2019 DLC

April 1 - 3 • St. Louis, MO

STAKEHOLDER MEETING

2019 DLC STAKEHOLDER MEETING

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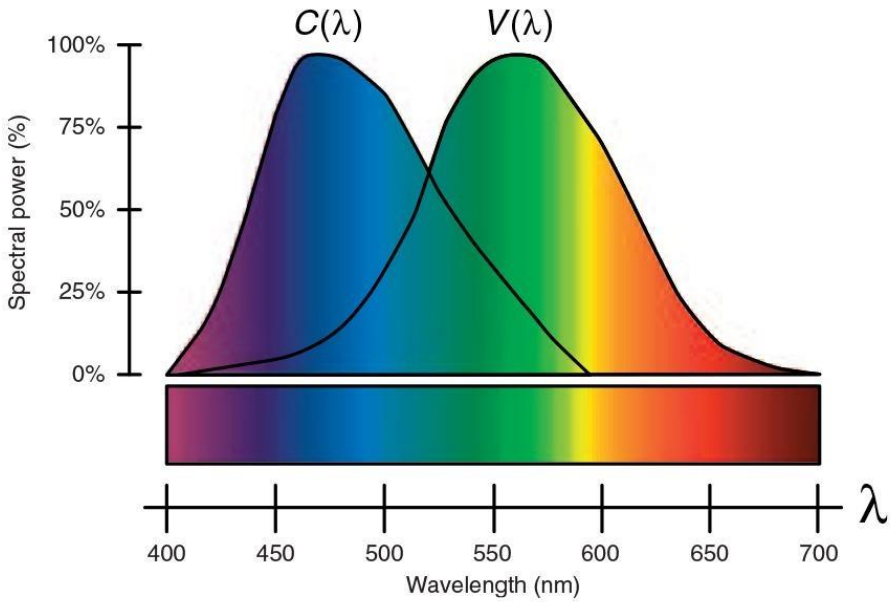
Light, Health and Energy: A Balancing Act for Wellness and Efficiency

"For the last 30 years in lighting, the primary concern has been energy: How do we get our lighting for the least amount of power so we save money and energy in buildings?

That's fine; but the result has been to shift the focus of lighting from human beings to power meters. If buildings – and lighting – are for people … to get work done in a healthy and productive environment, how should we now be designing and using lighting?"

Terry McGowan, in Light and Human Health, Buildings magazine 03/01/2004

15 years later …



Andersen, Marilyne, John Mardaljevic, and Steven W. Lockley. 2012. LR&T 44(1): 37-53.

https://googleplus-covers.com/abstract-covers/digital_nature-cover

Topics to be addressed by this panel

How light affects our health, wellness, and performance

Specific lighting characteristics needed to promote wellbeing

Best practices that include boosting or reducing light (and energy) at the right times

Strategies to manage energy use through product selection and lighting controls

Resources and tools to predict non-visual impacts of light

Agenda

- Panelist Presentations
  - Light, Health and Wellness: How can we (researchers) help you?
  - Building for Health
  - Light, Health and Energy: Design Implementation Experience
- Panel Discussion
- Overview of tools available
- Open for Audience Questions

Panelists

Mariana Figueiro
Lighting Research Center, RPI

Gayathri Unnikrishnan
International WELL Building Institute

Jim Benya
Benya Burnett Consultancy

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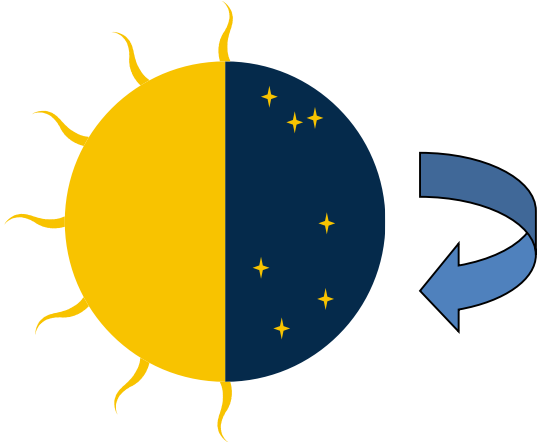
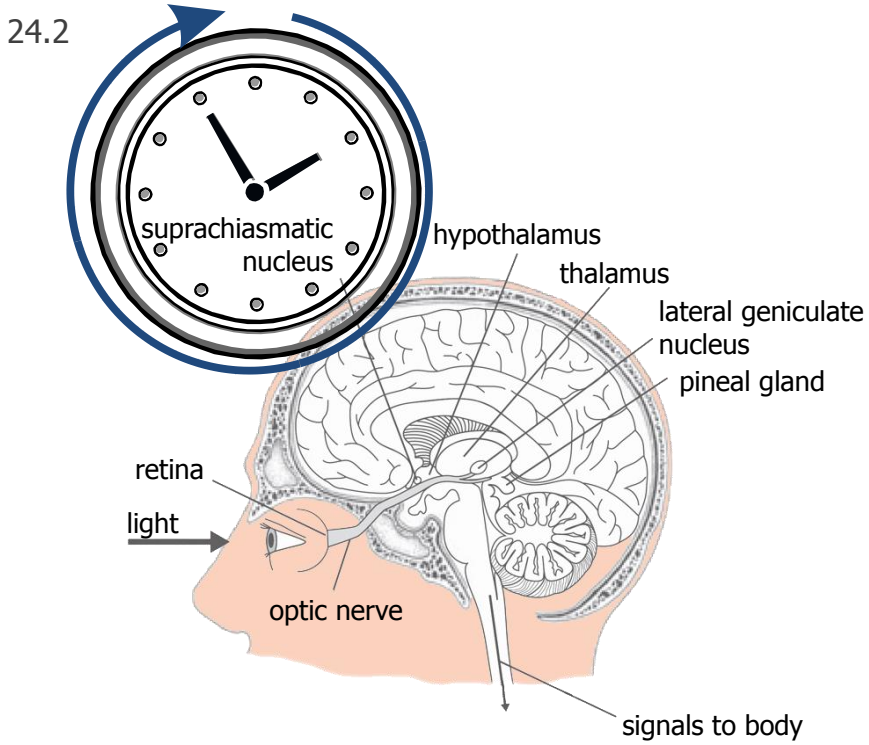
Light, Health and Wellness: How can we (researchers) help you?

