GSA

Icahn School of Medicine at Mount Sinai — *Light and Health Research Center*

Circadian Lighting for Better Sleep at Night

GSA's Buildings and Health Research Program

- May 23: Health in Buildings Partnerships
- June 27: Circadian Lighting
- July 27: Enhancing Ventilation
- Aug 22: Wellbuilt for Wellbeing
- Sept 26: The Health in Buildings Roundtable

This series is a call for co-sponsors - Health in Buildings Roundtable!

- Government agencies, companies, research organizations, non-profit groups, etc
- Pilot, measure, and evaluate health-enhancing strategies
- Join scoping meeting planned for this summer
- Email coskvig@nas.edu for more information

Polls 1 and 2

Slido.com: # 1569492; to access polls and Q&A

Major Points to cover

- Scientific evidence of the beneficial effects of lighting on sleep
- Importance of light reaching the eyes instead of the desk surface
- Circadian-effective lighting does not mean more glare or higher lighting power densities
- This is not just an academic exercise; field studies sponsored by GSA (and others) show the power of bright days and dark nights.
- Value-engineering of lighting at the end of buildings construction can ultimately cost more in terms of occupant performance and health.

Agenda

- Introduction
- Scientific Foundation
- Field Verification
- Design Guidelines
- GSA Requirements
- Possible Solutions
- What This Isn’t
- What’s Missing?

Poll 3 and 4

Slido.com: # 1569492; to access polls and Q&A

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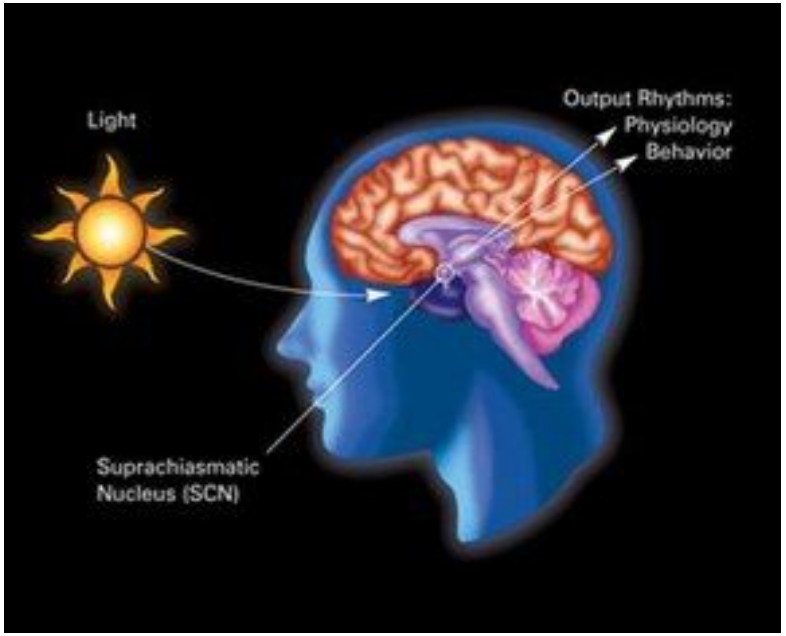
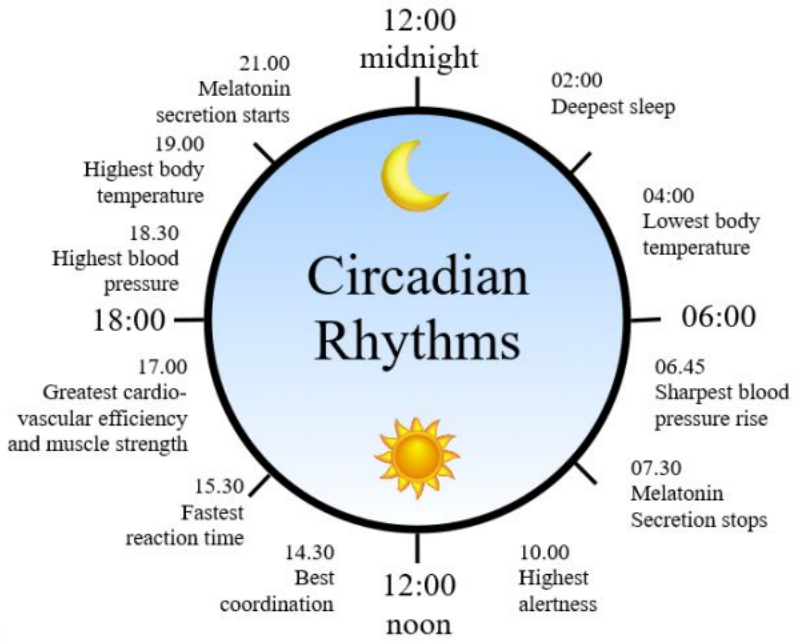
Light and Health Research Center

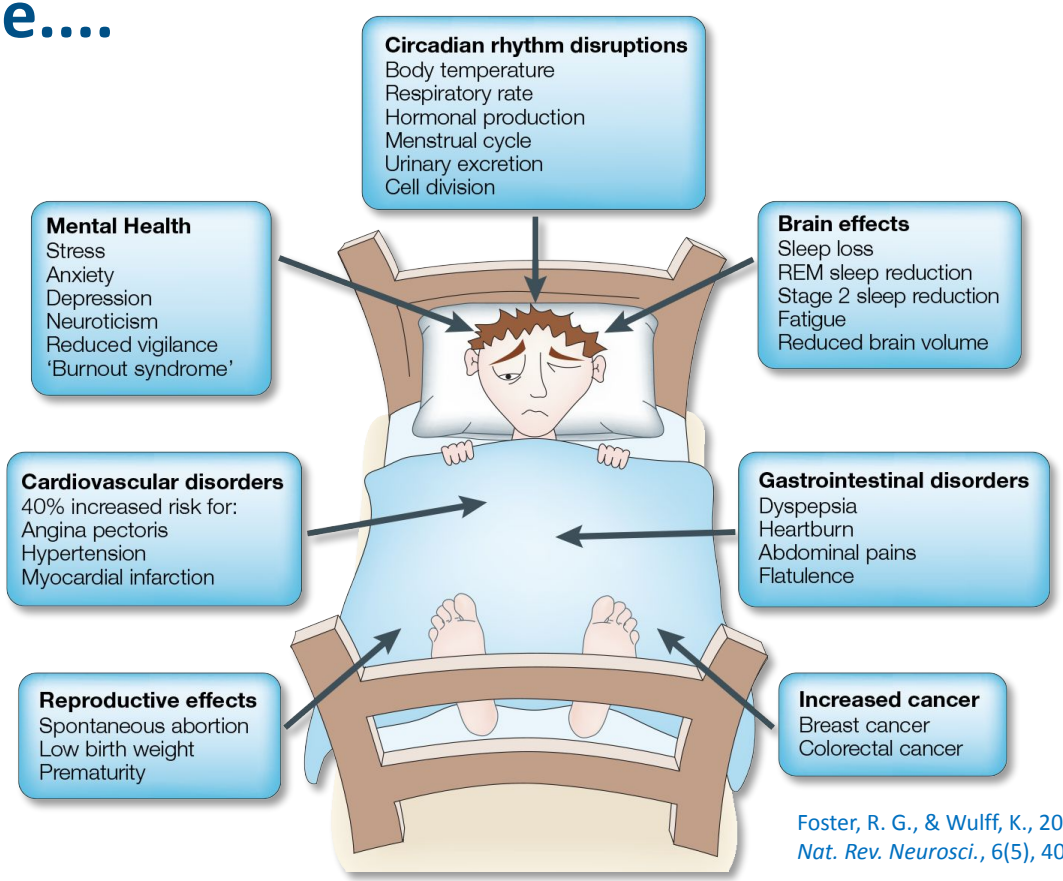
Scientific Foundation

Basic idea: Maintain a 24-hour light/dark cycle





Otherwise....



Foster, R. G., & Wulff, K., 2005. The rhythm of rest and excess. *Nat. Rev. Neurosci.*, 6(5), 407-414. DOI: 10.1038/nrn1670 .

In simple terms…bright days and dim nights

But what is bright and what is dim?

What we need: Define bright and dim

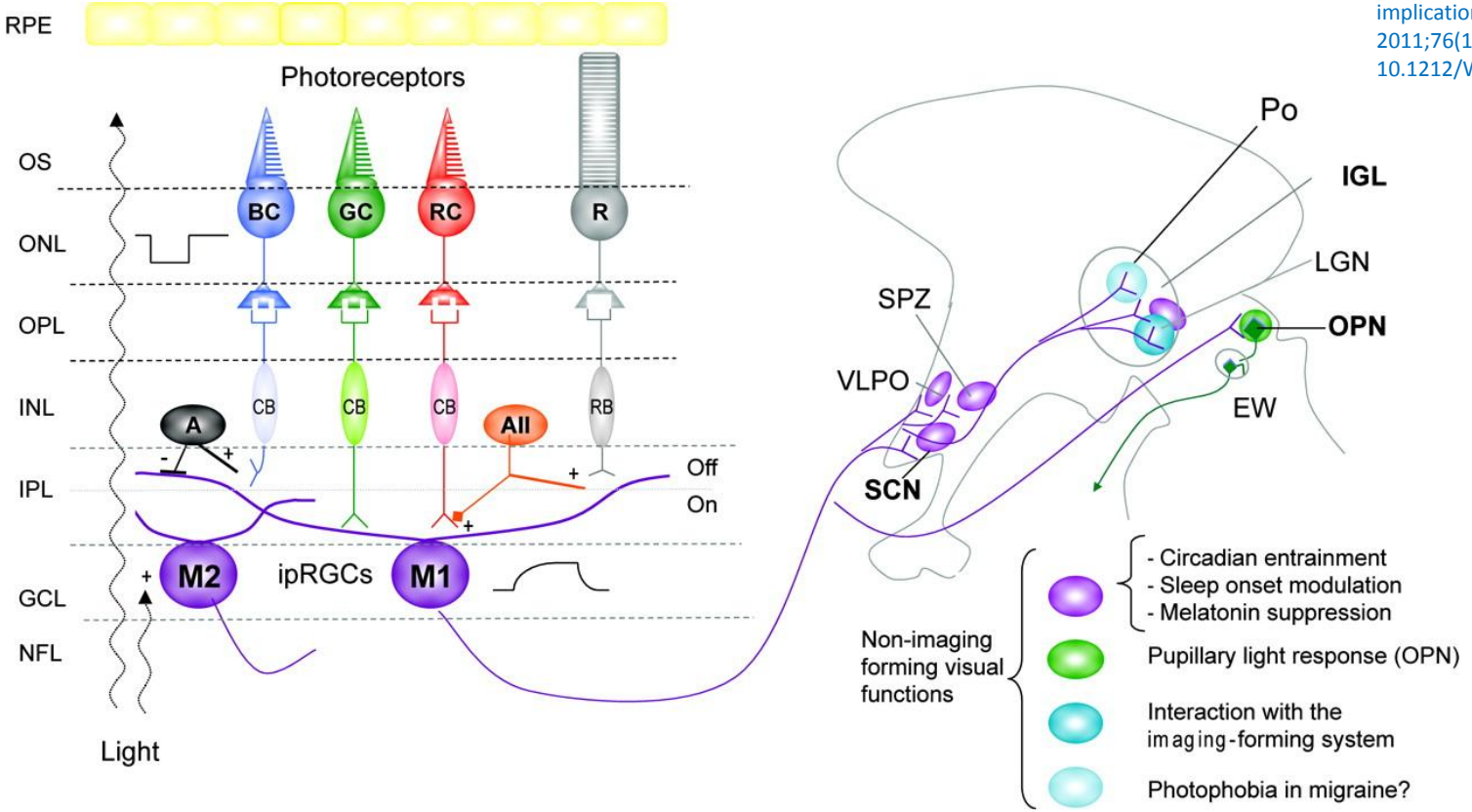
Based on psychophysics

- A reliable, repeatable, measurable and unconfounded response
- A well-controlled and defined physical stimulus to the retina

Actionable specification

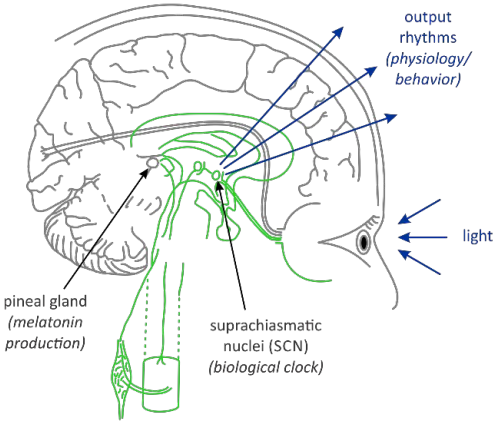
- A computational model relating the stimulus to the response which is accurate in terms of *spectral sensitivity* and *absolute sensitivity* and has a physiological foundation
- A method for implementation and verification

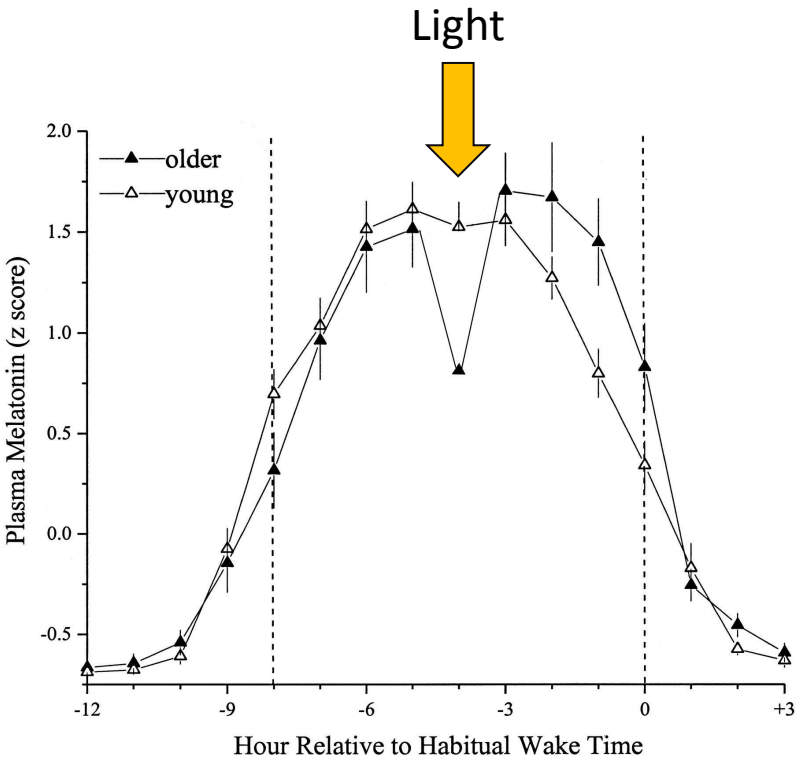
But it's complicated!



Benarroch EE. The melanopsin system: Phototransduction, projections, functions, and clinical implications. *Neurology*. 2011;76(16):1422-7. doi: 10.1212/WNL.0b013e31821671a5

Response

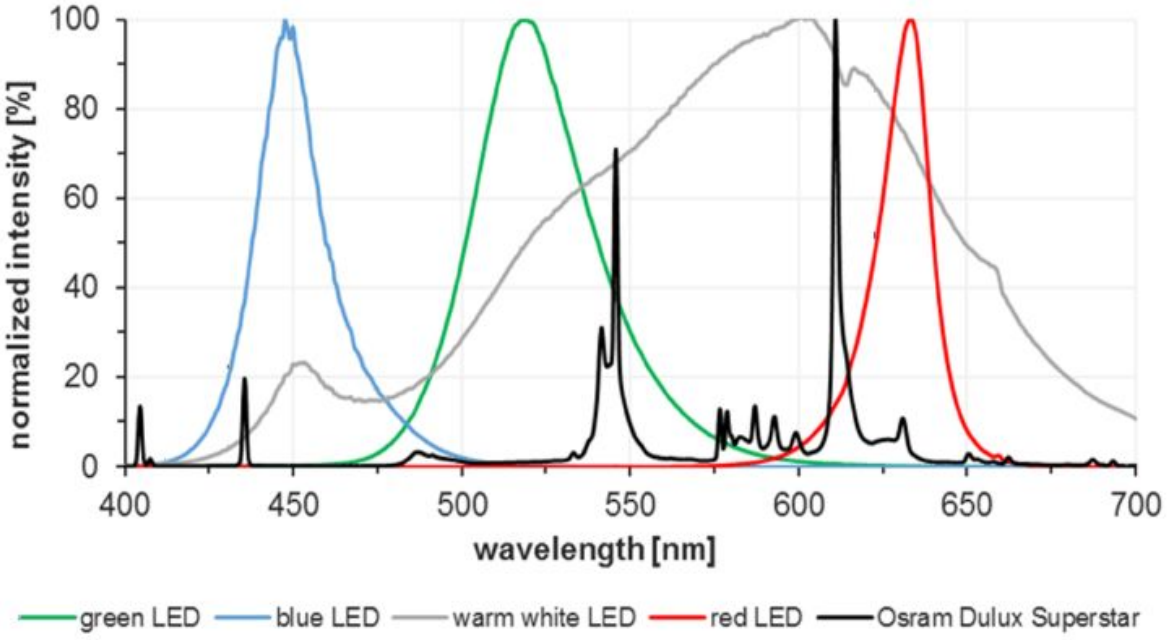




Duffy JF, Zeitzer JM, Rimmer DW, Klerman EB, Dijk DJ, Czeisler CA. Peak of circadian melatonin rhythm occurs later within the sleep of older subjects. *Am J Physiol Endocrinol Metab*. 2002;282(2):E297-E303. doi: 10.1152/ajpendo.00268.2001

