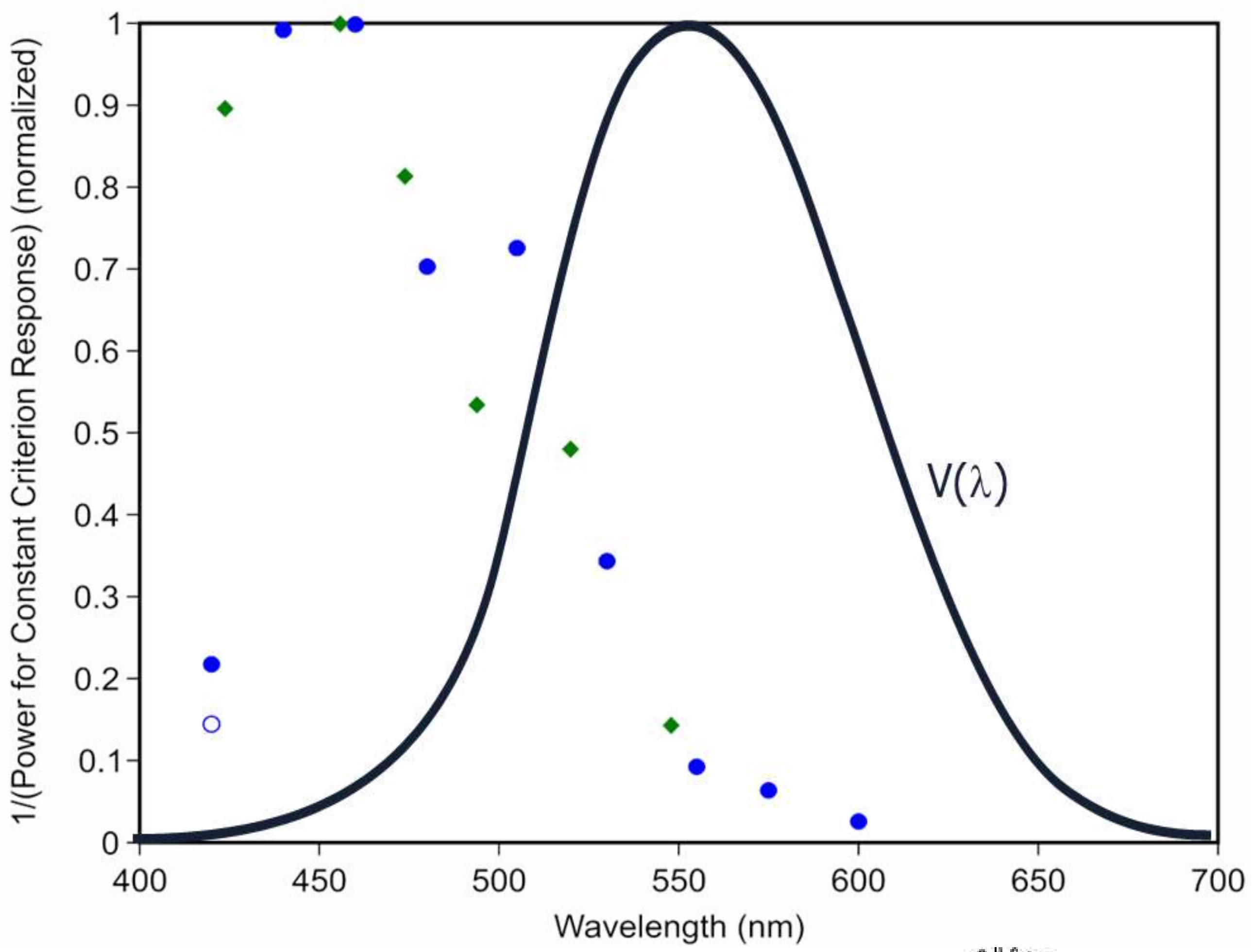
# Spectrum and Amount

- Illuminance as a design criterion will put you in the ballpark
  - It works, as long as you don't mind sitting in the nosebleed section



# Assume photopic illuminance (lux)

**Ultraviolet**




**Infrared**



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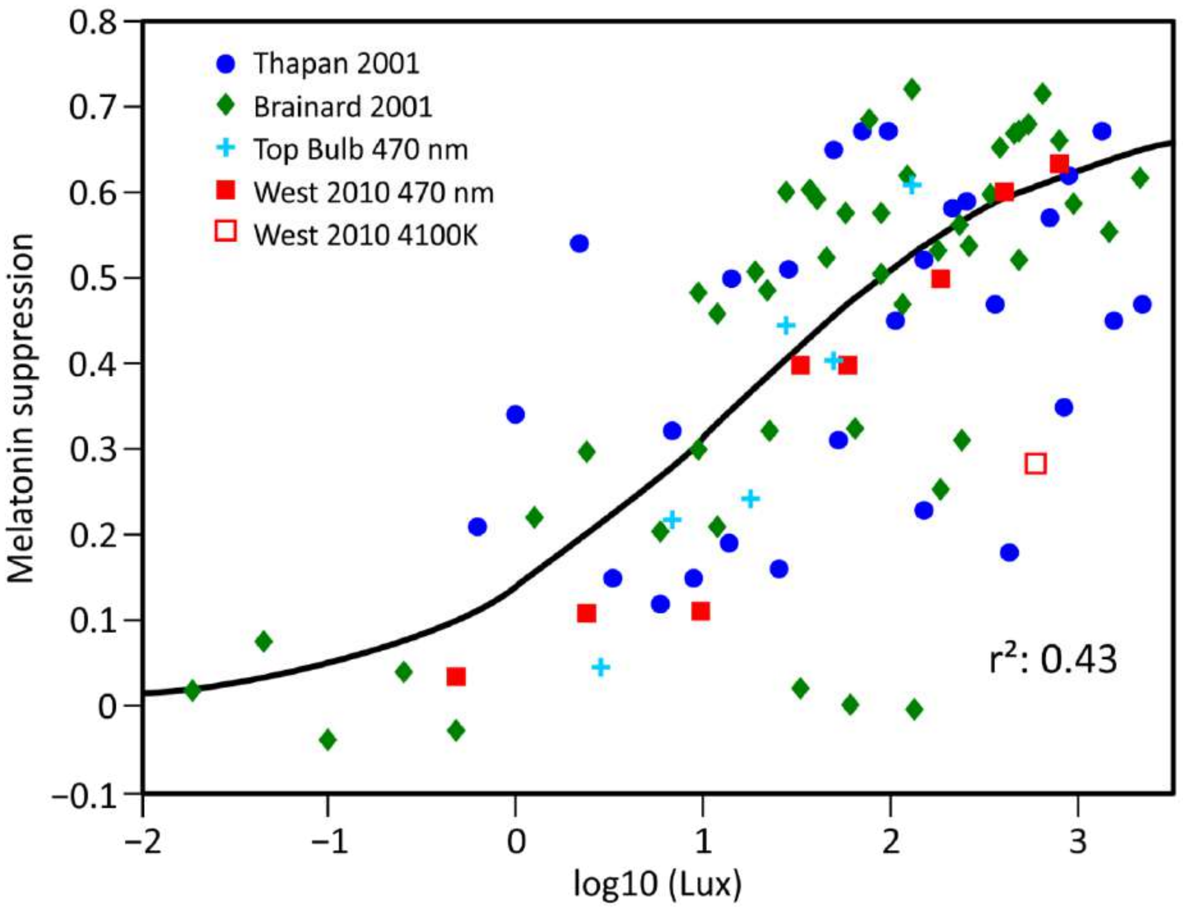
# Assume photopic illuminance (lux)



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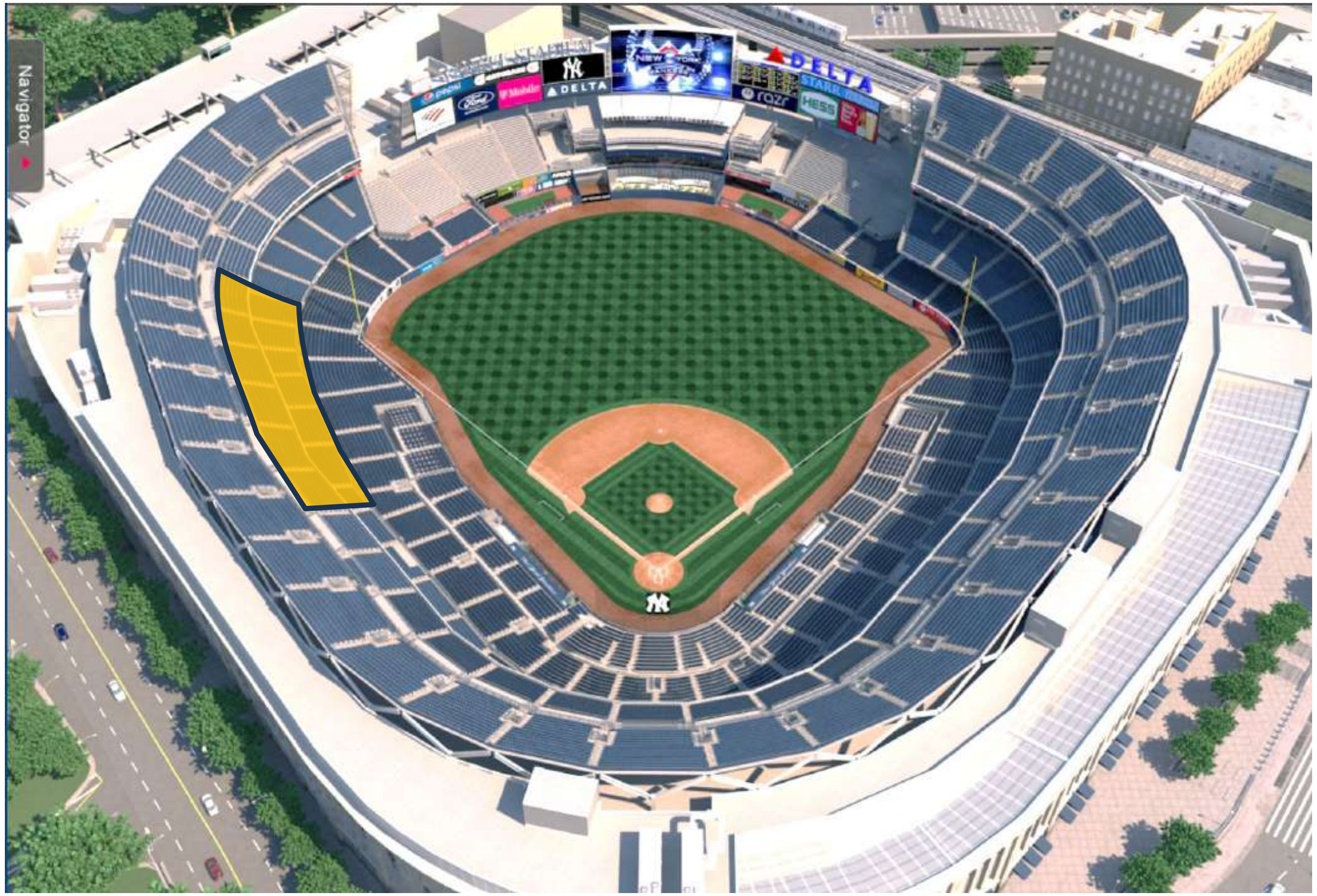
# Spectrum and amount

- Metrics based on melanopsin action spectrum put you a bit closer to the action



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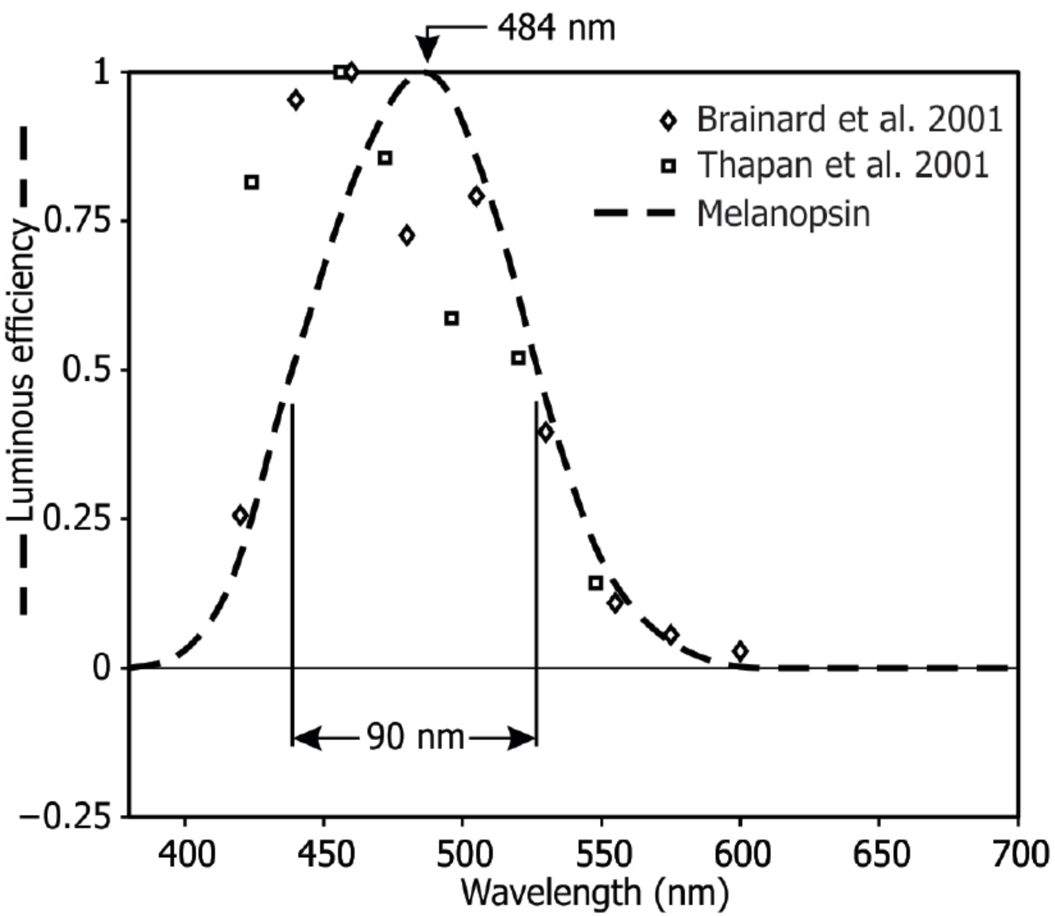
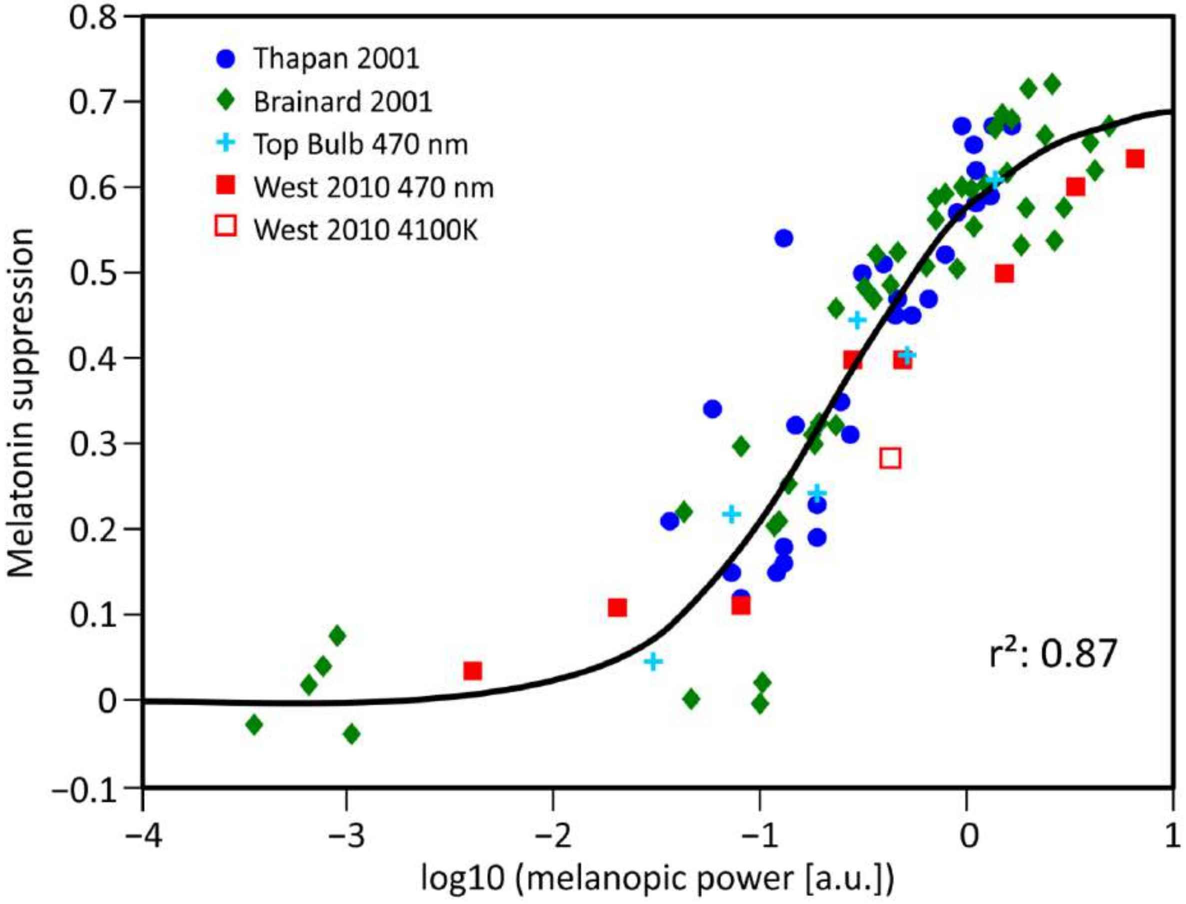
# Assume melanopic “lux”




Rea MS, Figueiro MG. Light as a circadian stimulus for architectural lighting. *Lighting Research and Technology* 2018; 50: 497-510.

# Assume melanopic "lux"





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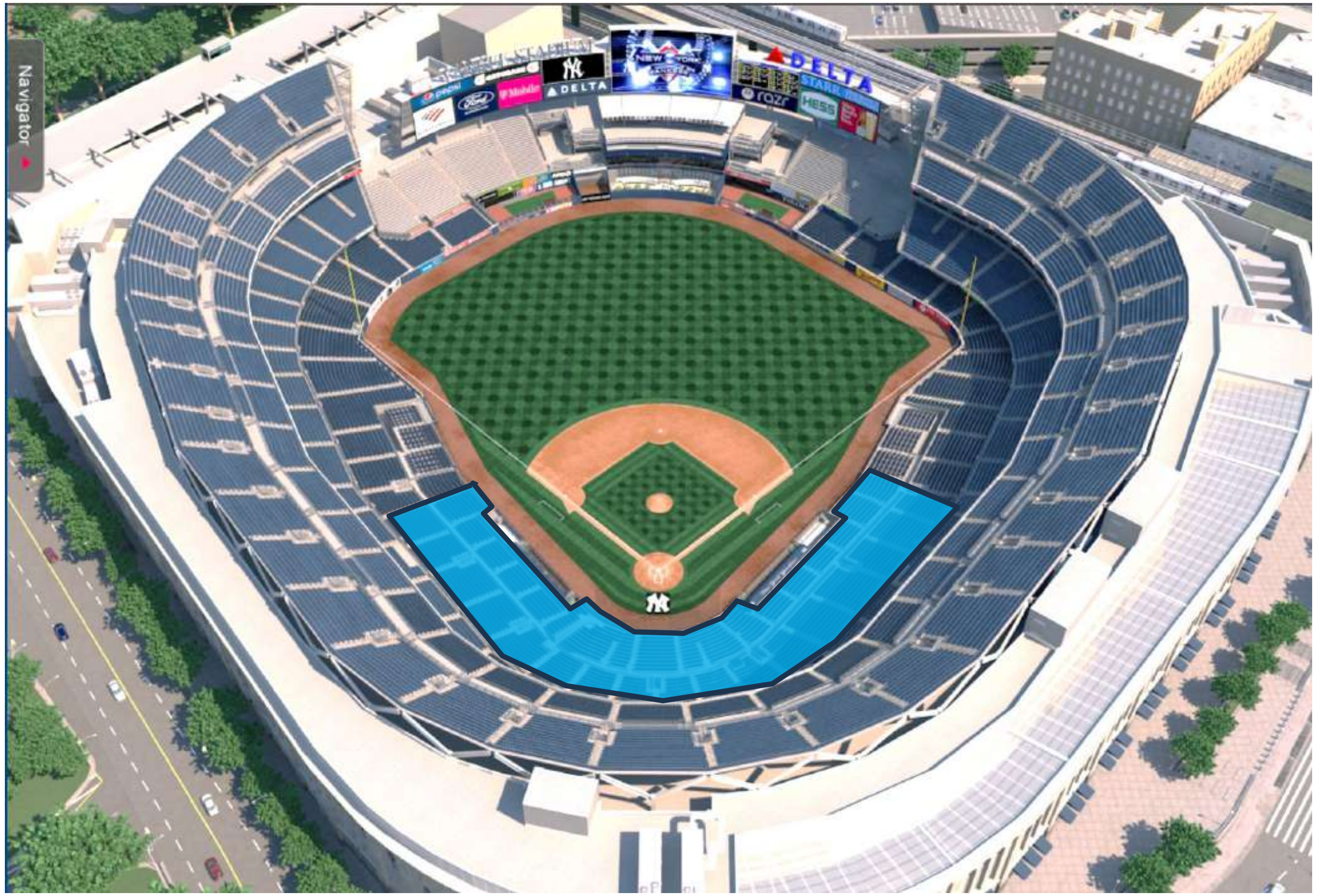
# Spectrum and amount