Light is the primary synchronizer of circadian rhythms to local time



The natural, 24-hour, light-dark cycle

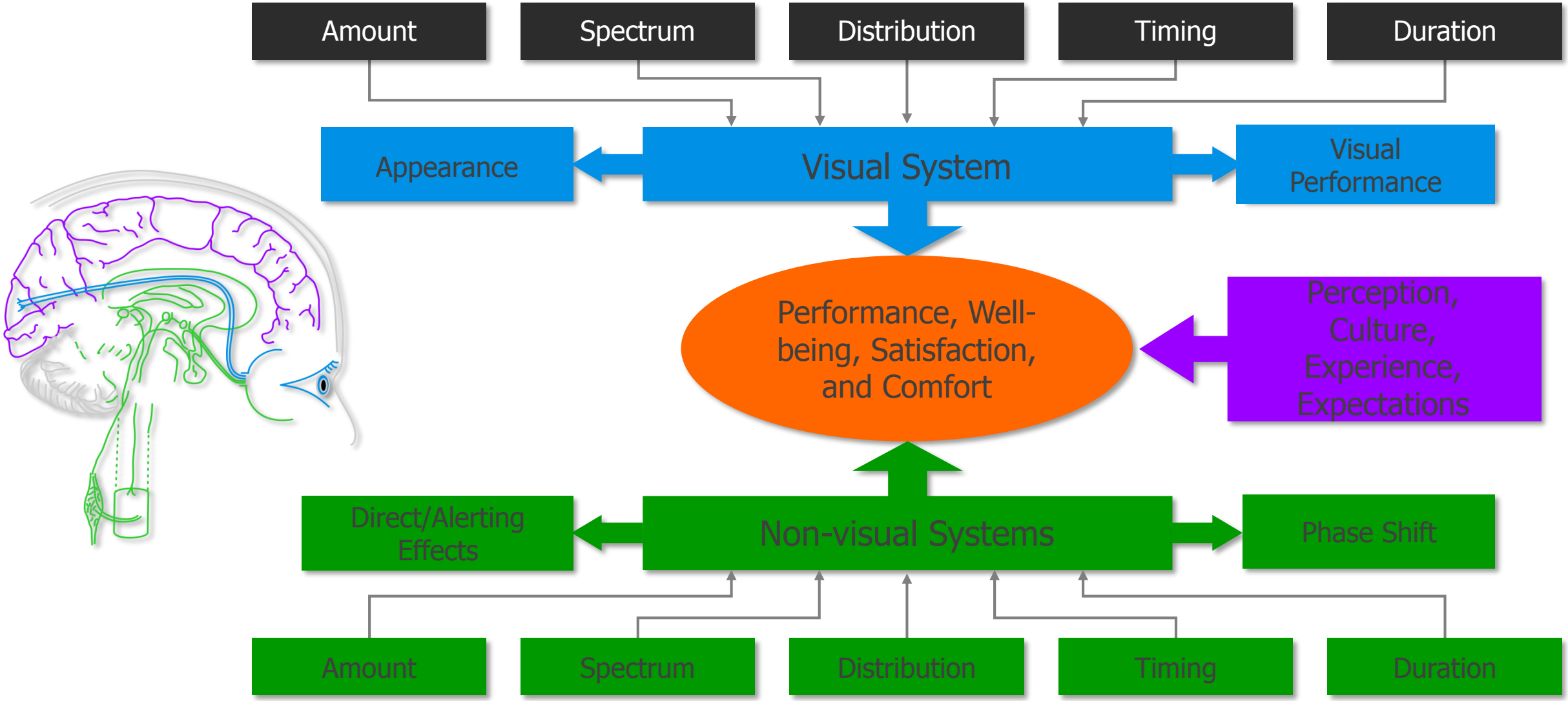


Adapted from National Library of Medicine image, 2007 (public domain)