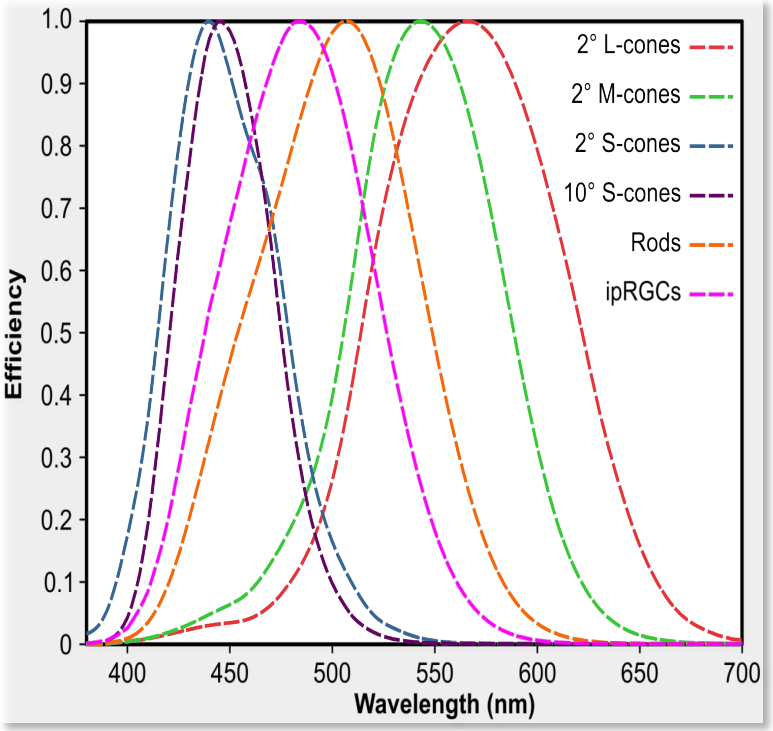
Based upon dose-response suppression of pineal gland synthesis of the hormone melatonin at night

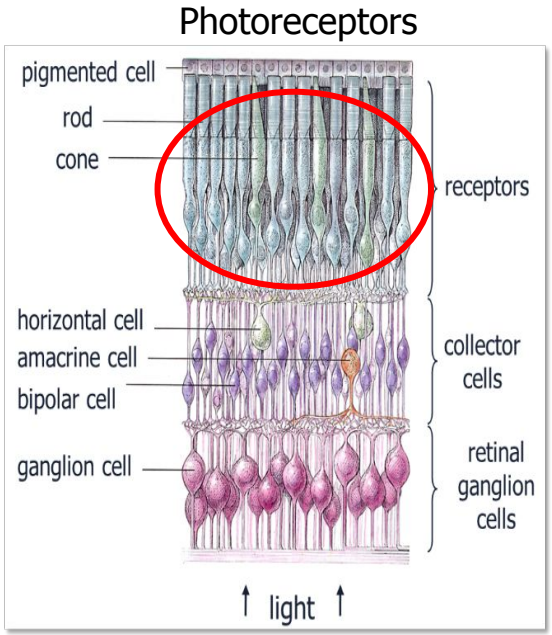
Stimulus



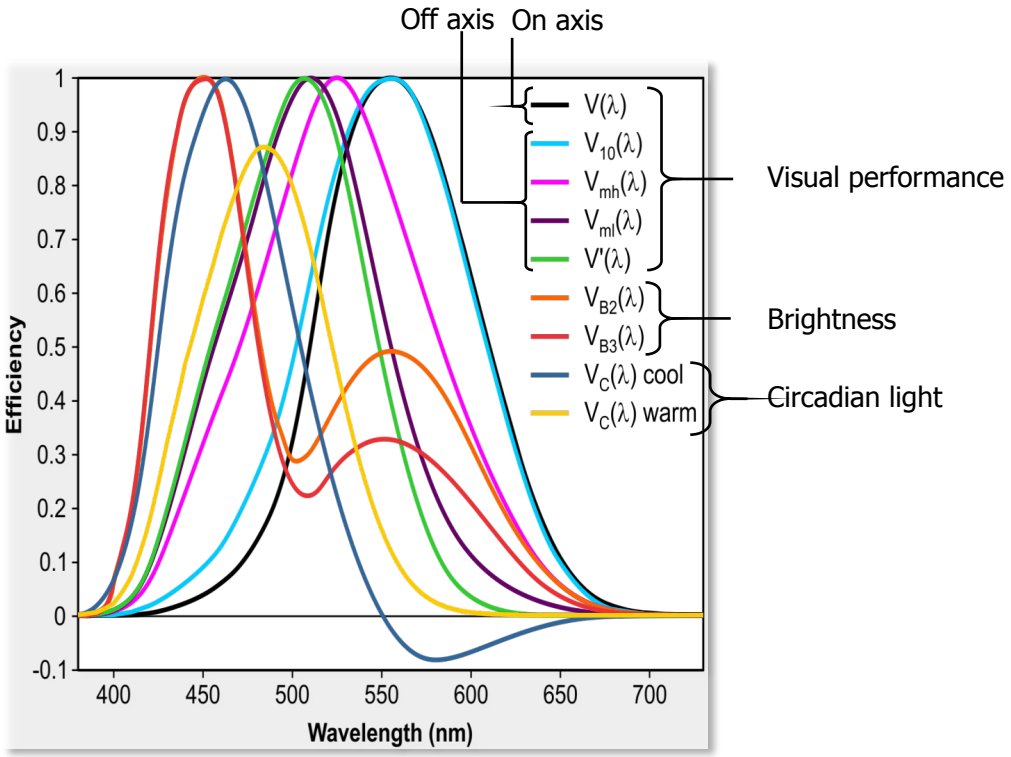
Radiant power in W m^{-2} at the cornea

Eye sensitivity is more than the photoreceptors

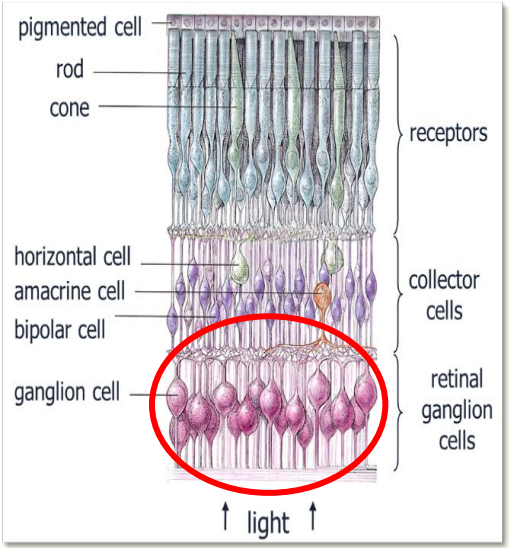




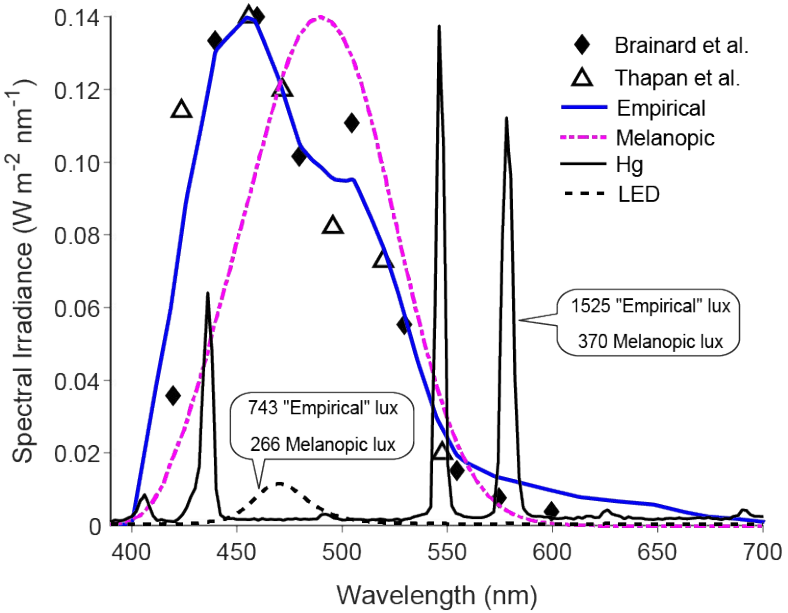
Eye sensitivity is defined by the neural channel response



Neural channels



Spectral sensitivity



Brainard, G.C., Hanifin, J.P., Greeson, J.M., Byrne, B., Glickman, G., Gerner, E., Rollag, M.D. (2001) Action spectrum for melatonin regulation in humans: Evidence for a novel circadian photoreceptor. *J. Neurosci.* 21(16):6405-6412.

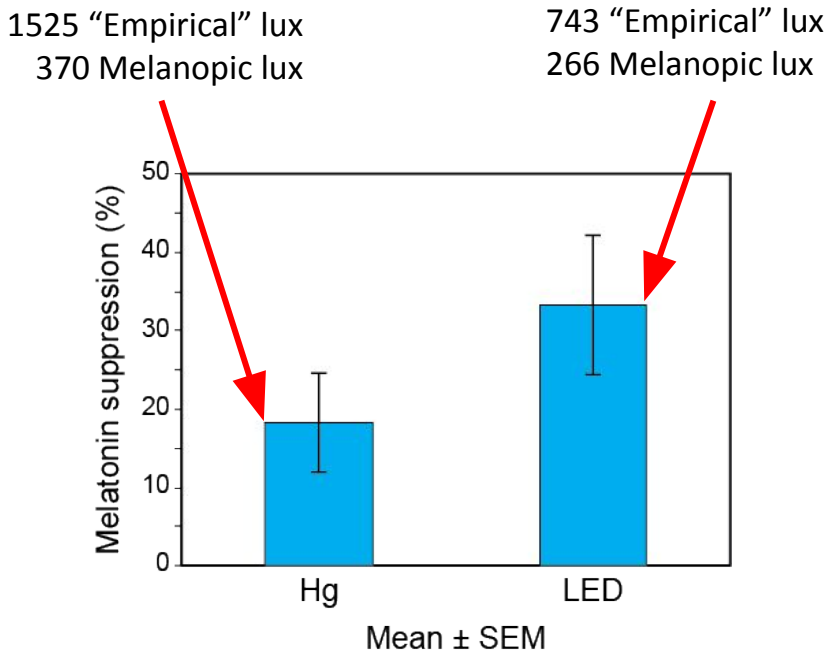
Thapan, K., Arendt, J., Skene, D.J. (2001) An action spectrum for melatonin suppression: Evidence for a novel non-rod, non-cone photoreceptor system in humans. *J Physiol.* 525(Pt 1):261-267.

Figueiro MG, Bullough JD, Parsons RH, Rea MS. Preliminary evidence for spectral opponency in the suppression of melatonin by light in humans. *Neuroreport*. 2004;15(2):313-316.

Results

Challenge is to accurately predict these non-linear responses while being consistent with retinal neurophysiology

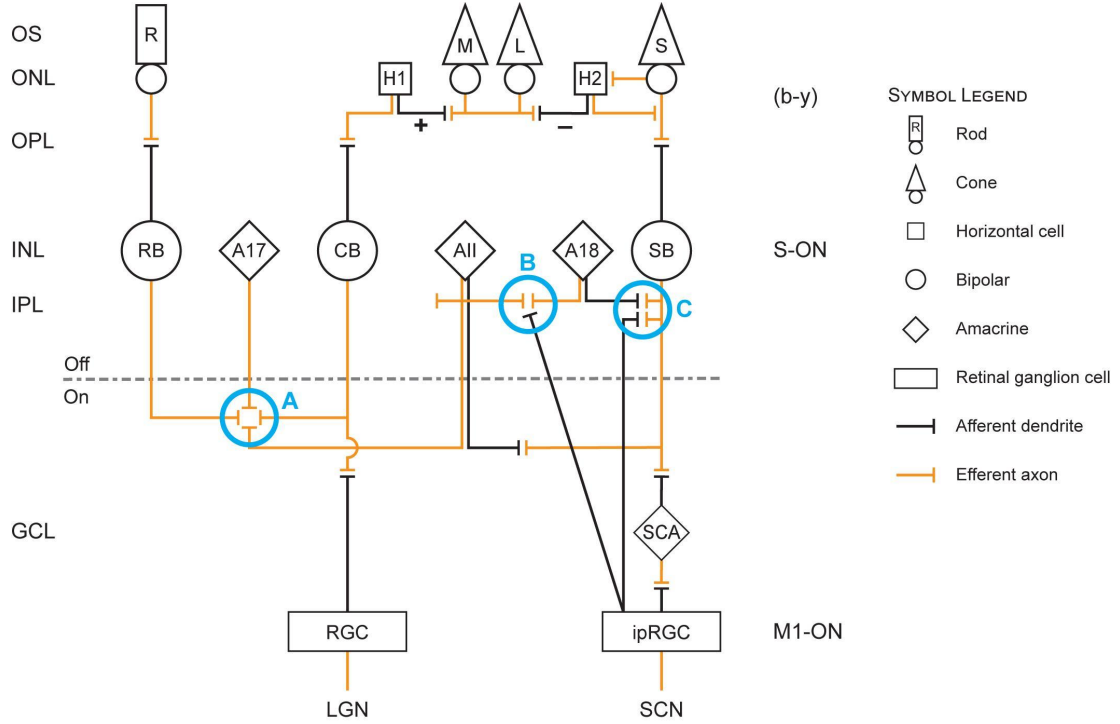
In other words, develop a computational model that can predict both retinal spectral and absolute sensitivities



Figueiro MG, Bullough JD, Parsons RH, Rea MS. Preliminary evidence for spectral opponency in the suppression of melatonin by light in humans. *Neuroreport*. 2004;15(2):313-316.

Neurophysiological foundation

Amount, spectrum, duration, spatial distribution and, most importantly, timing



Rea, M. S., Nagare, R., & Figueiro, M. G., 2021a. Modeling circadian phototransduction: Quantitative predictions of psychophysical data. *Front. Neurosci., 15*, 44. DOI: 10.3389/fnins.2021.615322

Rea, M. S., Nagare, R., & Figueiro, M. G., 2021b. Modeling circadian phototransduction: Retinal neurophysiology and neuroanatomy. *Front. Neurosci., 14*, 1467. DOI: 10.3389/fnins.2020.615305

Formulation for defining bright and dim

Spectral sensitivity (CL_A)

$$CL_A\ 2.0 = 1548 \begin{cases} \left(\int Mc_\lambda E_\lambda d\lambda - a_{rod1}\left(\frac{\int V'_\lambda E_\lambda d\lambda}{\int V_\lambda E_\lambda d\lambda + g_1 \int S_\lambda E_\lambda d\lambda}\right)\left(1 - e^{\frac{-\int V'_\lambda E_\lambda d\lambda}{RodSat}}\right)\right), & b-y \le 0 \\ \left(\int Mc_\lambda E_\lambda d\lambda - a_{rod1}\left(\frac{\int V'_\lambda E_\lambda d\lambda}{\int V_\lambda E_\lambda d\lambda + g_1 \int S_\lambda E_\lambda d\lambda}\right)\left(1 - e^{\frac{-\int V'_\lambda E_\lambda d\lambda}{RodSat}}\right)\right) + & \\ \left(a_{b-y}\left(\int \frac{S_\lambda}{mp_\lambda} E_\lambda d\lambda - k\int \frac{V_\lambda}{mp_\lambda} E_\lambda d\lambda\right) - a_{rod2}\left(\frac{\int V'_\lambda E_\lambda d\lambda}{\int V_\lambda E_\lambda d\lambda + g_2 \int S_\lambda E_\lambda d\lambda}\right)\left(1 - e^{\frac{-\int V'_\lambda E_\lambda d\lambda}{RodSat}}\right)\right), & b-y > 0 \end{cases}$$

where,

$$b - y = \int \frac{S_\lambda}{mp_\lambda} E_\lambda d\lambda - 0.2616 \int \frac{V_\lambda}{mp_\lambda} E_\lambda d\lambda$$

$a_{b-y} = 0.21$

$a_{rod1} = 2.30$

$a_{rod2} = 1.60$

g_1=1.00

g_2= 0.16

$RodSat = 6.50\ W/m^2$

E_λ: light source spectral irradiance

Mc_λ: melanopsin sensitivity (corrected for crystalline lens transmittance)

S_λ: S-cone fundamental

mp_λ: macular pigment transmittance

V_λ: photopic luminous efficiency function

V'_λ: scotopic luminous efficiency function

Absolute sensitivity (CS)

$$CS = 0.7 * \left[1 - \frac{1}{1 + \left(\frac{CL_{A\ 2.0}}{355.7}\right)^{1.1026}}\right]$$

Rea, M. S., Figueiro, M. G., Bullough, J. D., & Bierman, A., 2005. A model of phototransduction by the human circadian system. *Brain Res. Rev., 50*(2), 213-228. DOI: 10.1016/j.brainresrev.2005.07.002

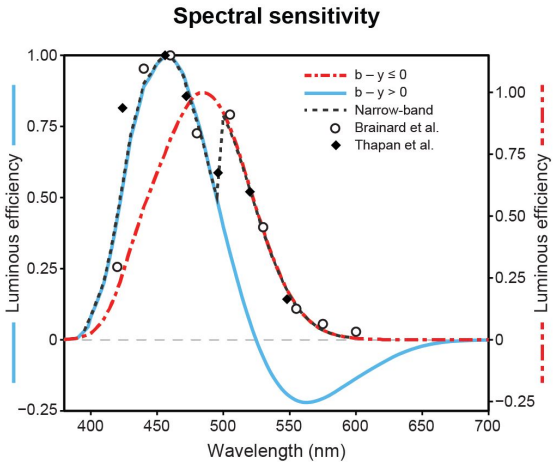
Rea, M. S., Figueiro, M. G., Bierman, A., & Hamner, R., 2012. Modelling the spectral sensitivity of the human circadian system. *Lighting Res. Technol., 44*(4), 386-396. DOI: 10.1177/1477153511430474