- $CL_A$ and CS put you on the infield



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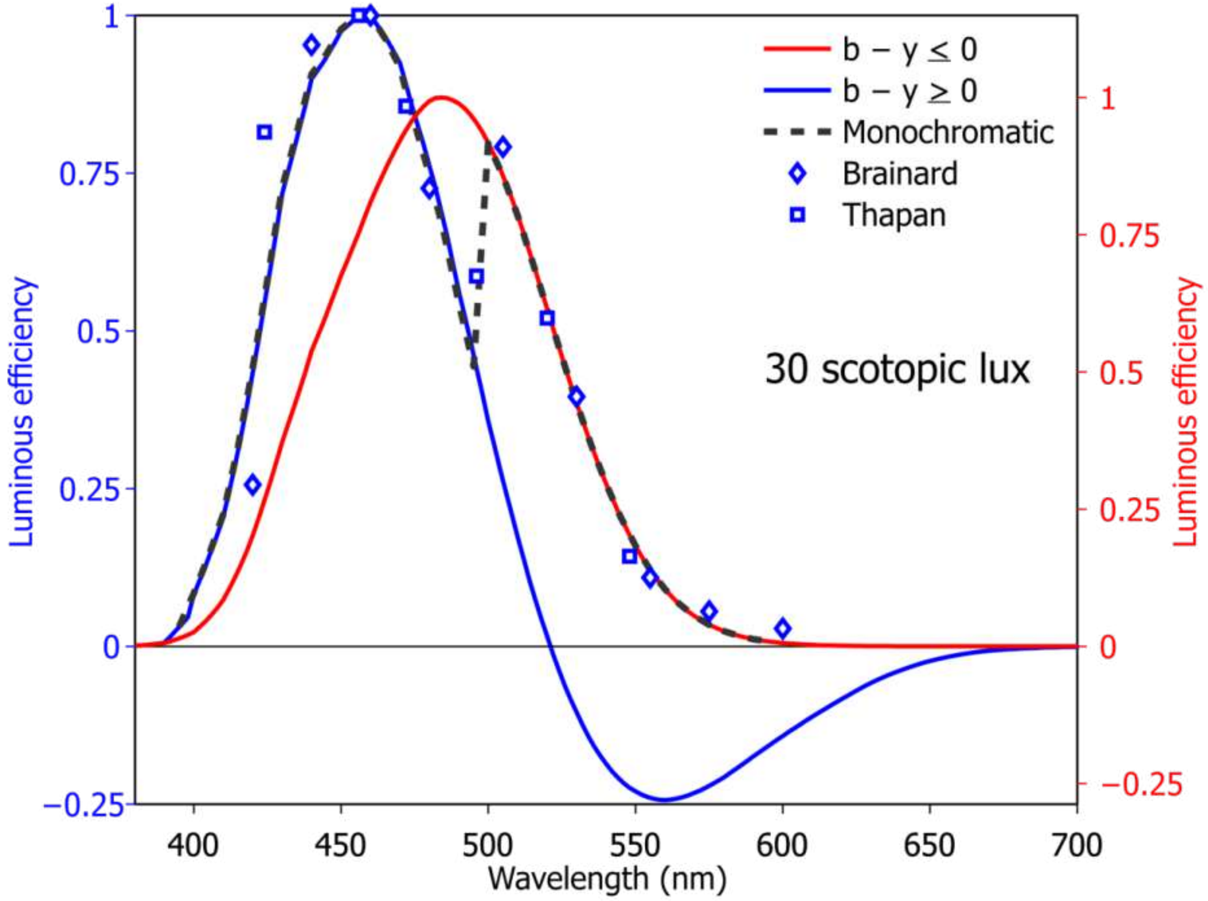
# Assume circadian-effective light ($CL_A$)



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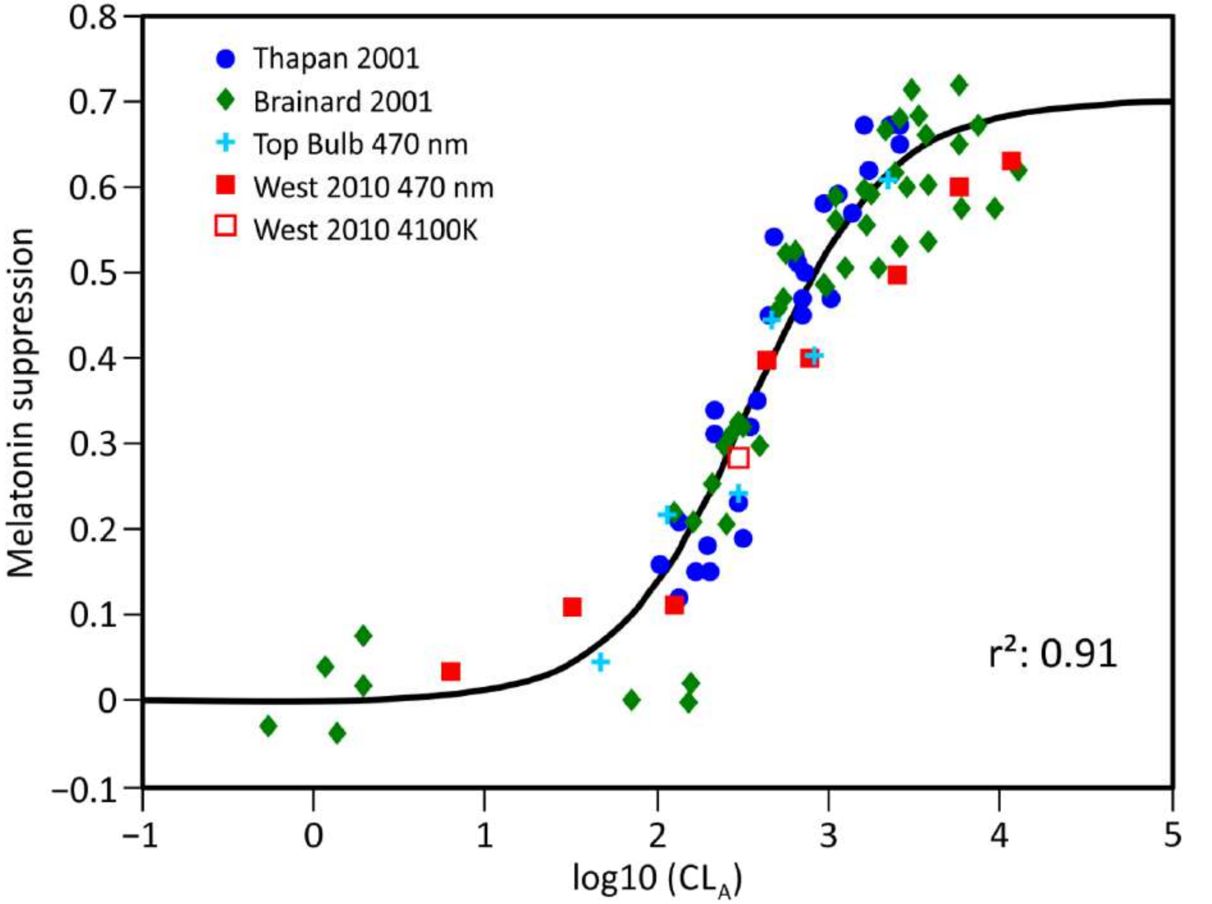
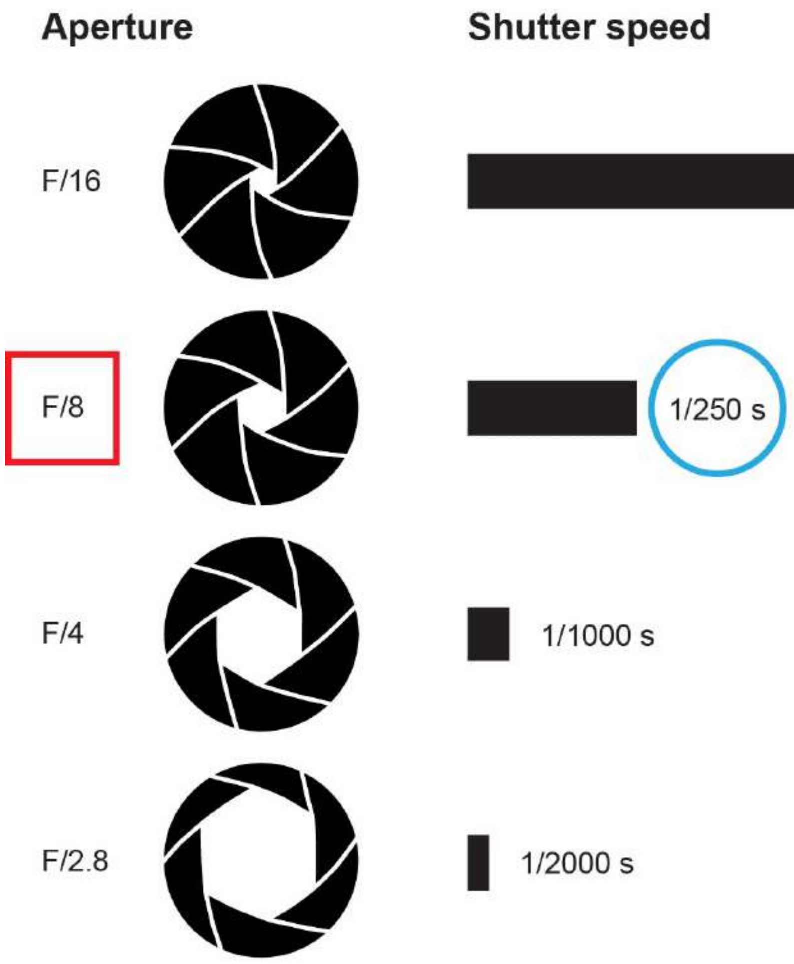
# Assume $CL_A$ and circadian stimulus (CS)

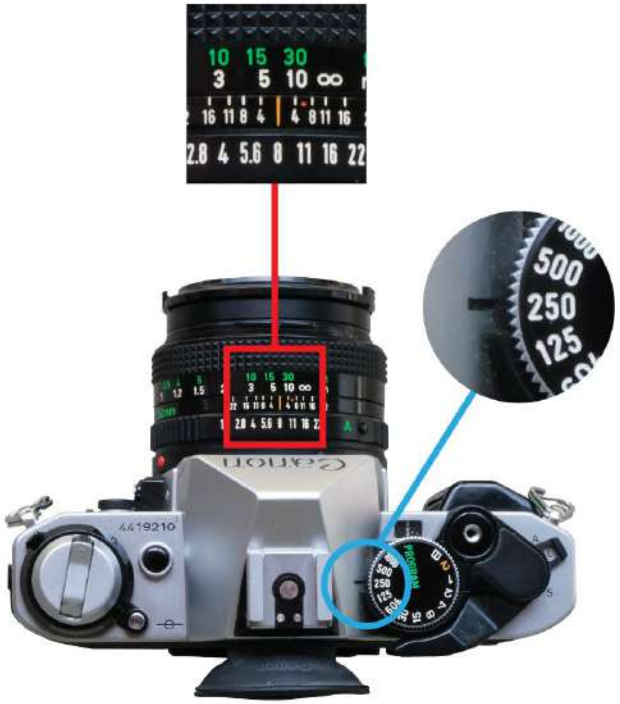


# $CL_A$ and CS

- $CL_A$ and CS are instantaneous measurements of light, just like lux
- What about duration?
- It's about dose, not just spectrum and amount

# Law of reciprocity in photography



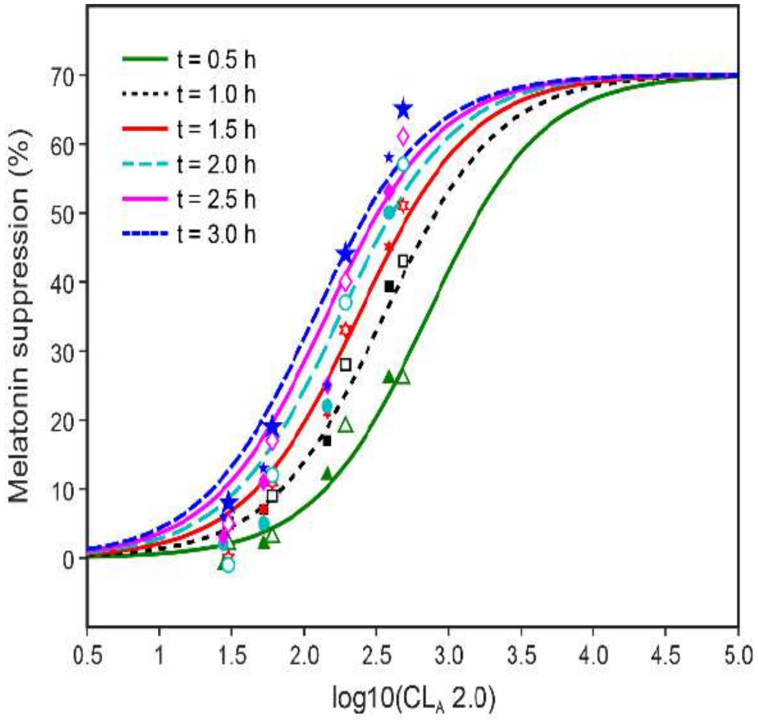

Rea MS. The law of reciprocity holds (more or less) for circadian-effective lighting. *Lighting Research & Technology*. 2022: 14771535211061871.

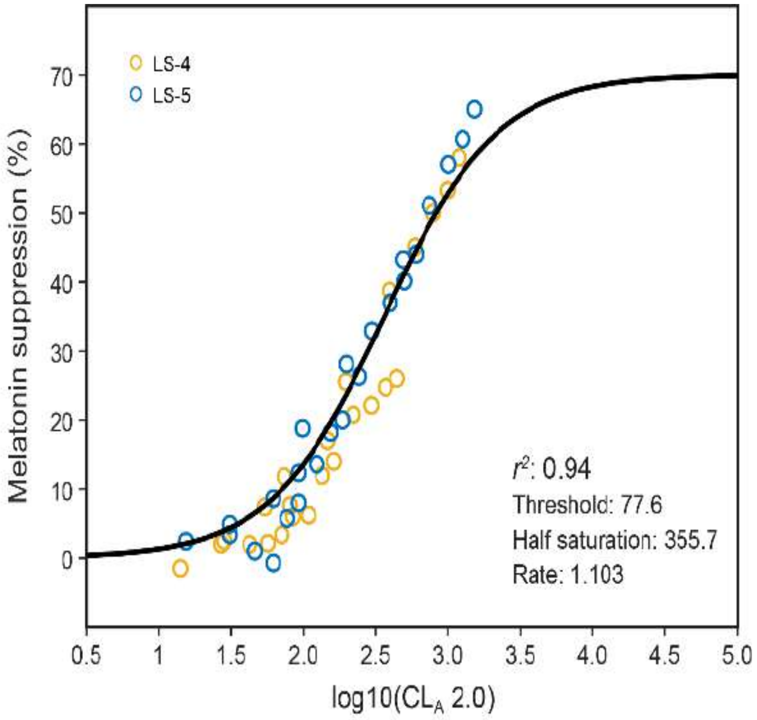
| F-stop | Relative amount (area) | Duration | Dose |
|---|---|---|---|
| **F/16** | 1/64 | 1/60 | 1/3840 |
| **F/8** | 1/16 | 1/250 | 1/4000 |
| **F/4** | 1/4 | 1/1000 | 1/4000 |
| **F/2.8** | 1/1.96 | 1/2000 | 1/3920 |

A change of one f-stop doubles or halves the area of the camera aperture, so the shutter speed must be halved or doubled, respectively, to maintain the same exposure. This is the law of reciprocity in photography.

# Circadian-effective light dose

- Between 0.5 and 3.0 hours, duration is largely independent of amount ($CL_A$ 2.0)
- Therefore, it's possible to tradeoff light level with duration of light exposure



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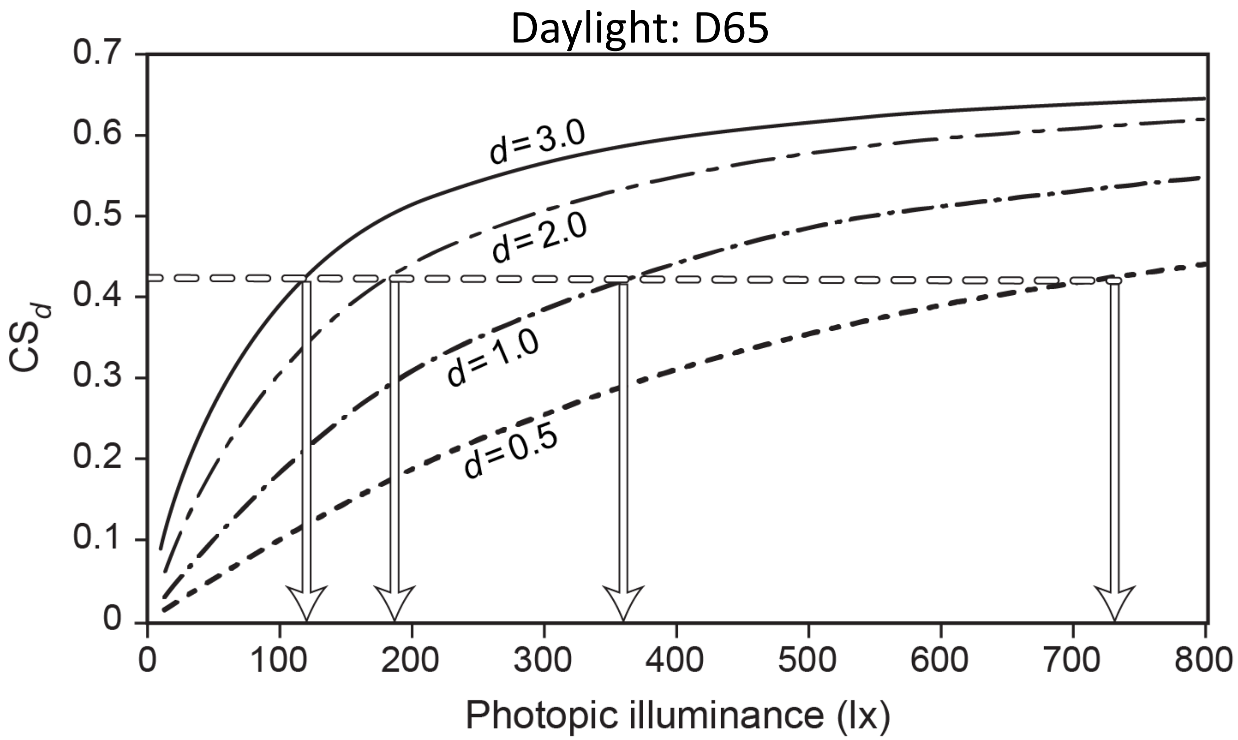
# Circadian-effective light dose



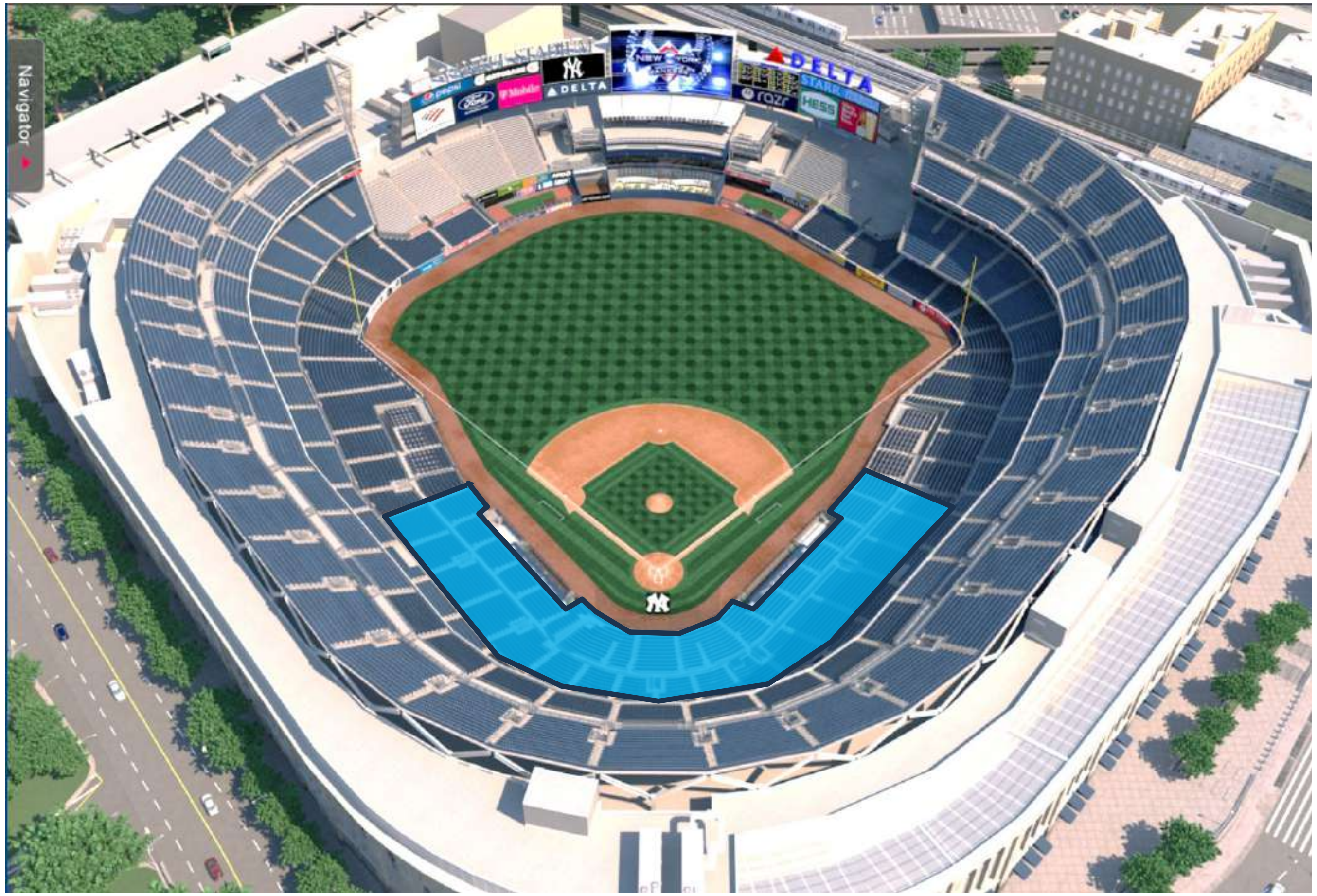

| Duration (*d*, hours) | 0.5 | 1.0 | 2.0 | 3.0 |
|---|---|---|---|---|
| Photopic illuminance (lx) | 736 | 377 | 190 | 127 |
| CS | 0.54 | 0.43 | 0.30 | 0.23 |
| $CL_A$ 2.0 | 1097 | 550 | 274 | 183 |

| CS | $CL_A$ | Duration | Dose |
|---|---|---|---|
| 0.54 | 1097 | 0.5 h | 548.5 |
| 0.43 | 550 | 1.0 h | 550 |
| 0.30 | 274 | 2.0 h | 548 |
| 0.23 | 183 | 3.0 h | 549 |