Light is the primary synchronizer of circadian rhythms to local position on Earth

Lighting Characteristics

Visual + non-visual + perception/psychological



All photoreceptors (rods, cones, and ipRGCs) participate in circadian phototransduction

Published in final edited form as:
Nature. 2003 July 3; 424(6944): 76–81. doi:10.1038/nature01761.

Melanopsin and rod–cone photoreceptive systems account for all major accessory visual functions in mice

S. Hattar*, R. J. Lucas†, N. Mrosovsky‡, S. Thompson†, R. H. Douglas§, M. W. Hankins†, J. Lem||, M. Biel¶, F. Hofmann#, R. G. Foster†, and K.-W. Yau*
*Howard Hughes Medical Institute and Department of Neuroscience, Johns Hopkins University School of Medicine, Baltimore, Maryland 21205, USA

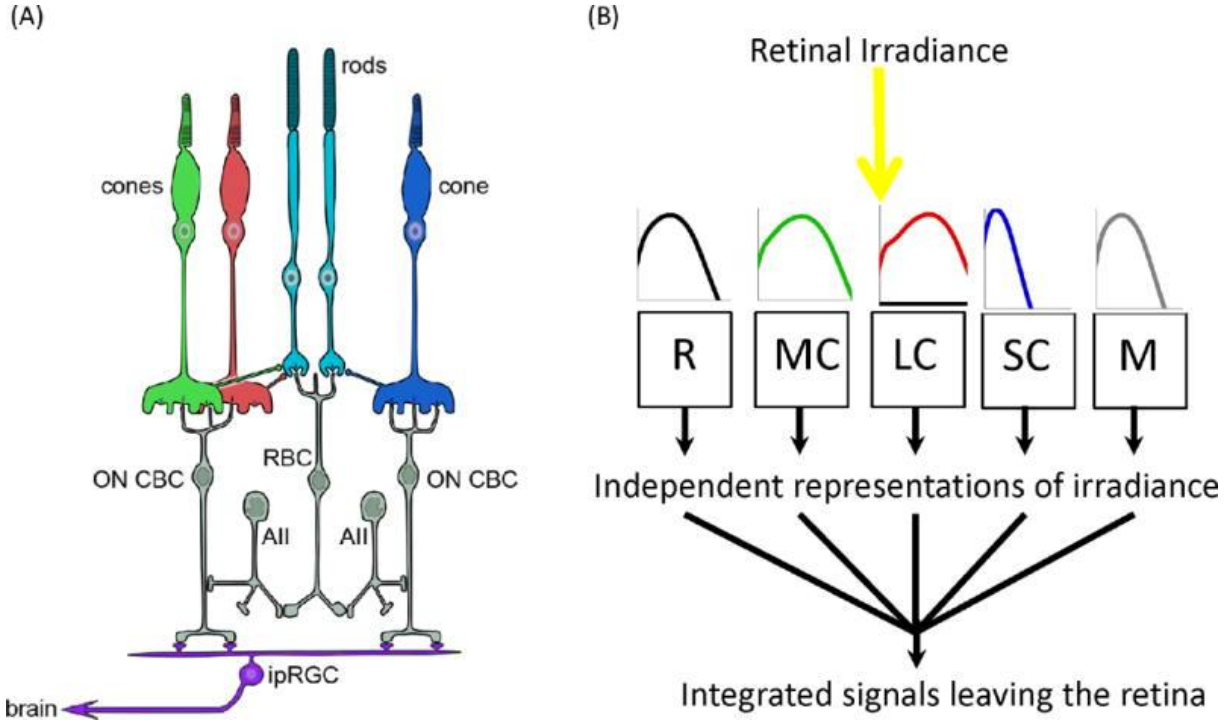


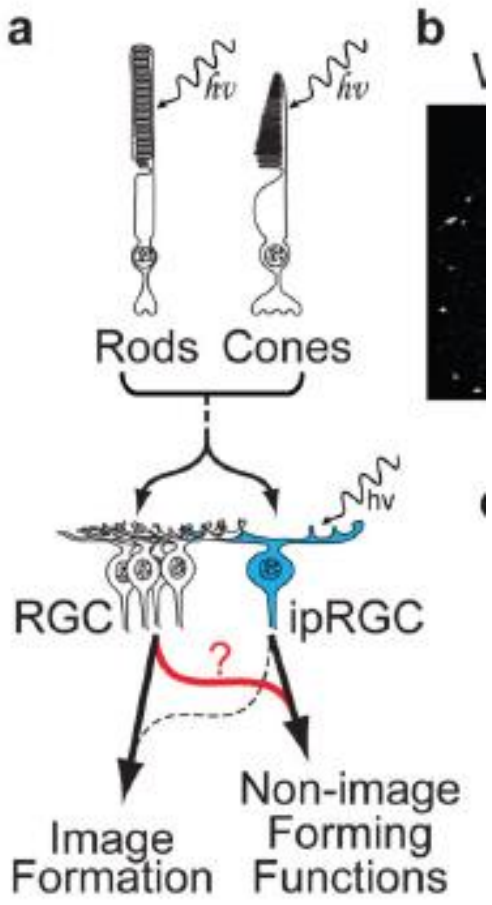
Figure from Lucas et al., 2014. Measuring and using light in the melanopsin age. *Trends in Neurosciences*. 2014 Jan; 37(1): 1–9.

ipRGCs are needed to transduce signals to SCN

Melanopsin cells are the principal conduits for rod/cone input to non-image forming vision

Ali D. Güler[1,*], Jennifer L. Ecker[1,*], Gurprit S. Lall[2,*], Shafiqul Haq[3], Cara M. Altimus[1], Hsi-Wen Liao[3], Alun R. Barnard[2], Hugh Cahill[3], Tudor C. Badea[4], Haiqing Zhao[1], Mark W. Hankins[5], David M. Berson[6], Robert J. Lucas[2,†], King-Wai Yau[3], and Samer Hattar[1,†]
[1] Department of Biology, Johns Hopkins University, Baltimore, MD 21218, USA

IpRCGS are needed to transduce the signals from rods and cones, but melanopsin is not: knockout mice can still entrain to a light pulse



Lucas et al., 2014

- Proposed that researchers record SPDs at the cornea and calculate the effective irradiance experienced by each of the 5 photoreceptors (rods, S-, M-, L-cones, and ipRGCs)