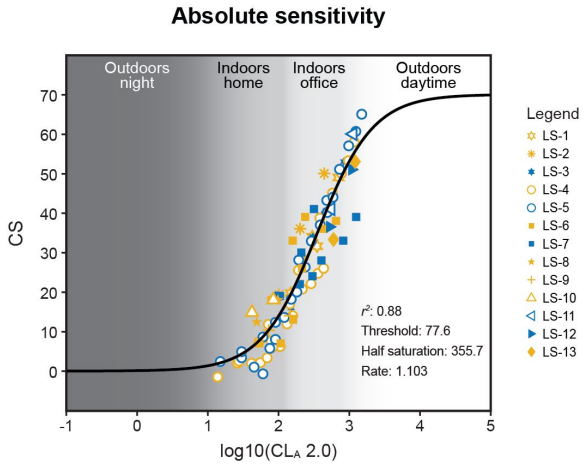
Rea, M. S., Nagare, R., & Figueiro, M. G., 2021a. Modeling circadian phototransduction: Quantitative predictions of psychophysical data. *Front. Neurosci., 15*, 44. DOI: 10.3389/fnins.2021.615322

Rea, M. S., Nagare, R., & Figueiro, M. G., 2021b. Modeling circadian phototransduction: Retinal neurophysiology and neuroanatomy. *Front. Neurosci., 14*, 1467. DOI: 10.3389/fnins.2020.615305

Actionable specification

Circadian stimulus (**CS**) is a metric that combines both the spectral and absolute sensitivities of the circadian phototransduction mechanisms in the human retina





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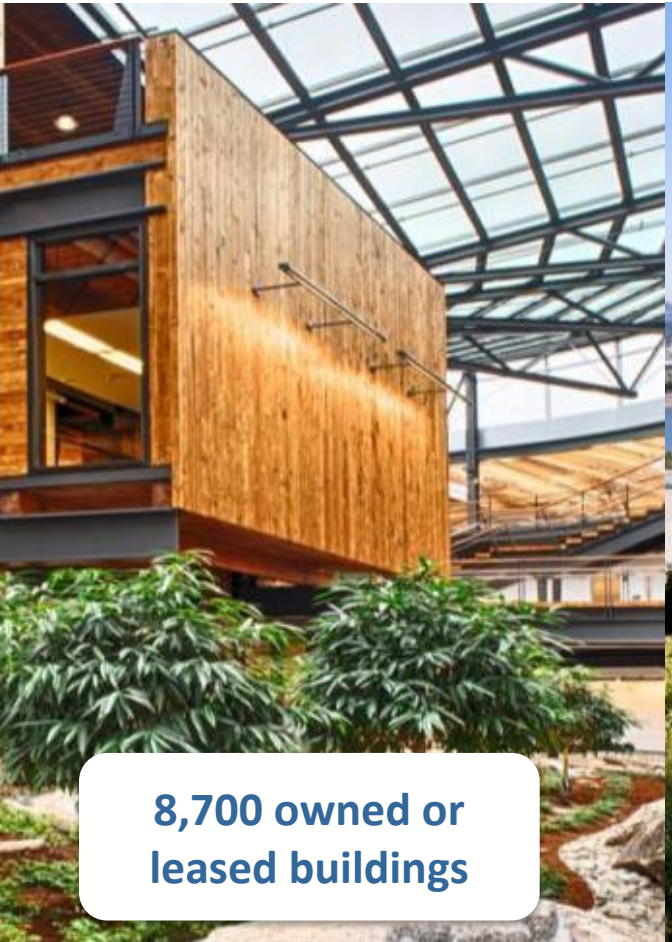
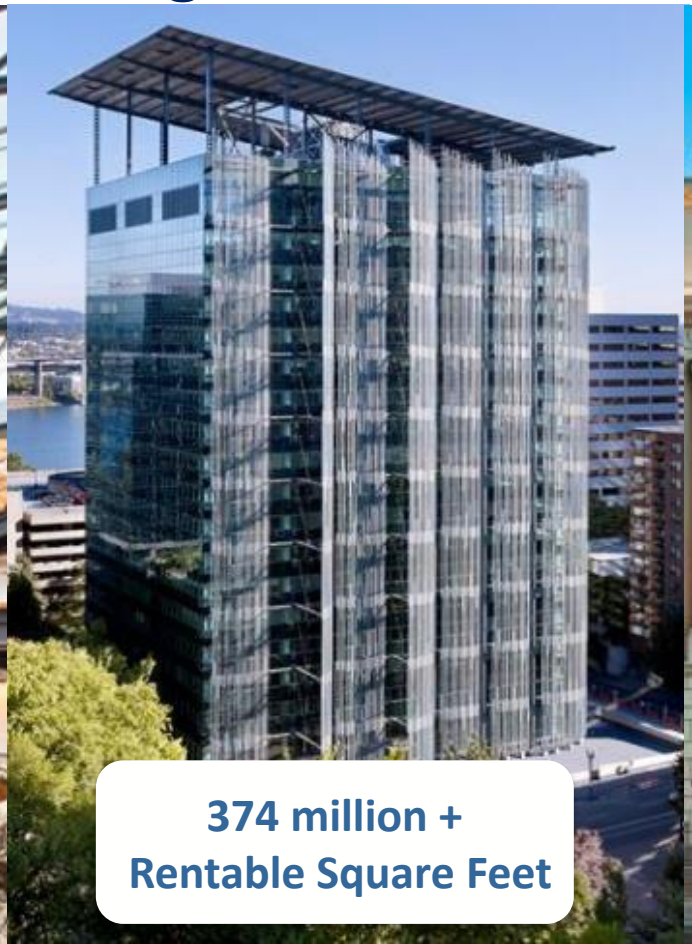
GSA Portfolio of Buildings

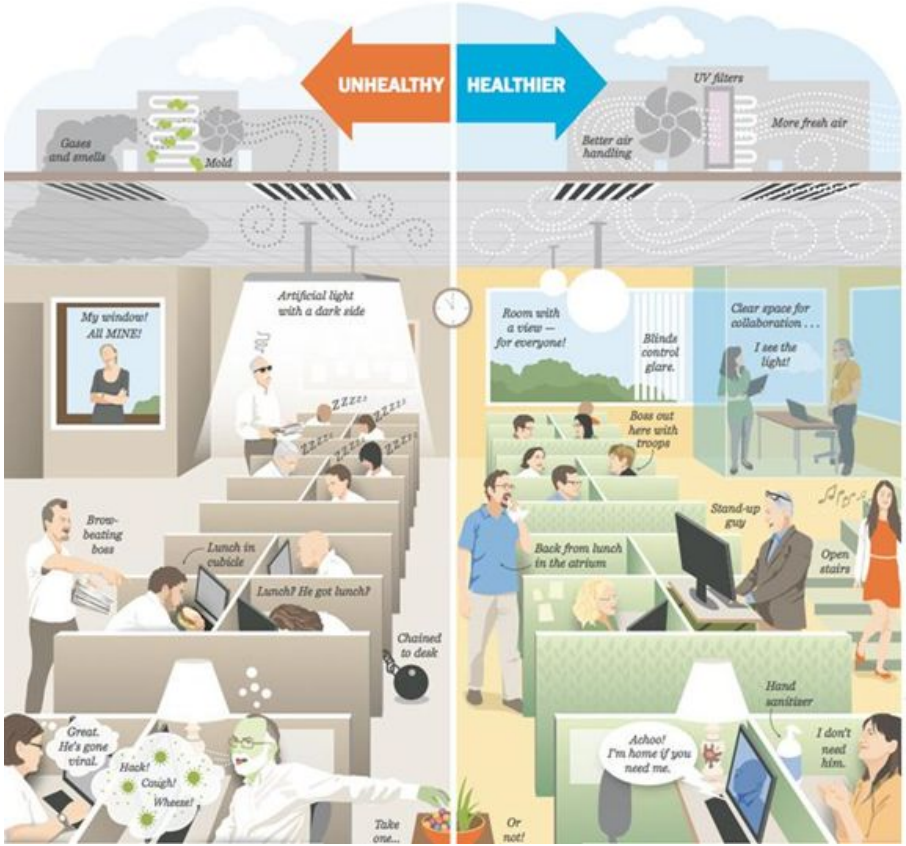


8,700 owned or leased buildings



374 million + Rentable Square Feet

482 Historic Buildings



We spend 90% of our time indoors

Workplace-related illness costs the U.S. $225B per year

Our design and operating decisions can make a difference

"Are You in an Unhealthy Office Relationship?"
Washington Post, June 2014

Poll 5

Slido.com: # 1569492; to access polls and Q&A

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Light and Health Research Center

Field Verification

Summarizing what we know so far…

Light sets the timing of the biological clock (promotes entrainment)

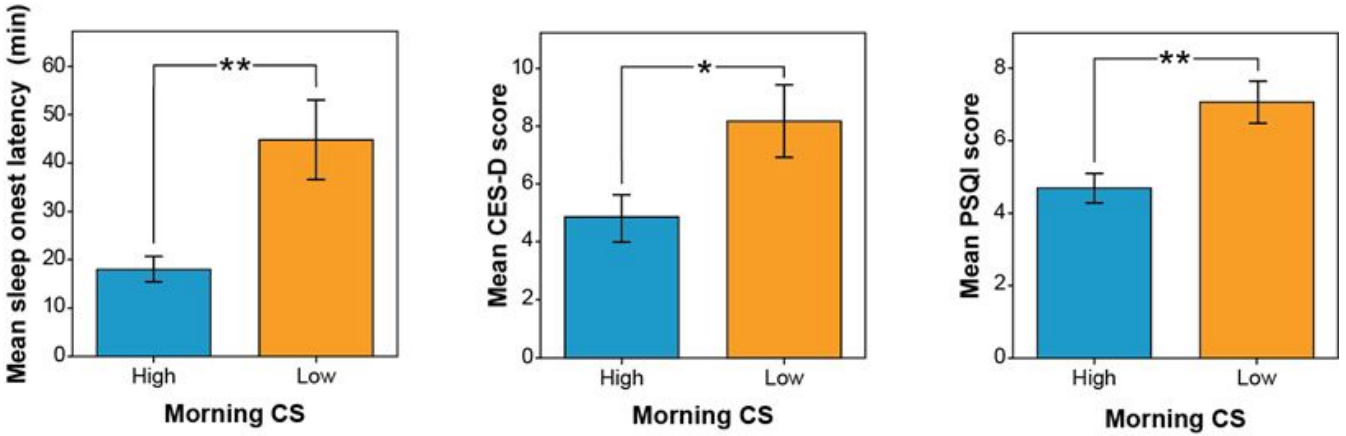
- Morning light is needed to advance the timing of the clock (timing is important)
- Short-wavelength and high light levels at the eye are most effective
- Any white light can be used; however, if you increase light levels, change fixture distribution or increase duration
- Prolonged/continuous duration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

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)



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

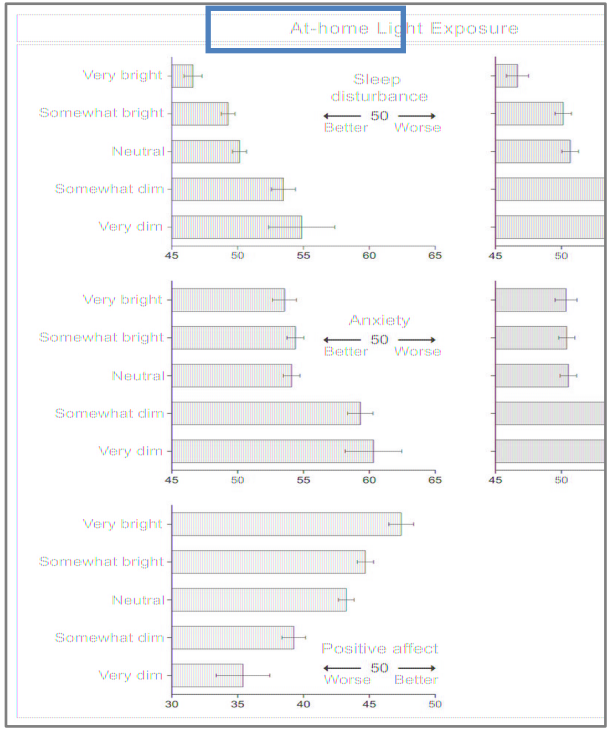
Figueiro M.G., Steverson B., Heerwagen J., Kampschroer K., Hunter C.M., Gonzales K., Rea, M.S. (2017). The impact of daytime light exposures on sleep and mood in office workers. Sleep Health; 3(3):204-215.

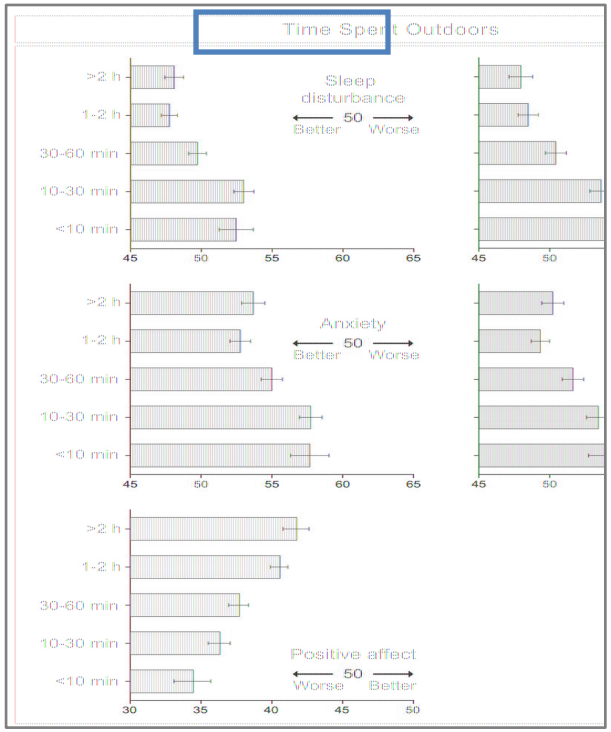
Sponsor: U.S. General Services Administration

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

Light and sleep survey during COVID-19 shutdown





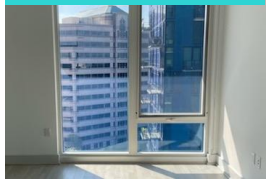
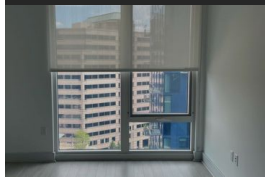
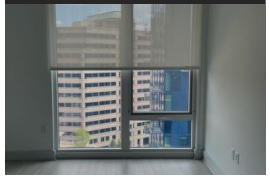
Figueiro M, Jarboe C, Sahin L. The sleep maths: A strong correlation between more daytime light and better night-time sleep. *Lighting Research & Technology*. 2021; 53: 423-435.