UL 24480: CS > 0.3 for 2 hours in the morning

# Dose: Spectrum, duration, and amount

- $CL_A$ (spectrum) duration (hours), and CS (amount) put you on the infield
  to quantify circadian entrainment
  (or disruption)



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# Dose: Spectrum, duration, and amount

- Other metrics only consider spectrum
- “Experts” then give opinions on spectrum, amount and duration (dose) needed for entrainment

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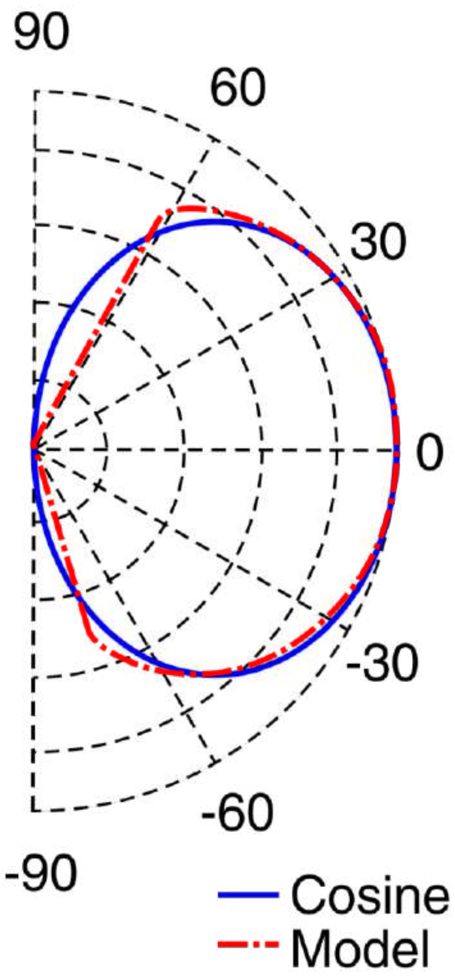
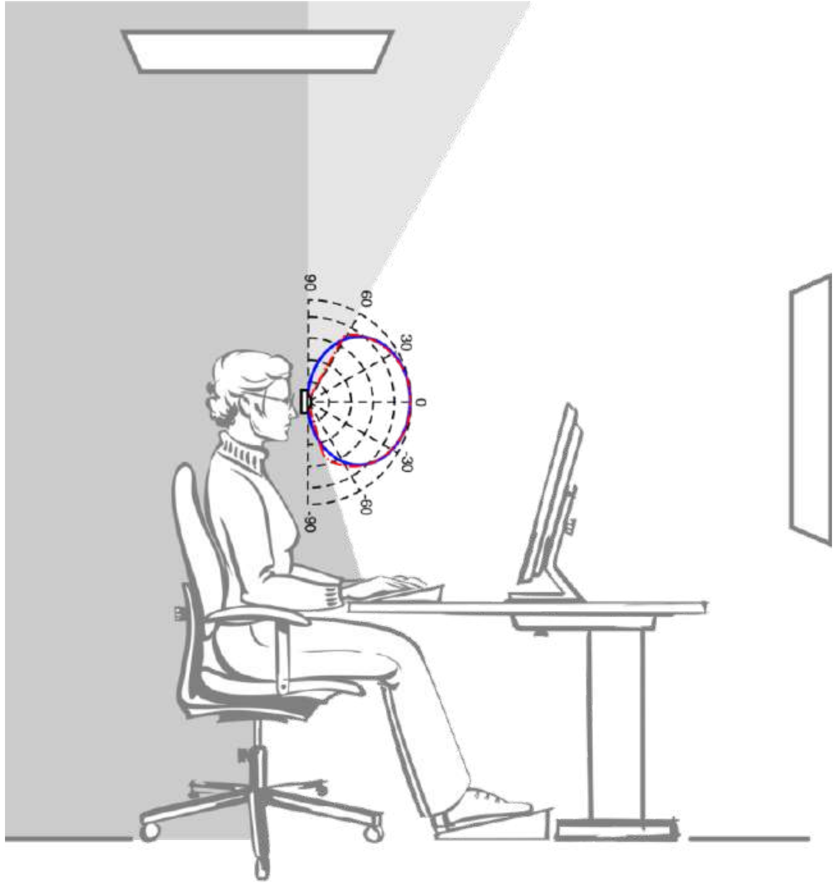
# Distribution





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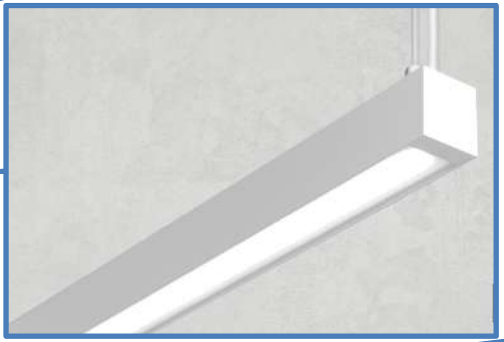
# How important is lighting distribution?

Like golf –
Lower W is better

| | CS = 0.3 |
|---|---|
| **Luminaire line** | **Mean (W)** |
| Ceiling | |
| Direct cosine distribution | 148 |
| Direct batwing distribution | 140 |
| Direct asymmetric distribution | 223 |
| Direct wide distribution | 236 |
| Direct narrow distribution | 950 |
| Direct pendant | 247 |
| Direct/indirect pendant | 193 |
| Linear recessed wall wash | 340 |
| Downlight wall wash | 2486 |
| Wall | |
| Sconce facing observer | 57.9 |
| Direct/indirect sconce | 184 |
| Desktop | |
| On-axis luminaire | 5.9 |
| Off-axis luminaire | 21.3 |





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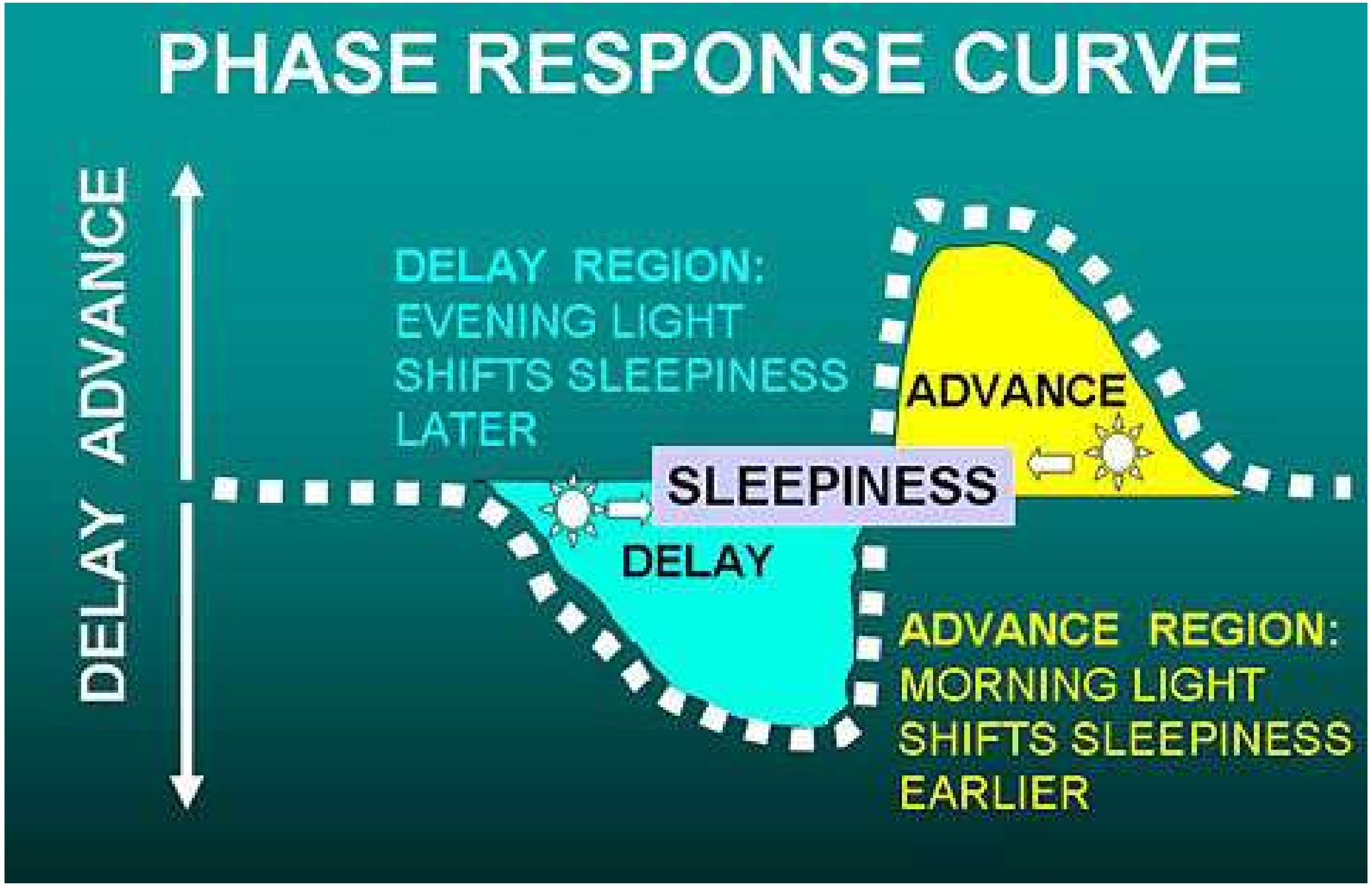
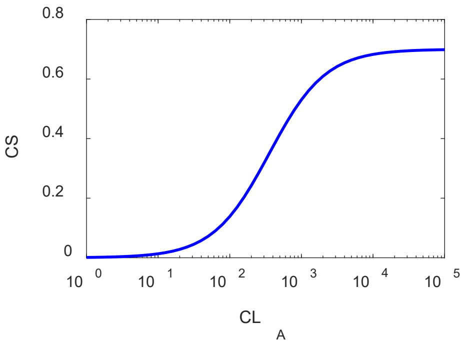
# Timing

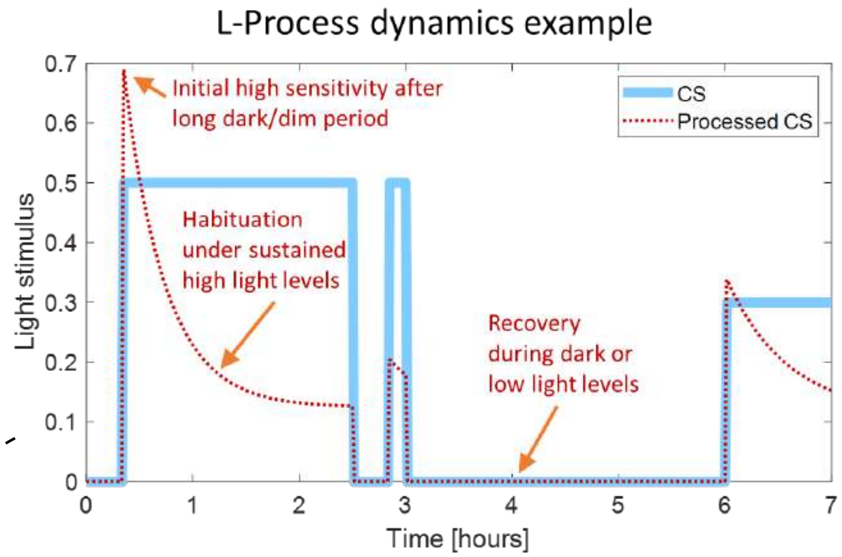


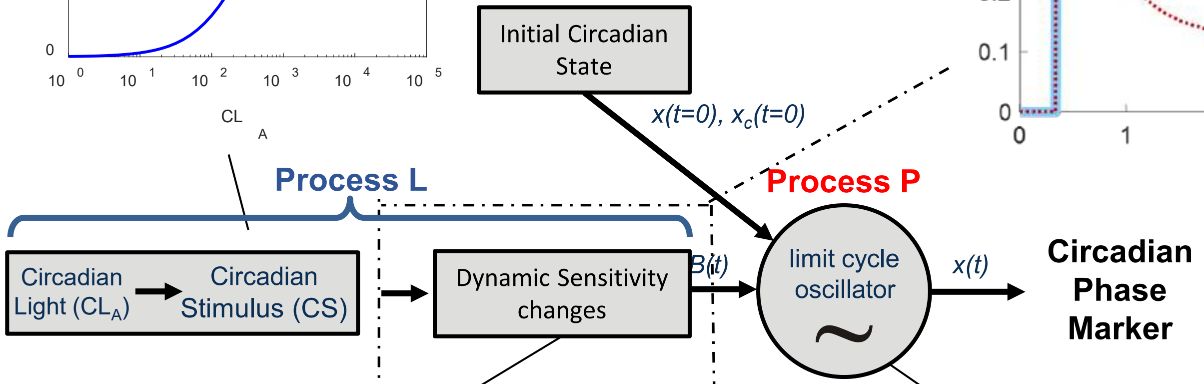

https://www.brightenyourlife.info/ch6.html

The same light pulse (spectrum, amount and duration) has very different effects on the biological clock depending upon time of exposure

# CS oscillator model




$$\alpha = \alpha_o \left(\frac{CS}{0.7}\right)$$

$$\dot{n} = 60[\alpha(1-n) - \beta n]$$

$$B = G\alpha(1-n)$$

$B$ = Light drive
$\alpha_0$ = 0.05 min$^{-1}$
$\beta$ = 0.0075 min$^{-1}$
$G$ = 19.9

$$\dot{x} = \frac{\pi}{12}\left[\mu\left(\frac{x}{3} + \frac{4}{3}x^3 - \frac{256}{105}x^7\right) + x_c + B\right]$$

$$\dot{x}_c = \frac{\pi}{12}\left[qBx_c - \left(\frac{24}{0.99729\tau}\right)^2 x + kBx\right]$$

$B$ = Light drive
$\mu$ = 0.13
$q$ = 0.50
$k$ = 0.55

Re-addition of the L-process dynamics

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# Seasonal time changes

- What should you do?

**Delay** the biological clock

**Advance** the biological clock




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# Seasonal time changes

- Qualitative impacts of using a self-luminous display for 30 min at dinner time (19:00) for larks and owls immediately after the fall and spring DST/ST transitions

**Self-luminous displays: Evening**

| | **Lark** | **Owl** |
|---|---|---|
| **Fall** (Goal: Delay) | Good | Neutral |
| **Spring** (Goal: Advance) | Very bad | Neutral |



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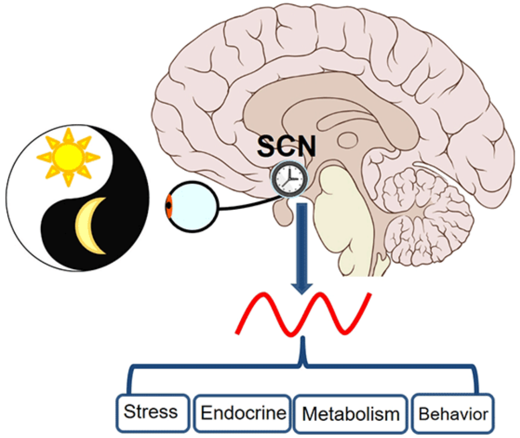
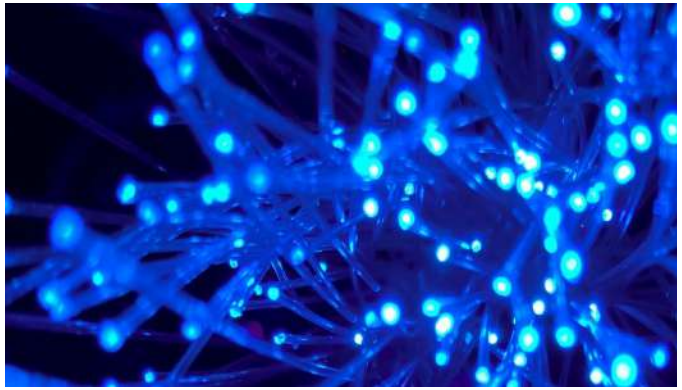
# Key takeaways

- Light input: Spectrum ($CL_A$) amount (CS) and duration matter
- Every photon matters: Need full 24-h pattern
- Calibrated field devices: Sampling rate matters
- $CBT_{min}$ (chronotype) matters

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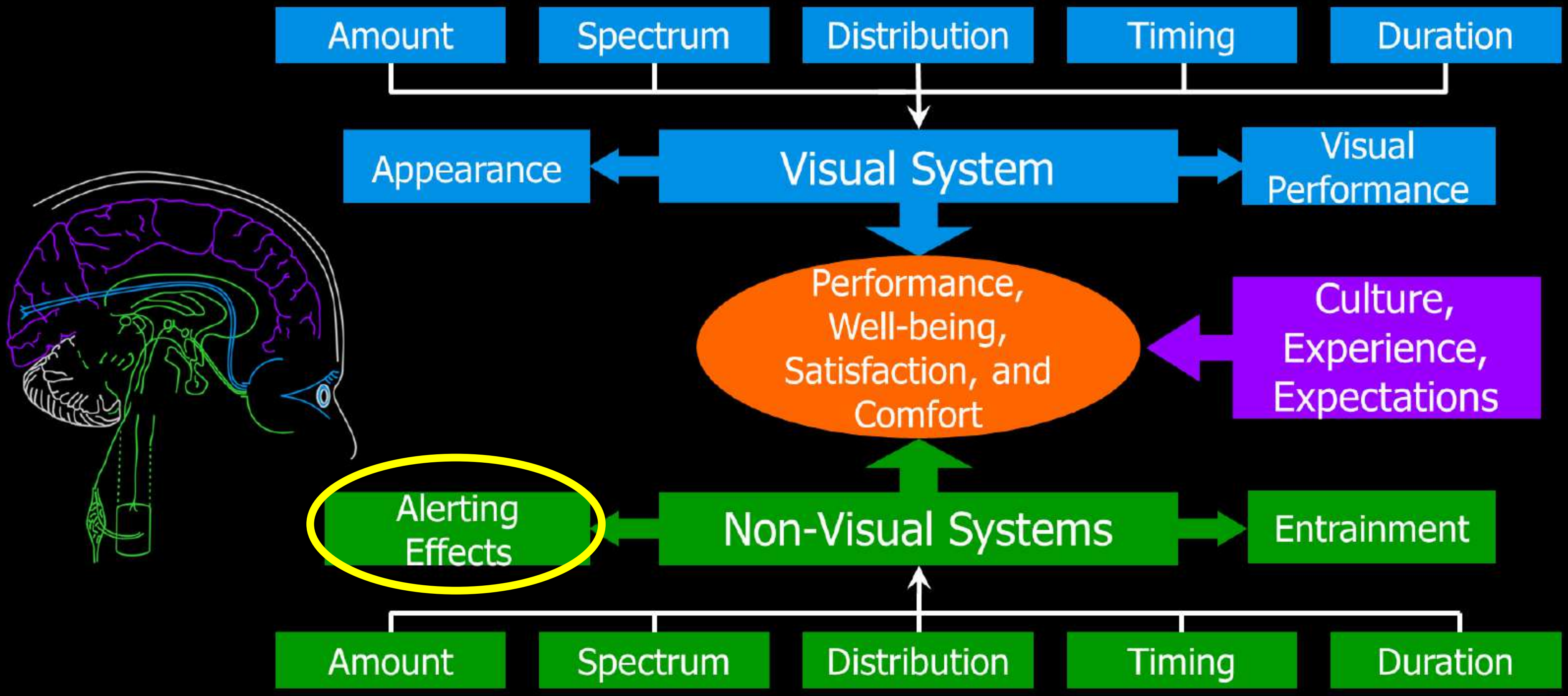
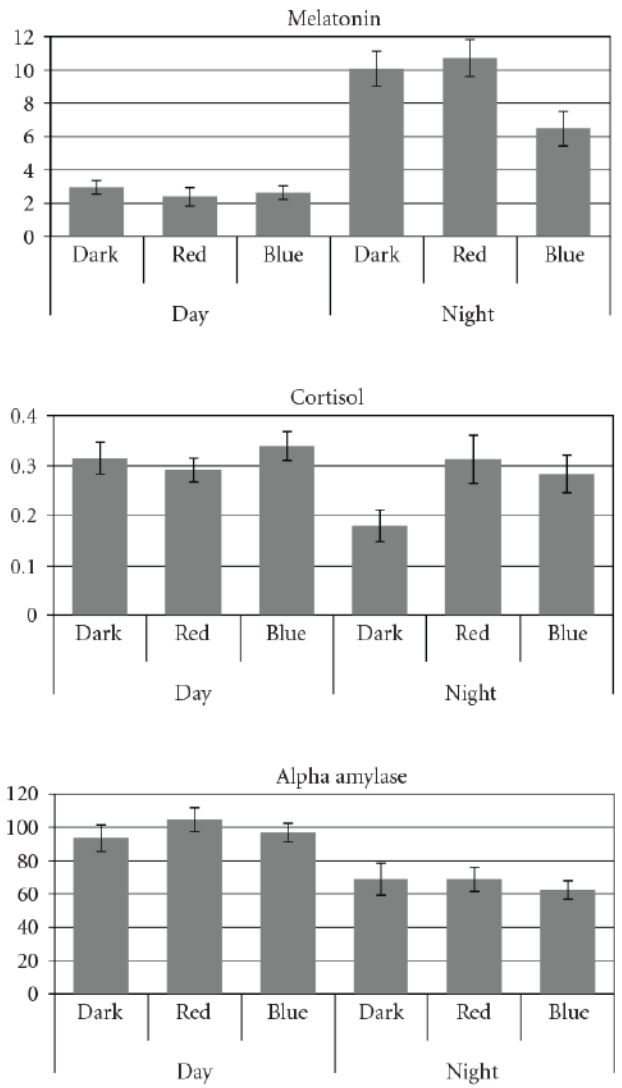
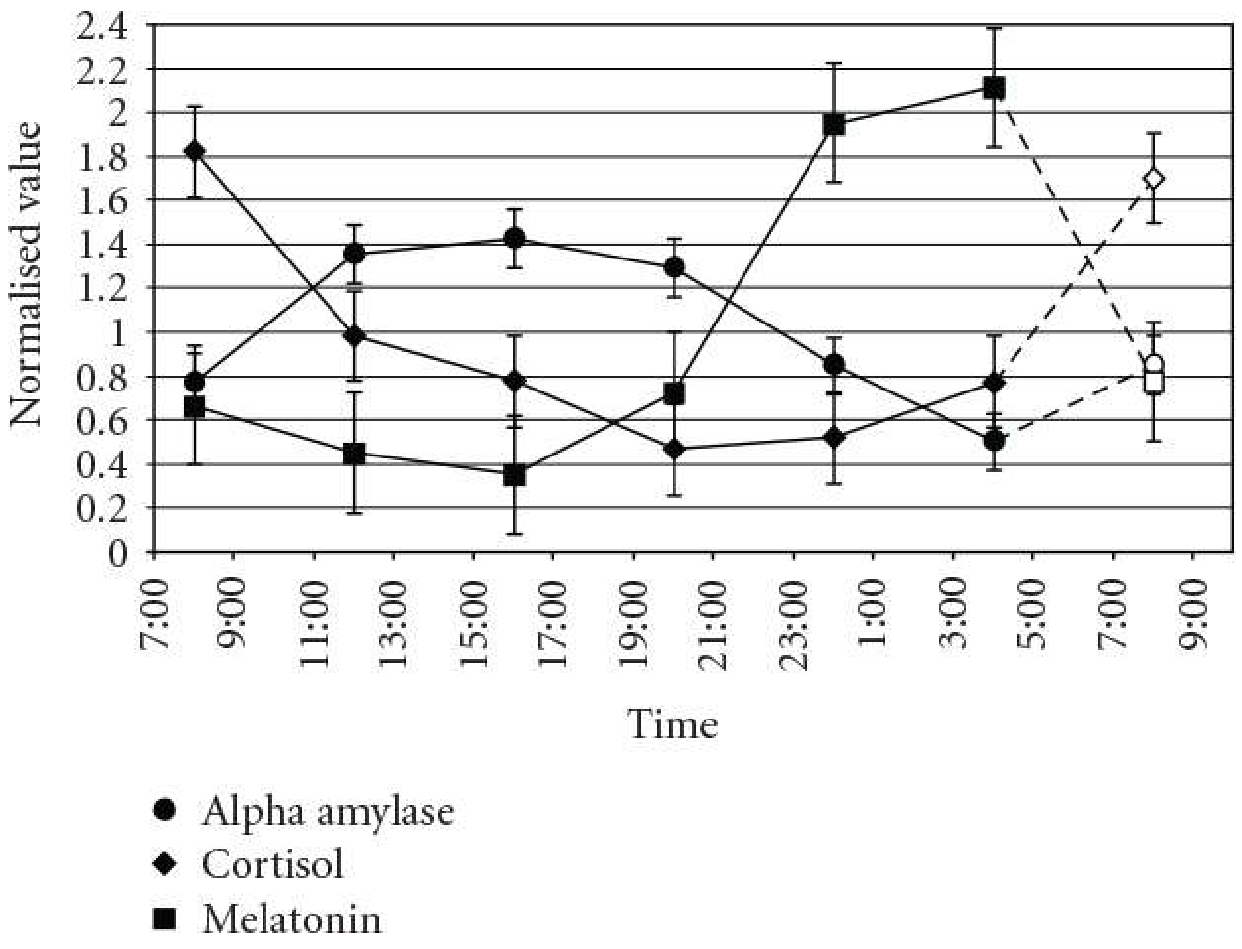
# Alerting effects