Good start, but this method does not account for how the retina combines these neural signals, and it does not speak to the non-visual *responses!*

Published in final edited form as:
Trends Neurosci. 2014 January ; 37(1): 1–9. doi:10.1016/j.tins.2013.10.004.

Measuring and using light in the melanopsin age

Robert J. Lucas[1,†], **Stuart Peirson**[2,†], **David M. Berson**[3], **Timothy M. Brown**[1], **Howard M. Cooper**[4], **Charles A. Czeisler**[5], **Mariana G Figueiro**[6], **Paul D. Gamlin**[7], **Steven W. Lockley**[5], **John B. O'Hagan**[8], **Luke L. A. Price**[8], **Ignacio Provencio**[9], **Debra J. Skene**[10], and **George C. Brainard**[11]

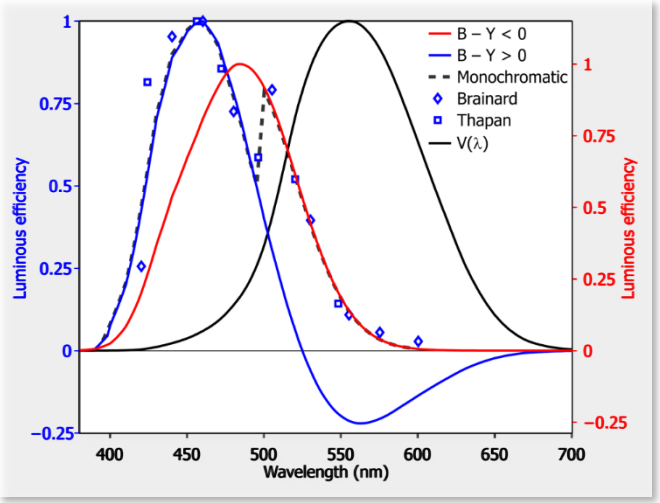
The firing rate of ipRGCs may thus be influenced by five (or four in the case of non-primates) spectrally distinct photoreceptors (Figure 1B). It follows that the spectral sensitivity of downstream responses (and thus the spectral weighting function that should be applied during light measurement) will be determined by the manner in which these various channels are combined. In fact, the contribution of each photoreceptive input to evoked responses appears to be fundamentally context dependent, a feature clearly illustrated by studies of a well-understood ipRGC-driven response, the pupillary light reflex (PLR).

At present, it is therefore recommended that quantities reflecting the activity of each of these individual inputs be reported. This does not achieve the ideal of describing light as a one-dimensional quantity that predicts non-image-forming responses. Nonetheless, reducing the spectral power distribution to a limited number of biologically meaningful quantities (five in the case of humans; four for most other mammalian species) makes the problem of comparing polychromatic lights of different spectral quality significantly more tractable.