Circadian entrainment in workers working from home (WFH)

20
Residents

28 Days
in 2020

EXO Apartments
Reston, Virginia

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

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

ENVIRONMENTAL MONITORING

SLEEP TRACKING

SURVEYS

PERSONAL LIGHT

		BLINDS	BASELINE	SMART WINDOWS

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

SMART WINDOWS	BLINDS
Melatonin	
Consistent melatonin onset	15 minutes delay over the course of the week
Sleep	
Earlier sleep onset by 22 min	Sleep debt compensation on Friday night
Vitality	
Consistent cycle of vitality with high morning and daytime energy levels	Delayed peak vitality, high nighttime energy levels and low morning vitality

Circadian entrainment in myeloma transplant patients

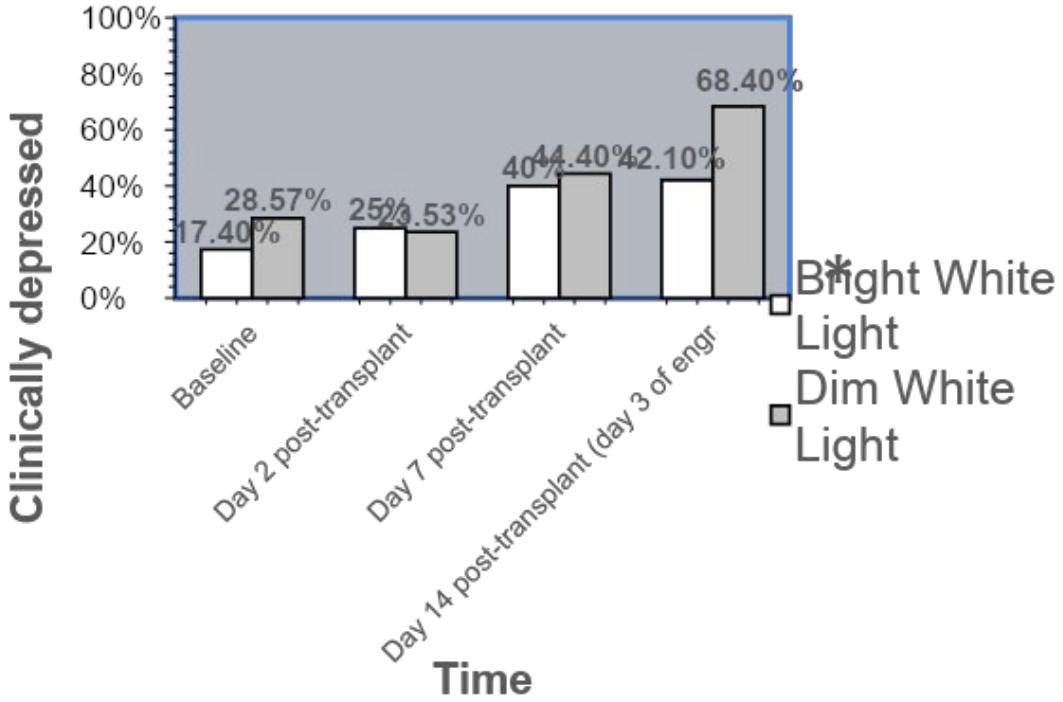
Our team investigated the impact of a CS of 0.3 (1000 lx at pillow, 3000 K light source) between 07:00 and 10:00 on:

- Symptom burden (i.e., depression)
- Melatonin levels (circadian entrainment)
- Inflammation (IL-6) and neutropenic fever

Sponsors: National Cancer Institute and Acuity Brands

Circadian entrainment in myeloma transplant patients

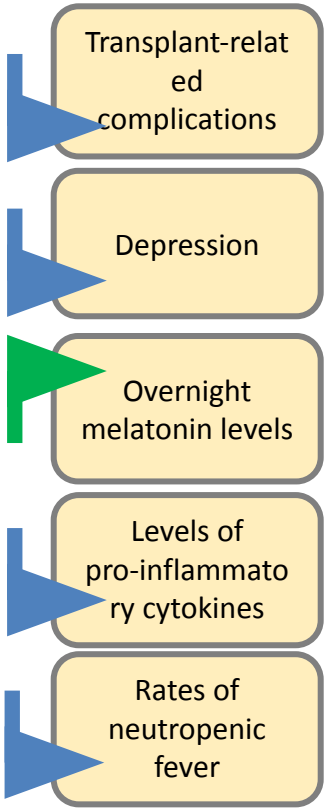
Clinical Depression (CES-D) as a function of Time by Condition



Sponsors: National Cancer Institute and Acuity Brands

Circadian entrainment in myeloma transplant patients

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



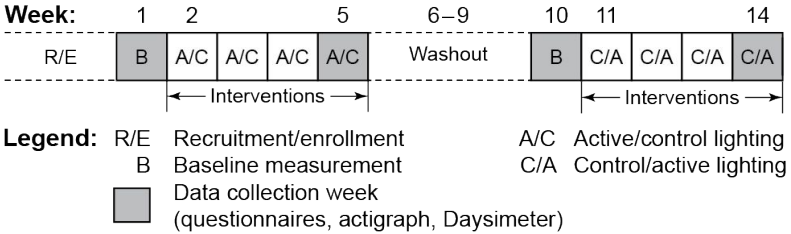
...compared to those who were exposed to **circadian-ineffective light**

Sponsors: National Cancer Institute and Acuity Brands

Circadian entrainment in Alzheimer's disease and related dementia (ADRD)

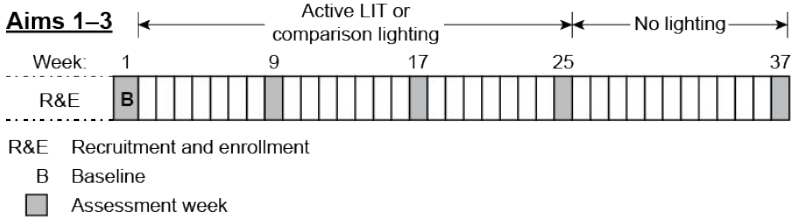
Long term (6 months)

- Randomized single-arm, within-subjects design clinical trial
- 47 patients with Alzheimer's disease and related dementias (ADRD) in 9 long-term care facilities



Short term (14 weeks)

- Randomized, placebo-controlled, crossover design clinical trial
- Two 4-week periods (4-week washout)
- 46 patients with ADRD in 8 long-term care facilities



Administered all-day (≈ 06:00 to 08:00 – 18:00) **active TLI** (high circadian stimulus [CS] = 0.4) for both studies

Administered all-day **control TLI** (low CS < 0.1) for short-term study only

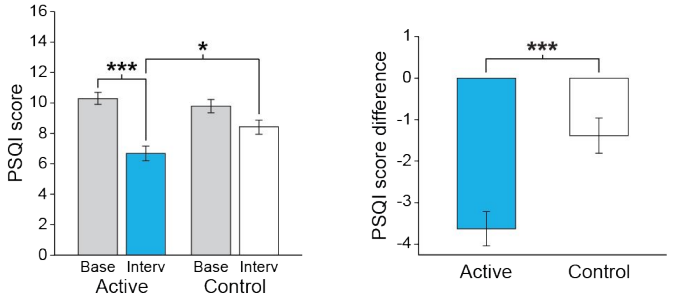
Sponsor: NIA (R01AG034157)

Circadian entrainment in Alzheimer's disease and related dementia (ADRD)

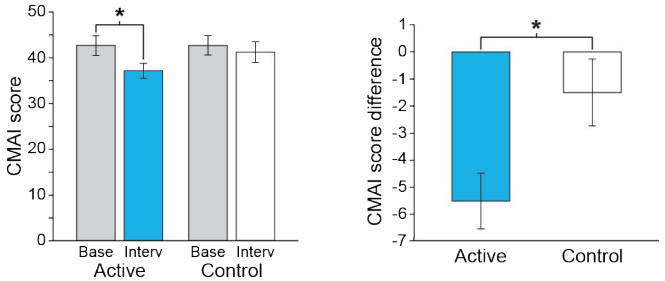
Short-term study

- Fewer sleep disturbances (PSQI) and depressive symptoms (CSDD) during active TLI compared to baseline and the control
- Fewer agitation behavior symptoms (CMAI) during the active TLI compared to baseline and greater reductions in symptoms compared to the control

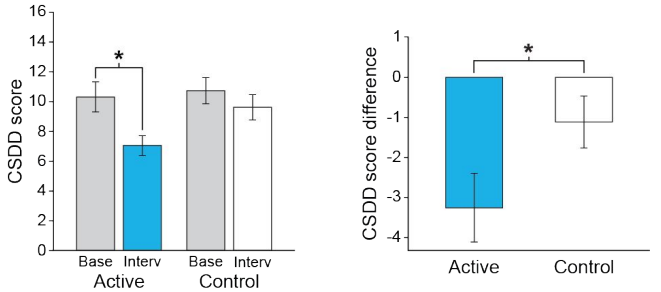
Sleep disturbance



Agitation



Depression



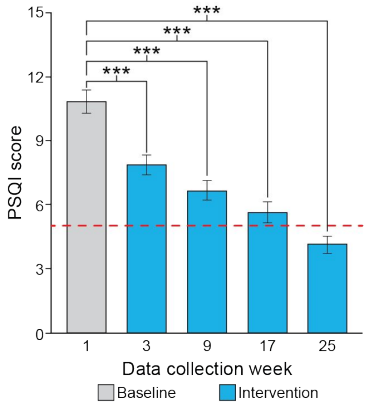
Sponsor: NIA (R01AG034157)

Circadian entrainment in Alzheimer's disease and related dementia (ADRD)

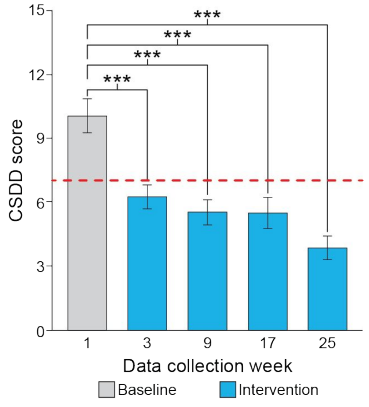
Long-term study

- 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

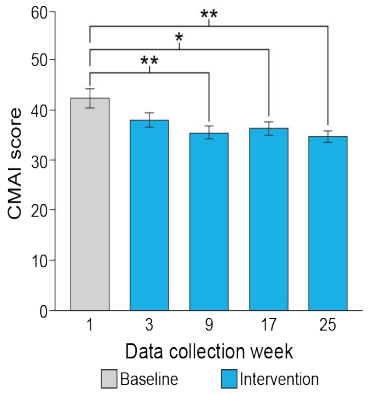
Sleep disturbance



Depression



Agitation



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

Sponsor: NIA (R01AG034157)

Sleep Math:
Brighter days =
Better Nights

Nagare R, Woo M, MacNaughton P, Plitnick B, Tinianov B, Figueiro M. Access to Daylight at Home Improves Circadian Alignment, Sleep, and Mental Health in Healthy Adults: A Crossover Study. *International Journal of Environmental Research and Public Health*. 2021; 18: 9980.

Daytime exposure to high Circadian Stimulus (CS) and impact on alertness

FHWA - Turner Fairbank Highway Research Center, Mclean, VA

FHWA - Turner Fairbank Highway Research Center, McLean, VA

White River Junction VA Medical Center, White River Junction, VT

White River Junction VA Medical Center, White River Junction, VT

U.S. Embassy Riga, Latvia

U.S. Embassy Reykjavik, Iceland

Federal Highway Administration

Figueiro MG, Kalsher M, Steverson BC, Heerwagen J, Kampschroer K, Rea MS. Circadian-effective light and its impact on alertness in office workers. Lighting Research & Technology. 2019; 51: 171-183.

Sponsor: U.S. General Services Administration and U.S. Department of State

CS and impact on daytime alertness

Turner–Fairbank Highway Research Center (FHWA)
- 25 participants (16 M, 9 F) in summer
- 18 (11 M, 7 F) participants in fall

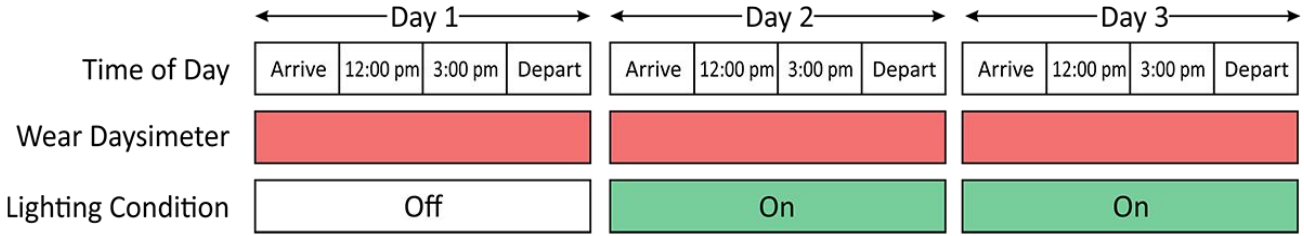
White River Junction Department of Veterans Affairs (VA)
- 11 participants (3 M, 8 F) in summer
- 8 participants (1 M, 7 F) in fall

Total participants, both sites: 36 summer, 26 fall

U.S. Embassy, Riga, Latvia
- 13 participants in winter only
- 8 males, 5 females

U.S. Embassy, Reykjavik, Iceland
- 19 participants in winter only
- 12 males, 7 females

Total participants, both sites: 32 winter only



Sponsor: U.S. General Services Administration and U.S. Department of State

CS and impact on daytime alertness

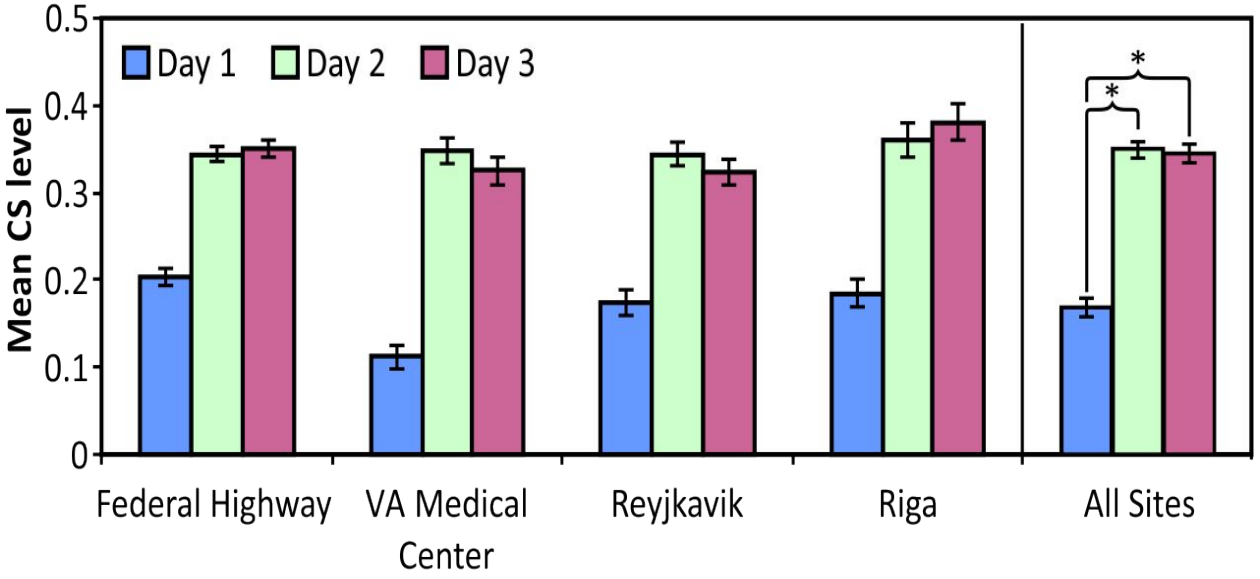
Built desktop lamps that delivered a CS>0.3 at participants' eyes

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

Sponsor: U.S. General Services Administration and U.S. Department of State

CS and impact on daytime alertness

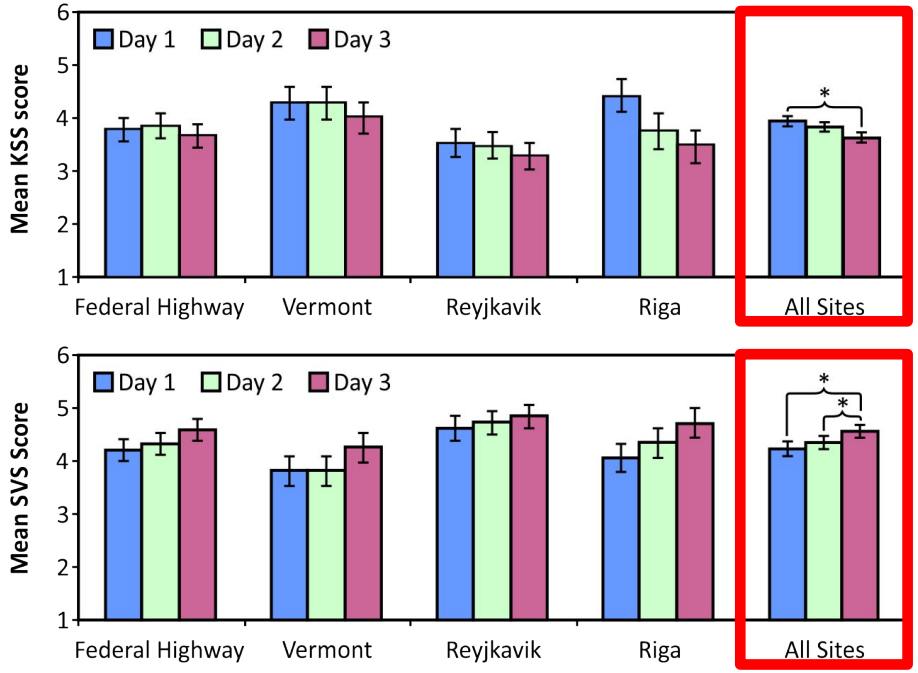
Daysimeter (CS values)



* Significant main effect of day of intervention (p <0.05)

CS and impact on daytime alertness

Questionnaires



Sleepiness (KSS) significantly decreased

* Significant main effect of day of intervention (p <0.05)

Vitality (SVS) significantly increased

Sponsor: U.S. General Services Administration and U.S. Department of State

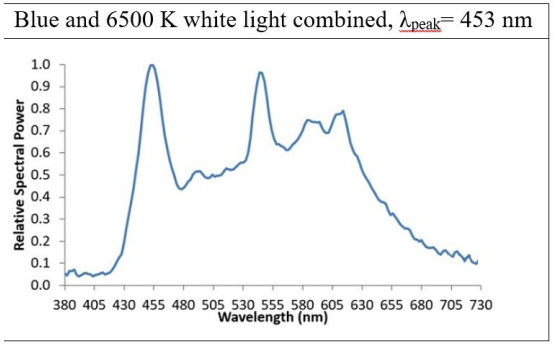
Circadian entrainment and alertness in a train dispatch center