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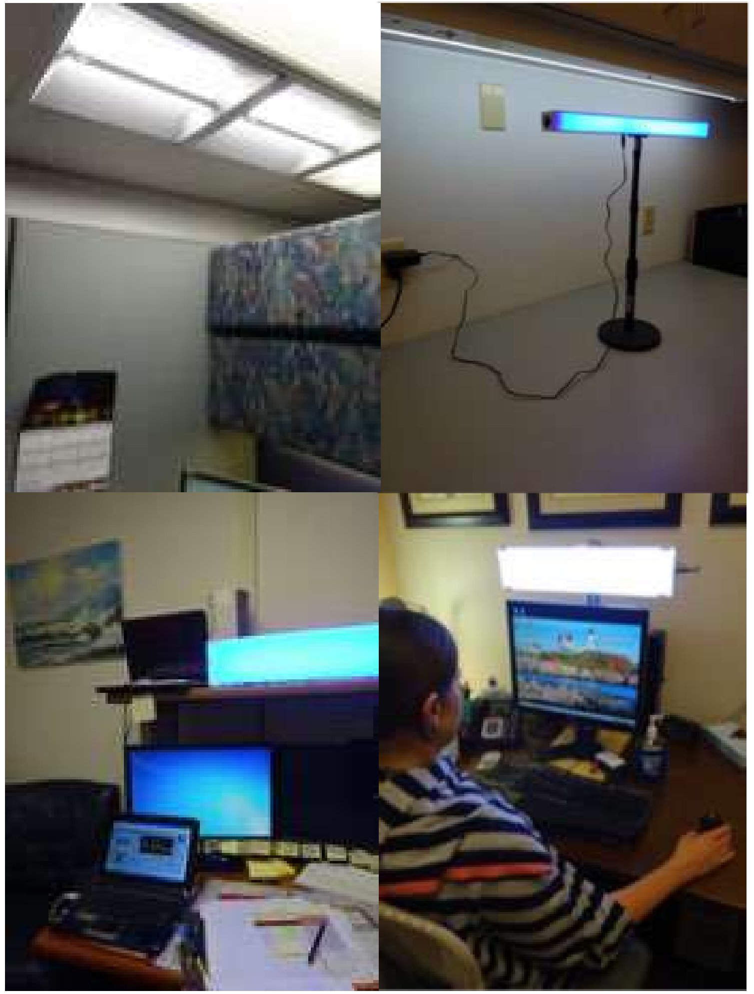
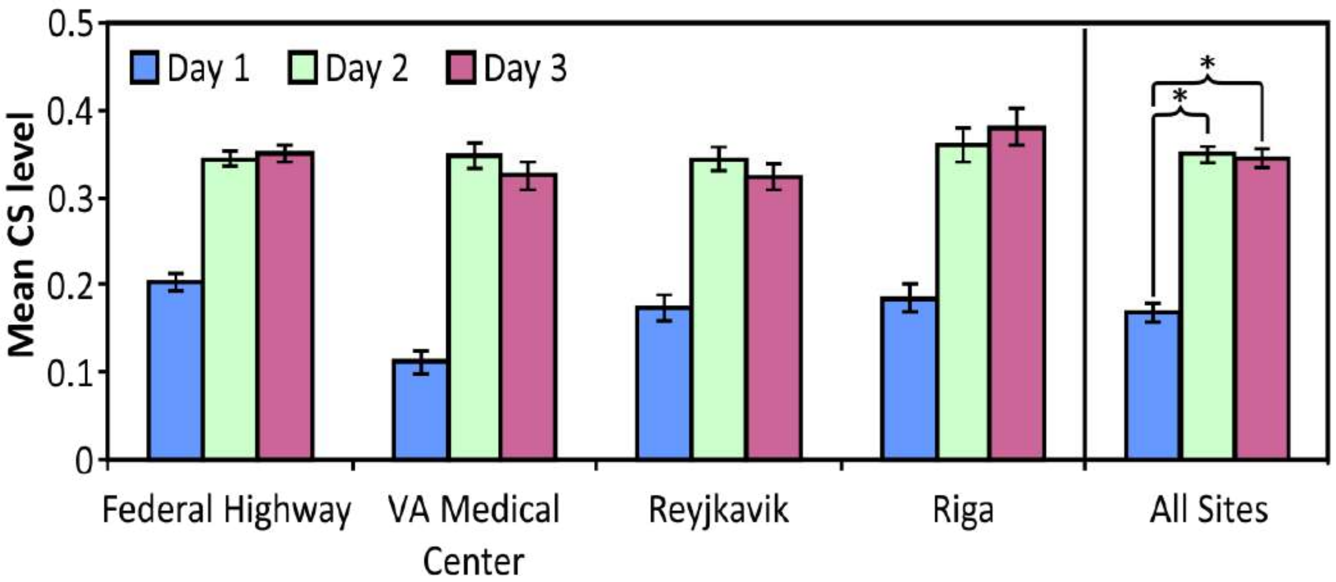
# Direct effects of light

**Sponsors: General Services Administration and U.S. Department of State**






** Significant main effect of day of intervention (p<0.05). Error bars represent standard error of the mean.*

To achieve the CS > 0.3, used low levels of blue light (40 lx at eye) or high levels of cool white light (300-400 lx at eye)



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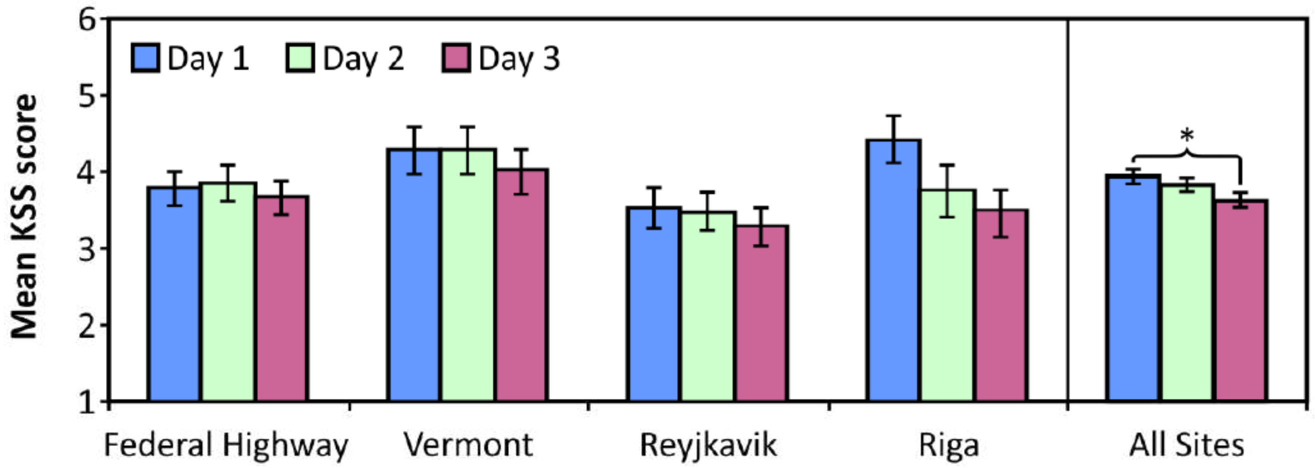
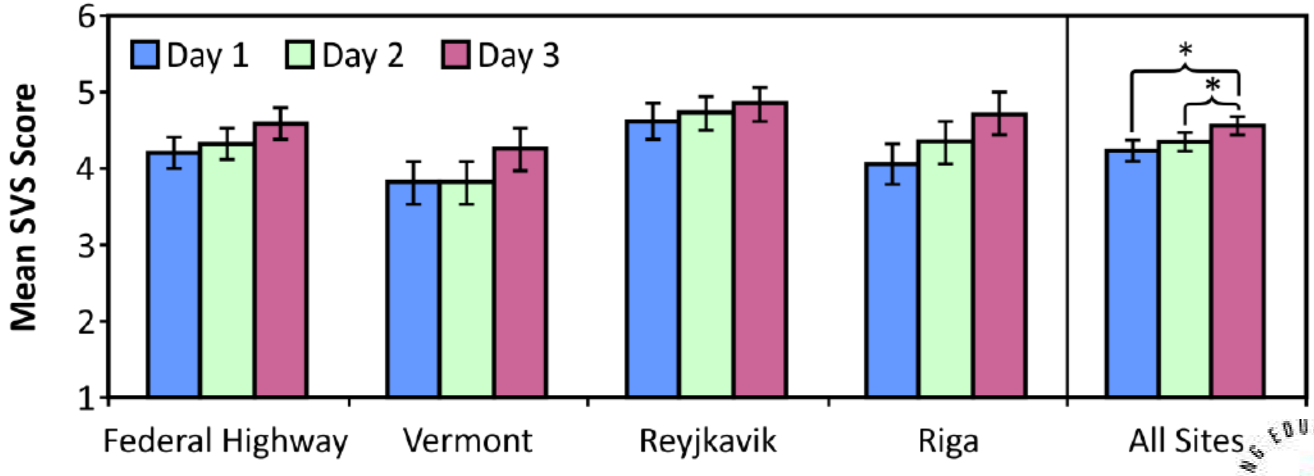
# Blue light and the direct effects of light

**Sponsors: General Services Administration and U.S. Department of State**




Subjective sleepiness (KSS) decreased significantly




- *Significant main effect of day of intervention ($p < 0.05$)*
- *Error bars represent standard error of the mean*

Subjective vitality (SVS) increased significantly



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Mariana G. Figueiro

# FIELD STUDIES

# Summarizing what we know so far…

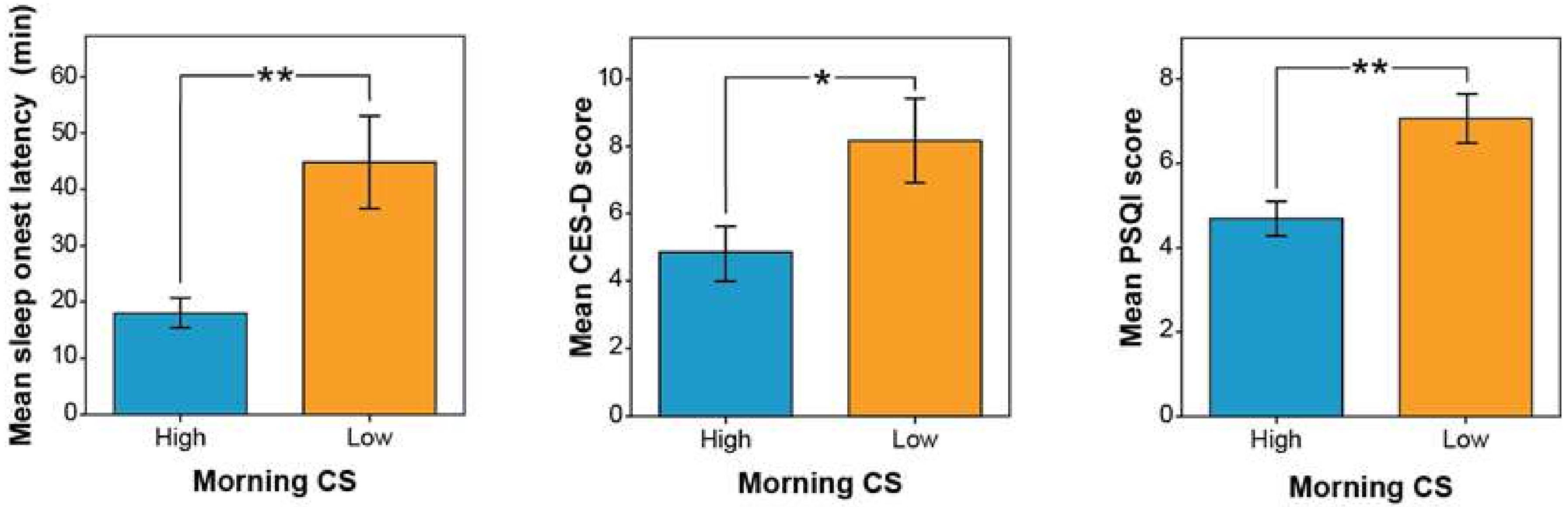
- Light sets the timing of the biological clock (that is, it promotes *entrainment*)
  - Morning light is needed to advance the timing of the clock (timing is important)
  - Short-wavelength and high light levels at the eye are most effective
  - Any white light can be used; however, you need to increase light levels, change fixture distribution or increase duration
  - Prolonged/continuous duration preferable (e.g., 2-h morning light)

# Summarizing what we know so far…

- Light has a direct (acute) alerting effect on people (like a cup of coffee)
  - Any time of day is effective
  - Does not have to be blue light, but it must be at the eye!
  - Effect is generally observed within 15-30 min

# Circadian entrainment in office workers

- Those exposed to higher morning (08:00 a.m. to noon) CS (CS > 0.3) fell asleep faster (less sleep onset latency) and reported better sleep and feeling less depressed than those exposed to low morning CS (CS < 0.15)




(** = $p < .01$; * = $p < 0.05$)

Figueiro M.G., Steverson B., Heerwagen J., Kampschroer K., Hunter C.M., Gonzales K., Rea, M.S. (2017). The impact of daytime light exposures on sleep and mood in office workers. Sleep Health; 3(3):204-215.

# Light and sleep survey

- During the COVID-19 pandemic we surveyed people's light exposures (indoors and outdoors) and how they impacted measures of sleep, mood, and anxiety
- Hypothesis: More light during the day = better sleep and mood
  - Over 700 responses
  - Included in the analyses are those who were employed but working at home or unemployed and staying home



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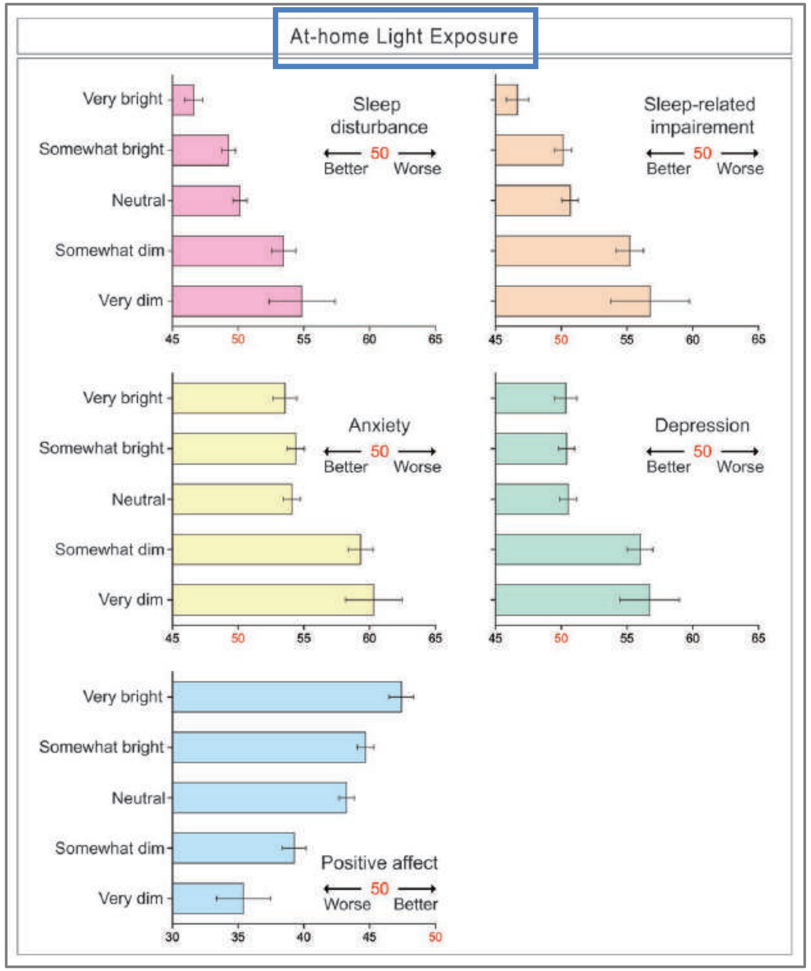
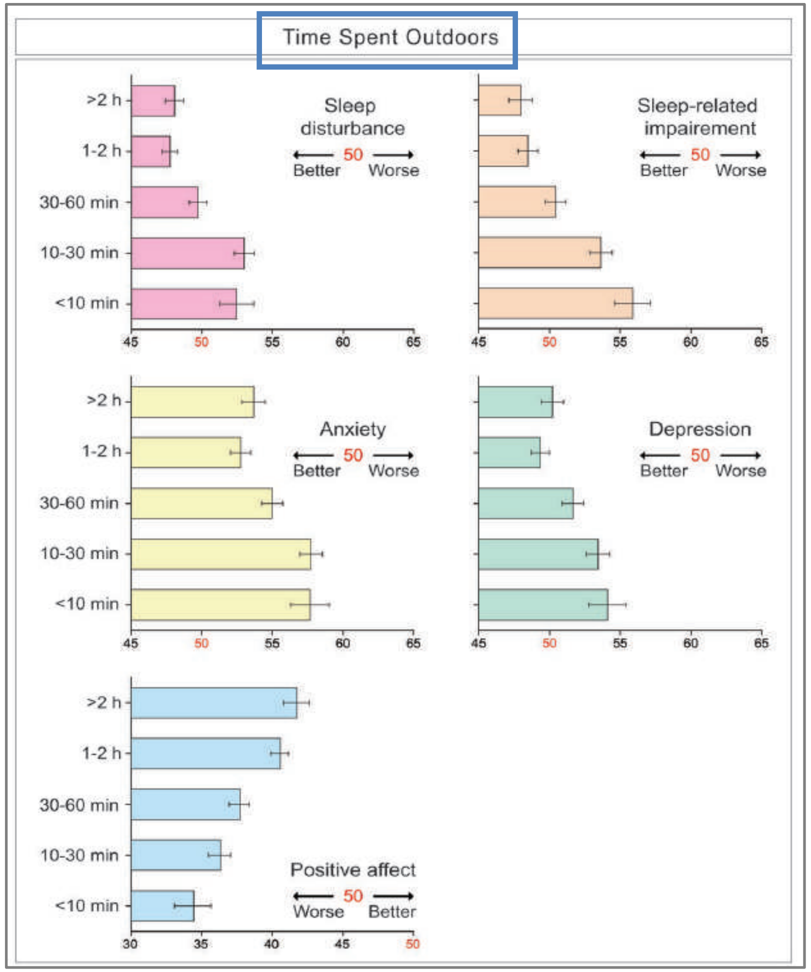
# Light and sleep survey




Figueiro M, Jarboe C, Sahin L. The sleep maths: A strong correlation between more daytime light and better night-time sleep. *Lighting Research & Technology*. 2021; 53: 423-435.