Circadian-effective light: Spectrum and amount

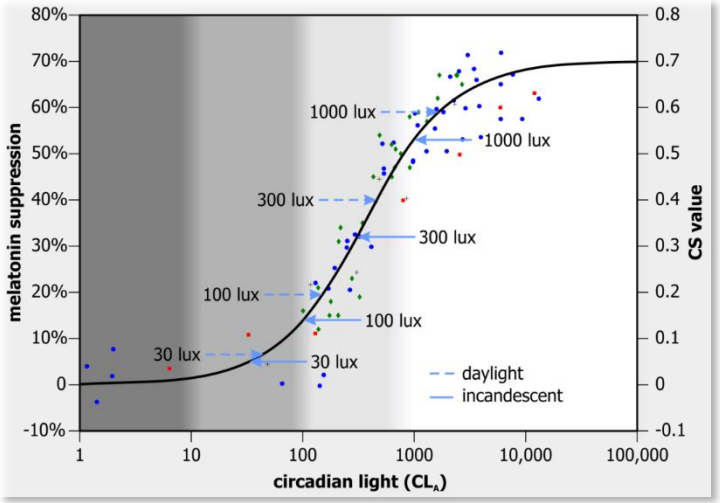
Spectral sensitivity

Circadian Light (CL_A)



Absolute sensitivity

Circadian Stimulus (CS)



CS is related to one response by the circadian system

Rea MS, Figueiro MG, Bierman A, et al. (2012) Modelling the spectral sensitivity of the human circadian system. *Lighting Research & Technology* 44: 386-396.

Rea MS, Figueiro MG, Bullough JD, et al. (2005) A model of phototransduction by the human circadian system. *Brain Research Reviews* 50: 213-228.

Circadian-effective light: Spectrum and amount

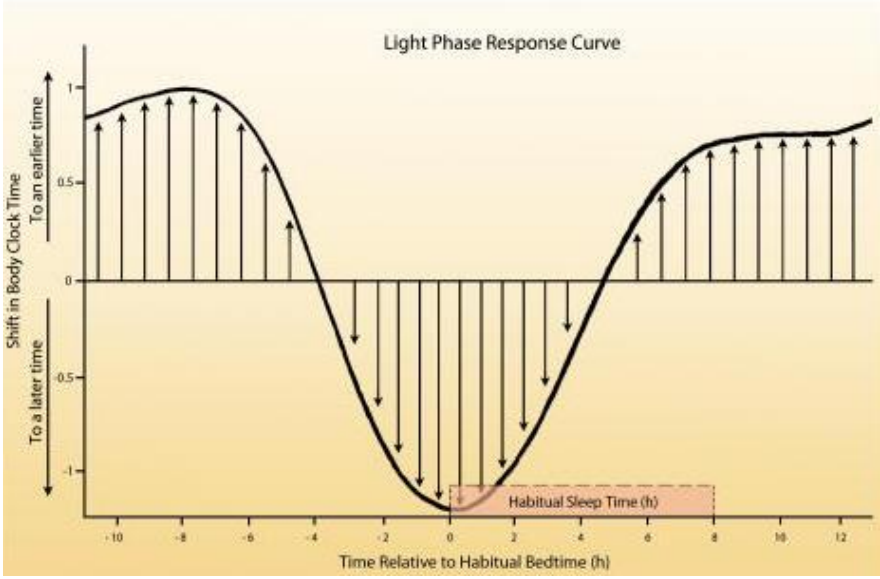
- Illuminance levels play a larger role in CS than CCT
- Average LPD of fixtures providing a CS ≥ 0.3 at 5000 K was 5% lower than at 3000 K

Fraction of luminaires that provided CS ≥ 0.3

	3000 K	5000 K
300 lx	0/12	2/12
500 lx	9/12	11/12

Sponsors: Natural Resources Canada
LRC Light and Health Alliance
LRC Lighting Energy Alliance