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

Sponsor: METRO İSTANBUL

Circadian entrainment and alertness in a train dispatch center



Morning Schedule

07:00 AM – 12:00 PM

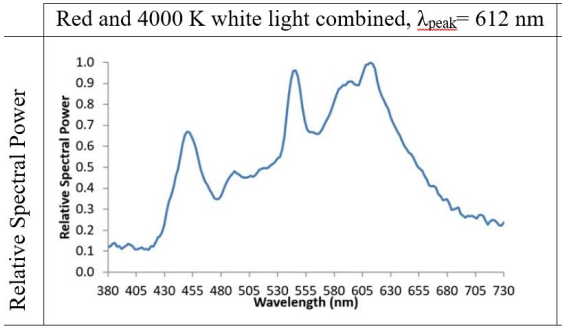
CS >0.3

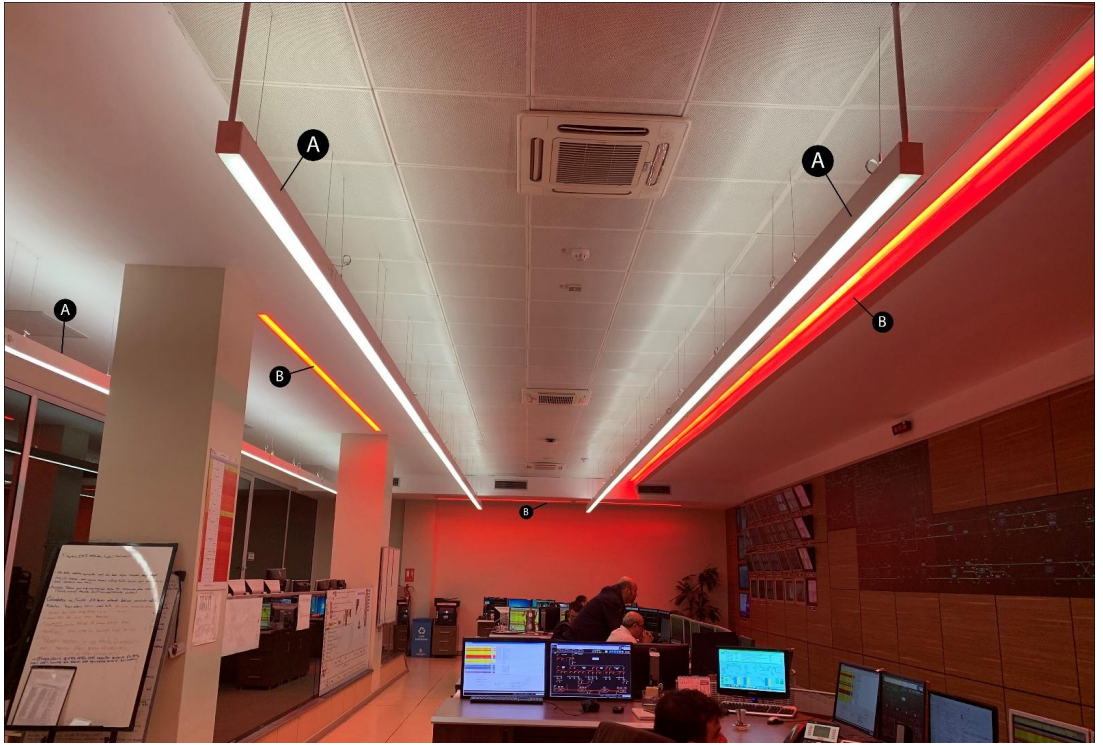
(A) 6500K white light

(B) (B) 470 nm blue light

Sponsor: METRO İSTANBUL

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

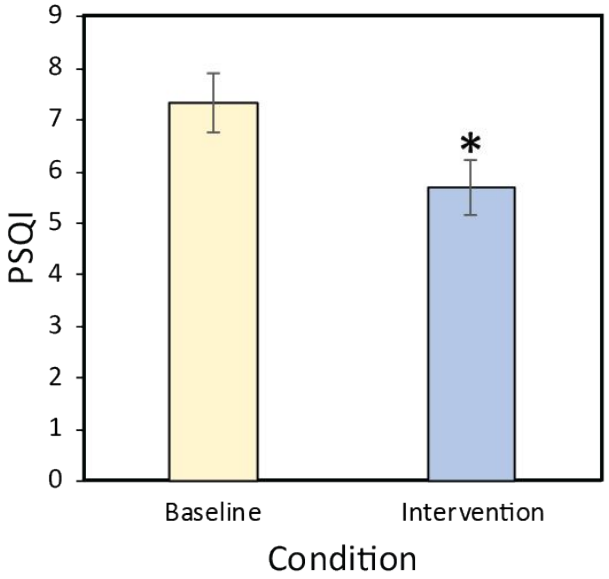
(B) 630 nm red light

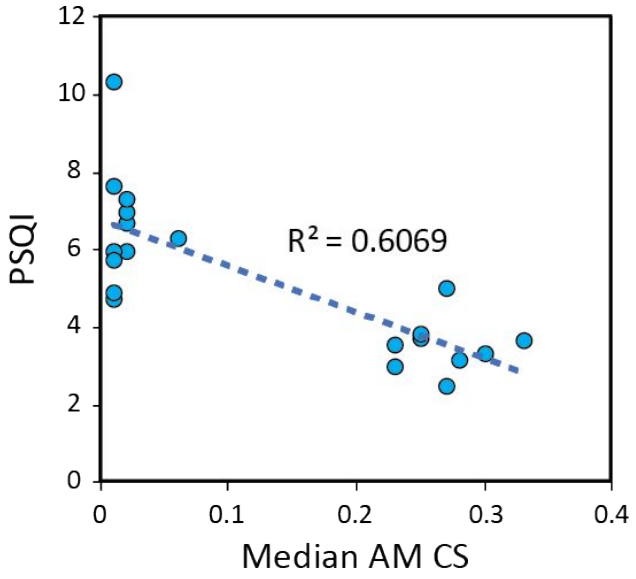
Sponsor: METRO İSTANBUL

Circadian entrainment and alertness in a train dispatch center

Sleep disturbance (PSQI)

Better sleep





(* = $p < 0.05$)

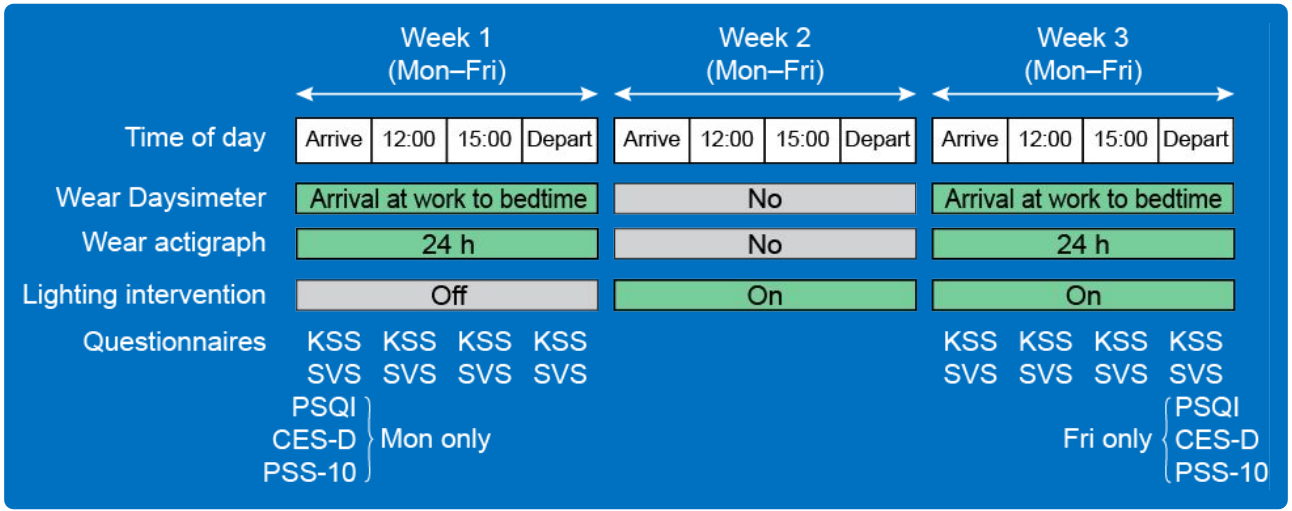
Sleep Math:
Brighter days =
More daytime alertness

Nagare R, Woo M, MacNaughton P, Plitnick B, Tinianov B, Figueiro M. Access to Daylight at Home Improves Circadian Alignment, Sleep, and Mental Health in Healthy Adults: A Crossover Study. *International Journal of Environmental Research and Public Health*. 2021; 18: 9980.

Circadian entrainment and alertness in daytime workers

Test, in a 3-week field study, the impact of morning blue light and afternoon red light on:

- Sleep quality at home
- Subjective sleepiness and vitality scores during work



Sponsor: U.S. General Services Administration

Circadian entrainment and alertness in daytime workers

Morning blue light (CS ≥ 0.3):

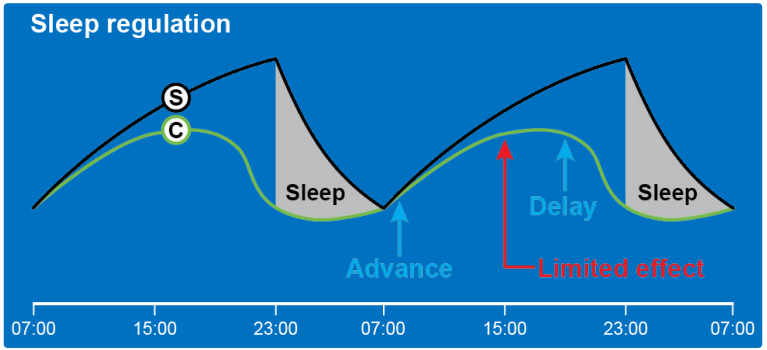
- Promote circadian entrainment, advance circadian phase
- Advance sleep onset at night, sleep offset in the morning
- Advance activity acrophase

Morning blue light (CS ≥ 0.3):

- Elicit acute alerting response
- Reduce subjective sleepiness
- Increase subjective vitality/energy

Afternoon red light (CS = 0):

- Elicit acute alerting response
- Reduce subjective sleepiness
- Increase subjective vitality/energy, especially around 15:00 (the post-lunch dip)
- Avoid excessive CS exposure in late afternoon, thereby limiting any possible light-induced delay of circadian phase



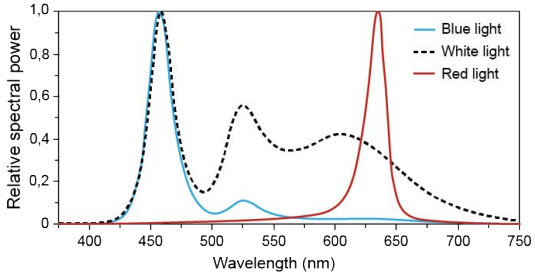
Homeostatic sleep Process S vs. circadian Process C and the effects of blue vs. red light on circadian phase

Graphic adapted from Borbély, A. A. (1982). A two-process model of sleep regulation. *Human Neurobiology*, 1(3), 195-204.

Sponsor: U.S. General Services Administration

Circadian entrainment and alertness in daytime workers

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



Time of Day	Lighting Intervention	λ_{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

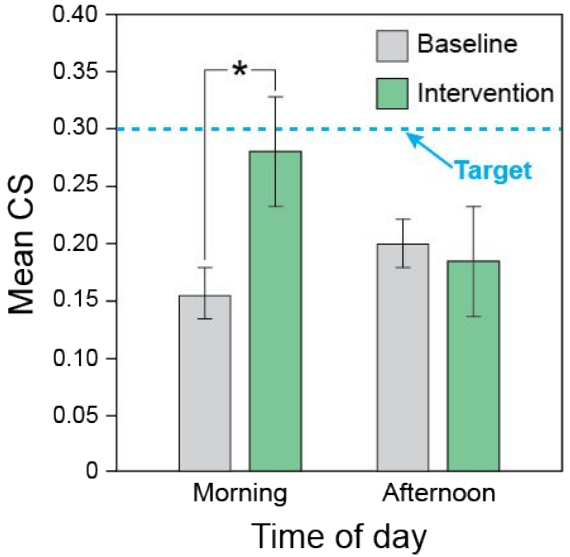
Sponsor: U.S. General Services Administration

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



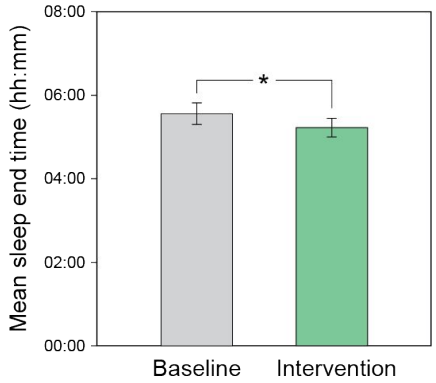
Error bars represent standard error of the mean, * p <0.05

Sponsor: U.S. General Services Administration

Circadian entrainment and alertness in daytime workers

Sleep end time

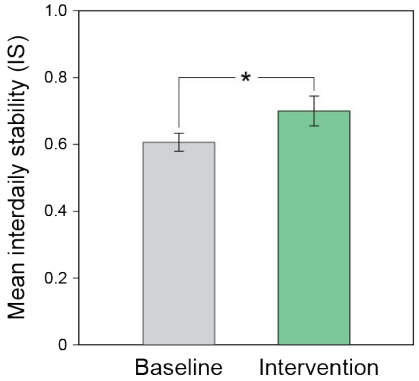
- The intervention advanced circadian phase by 20 min



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

Interdaily stability (IS)

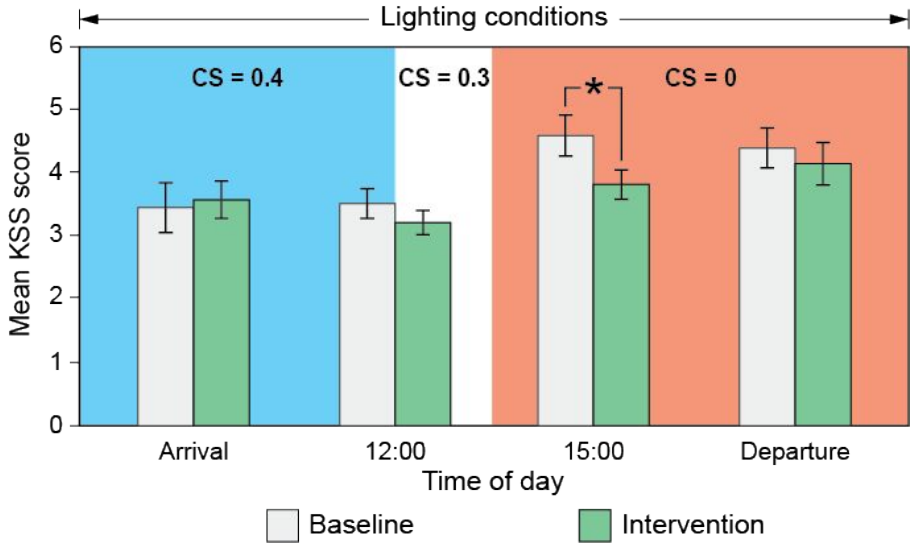
- The intervention shows stronger coupling between rest–activity rhythm and environmental cues (i.e., light stimulus), indicating significantly better circadian entrainment



Sponsor: U.S. General Services Administration

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

Sponsor: U.S. General Services Administration

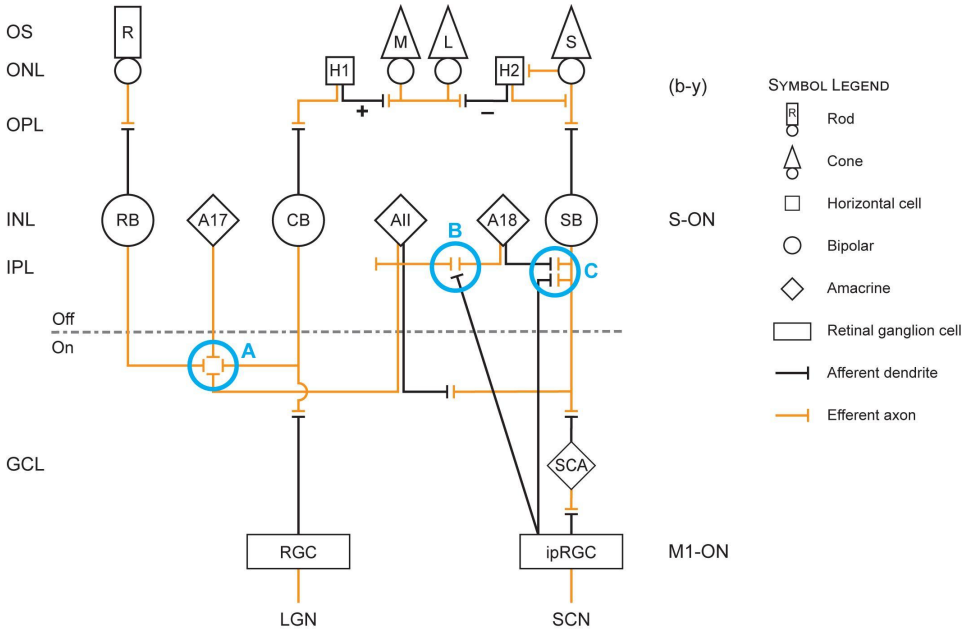
Sleep Math:
Brighter days =
More daytime alertness
Better Nights

Nagare R, Woo M, MacNaughton P, Plitnick B, Tinianov B, Figueiro M. Access to Daylight at Home Improves Circadian Alignment, Sleep, and Mental Health in Healthy Adults: A Crossover Study. *International Journal of Environmental Research and Public Health*. 2021; 18: 9980.