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# Circadian entrainment in workers working from home

**20**
**Residents**

**28 Days**
**in 2020**

**EXO Apartments**
**Reston, Virginia**



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| PARTICIPANTS | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|---|
| 10 | BASELINE | SMART WINDOWS  | BASELINE | BLINDS  |
| 10 | BASELINE | BLINDS  | BASELINE | SMART WINDOWS  |



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| PARTICIPANTS | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|---|
| 10 | BASELINE | SMART WINDOWS | BASELINE | BLINDS |

| | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|---|
| ENVIRONMENTAL MONITORING | | | | |
| SLEEP TRACKING | BASELINE | BLINDS | BASELINE | SMART WINDOWS |
| SURVEYS | | | | |
| PERSONAL LIGHT | | | | |


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| PARTICIPANTS | WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|---|
| 10 | BASELINE | SMART WINDOWS | BASELINE | BLINDS |
| 10 | BASELINE | BLINDS | BASELINE | SMART WINDOWS |


**VITALITY SURVEY**

- 7:00 am
- 11:00 am
- 3:00 pm
- 7:00 pm
- 11:00 pm

**SALIVA TESTS**

| | |
|---|---|
| 7:30 pm | 10:00 pm |
| 8:00 pm | 10:30 pm |
| 8:30 pm | 11:00 pm |
| 9:00 pm | 11:30 pm |
| 9:30 pm | 12:00 am |


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SMART WINDOWS | BLINDS

## Melatonin

| SMART WINDOWS | BLINDS |
| --- | --- |
| Consistent melatonin onset | 15 minutes delay over the course of the week |

## Sleep

| SMART WINDOWS | BLINDS |
| --- | --- |
| Earlier sleep onset by 22 min | Sleep debt compensation on Friday night |

## Vitality

| SMART WINDOWS | BLINDS |
| --- | --- |
| Consistent cycle of vitality with high morning and daytime energy levels | Delayed peak vitality, high nighttime energy levels and low morning vitality |

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# Circadian entrainment in myeloma transplant patients

- Our team investigated the impact of a CS of 0.3 (1000 lx at pillow, 3000 K light source) between 07:00 and 10:00 on:
  - Symptom burden (i.e., depression)
  - Melatonin levels (circadian entrainment)
  - Inflammation (IL-6) and neutropenic fever



Sponsor: National Cancer Institute

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# Circadian entrainment in myeloma transplant patients

- Among MM patients undergoing ASCT, those who were exposed to **circadian-effective light** in their hospital room had...

...compared to those who were exposed to **circadian-ineffective light**

- ↓ Transplant-related complications
- ↓ Depression
- ↑ Overnight melatonin levels
- ↓ Levels of pro-inflammatory cytokines
- ↓ Rates of neutropenic fever


Sponsor: National Cancer Institute
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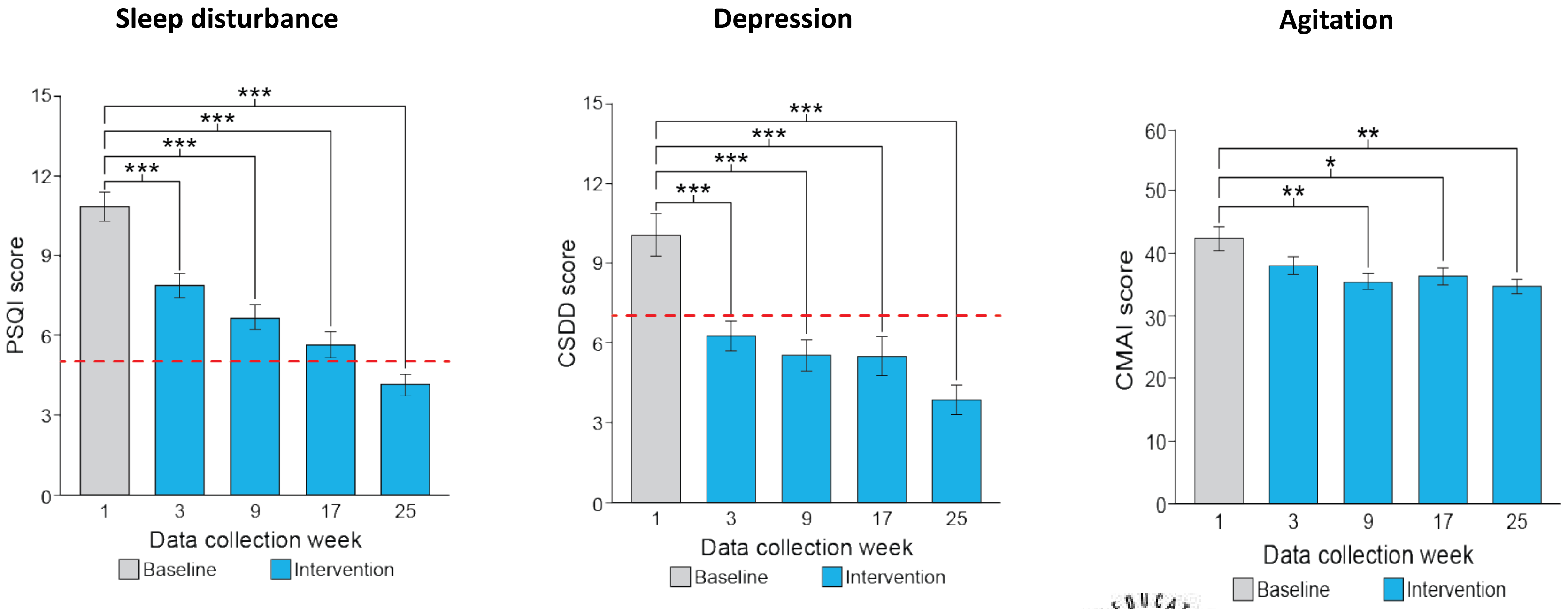
# Circadian entrainment in Alzheimer's disease and related dementias (ADRD)

- Long-term study
  - Fewer sleep disturbances (PSQI scores) and depressive symptoms (CSDD scores) during the TLI compared to baseline
  - Fewer agitation behavior symptoms (CMAI scores) during the TLI compared to baseline




* $p$ <0.05, ** $p$ <0.01*** $p$ <0.001



Sponsor: NIA (R01AG034157)

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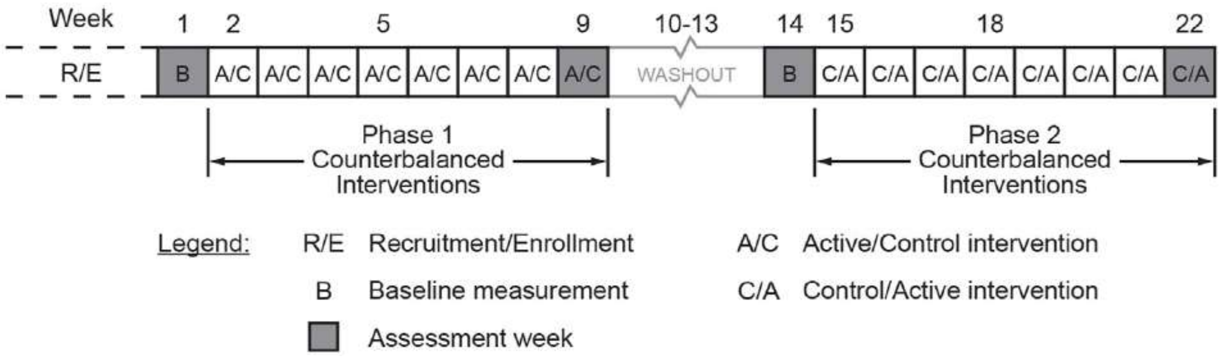
# Improving sleep-wake cycles in older adults living with dementia — Methods

- 14 participants (11 females, mean age = 84.1 [SD 8.9] years)
- Recruited from 3 assisted living and memory care facilities
- Crossover, placebo-controlled design
- 3 different modes used to deliver light to subject's eyes
  - Both high CS (active) and low CS (placebo) interventions
- Two 8-week intervention periods separated by 4-week washout




- Outcomes
  - Collected during assessment weeks
  - Actigraphy (sleep duration, sleep time, sleep efficiency, sleep start time, and sleep end time)
  - Questionnaires
    - Cornell Scale for Depression in Dementia (CSDD)
    - Pittsburgh Sleep Quality Index (PSQI)
    - Sleep Disorders Inventory (SDI)



Sponsor: NIA (R01AG034157, 2R44AG060857)

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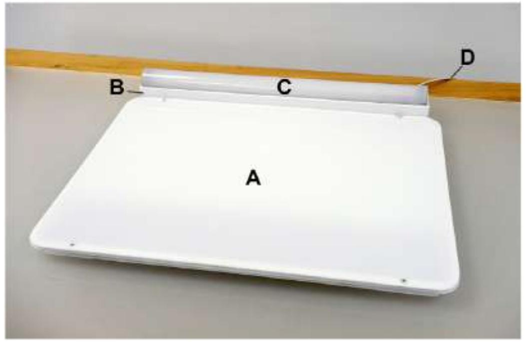
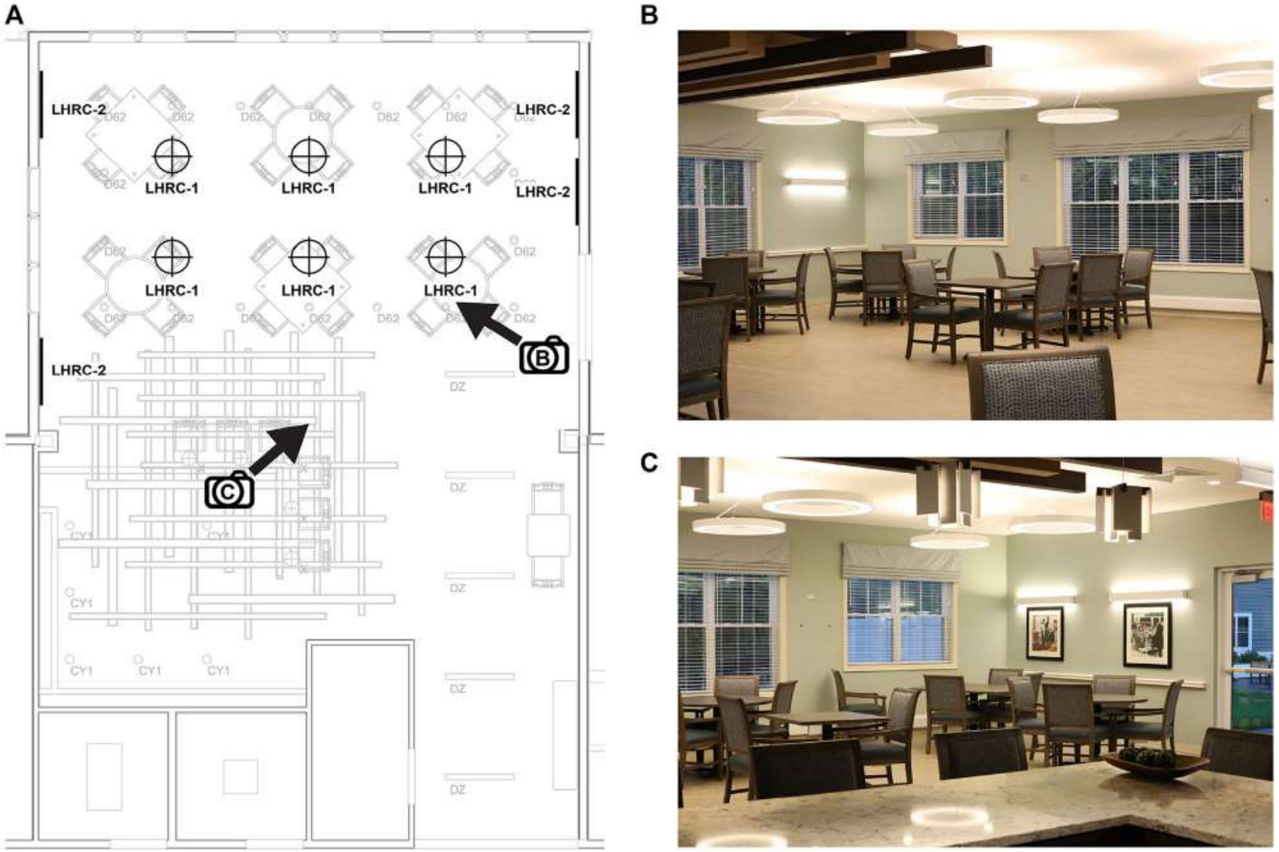
# Improving sleep-wake cycles in older adults living with dementia — Lighting

- 3 delivery modes
  - Light table (below, left)
  - Light tray (below, right)
  - Ambient room lighting retrofit (right)






Sponsor: NIA (R01AG034157, 2R44AG060857)

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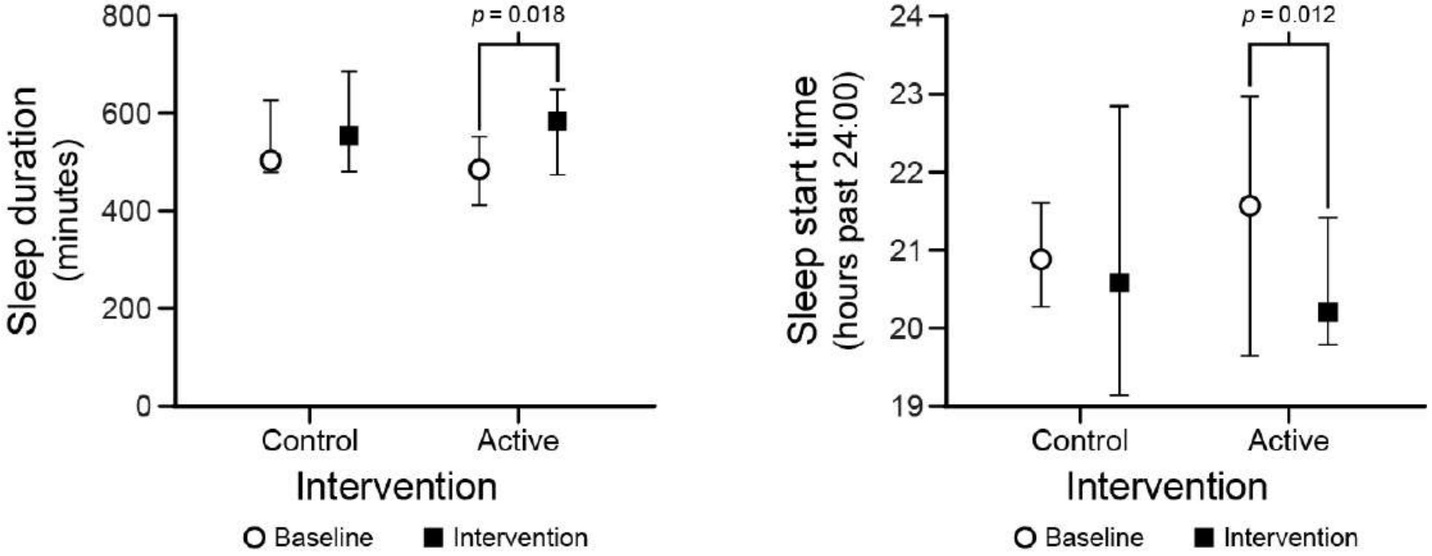
# Improving sleep-wake cycles in older adults living with dementia — Results

- Active condition, after intervention compared to baseline:
  - Sleep duration significantly (*p* = 0.018) increased
  - Sleep start time significantly (*p* = 0.012) advanced

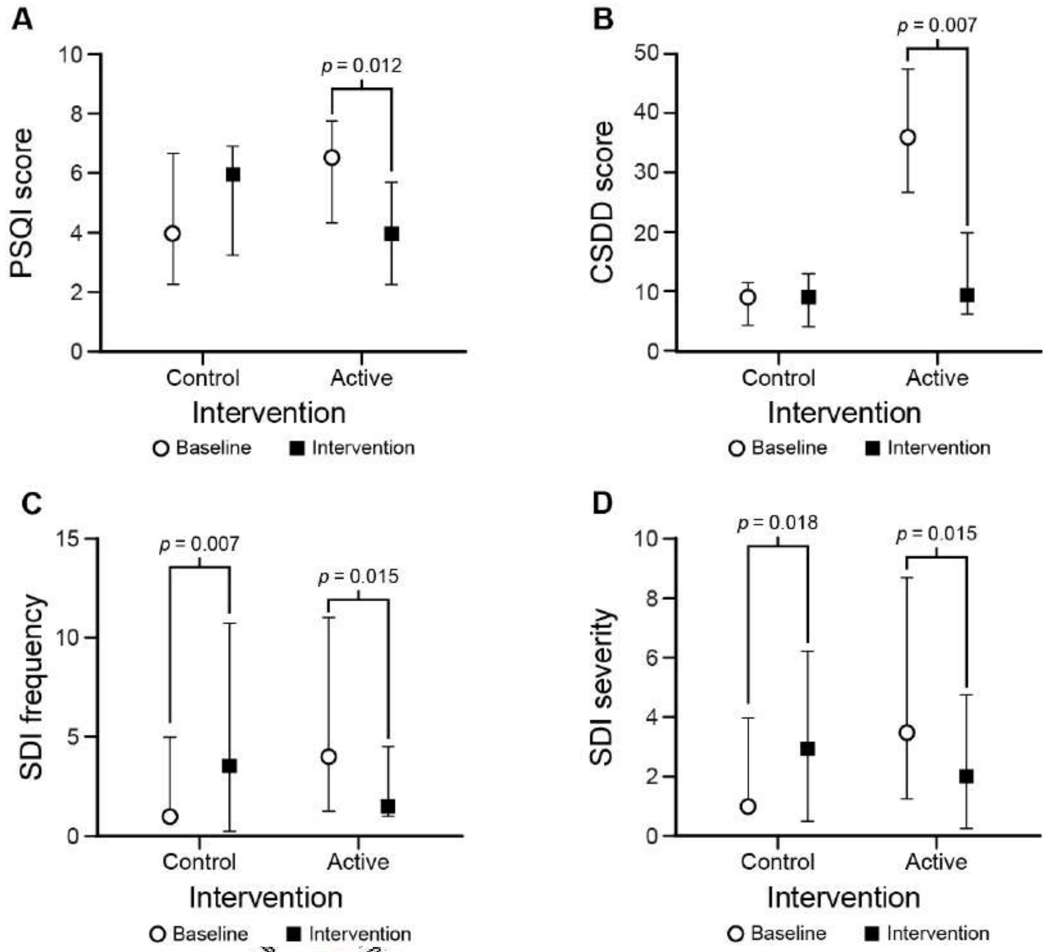




Sponsor: NIA (R01AG034157, 2R44AG060857)

# Improving sleep-wake cycles in older adults living with dementia — Results

- Active condition, scores significantly lower after intervention compared to baseline
  - A. PSQI ($p = 0.012$)
  - B. CSDD ($p = 0.007$)
  - C. SDI frequency ($p = 0.015$)
  - D. SDI severity ($p = 0.015$)





Sponsor: NIA (R01AG034157, 2R44AG060857)

# Sleep Math: Brighter days = Better Nights



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# Circadian entrainment and alertness in a train dispatch center

- In an operational context, investigate whether circadian entrainment, objective and subjective sleep quality, and subjective alertness would be promoted by:
  - Exposure to high CS (combined blue and white light) in the morning
  - Exposure to low CS (combined red with white light) in the afternoon and at night