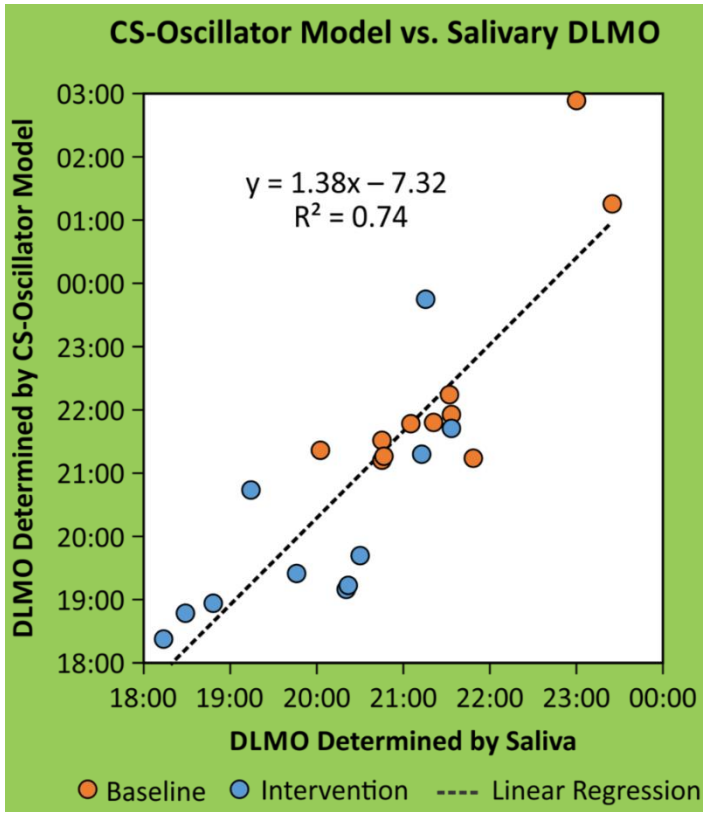
Circadian-effective light: Timing



Phase response curve for 1-h exposure to 4100 K fluorescent (mean ± SD illuminance was 8334 ± 1048 lx at eye level)

Image: Emens JS and Burgess HJ. (2015) Effect of light and melatonin and other melatonin receptor agonists on human circadian physiology. *Sleep Medicine Clinics* 10: 435-453.

Adapted from: St Hilaire MA, Gooley JJ, Khalsa SB, et al. (2012) Human phase response curve to a 1 h pulse of bright white light. *The Journal of Physiology* 590: 3035-3045.

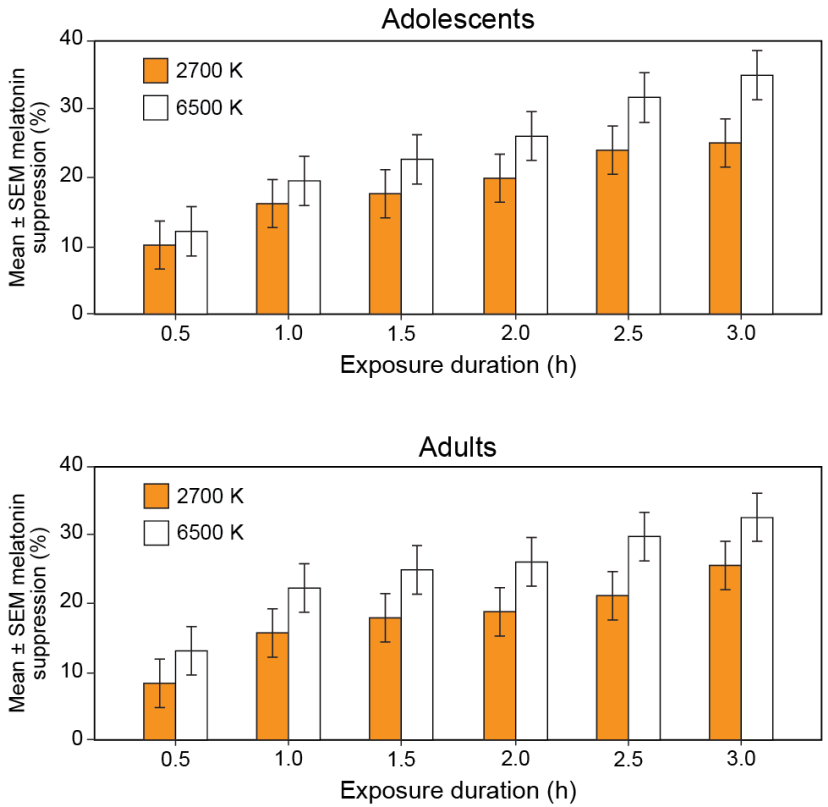


Using total waking light exposures and a mathematical model of human circadian entrainment, we are able to predict circadian phase shift resulting from a light treatment designed to advance DLMO