Literature

Science

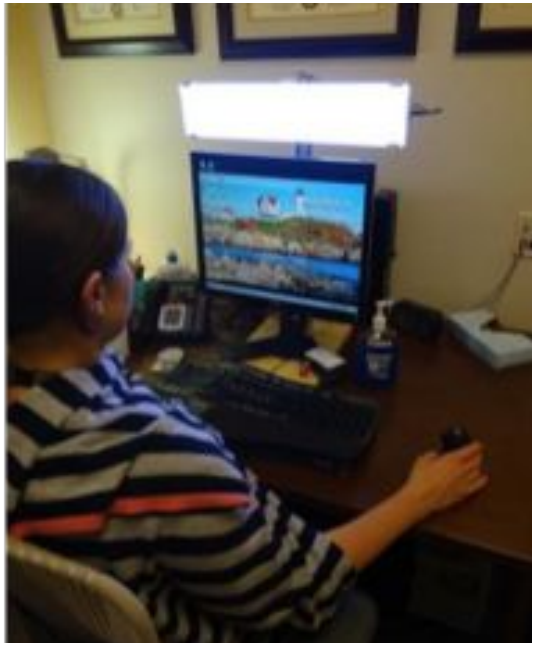
- Rea, M. S., Figueiro, M. G., Bullough, J. D., & Bierman, A., 2005. A model of phototransduction by the human circadian system. *Brain Research Reviews*, 50(2), 213-228. DOI: 10.1016/j.brainresrev.2005.07.002
- Rea, M. S., Figueiro, M. G., Bierman, A., & Hamner, R., 2012. Modelling the spectral sensitivity of the human circadian system. *Lighting Research and Technology*, 44(4), 386-396. DOI: 10.1177/1477153511430474
- Rea, M. S., Nagare, R., & Figueiro, M. G., 2021a. Modeling circadian phototransduction: Quantitative predictions of psychophysical data. *Frontiers in Neuroscience*, 15, 44. DOI: 10.3389/fnins.2021.615322
- Rea, M. S., Nagare, R., & Figueiro, M. G., 2021b. Modeling circadian phototransduction: Retinal neurophysiology and neuroanatomy. *Frontiers in Neuroscience*, 14, 1467. DOI: 10.3389/fnins.2020.615305



Literature

GSA

- **Figueiro MG**, Steverson B, Heerwagen J, **Rea MS**, editors. Daylight in office buildings: impact of building design on personal light exposures, sleep and mood. 28th CIE Session; 2015 June 28 – July 4; Manchester, UK: Commission Internationale de l'Éclairage.
- **Figueiro MG**, Steverson B, Heerwagen J, Kampschroer K, **Hunter CM, Gonzales K**, et al. The impact of daytime light exposures on sleep and mood in office workers. *Sleep Health*. 2017;3(3):204-15. doi: 10.1016/j.sleh.2017.03.005
- **Figueiro MG**, Kalsher M, Steverson BC, Heerwagen J, Kampschroer K, **Rea MS**. Circadian-effective light and its impact on alertness in office workers. *Lighting Research and Technology*. 2019;51(2):171-83. doi: 10.1177/1477153517750006
- **Figueiro MG**, Steverson B, Heerwagen J, Yucel R, Roohan C, Sahin L, et al. Light, entrainment and alertness: A case study in offices. *Lighting Research and Technology*. 2020;52(6):736-50. doi: 10.1177/1477153519885157



Literature

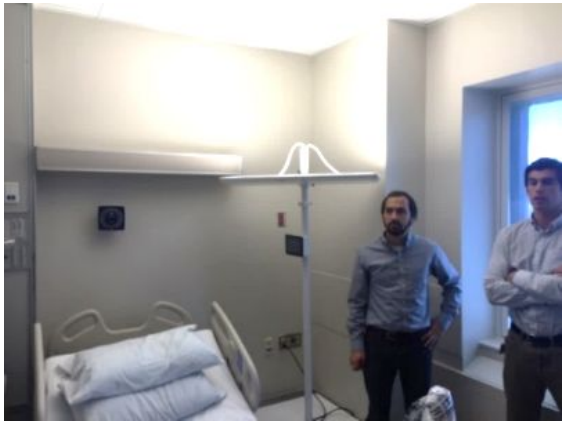
Alzheimer’s disease and related dementias

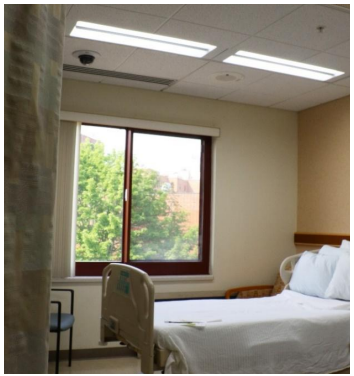
- **Figueiro MG, Plitnick BA**, Lok A, **Jones GE, Higgins P, Hornick TR,** et al. Tailored lighting intervention improves measures of sleep, depression, and agitation in persons with Alzheimer's disease and related dementia living in long-term care facilities. *Clinical Interventions in Aging*. 2014;9:1527-37. doi: 10.2147/CIA.S68557
- **Figueiro MG, Hunter CM, Higgins PA, Hornick TR, Jones GE, Plitnick B**, et al. Tailored lighting intervention for persons with dementia and caregivers living at home. *Sleep Health*. 2015;1(4):322-30. doi: 10.1016/j.sleh.2015.09.003
- **Figueiro M, Plitnick B, Rea M**. Research Note: A self-luminous light table for persons with Alzheimer’s disease. *Lighting Research and Technology*. 2016;48(2):253-9. doi: 10.1177/1477153515603881
- **Figueiro MG.** Light, sleep and circadian rhythms in older adults with Alzheimer's disease and related dementias. *Neurodegenerative Disease Management*. 2017;7(2):119-45. doi: 10.2217/nmt-2016-0060
- **Figueiro MG, Plitnick B, Roohan C, Sahin L**, Kalsher M, **Rea MS**. Effects of a tailored lighting intervention on sleep quality, rest–activity, mood, and behavior in older adults with Alzheimer’s disease and related dementias: A randomized clinical trial. *Journal of Clinical Sleep Medicine*. 2019;15(12):1757-67. doi: 10.5664/jcsm.8078
- **Figueiro MG, Sahin L, Kalsher M, Plitnick B, Rea MS**. Long-term, all-day exposure to circadian-effective light improves sleep, mood, and behavior in persons with dementia. *Journal of Alzheimer’s Disease Reports*. 2020;4(1):297-312. doi: 10.3233/ADR-200212

Literature

Cancer

- **Bullough JD, Rea MS, Figueiro MG**. Of mice and women: Light as a circadian stimulus in breast cancer research. *Cancer Causes Control*. 2006;17(4):375-83. doi: 10.1007/s10552-005-0574-1
- Valdimarsdottir HB, **Figueiro MG**, Holden W, Lutgendorf S, Wu LM, Ancoli-Israel S, et al. Programmed environmental illumination during autologous stem cell transplantation hospitalization for the treatment of multiple myeloma reduces severity of depression: A preliminary randomized controlled trial. *Cancer Medicine*. 2018;7(9):4345-53. doi: 10.1002/cam4.1690
- Kaur P, Mohamed NE, Archer M, **Figueiro MG**, Kyprianou N. Impact of circadian rhythms on the development and clinical management of genitourinary cancers. *Frontiers in Oncology*. 2022;12. doi: 10.3389/fonc.2022.759153
- Dasari SS, Archer M, Mohamed NE, Tewari AK, **Figueiro MG**, Kyprianou N. Circadian rhythm disruption as a contributor to racial disparities in prostate cancer. *Cancers*. 2022;14(20):5116. doi: 10.3390/cancers14205116





Literature

Shift workers

- **Young CR, Jones GE, Figueiro MG,** Soutiere SE, Keller MW, Richardson AM, et al. At-sea trial of 24-h-based submarine watchstanding schedules with high and low correlated color temperature light sources. *Journal of Biological Rhythms*. 2015;30(2):144-54. doi: 10.1177/0748730415575432
- **Figueiro MG, Sahin L, Wood B, Plitnick B.** Light at night and measures of alertness and performance: Implications for shift workers. *Biological Research in Nursing*. 2016;18(1):90-100. doi: 10.1177/1099800415572873
- Razavi P, Devore EE, Bajaj A, Lockley SW, **Figueiro MG,** Ricchiuti V, et al. Shift work, chronotype, and melatonin rhythm in nurses. *Cancer Epidemiology, Biomarkers and Prevention*. 2019;28(7):1177-86. doi: 10.1158/1055-9965.epi-18-1018
- **Figueiro MG, Pedler D.** Red light: A novel, non-pharmacological intervention to promote alertness in shift workers. *Journal of Safety Research*. 2020;74:169-77. doi: 10.1016/j.jsr.2020.06.003
- **Figueiro MG,** Goo YH, Hogan R, **Plitnick B,** Lee JK, Jahangir K, et al. Light–dark patterns mirroring shift work accelerate atherosclerosis and promote vulnerable lesion phenotypes. *Journal of the American Heart Association*. 2021;10(2):e018151. doi: doi:10.1161/JAHA.120.018151

Polls 6 and 7

Slido.com: #1569492; to access polls and Q&A

GSA

Icahn School of Medicine at Mount Sinai

Light and Health Research Center

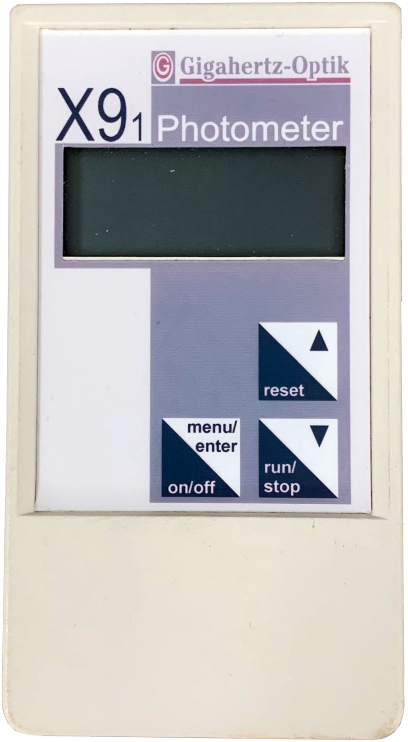
Design Guidelines

Design guidelines

UL 24480

WELL

Agnostic (illuminance)



What is UL 24480?

A design guideline for the measurement and application of light for daytime work environments that support circadian entrainment of day-active and night-resting occupants

Provides a light measurement and lighting specification methodology that is aimed at promoting better sleep through circadian entrainment

Provides a method for photometric validation and for assessing whether occupants sleep better or not

Design Guidelines for Promoting Circadian Entrainment with Light for Day-active People

Preface

Quick Guide

Worked Examples

Brief Overview

Design Guideline

Appendix A - Informative General Research and Supporting Science

Appendix B - Circadian Entrainment

Appendix C - Examples

References

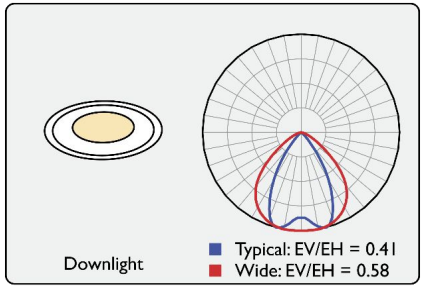
https://www.shopulstandards.com/ProductDetail.aspx?productId=UL24480_1_D_20191219

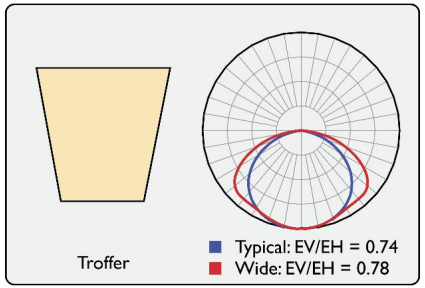
Step 1: Establish the circadian-effective lighting design criterion

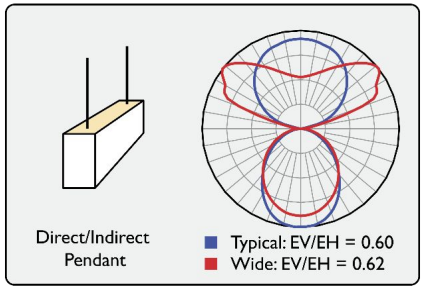
- UL Design Guideline 24480 criterion: The circadian stimulus (**CS**) should be greater than or equal to **0.30** and should be continuously available at the occupant's eyes for a minimum of **2 h** during daytime
  - Timing and duration of circadian effective light should be specified and documented

Step 2: Select luminaires

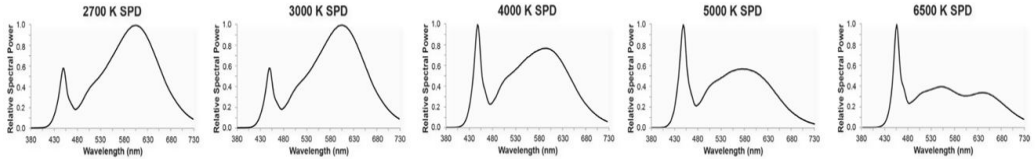
- Lighting designs for commercial architecture typically must meet horizontal illuminance (E_H) requirements on the floor/ground or workplane
- When designing for circadian entrainment, vertical illuminance at the eye (E_V) becomes the primary objective
- The ratio of vertical illuminance (E_V) to horizontal illuminance (E_H) becomes important when looking at the optics of a fixture
  - Typically $E_H > E_V$ but for circadian entrainment E_V is more important





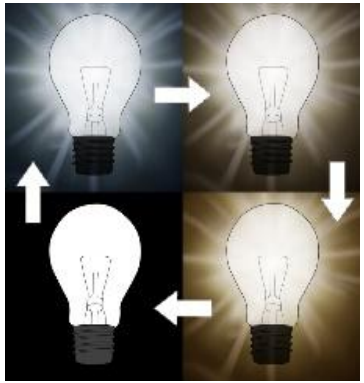


Step 3: Select light sources



- Spectral power distribution (SPD), *not* correlated color temperature (CCT), must be specified
  - May need to request the SPD from the manufacturer
- Can be fixed SPD *or* tunable spectra
  - For tunable spectra, it is necessary to specify the SPD used to meet the design criterion of **CS ≥ 0.30**

Static spectrum

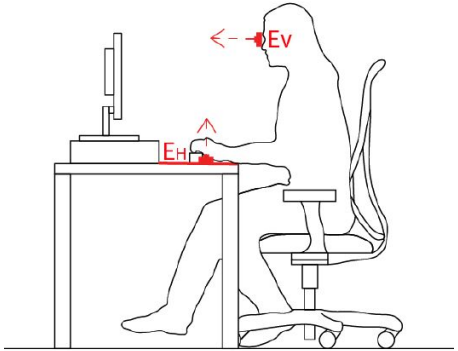


Tunable spectrum

Step 4: Run photometric simulations

- Formulate a 3-D model to evaluate the proposed lighting design solution using a lighting calculation software such as AGi32
- Define vertical illuminance (E_V) calculation points in the plane of the eye of a space occupant
- E_V points should be approximately 0.9 to 1.3 m (3 to 4 ft) above the finished floor aimed in the direction of the occupant's gaze

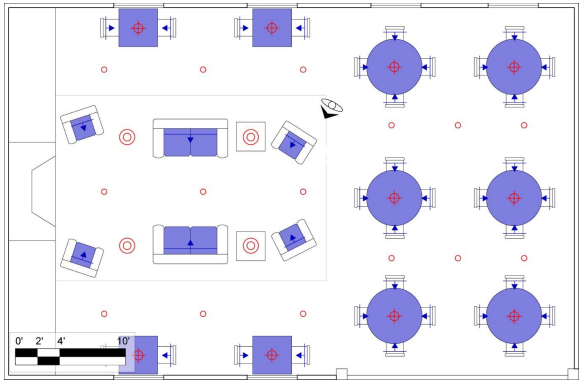
Direction of measuring horizontal illuminance (EH) (light received on a workplane)



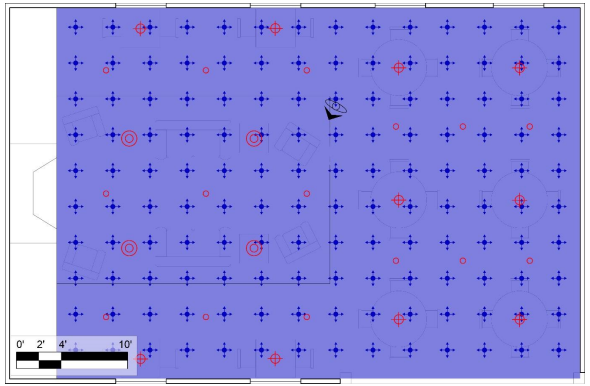
Direction of measuring vertical illuminance (EV) (light received at the eye)

Step 4: Run photometric calculations

- When furniture locations are known:
  - Place E_V calculation points at those locations
  - At least 10 locations throughout space



- When furniture locations are unknown/changeable:
  - Place grids of E_V throughout the space, aimed in four cardinal directions, and average

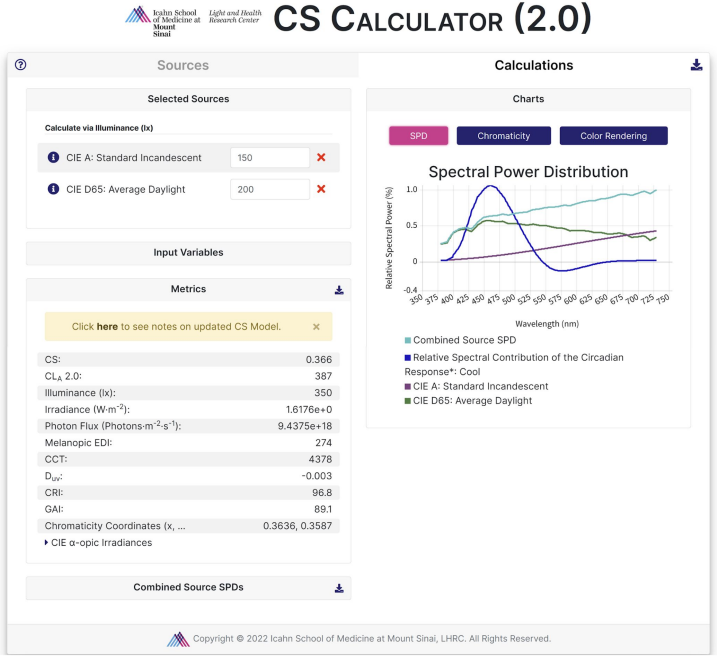


Step 5: Calculate CS

When photometric calculations are complete:

- Utilize the LHRC's web-based Circadian Stimulus Calculator
  - Input light source SPD values
  - Input E_V calculations
  - Calculate CS

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



Step 6: Check and adjust — Iterative design process

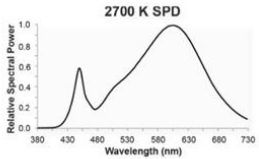
- CS targets are rarely met on the first try
- Adjust luminaire spacing to increase E_V at furniture locations
- Try wide intensity distributions or direct/indirect ceiling mounted luminaires to increase E_V : E_H ratios (aim for around 0.6:1)
- Adjust lumen output or change light source spectrum
- Consider additional layers of light geared solely towards the efficient delivery of daytime CS
  - Vertical surface luminance (**must be less than 8,500 cd m^{-2}**)
  - Blue light

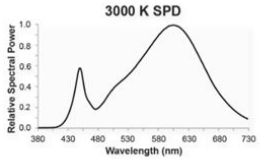
Worked example — 2’ × 4’ troffer

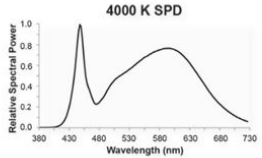


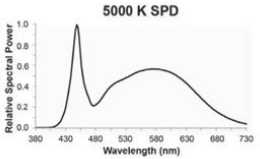


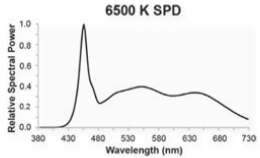
Time	CS	2700 K		3000 K		4000 K		5000 K		6500 K	
		E_V (lx)	E_H (lx)	E_V (lx)	E_H (lx)	E_V (lx)	E_H (lx)	E_V (lx)	E_H (lx)	E_V (lx)	E_H (lx)
7 AM – 4 PM	0.3	345	500	290	420	370	536	270	391	195	283
4 – 5 PM	Transition	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
5 – 7 PM	0.2	200	290	165	239	215	311	155	225	115	167
7 – 8 PM	Transition	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
8 pm – EOB	0.1	90	130	75	109	100	145	75	109	55	80





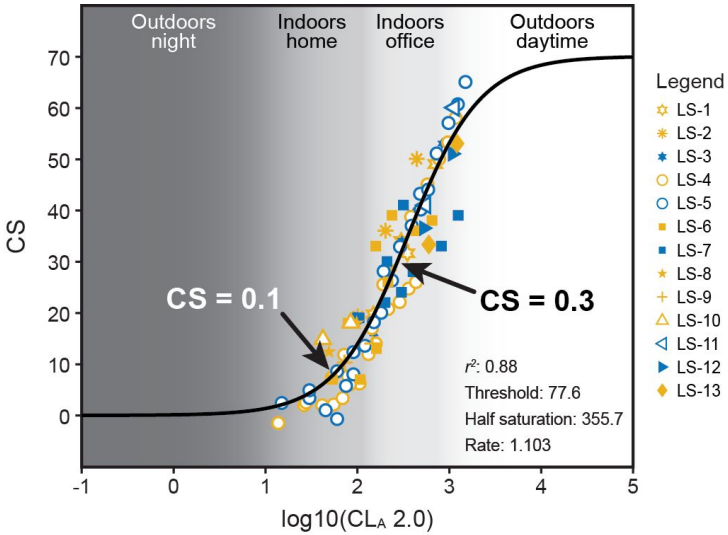


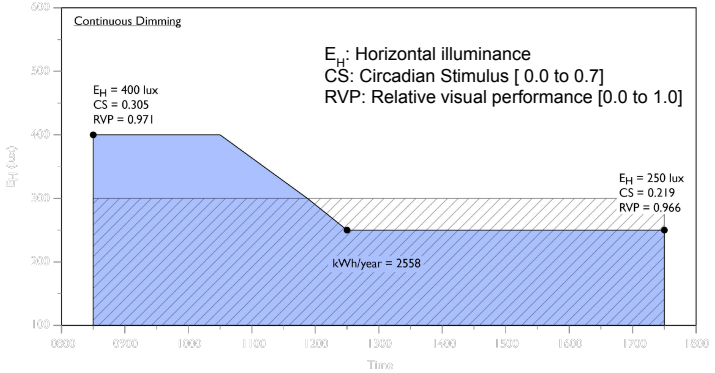




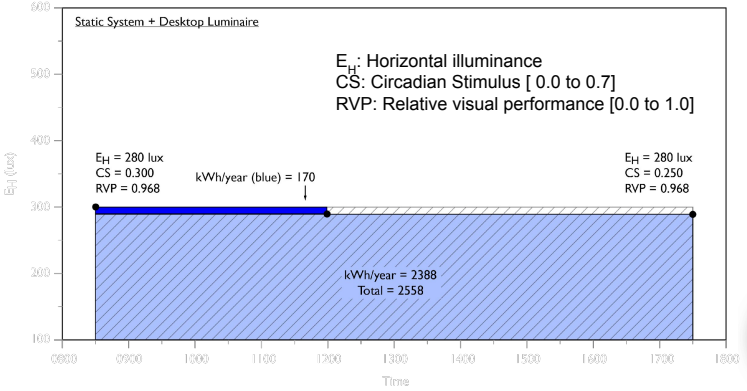
Implementation

CS > 0.3 = about 400 lx at eyes
For 2 hours in the morning.
CS < 0.1 at home at night

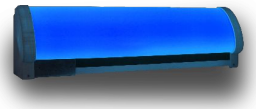




With dimming



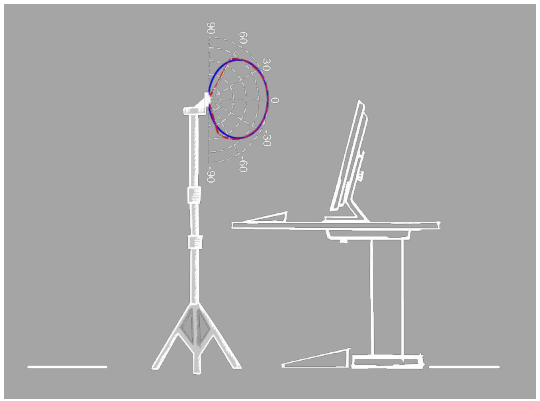
No dimming



Measurement verification

After design phase and before occupancy, need to verify design conforms to UL 24480
Method:

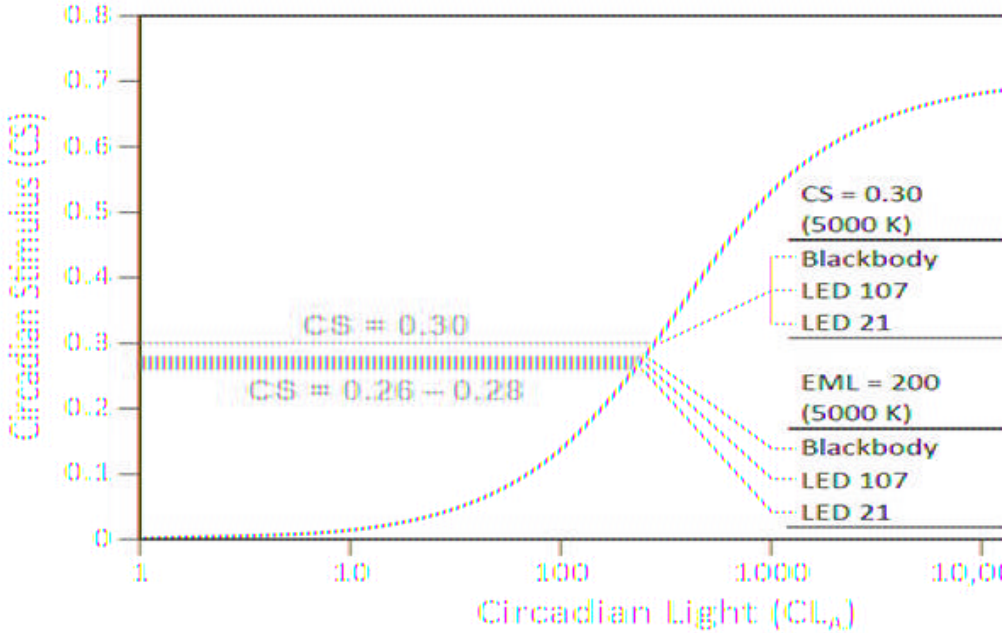
1. Illuminance meter, reported SPD and CS calculator
2. Portable spectroradiometer



In both cases, need to make a minimum of 10 representative sample measurements

General method using WELL guidelines

WELL recommends Equivalent Melanopic Lux (EML), Version 1, EML = 200



General method — WELL recommendations (versions 1 and 2) + Illuminance

Little functional difference between WELL and UL recommendations

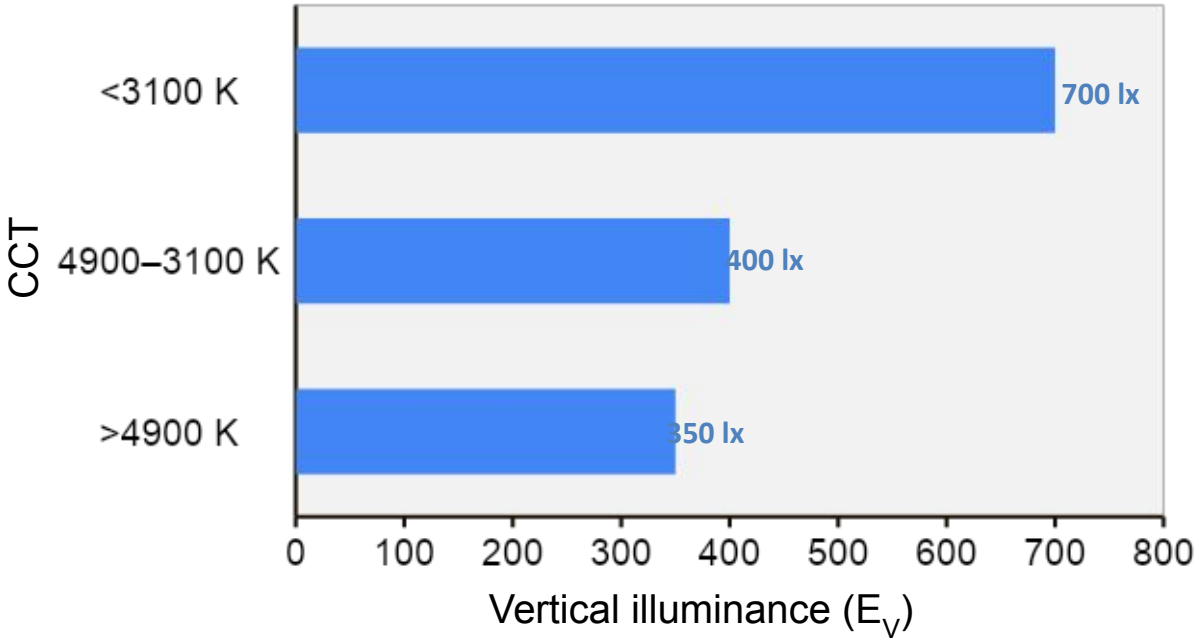
Differences lie in

a. use of the ANSI process
b. prediction accuracy
c. physiological foundation

Light source		Equivalent melanopic lux (EML)		
		150	200	240
Blackbody (5000 K)	CS	0.22	0.28	**0.31**
	E_V (E_H)	161 (230)	214 (349)	257 (368)
LED 107 (5000 K)	CS	0.21	0.27	**0.30**
	E_V (E_H)	230 (329)	307 (439)	368 (526)
LED 21 (5000 K)	CS	0.21	0.26	**0.29**
	E_V (E_H)	239 (342)	318 (454)	382 (546)
D65 (6500 K)	CS	0.25	**0.3**	**0.34**
	E_V (E_H)	136 (194)	181 (259)	218 (312)

Agnostic method — Vertical illuminance at eye

Illuminance at which 100% of commercial LEDs reach criterion CS = 0.3



Maximum effect of spectrum for "white" light (6500–3000 K) = **3×**

For a given CCT, half that effect = **1.5×**

This is small compared to light level

$E_V / E_H \approx 0.7$

(If a ceiling luminaire; e.g., 400 E_V / 570 E_H)

Poll 8

Slido.com: # 1569492; to access polls and Q&A

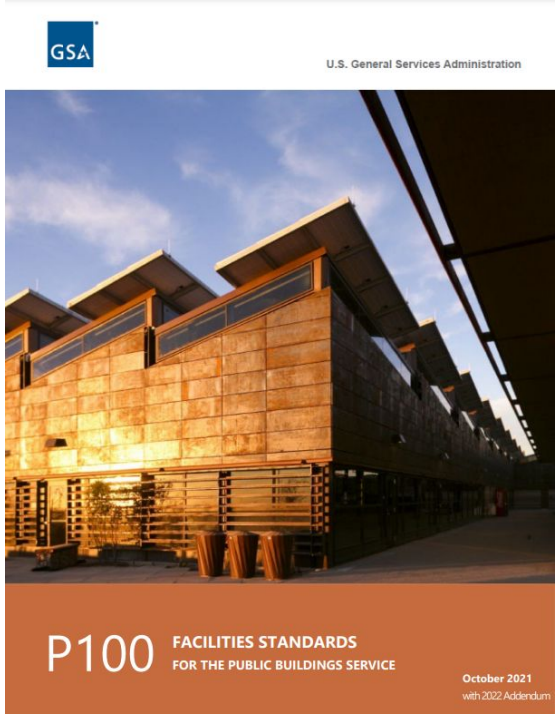
Icahn School of Medicine at Mount Sinai *Light and Health Research Center*

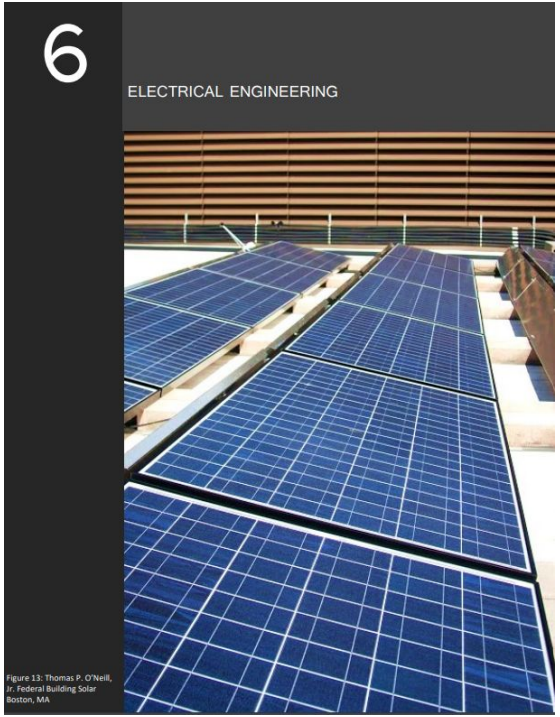
GSA Requirements

Facilities Standards for the Public Buildings Service (P100)

Establishes design standards and performance criteria for GSA's Public Buildings Service.

This document contains policy and technical criteria to be used in the programming, design, and documentation of GSA buildings.





Facilities Standards for the Public Buildings Service (P100)

CHAPTER 6 • ELECTRICAL ENGINEERING

Color Saturation (Rg)		
Baseline		N/A
Tier 1		110
Tier 2		110
Tier 3		110
M & V		
Plans & Specs		
Calculations & Analysis		
References		
Basis of Design		
Construction Verification		
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

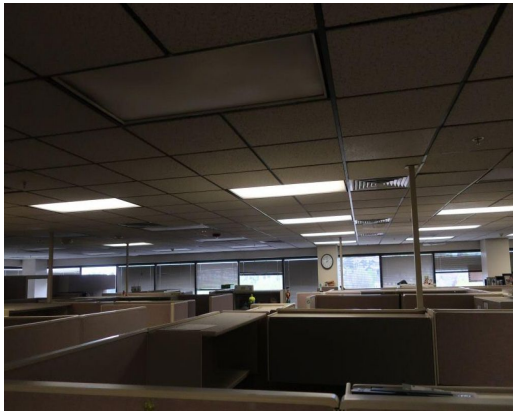
DG 24480

Underwriters Laboratories, Inc.

Design Guidelines for Circadian Entrainment*

Denver Federal Center – Building 48

Current office lighting of client



Design concept of “Forest”

Building 48 “Forest” – under construction

Building 48 – Outdoor space

Future pilots

Promoting Health in Buildings

Sustainable Facilities Tool
U.S. General Services Administration

Log On

LEARN Sustainability Topics | PLAN Strategies & Tools | EXPLORE Virtual Facility | PROCURE Products & Services | APPLY Case Studies | TRAIN Career Planning

Facility Topics

The first step to a creating a high-performance facility is to learn about the components. Use the sections below to learn how you can reduce utility costs and improve occupant health in your facility. And be sure to check out our other Helpful Tools for everyday tasks.

CLIMATE

ENERGY

WATER

HEALTH

OTHER TOPICS

FEDERAL REQUIREMENTS

GSA U.S. General Services Administration

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Home › Governmentwide Initiatives › Federal High-Performance Green Buildings › Resource Library › Health › Circadian Lighting

Federal High-Performance Green Buildings

- Overview
- Policy
- **Resource Library**
  - Energy & Water
  - Health
    - **Circadian Lighting**
      - Edith Green-Wendell Wyatt Federal Building
      - Federal Center South Building 1202
      - GSA Headquarters - 1800 F Street
      - NCR Regional Office Building
      - Wayne N. Aspinall Federal Building
      - Dept of State Harry S. Truman Building
      - FHWA and Department of VA
    - Wellbuilt for Wellbeing
    - Total Workplace Scorecard
    - Biophilic Design
  - Integrative Strategies
  - Building Operations
  - Safeguarding Assets
  - Sustainable Acquisition

Circadian Light For Your Health

The use of daylighting in buildings has focused primarily on reducing energy consumption and providing pleasant interior environments. However, light, especially daylight, may be good for one's health through impacts on the body's circadian rhythms. Given that people spend a majority of their waking hours indoors at work, daylight- if appropriately engineered and supplemented by electric light when necessary - may have unrecognized health benefits.