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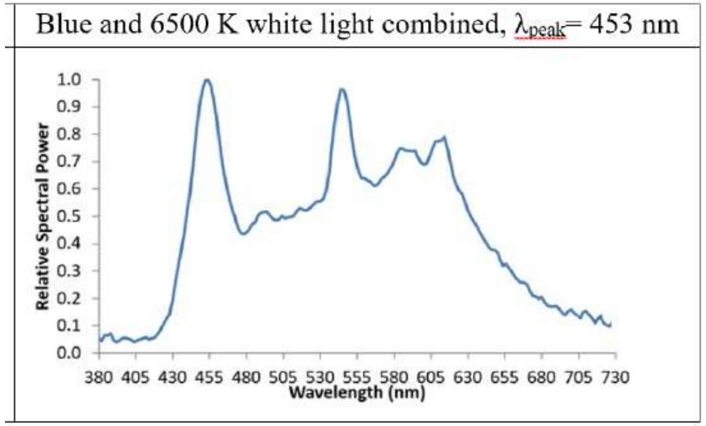
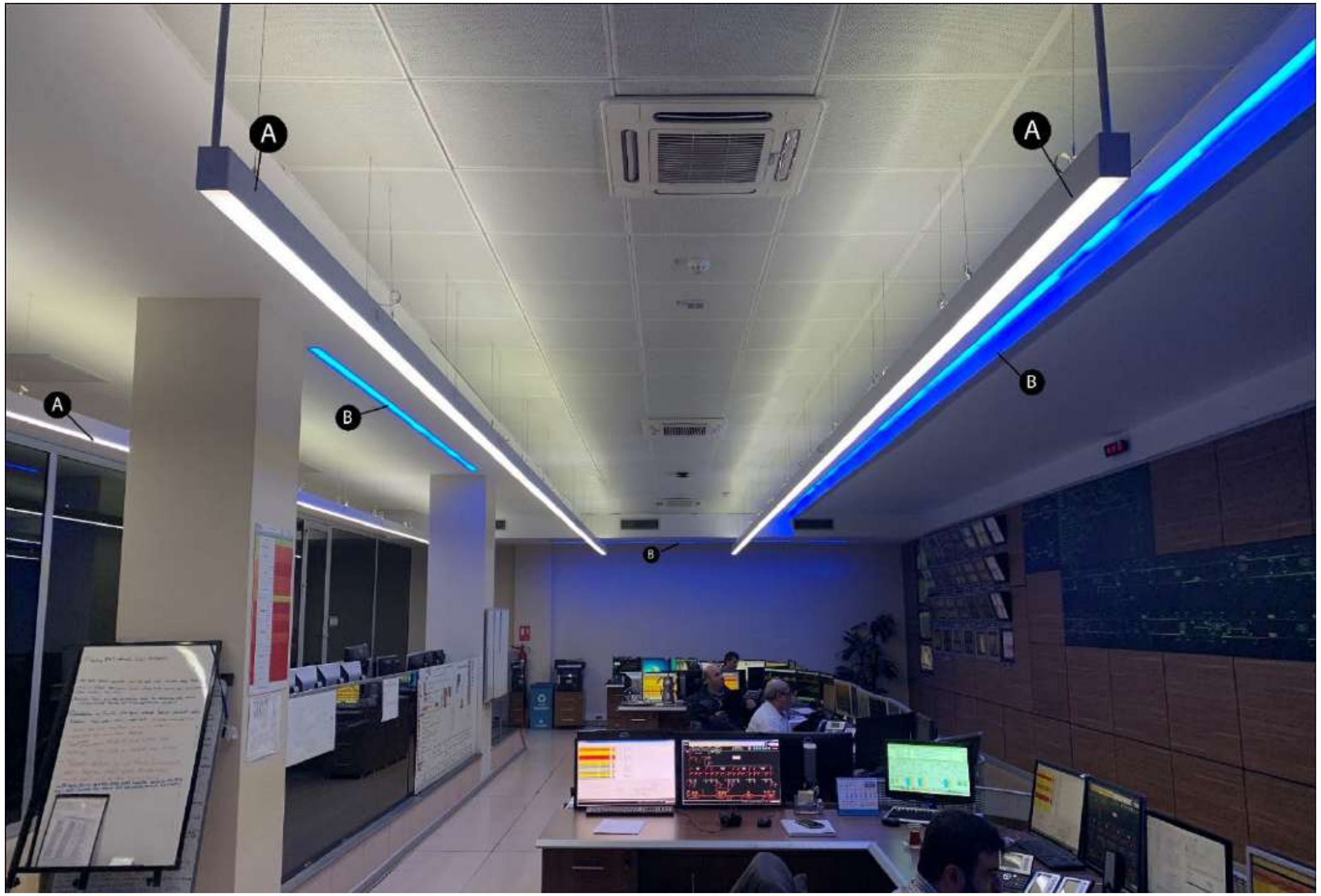
# Circadian entrainment and alertness in a train dispatch center




**Morning Schedule**

07:00 AM – 12:00 PM

CS >0.3

(A) 6500K white light

(B) (B) 470 nm blue light



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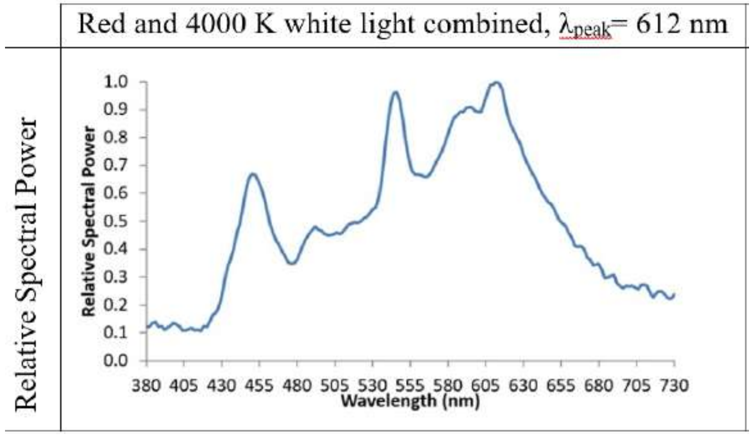
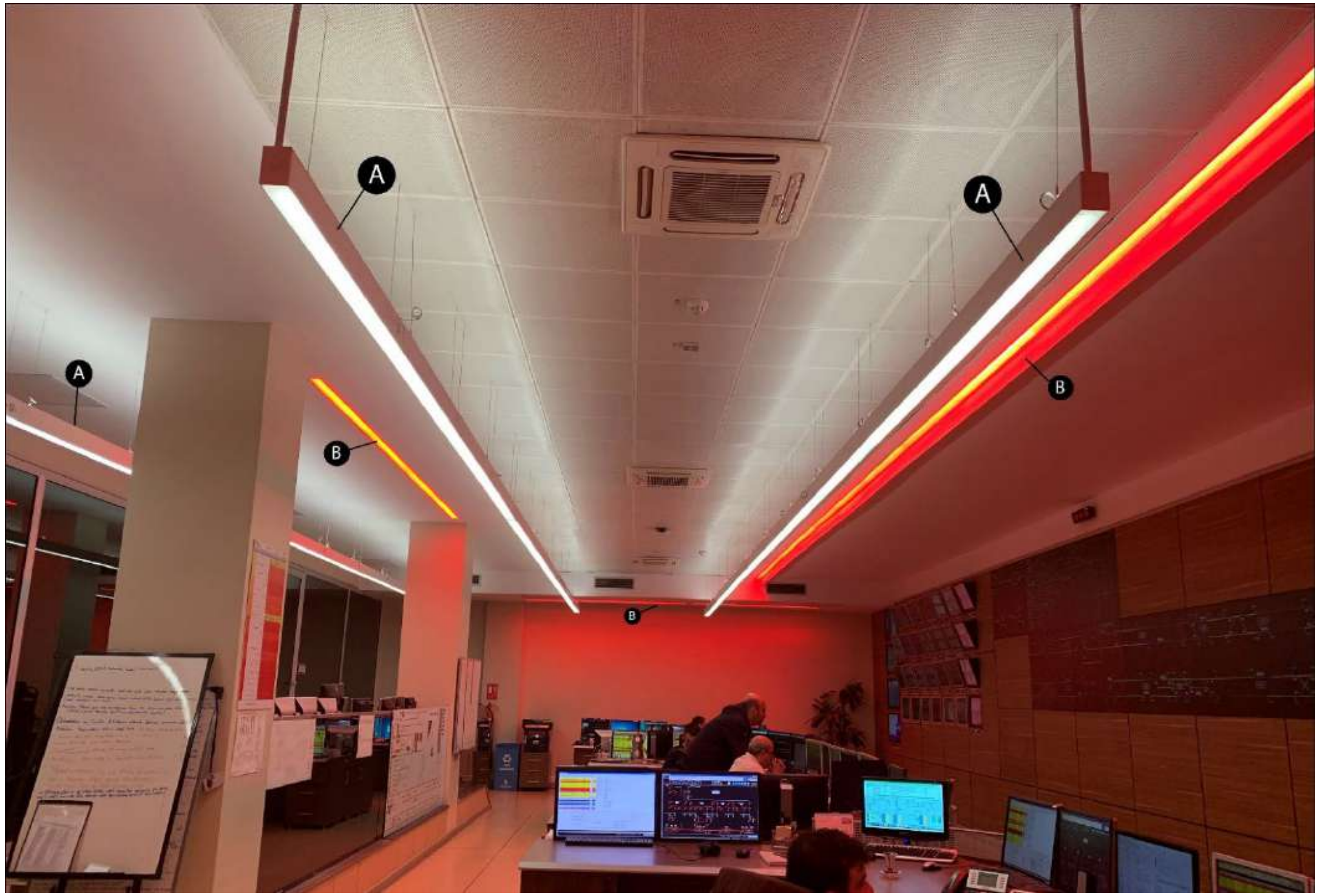
# Circadian entrainment and alertness in a train dispatch center




**Afternoon and Night Schedule**

12:00 PM – 07:00 AM

CS <0.1

(A) 4000 K white light

(B) 630 nm red light



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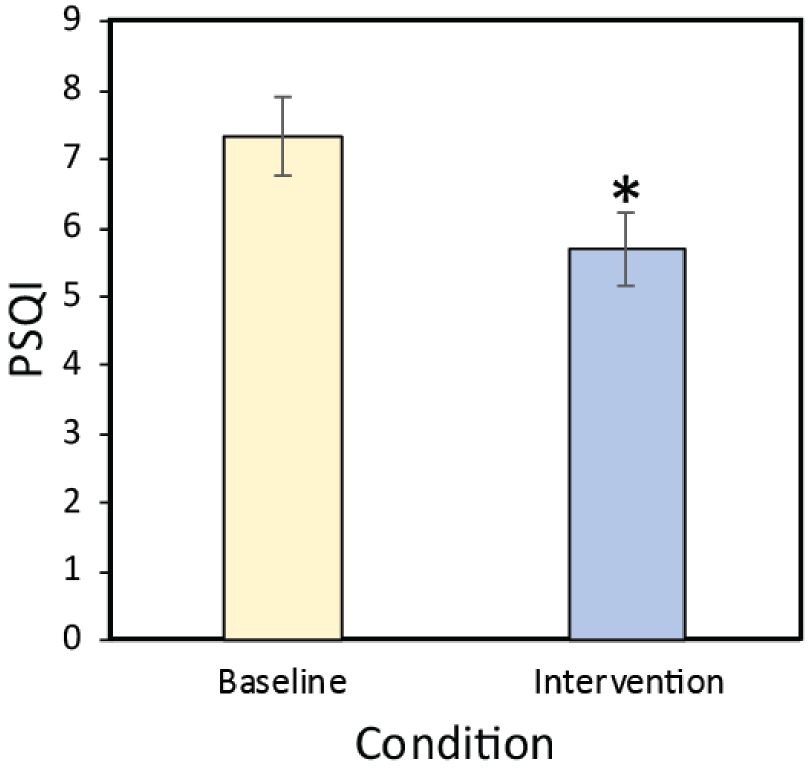
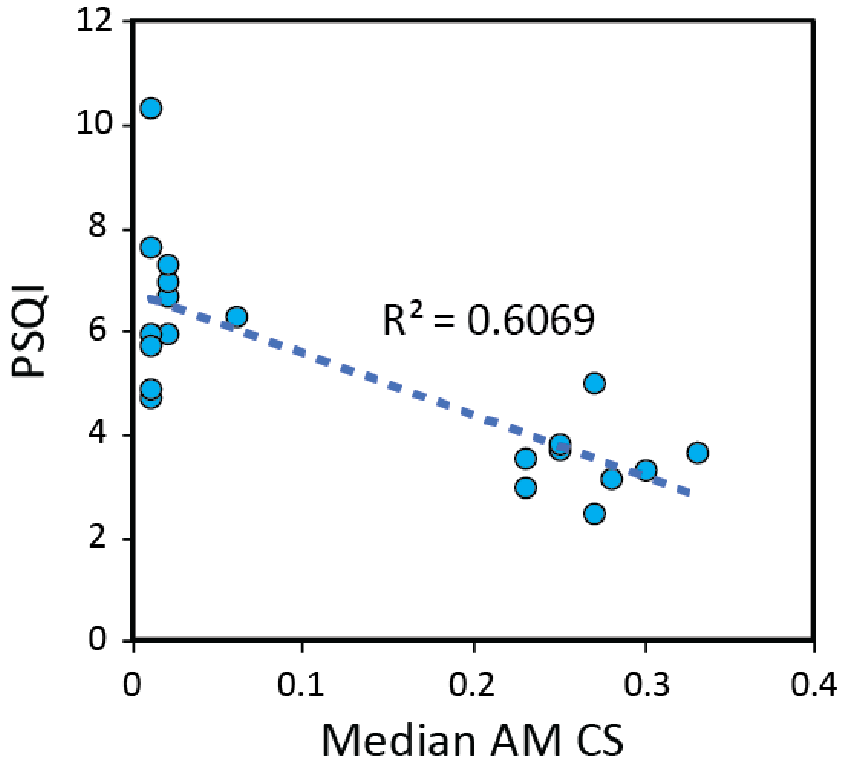
# Circadian entrainment and alertness in a train dispatch center

- Sleep disturbance (PSQI)

Better sleep




(* = $p < 0.05$)



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# Sleep Math:
# Brighter days = Better Nights

# Circadian entrainment and alertness in daytime workers

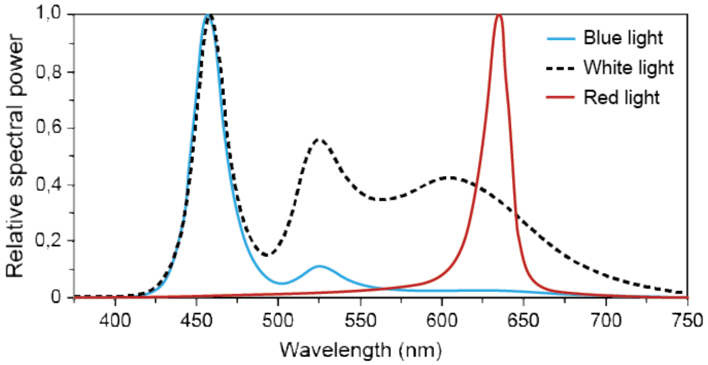
- 3-week field study testing the impact of morning blue light and afternoon red light on:
  - Sleep quality at home
  - Subjective sleepiness (KSS) and vitality (SVS) scores at work

| | Week 1 (Mon–Fri) | Week 2 (Mon–Fri) | Week 3 (Mon–Fri) |
|---|---|---|---|
| Time of day | Arrive / 12:00 / 15:00 / Depart | Arrive / 12:00 / 15:00 / Depart | Arrive / 12:00 / 15:00 / Depart |
| Wear Daysimeter | Arrival at work to bedtime | No | Arrival at work to bedtime |
| Wear actigraph | 24 h | No | 24 h |
| Lighting intervention | Off | On | On |
| Questionnaires | KSS SVS (Arrive, 12:00, 15:00, Depart); PSQI, CES-D, PSS-10 Mon only | | KSS SVS (Arrive, 12:00, 15:00, Depart); Fri only PSQI, CES-D, PSS-10 |


Sponsor: U.S. General Services Administration

# Circadian entrainment and alertness in daytime workers

- LHRC developed and built 20 plug-in LED luminaires, mounted on participants' desktops




| Time of Day | Lighting Intervention | $\lambda_{max}$ (nm) | $E_V$ (lux) | CS |
|---|---|---|---|---|
| 06:00 to 12:00 | blue | 455 | 50 | 0.30 |
| 12:00 to 13:30 | white (6500 K) | n/a | 200 | 0.30 |
| 13:30 to 17:00 | red | 634 | 50 | 0 |



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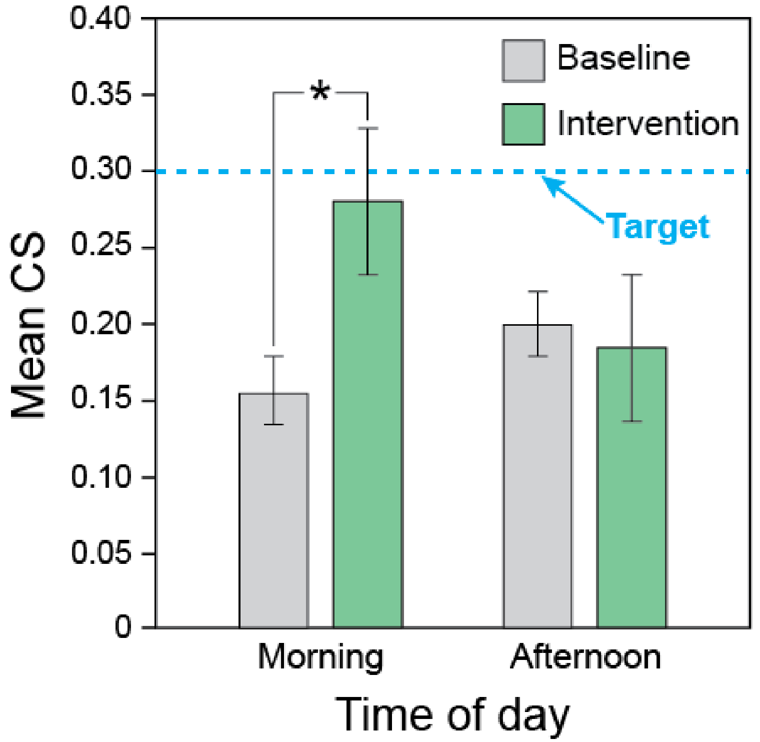
# Circadian entrainment and alertness in daytime workers

- Participants (N = 20) received significantly greater CS in the morning but not in the afternoon
- CS values lower than target CS of 0.3 possibly because:
  - Participants were not seated in workspace
  - Arrival later than 06:00
  - Morning meetings
  - Less daylight/sunlight penetrating workspaces




Error bars represent standard error of the mean, * $p < 0.05$



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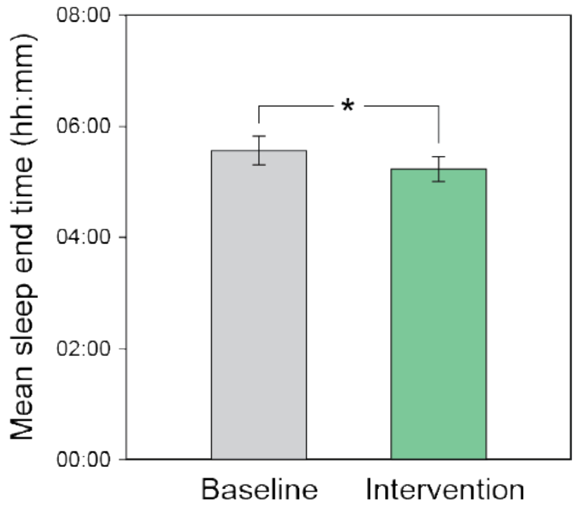
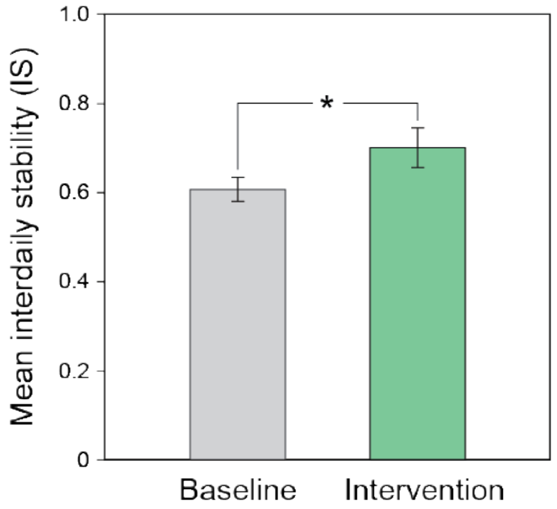
# Circadian entrainment and alertness in daytime workers

- Sleep end time
  - The intervention advanced circadian phase by 20 min
- Interdaily stability (IS)
  - The intervention shows stronger coupling between rest–activity rhythm and environmental cues (i.e., light stimulus), indicating significantly better circadian entrainment




Error bars represent standard error of the mean, * $p$ <0.05





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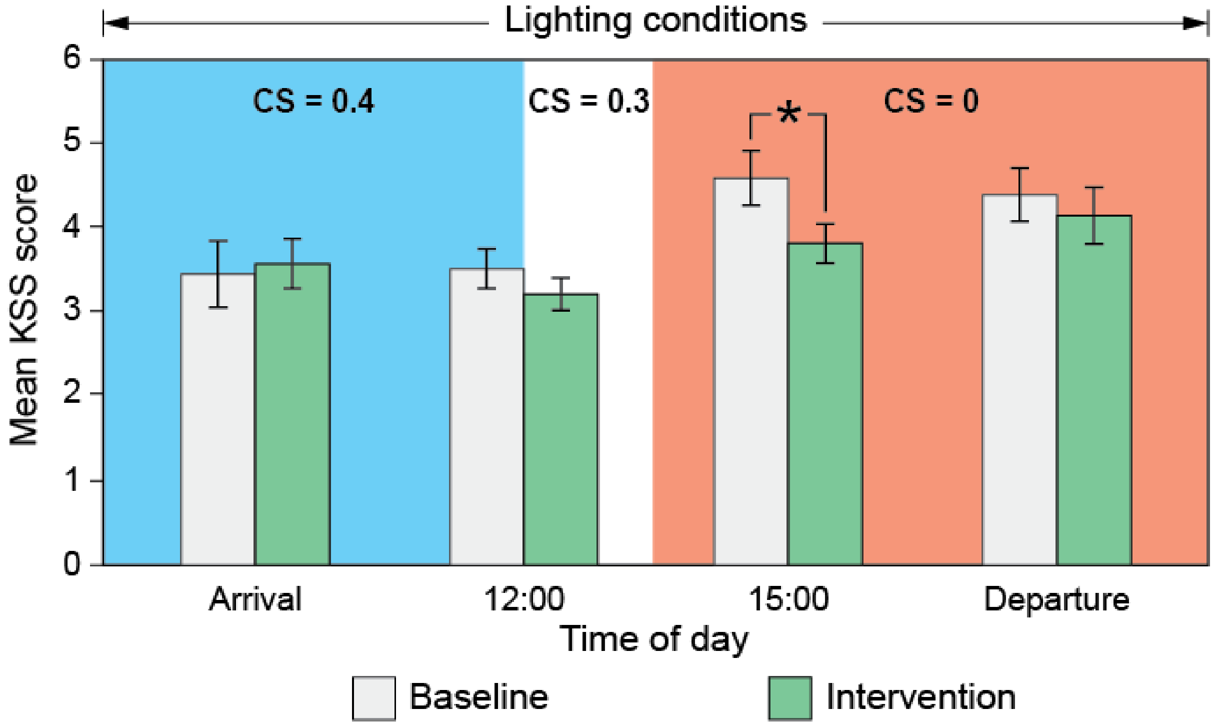
# Circadian entrainment and alertness in daytime workers

- Sleepiness (KSS) scores were reduced significantly during the intervention (week 3) at 15:00 (with red light)