(LRC unpublished)/Sponsor: Army Research Office/IAI

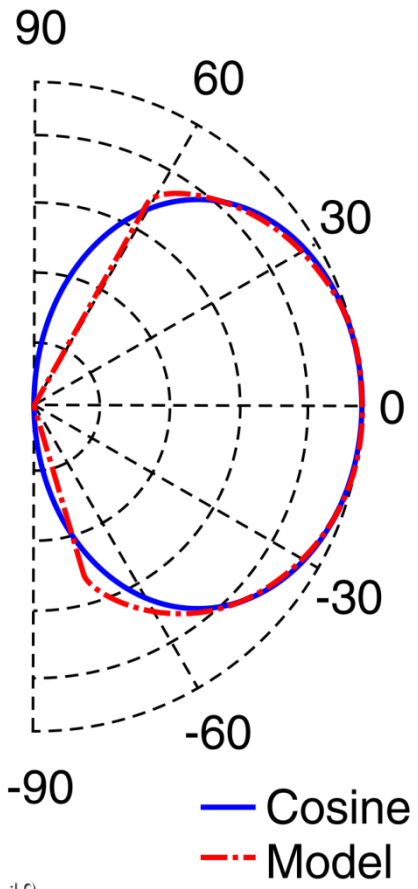
Circadian-effective light: Duration

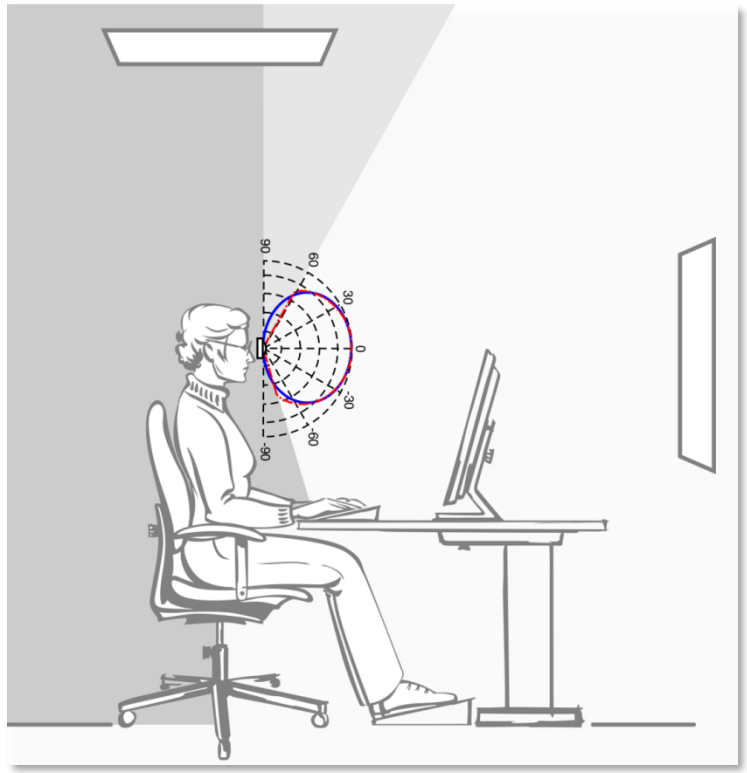
- Light seems to be more effective at suppressing melatonin in the first couple of hours of exposure
- No evidence for change in spectral sensitivity over time



Sponsor: McClung Foundation Lighting Research Foundation

Circadian-effective light: Distribution





It is not about horizontal footcandles!

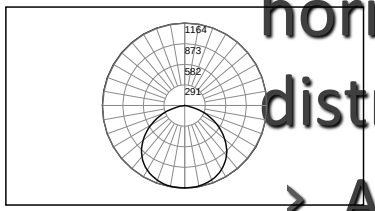
Circadian-effective light: Spectrum, Amount and Distribution

- Except for one 2x4 troffer with a 5000 K source, 300 lux horizontal won't get you there, irrespective of CCT and distribution
  - Add a desktop luminaire delivering 30 lux of 470 nm
- Circadian-effective horizontal E to 500 lux, except for one downlight, all other fixture types deliver the CS of 0.3 irrespective of CCT
- Note that layouts were optimized to increase horizontal/vertical ratio (0.65 or higher)

2 × 2rTroffe

Typical Distribution

	300 lux horizontal	500 lux horizontal
Output	3284 lm	3284 lm
Power	32.5 W	32.5 W
Spacing	10' × 10'	8' × 8'
LPD	0.31 W/ft² (3.34 W/m²)	0.45 W/ft² (4.84 W/m²)



$E_V/E_H = 0.71$

300 lux horizontal

2700 K	3000 K	3500 K	4000 K	5000 K	6500 K
247	263	268	276	[illegible]	300
182	194	198	204	213	221
148	194	98	153	226	329
0.19	0.24	0.14	0.20	[illegible]	[illegible]
0.62	0.77	0.44	0.64	[illegible]	[illegible]
9	12	14	17	21	27
14	17	19	22	26	32
3	6	8	10	[illegible]	[illegible]
24	26	28	30	[illegible]	[illegible]
31	33	34	34	36	38
78	100	119	143	175	228
0.43	0.52	0.60	0.70	0.82	1.03

500 lux horizontal

2700 K	3000 K	3500 K	4000 K	5000 K	6500 K
441	469	479	493	516	535
296	315	321	331	347	359
241	316	161	252	370	540
0.28	**0.33**	0.21	0.28	**0.36**	**0.43**
0.62	0.73	0.46	0.64	0.80	0.96
15	20	23	28	34	44
23	28	31	36	43	52
6	9	12	17	22	27
38	43	45	48	53	58
51	54	55	56	58	61
127	162	193	233	284	370
0.43	0.52	0.60	0.70	0.82	1.03