What are Circadian Rhythms and What is Circadian Light?

A person's "body clock" is regulated by circadian rhythms, which are physiological processes that occur approximately every 24-hours. These 24-hour rhythms have also been widely observed in plants, animals, fungi, and even bacteria. An example of a circadian rhythm is a person's wake/sleep cycle. A function of light is to entrain the body's circadian system to the solar day so that the wake/sleep cycle is entrained or synchronized with the natural light/dark cycle on Earth. If a person's circadian functioning is entrained, a person sleeps well at night and is alert during the day.

Purpose of GSA's Circadian Research

GSA's research has been focused on identifying the links between the amount of light people receive at work and their wake/sleep patterns, daytime alertness, and emotional functioning. GSA's overall goal is to identify specific health benefits of lighting practices that can be replicated in new and existing buildings to achieve innovative and cost effective ways to improve employee health and well-being at work.

GSA conducted this research in several phases. The first phase consisted of taking both space and personal circadian light measurements, and the results showed that while daylight is valuable, it is an insufficient source of circadian stimulation when used alone due to occupant behavior, interior design, low levels of daylight penetration, and other circumstances. In the first phase, GSA conducted its research in five of its buildings in different geographical locations and in both the summer and the winter to account for seasonal variability in daylight.

- GSA Headquarters, Washington, DC
- Edith Green-Wendell Wyatt Federal Building, Portland, Oregon
- Federal Center South Building 1202, Seattle, Washington

Additional Information

- A Case for Circadian Lighting in Federal Buildings [PDF - 377 KB]
- Lighting and Health Research Center, Icahn School of Medicine at Mt. Sinai
- NIH Fact Sheet on Circadian Rhythms
- More Information on Circadian Light

What We Have Learned So Far

- People receive more light at work than anywhere else
- The best time of day for circadian stimulus is in the morning for at least 30 minutes
- People seated near windows and on higher floors receive more circadian stimulus
- Daylight is sometimes not enough; even in well-daylit buildings, there are pockets of biological darkness and low levels of circadian stimulus that may require additional electric light
- Interior workspace design can aid or limit daylight exposure
- Occupant behavior matters in promoting or diminishing circadian stimulus
- Shade use, primarily to reduce glare on computer screens, also reduces circadian stimulation if shades are not adjusted when glare is no longer a problem

https://www.gsa.gov/circadianlight

https://sftool.gov

Background on Lighting and Circadian Rhythms

Video 2 — Mariana G. Figueiro, Director & Professor, Mount Sinai Light and Health Research Center

Icahn School of Medicine at Mount Sinai | Light and Health Research Center | UL Solutions | GSA

0:02 / 16:18

Poll 9

Slido.com: # 1569492; to access polls and Q&A

Icahn School of Medicine at Mount Sinai
Light and Health Research Center

Possible Solutions

Options

Bright light-box in the morning

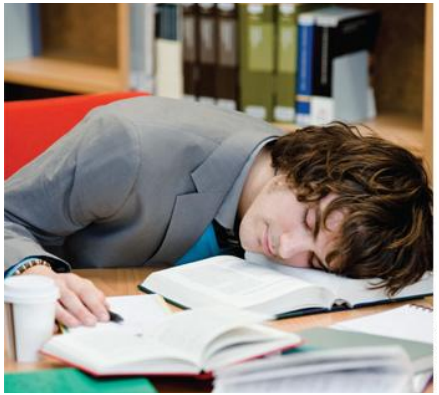
Change the color of streetlights

“Blue-enriched” illumination for commercial spaces

Start school later

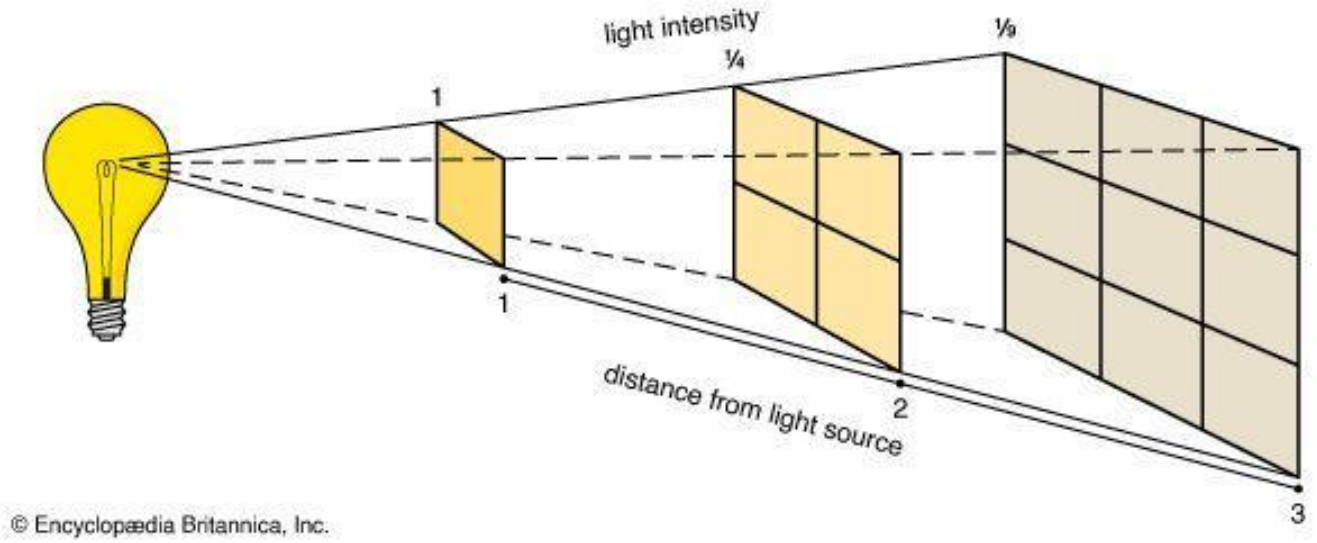
With an understanding of how the circadian system works, additional opportunities:

- Local lighting
- Walk at lunch



Collaborating with American Lighting Association (ALA)

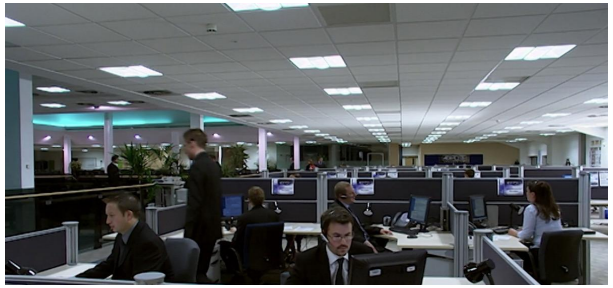
Local lighting that takes advantage of the inverse square law can translate into 1/9 of the electric lighting energy needed to deliver the same CS

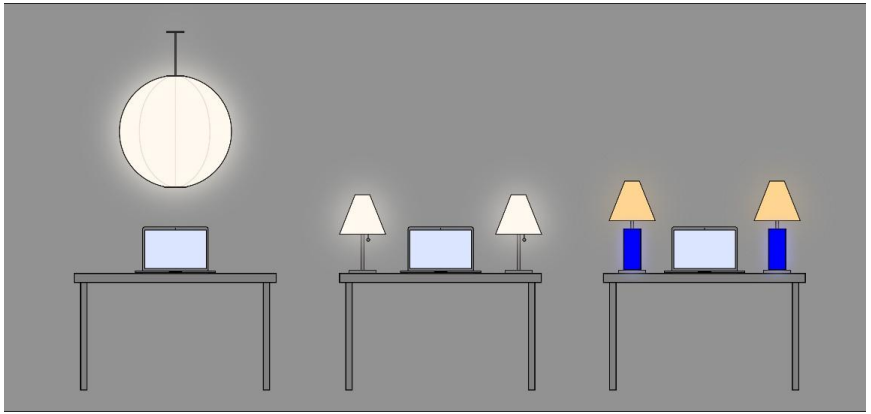


Collaborating with American Lighting Association (ALA)

During the day, by bringing circadian-effective light out of the ceiling and use local lighting that is closer to the occupant one can:

- Provide bright days
- Minimize glare
- Deliver “warm” illumination
- Reduce electric energy





CS-oscillator model: Added value

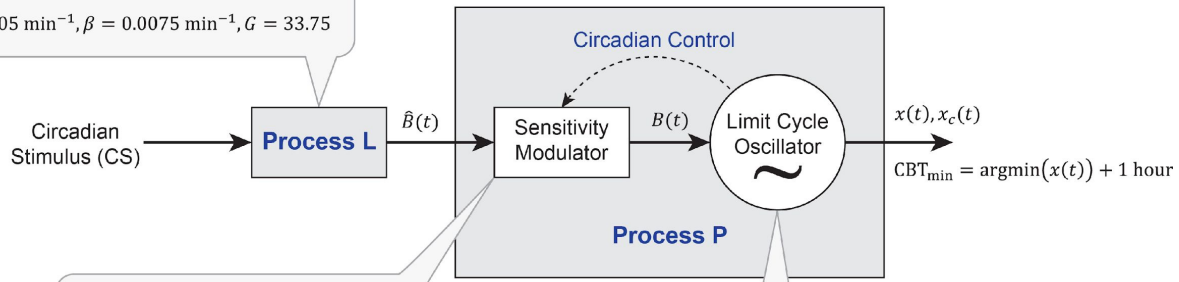
CS-oscillator model

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

$$\alpha = \alpha_o \left(\frac{I}{I_o}\right)^p \quad (2)$$

$$\hat{B} = G\alpha(1-n) \quad (3)$$

$\alpha_o = 0.05\ \text{min}^{-1}, \beta = 0.0075\ \text{min}^{-1}, G = 33.75$



$$B(t) = (1 - 0.4x)(1 - 0.4x_c)\hat{B}(t) \quad (4)$$

$$\dot{x} = \left(\frac{\pi}{12}\right)\left[x_c + \mu\left(\frac{1}{3}x + \frac{4}{3}x^3 - \frac{256}{105}x^7\right) + B\right] \quad (5)$$

$$\dot{x}_c = \left(\frac{\pi}{12}\right)\left[qBx_c - \left(\frac{24}{\tau - 0.064}\right)^2 x - kBx\right] \quad (6)$$

$\mu = 0.13, k = 0.55, q = \frac{1}{3}, \tau = 24.2$

Rea MS, Nagare R, Bierman A, et al. The circadian stimulus-oscillator model: Improvements to Kronauer's model of the human circadian pacemaker. Front Neurosci 2022; 16. DOI: 10.3389/fnins.2022.965525

Problem: Teenagers are very sleepy in the morning

The proposed solution

California is pushing back school start times. The move could sweep the nation — or backfire.

"Everyone is going to be watching to see what the results are going to be," an education researcher said.

Research shows that later school start times can increase the duration and quality of adolescent sleep, which has been linked to health benefits. Anuj Shrestha / for NBC News

Why is there resistance to this move when the science is clear that it will improve teenager health?

- Social obligations of parents
- Less time and opportunity for after-school jobs for teenagers
- After school availability of teenagers to watch younger siblings
- Conflict with scheduling sports practices (especially during winter)
- Lack of extra funds to adjust bus routes and other logistics

Non-obvious solution

Get some daylight at noon!

30 min of daylight at lunch can advance internal phase by 40 min in late chronotypes (owls), like teenagers

- From a biological perspective, this approach is equal to starting school later

Plus this approach maintains phase in early chronotypes (larks), like teachers

Poll 10

Slido.com: # 1569492; to access polls and Q&A

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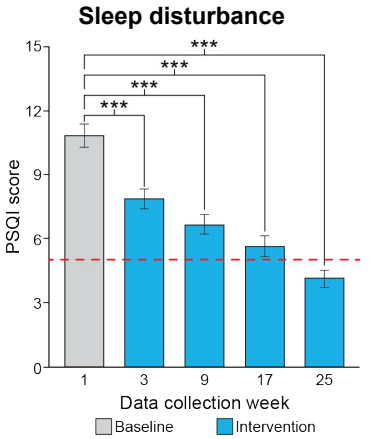
What This Isn't

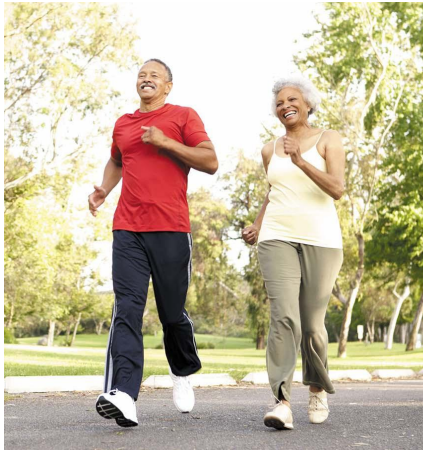
What this isn’t

Not a quick fix

It takes commitment and feedback

Just like diet and exercise





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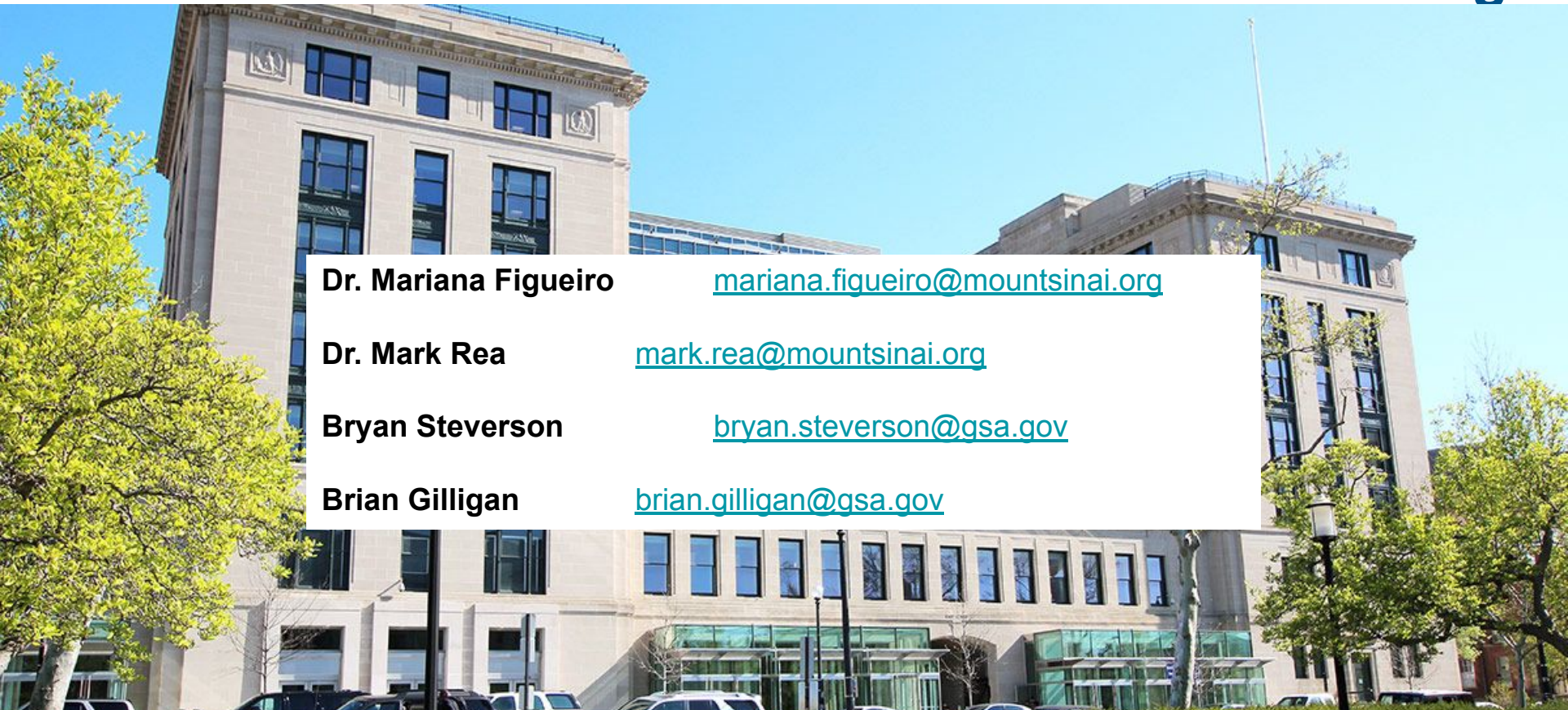
What's Missing?

Poll 11

Slido.com: # 1569492; Polls and Q&A

Circadian Lighting for Better Sleep at Night



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Brian Gilligan brian.gilligan@gsa.gov

GSA's Buildings and Health Research Program

- May 23: Health in Buildings Partnerships
- June 27: Circadian Lighting
- **July 27: Enhancing Ventilation**
- Aug 22: Wellbuilt for Wellbeing
- Sept 26: The Health in Buildings Roundtable

This series is a call for co-sponsors - Health in Buildings Roundtable!

- Government agencies, companies, research organizations, non-profit groups, etc
- Pilot, measure, and evaluate health-enhancing strategies
- Join scoping meeting planned for this summer
- Email coskvig@nas.edu for more information