Error bars represent standard error of the mean, * *p* <0.05



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# Summary

- We can design spaces to both promote circadian entrainment and maintain alertness, but it does NOT need to:
  - Have all the lights installed in the ceiling
  - Be ”blue-enriched”
  - Use white light sources only
  - Be bright and glary



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# Sleep Math: Brighter days = Better Nights

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Jennifer Brons

# CIRCADIAN LIGHTING STANDARDS, GUIDELINES

# Circadian design standards and guidelines

- WELL Building Standard v2
- Measurement standard: CIE S 026/E:2018
  - "Pre-standard" DIN/TS 67600:2022-08
- UL 24480
  - GSA P100



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# WELL Building Standard

- Equivalent Melanopic Lux (EML, m-lux)
- Calculate vertical illuminance at 4’ height, 18” above workplane
- Multiply photopic illuminance x melanopic ratio
  - Weighted to ipRGCs
  - Need tabular SPD
- Performance verification: measure EML at eye
- Earn “points”
  - 1 point: EML >150
  - 3 points: EML >275 (per v2 2021)
- 4 hours in the morning
- 75% of regularly occupied workstations

$E_V$ x Melanopic Ratio = EML

| λ (nm) | Lamp data | circadian | visual | lamp*c | lamp*v |
|---|---|---|---|---|---|
| 380 | 0.089 | 0.0009 | 0.0000 | 0.0001 | 3.6E-06 |
| 385 | 0.088 | 0.0017 | 0.0001 | 0.0001 | 5.3E-06 |
| 390 | 0.087 | 0.0031 | 0.0001 | 0.0003 | 1E-05 |
| 395 | 0.809 | 0.0059 | 0.0002 | 0.0048 | 0.00018 |
| 400 | 2.477 | 0.0114 | 0.0004 | 0.0283 | 0.00099 |
| 405 | 1.068 | 0.0228 | 0.0006 | 0.0244 | 0.00068 |
| 410 | 0.848 | 0.0462 | 0.0012 | 0.0391 | 0.00103 |
| 415 | 1.449 | 0.0795 | 0.0022 | 0.1151 | 0.00316 |
| 420 | 2.377 | 0.1372 | 0.0040 | 0.3262 | 0.00951 |
| 425 | 11.754 | 0.1871 | 0.0073 | 2.1991 | 0.0858 |
| 430 | 22.863 | 0.2539 | 0.0116 | 5.8042 | 0.26521 |
| 435 | 6.404 | 0.3207 | 0.0168 | 2.0538 | 0.10785 |
| 440 | 4.287 | 0.4016 | 0.0230 | 1.7215 | 0.0986 |
| 445 | 4.122 | 0.4740 | 0.0298 | 1.9537 | 0.12283 |
| 450 | 4.230 | 0.5537 | 0.0380 | 2.3422 | 0.16074 |
| 455 | 3.901 | 0.6297 | 0.0480 | 2.4562 | 0.18724 |
| 460 | 3.572 | 0.7080 | 0.0600 | 2.5289 | 0.2143 |
| 465 | 3.188 | 0.7852 | 0.0739 | 2.5031 | 0.23558 |
| 470 | 3.132 | 0.8603 | 0.0910 | 2.6945 | 0.28495 |
| 475 | 6.117 | 0.9177 | 0.1126 | 5.6133 | 0.68872 |
| 480 | 10.727 | 0.9656 | 0.1390 | 10.3576 | 1.4912 |
| 485 | 9.566 | 0.9906 | 0.1693 | 9.4766 | 1.61958 |
| 490 | 6.190 | 1.0000 | 0.2080 | 6.1900 | 1.28763 |
| 495 | 3.318 | 0.9920 | 0.2586 | 3.2917 | 0.85809 |
| 500 | 1.540 | 0.9660 | 0.3230 | 1.4875 | 0.4974 |
| 505 | 1.211 | 0.9223 | 0.4073 | 1.1167 | 0.49314 |
| 510 | 0.827 | 0.8629 | 0.5030 | 0.7135 | 0.41594 |
| 515 | 0.826 | 0.7852 | 0.6082 | 0.6484 | 0.50225 |
| 520 | 0.934 | 0.6996 | 0.7100 | 0.6535 | 0.66322 |
| 525 | 5.608 | 0.6094 | 0.7932 | 3.4177 | 4.44835 |
| 530 | 29.531 | 0.5193 | 0.8620 | 15.3355 | 25.4554 |
| 535 | 75.415 | 0.4325 | 0.9149 | 32.6196 | 68.9936 |

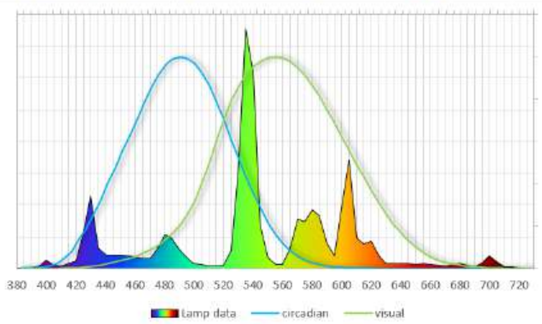
**Source**: Sample Fluorescent 4000 K

**Melanopic Ratio**: 0.588

Click here for data input

**Instructions**

1. Select built-in sample source, or user-entered source (above).
2. For user data, paste lamp spectral power distribution (5 nm increments) into Data sheet.
3. To add more user sources, insert columns to the left of User 2 on the Data sheet.
4. Multiply the Melanopic Ratio by measured or modeled lux to calculate equivalent melanopic lux.




Circadian | Data

https://standard.wellcertified.com/light/circadian-lighting-design



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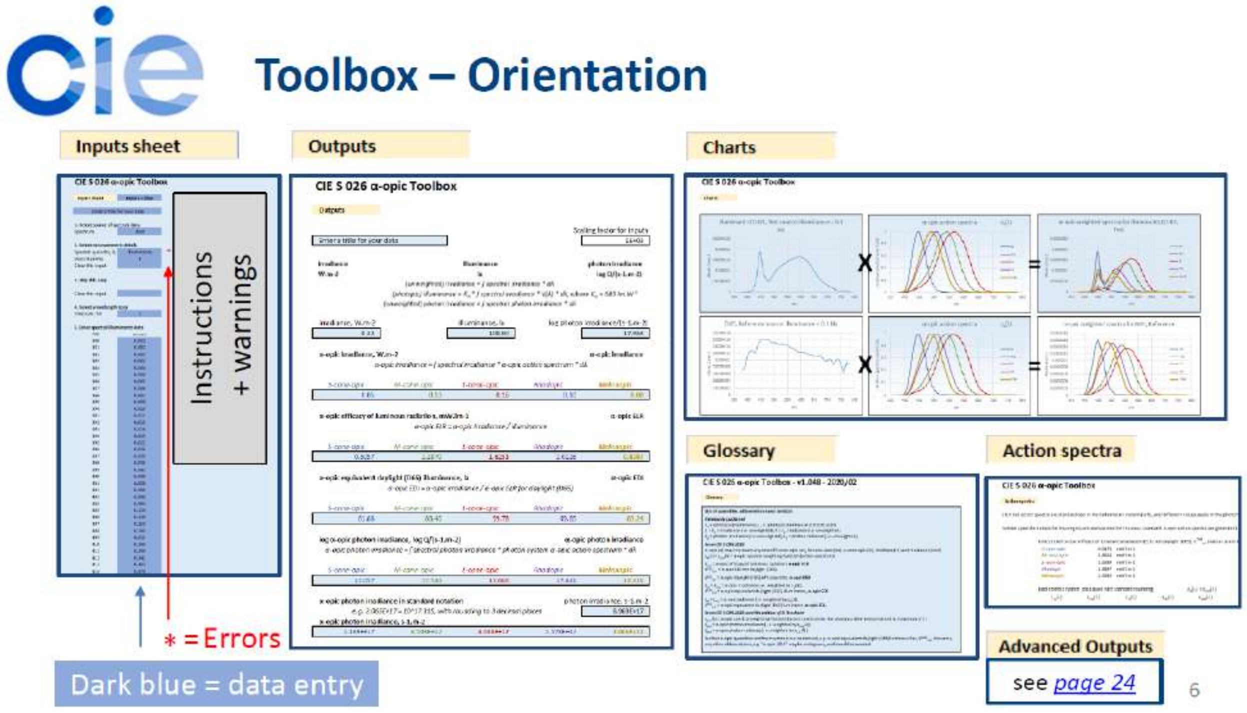
# CIE S 026/E:2018

- "CIE System For Metrology of Optical Radiation For ipRGC-Influenced Responses to Light"
- α-opic Irradiances
- Download "Toolbox"
  - Input: photopic illuminance at the eye
  - Input: Tabular SPD
- User Guide available: https://files.cie.co.at/CIE%20S%20026%20alpha-opic%20Toolbox%20User%20Guide.pdf
- **Measurement standard, not recommended practice**




https://files.cie.co.at/CIE%20S%20026%20alpha-opic%20Toolbox.xlsx

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# Recommendations using CIE S 026/E:2018

PLOS BIOLOGY

CONSENSUS VIEW

## Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults

Timothy M. Brown[1*], George C. Brainard[2], Christian Cajochen[3], Charles A. Czeisler[4,5], John P. Hanifin[2], Steven W. Lockley[4,5,6], Robert J. Lucas[1], Mirjam Münch[3,7], John B. O'Hagan[8], Stuart N. Peirson[9], Luke L. A. Price[8], Till Roenneberg[10], Luc J. M. Schlangen[11,12], Debra J. Skene[13], Manuel Spitschan[14,15,16], Céline Vetter[17], Phyllis C. Zee[18,19], Kenneth P. Wright, Jr[20*]

1 Centre for Biological Timing, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, United Kingdom, 2 Department of Neurology, Thomas Jefferson University, Philadelphia, Pennsylvania, United States of America, 3 Centre for Chronobiology, University Psychiatric Clinics Basel, Transfaculty Research Platform Molecular and Cognitive Neurosciences, University of Basel, Basel, Switzerland, 4 Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham and Women's Hospital, Boston, Massachusetts, United States of America, 5 Division of Sleep Medicine, Harvard Medical School, Boston, Massachusetts, United States of America, 6 Surrey Sleep Research Centre, Faculty of Health and Medical Sciences, University of Surrey, Guildford, United Kingdom, 7 Research Centre for Hauora and Health, Massey University, Wellington, New Zealand, 8 Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Chilton, Didcot, United Kingdom, 9 Sleep and Circadian Neuroscience Institute, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, United Kingdom, 10 Institutes for Medical Psychology and Occupational, Social and Environmental Medicine, Medical Faculty, Ludwig Maximilians University (LMU), Munich, Germany, 11 Human Technology Interaction Group, Department of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology, Eindhoven, the Netherlands, 12 Intelligent Lighting Institute, Eindhoven University of Technology, Eindhoven, the Netherlands, 13 Chronobiology, Faculty of Health and Medical Sciences, University of Surrey, Guildford, United Kingdom, 14 Translational Sensory & Circadian Neuroscience, Max Planck Institute for Biological Cybernetics, Tübingen, Germany, 15 TUM Department of Sport and Health Sciences (TUM SG), Technical University of Munich, Munich, Germany, 16 Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom, 17 Circadian and Sleep Epidemiology Laboratory, Department of Integrative Physiology, University of Colorado Boulder, Boulder, Colorado, United States of America, 18 Department of Neurology, Northwestern University, Chicago, Illinois, United States of America, 19 Center for Circadian and Sleep Medicine, Northwestern University, Chicago, Illinois, United States of America, 20 Sleep and Chronobiology Laboratory, Department of Integrative Physiology, University of Colorado Boulder, Boulder, Colorado, United States of America

Check for updates

OPEN ACCESS

**Citation:** Brown TM, Brainard GC, Cajochen C, Czeisler CA, Hanifin JP, Lockley SW, et al. (2022) Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. PLoS Biol 20(3): e3001571. https://doi.org/10.1371/journal.pbio.3001571

**Published:** March 17, 2022

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- **NOT a standard**
- Brown et al. 2022 "Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults"
- Refers to CIE S 026/E:2018
- Recommendations:
  - All day: M-EDI > 250 lux
  - Evening: M-EDI < 10 lux
  - Night:  M-EDI < 1 lux

https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.3001571



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# DIN/TS 67600:2022-08

- “Complementary criteria for lighting design and lighting application with regard to non-visual effects of light”
- German workplace lighting
- Refers to CIE S 026/E:2018
- >240 lx M-EDI at the eye, during the day
- Illuminance at the eye ≥ 250 lx at CCT = 8000 K
  or Illuminance at the eye ≥ 290 lx at CCT = 6500 K

https://www.beuth.de/en/pre-standard/din-ts-67600/354545584



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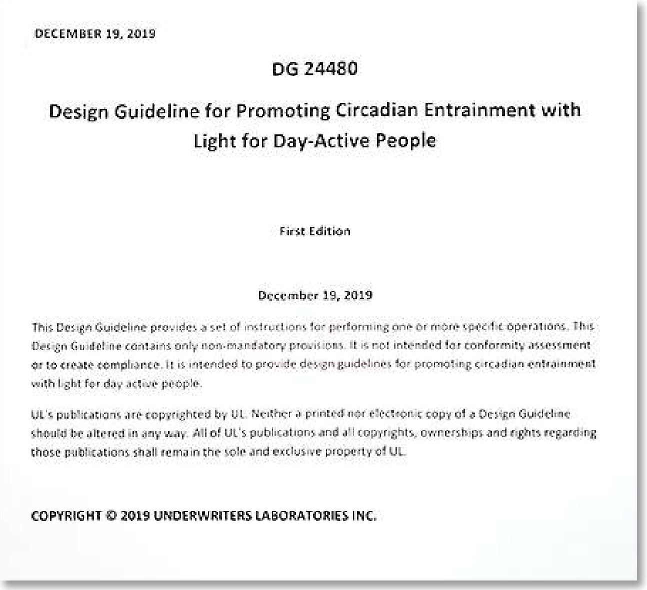
# UL 24480

- "Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People"
- Photometric calculations
  - Vertical illuminance ($E_V$)
  - Minimum 10 samples
  - Eye height, 0.9-1.3 m
- Criterion options
  - CS (recommended)
  - EML
  - Illuminance
- Recommendations:
  - Daytime: min. 2 hours CS ≥0.3
  - Night: CS ≤ 0.1


DECEMBER 19, 2019

DG 24480

Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People

First Edition

December 19, 2019

This Design Guideline provides a set of instructions for performing one or more specific operations. This Design Guideline contains only non-mandatory provisions. It is not intended for conformity assessment or to create compliance. It is intended to provide design guidelines for promoting circadian entrainment with light for day active people.

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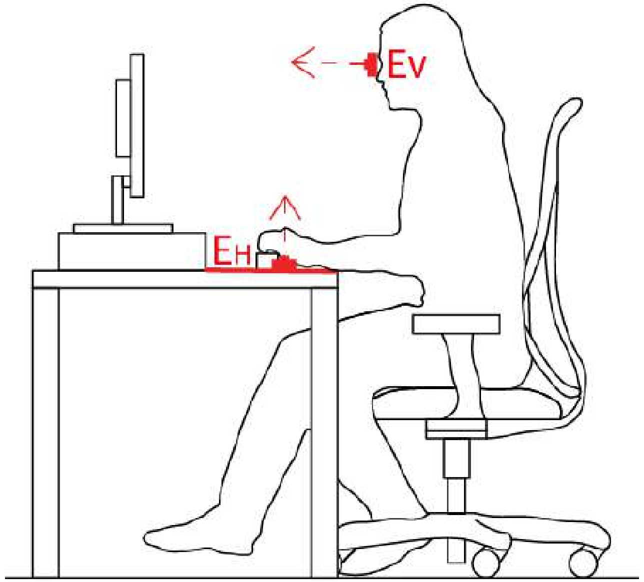


https://www.shopulstandards.com/ProductDetail.aspx?productId=UL24480



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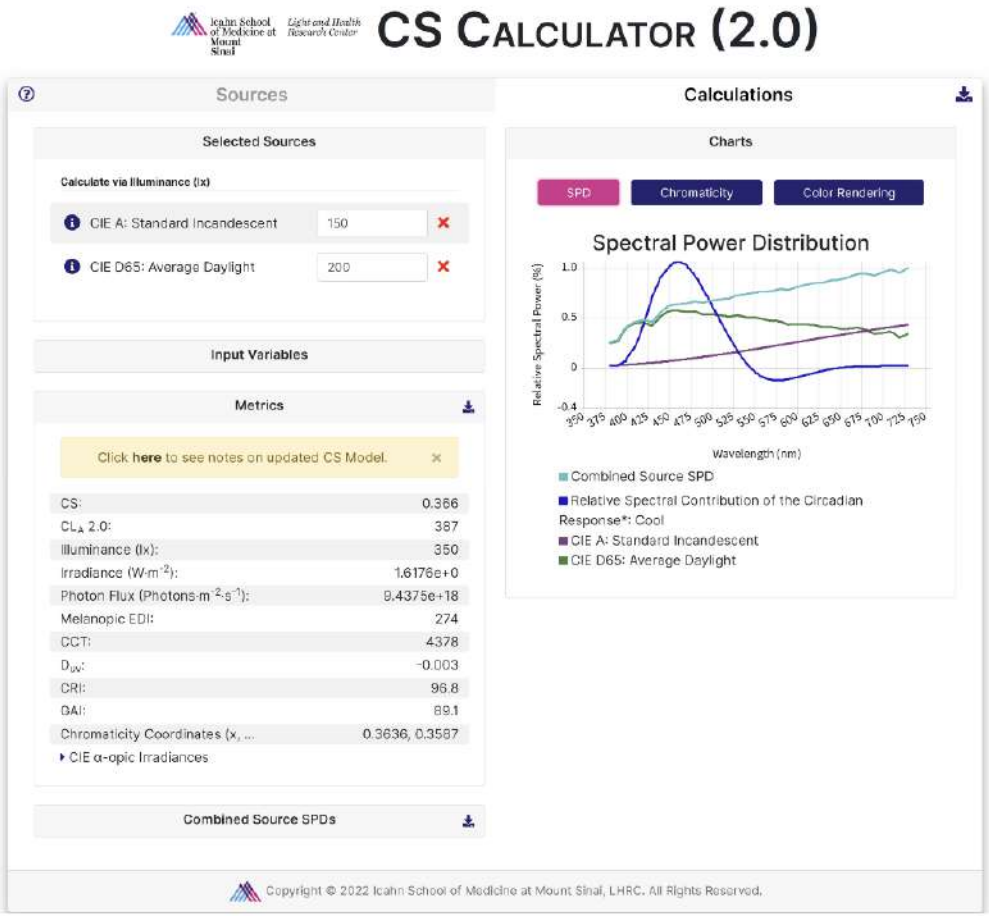
# CS Calculator

- Input $E_V$ calculations
- Input tabular SPD values
- Calculate CS
- Also includes calculations of:
  - CIE α-opic Irradiances
  - Color characteristics (CCT, CRI, GAI, Chromaticity)
- Allows blending of sources




https://cscalc.light-health.org/

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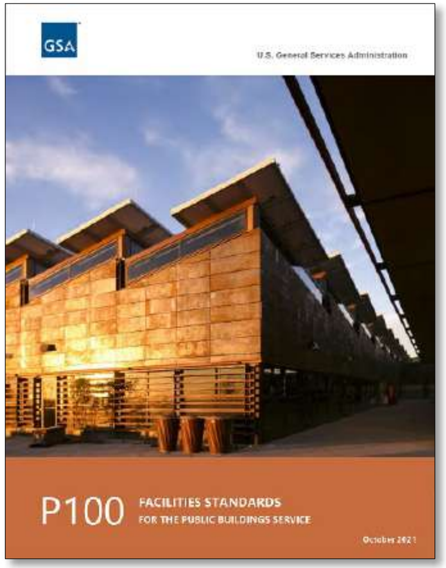
# Facilities Standards: GSA P100

- US General Services Administration (GSA) P100 *Facilities Standards for the Public Buildings Service*
- Design standards and performance criteria
- "Tier 2"
- Refers to UL 24480
  - CS 0.3 in the morning
  - EML 240 in the morning
  - Or 500 lux in the morning
- Verification: measure at eye level at sitting & standing height




| | Human Centric Lighting |
|---|---|
| Baseline | N/A |
| Tier 1 | |
| Tier 2 | Circadian Effective Lighting-Circadian Stimulus (CS) of 0.3 in morning, or equivalent melanopic lux (EML) of 240 in morning, or 500 photopic lx EV in morning on vertical plane at eye level |
| Tier 3 | |
| M & V | Yes |
| Plans & Specs | |
| Calculations & Analysis | Provide photometric calculations |
| References | |
| Basis of Design | Refer to UL 24480 Design Guideline |
| Construction Verification | Use photometer to measure vertical CS levels at eye level at sitting & standing height after construction |

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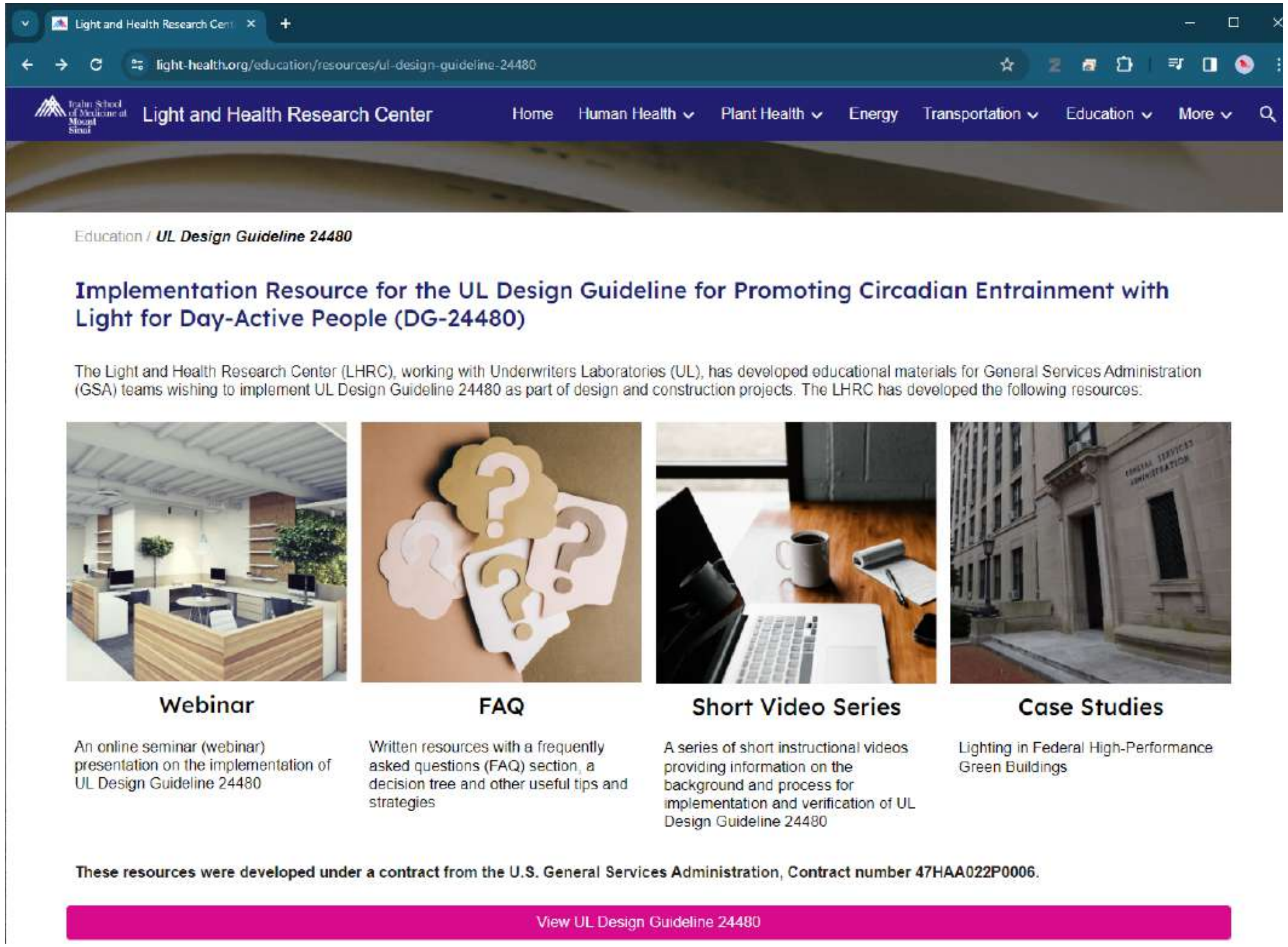
# For more information UL 24480




https://www.light-health.org/education/resources/ul-design-guideline-24480



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Daniel Frering

# INTEGRATED DESIGN



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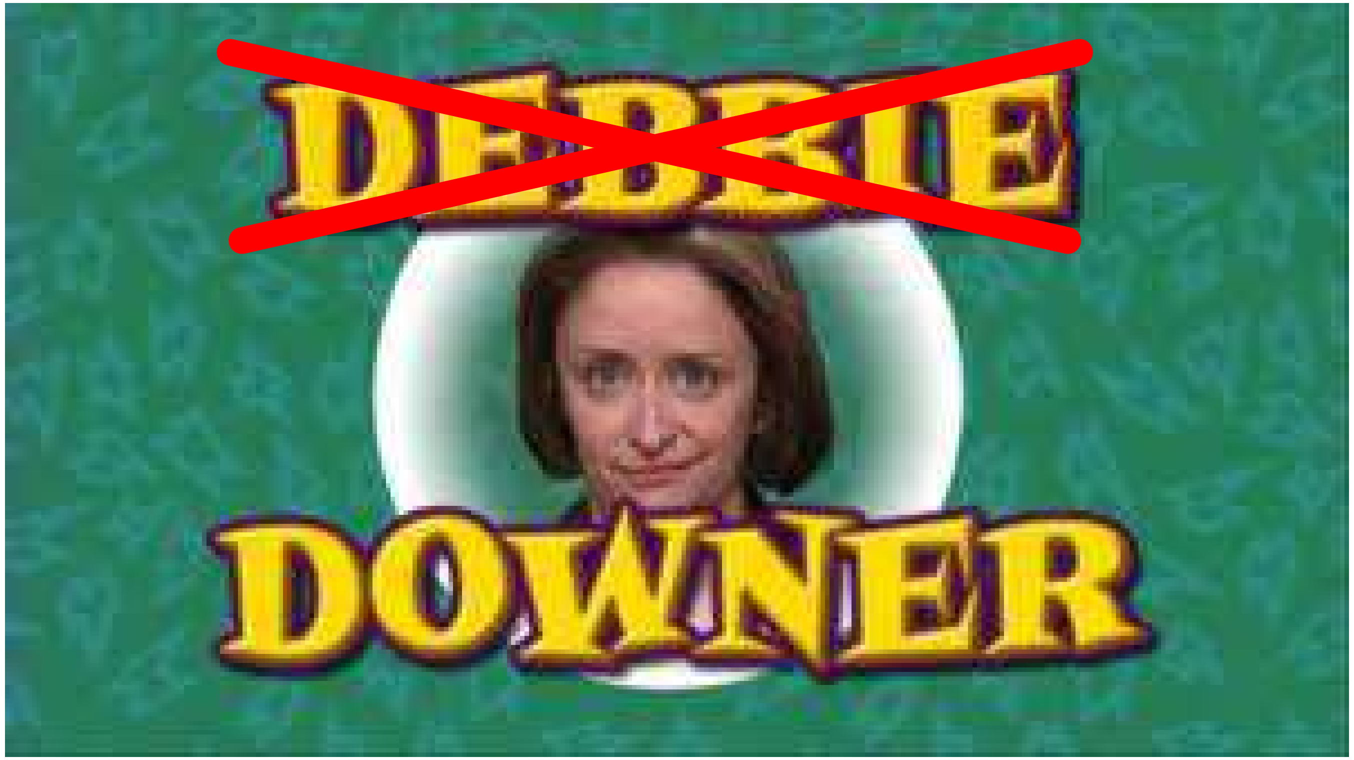
# Perceived barriers to designing lighting to provide non-visual benefits

**Dan**



# Perceived added costs

- Providing these benefits will add to the cost of the installation
  - Client may not recognize the value (be able to monetize) these benefits
  - Difficult to prove benefits are provided
  - Expensive lighting systems
    - “Blue-enriched” lamps, color-tuning systems, specialized controls, additional and/or most costly luminaires

$$\text{VALUE} = \frac{\text{BENEFITS}}{\text{COSTS}}$$

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# Perceived added complexity

- Lighting systems and design process are too complex
  - Added difficulty and cost for design, installation, programming, commissioning, and operation
  - Complex controls
    - Difficult to maintain, operate, and reprogram over time
  - Will often be "value engineered"
    - Will not provide the benefits promised
  - Will not be operated as designed

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# Perceived energy code conflicts

- Providing these benefits will add to the total connected lighting load
  - Installation will exceed lighting power density (LPD) allowances
  - No “credit” given for time of use
    - Bright morning, dimmer afternoon
- Lighting will use more energy
  - Reducing energy-cost savings (payback) in retrofit situations
  - Adding to operating costs
- Conflict with energy code requirements
  - Required daylight dimming systems

$$\text{VALUE} = \frac{\text{BENEFITS}}{\text{WATT}}$$


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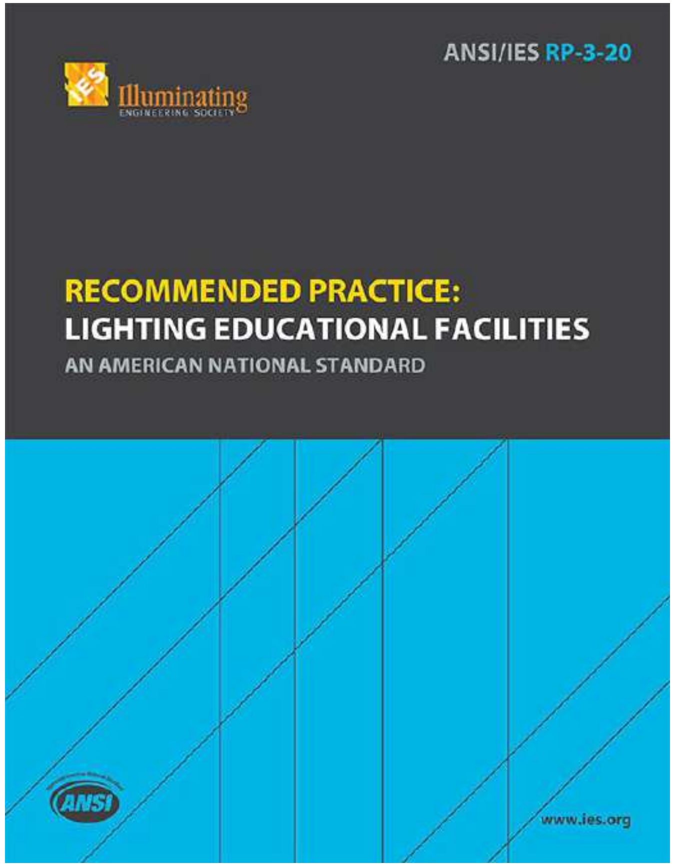
# Perceived conflict with visual-based lighting guidelines

- Visual-based lighting guidelines, standards, recommended practices, specifications, codes
  - Often interpreted as requirements rather than recommendations
  - Lighting design metrics may conflict
    - Vertical and horizontal illuminance
    - Light distribution
    - Others



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# Perceived lack of end user acceptance

- Lighting will not be accepted by end users
  - Too bright
  - Glaring
  - Dislike of color appearance of the ambient light
    - Too “blue”, too “cold”
  - Dislike of saturated colored light in the space
  - If used for circadian or alerting effects
  - Lack of personal control
    - If lights are controlled automatically
      - Bright mornings, dimmer in afternoon
      - Changing colors of light

# Perceived lack of influence for lighting designers on crucial design decisions

- Lighting designers often lack control over daylighting decisions
  - Unable to change window or skylight design or configuration
- Lighting designers often lack control over or knowledge of interior design decisions
  - Finishes, colors
  - Furniture selection, placement, configurations
  - Localized lighting solutions
- **Lack of integrated design teams**



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# Design — creativity is key!

- Overcome the barriers
- Think beyond the ceiling
- Integrated design approach
  - Consider all aspects of the design
    - Daylighting
    - Finishes
    - Color
    - Furniture



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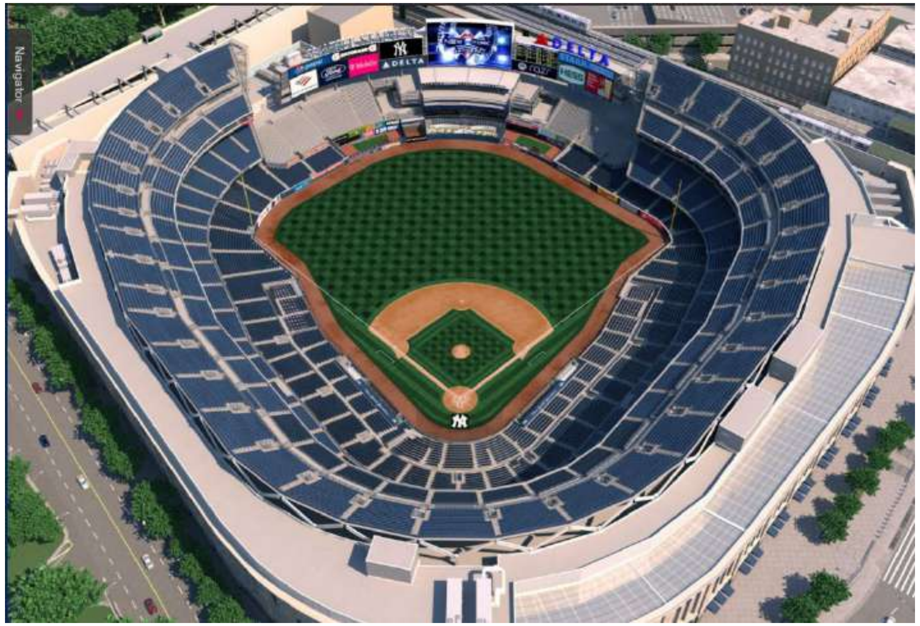
# Circadian-effective light — if you just want to get in the ballpark

- **Think → when, where, and how much**
- When?
  - 2 h in the morning, bright light
  - 2 h before bedtime, dim light
- Where?
  - Where will people spend most of their day?
  - Bring the people to the light, and the light to the people
- How much?
  - 350 lx ($E_V$) of white light at the eye
  - Avoid glare: limit max luminance of luminaires to 8,500 cd/$m^2$



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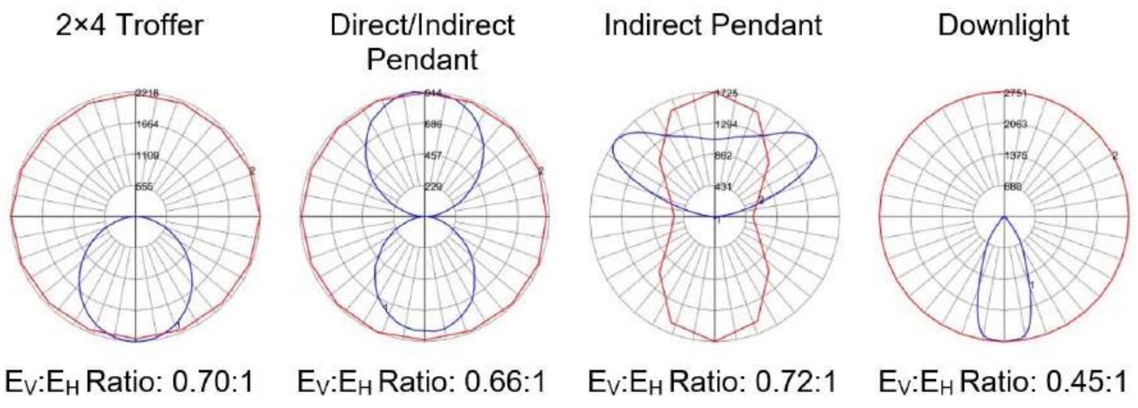
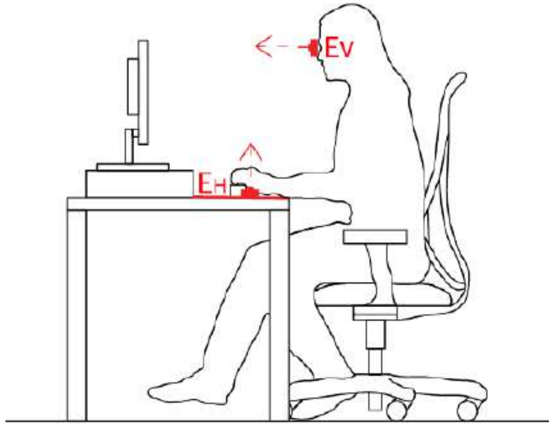
# Layers of light — optimize circadian entrainment with power demand

- Ceiling-mounted lighting: Vertical to horizontal illuminance ratio of minimum 0.65:1
- https://icahn.mssm.edu/files/ISMMS/Assets/Research/Light-Health/LHRC-OfficeGuidance.pdf
- Wide "batwing" distribution
- Pendants with some direct lighting component
- Power demand is related to SPD
- Does not need to cost more
  - No need for color tuning or complex controls







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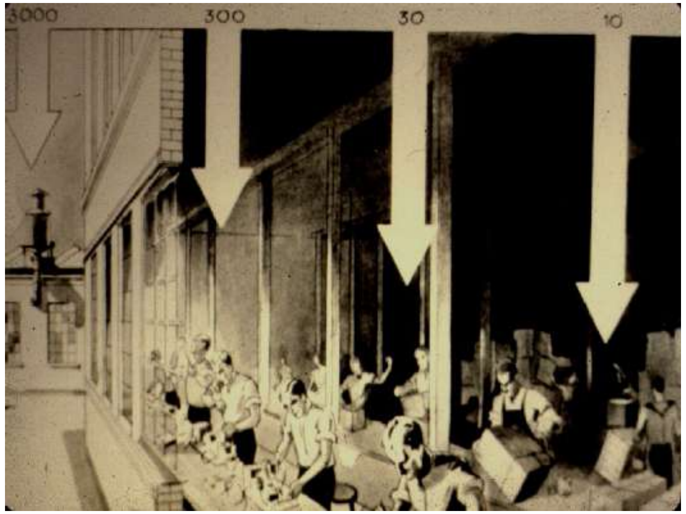
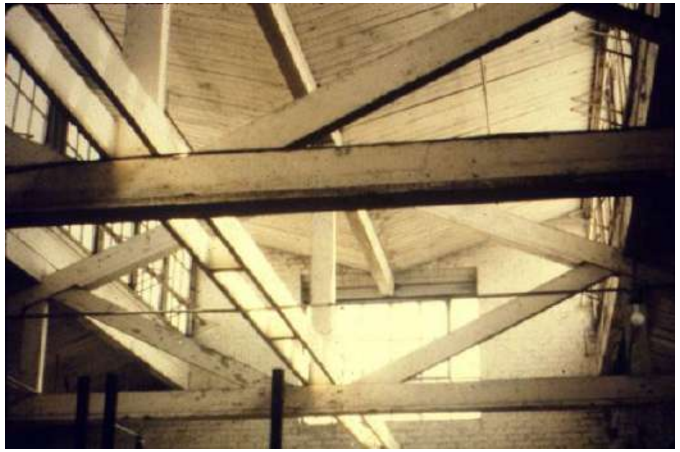
# Daylight is your friend

- Daylight has excellent characteristics to provide non-visual benefits
  - Amount and spectrum
- Daylighting rules of thumb:
  1. Bring people to the light
  2. Bring light in high
  3. Diffuse the sun
  4. Use light color surfaces
- Consider orientation when selecting windows strategy
- Consider skylights where possible



# Layers of light

- General ("ambient") lighting
- Dedicated circadian "layer"?
  - Ceiling vs. Plug-in
  - Furniture-integrated?
- To minimize power demand, place source close to occupant's eyes
  - Glare

http://lightenergystudio.com/LED-room-divider.htm

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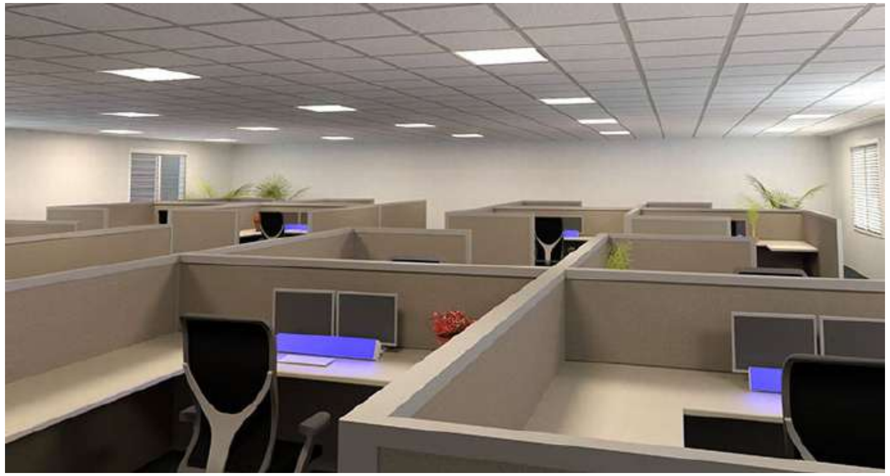
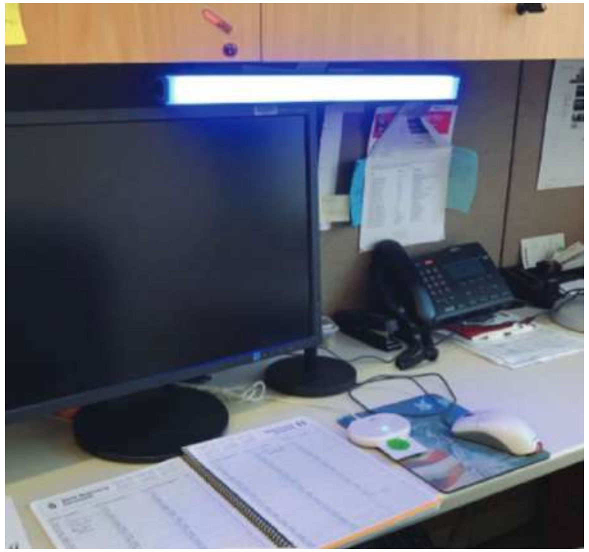
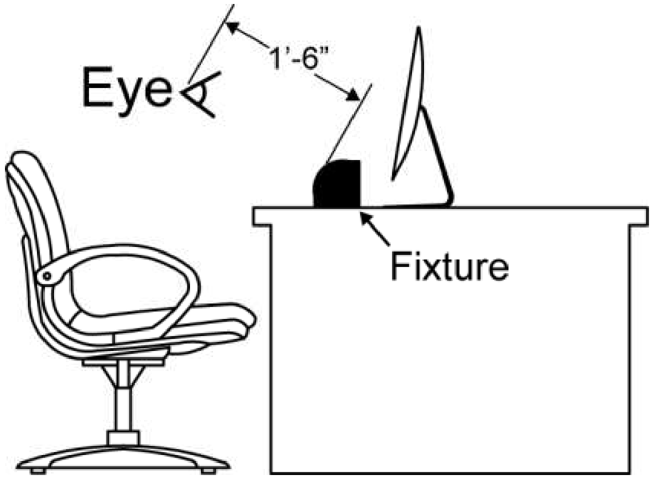
# Design suggestions — luminous vertical surfaces


# Design examples — "local" lighting





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# Design examples — color


# Coming soon

- American Lighting Association
  - Residential pre-tested products






american lighting association

https://www.youtube.com/watch?v=4oLGMwN7wDo

https://www.podbean.com/ew/pb-zq5fx-1511a74

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This concludes The American Institute of Architects Continuing Education Systems Course