Wide Distribution

	300 lux horizontal	500 lux horizontal
Output	3600 lm	3600 lm
Power	37 W	37 W
Spacing	10' × 10'	8' × 8'
LPD	0.35 W/ft² (3.77 W/m²)	0.51 W/ft² (5.49 W/m²)

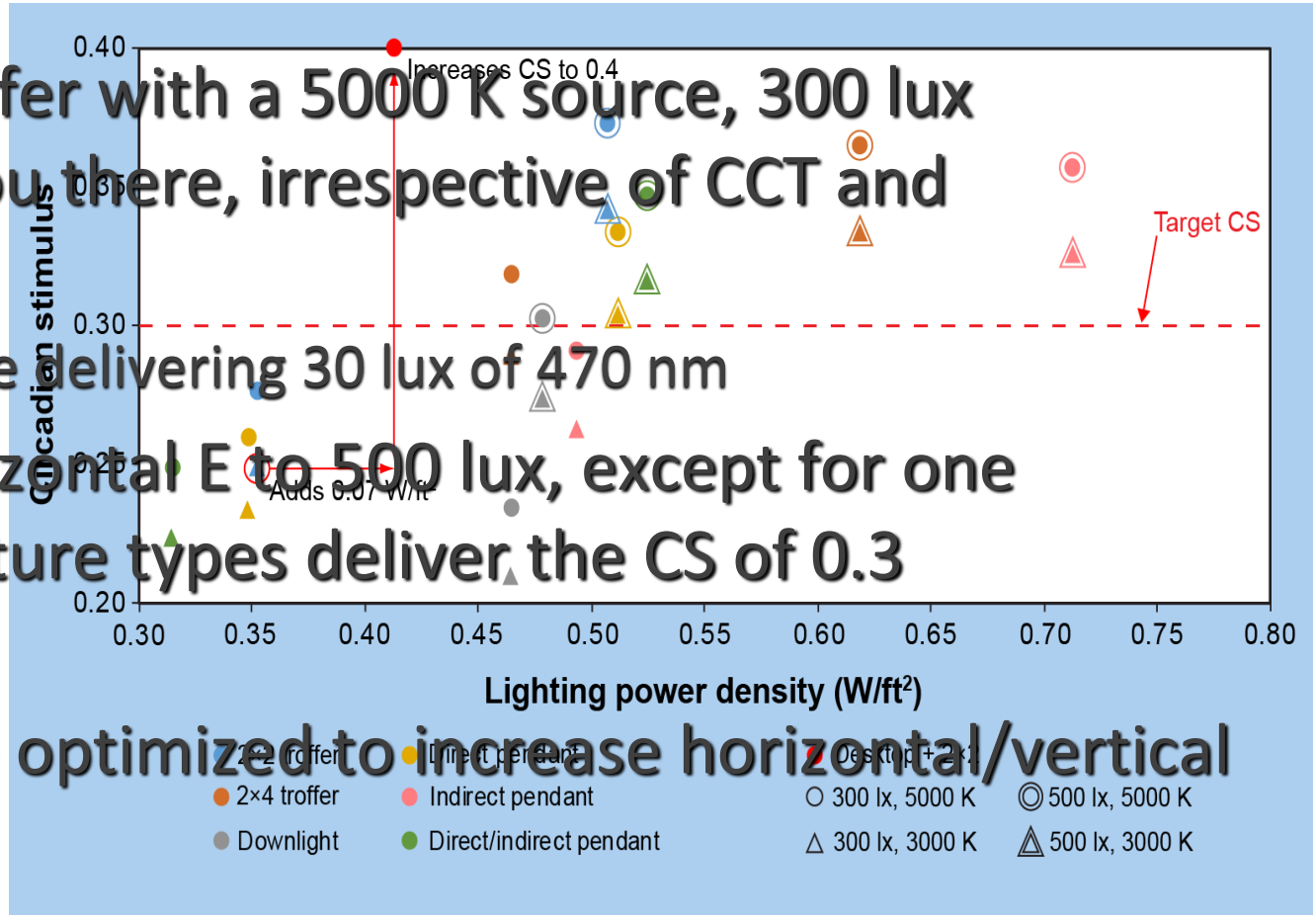
$E_V/E_H = 0.72$

300 lux horizontal

CCT	2700 K	3000 K	3500 K	4000 K	5000 K	6500 K
E_H	275	295	295	306	322	334
E_V	204	217	222	228	239	248
CL_A	166	218	110	172	253	369
CS	[illegible]	0.26	0.15	0.2[illegible]	0.29	0.36
CS/LPD	0.60	0.76	0.46	0.6[illegible]	0.81	1.01
Melanopsin	10	13	16	19	24	31
Rod	16	19	22	25	29	36
S-Cone	[illegible]	6	9	[illegible]	15	19
M-Cone	27	[illegible]	31	33	37	40
L-Cone	35	37	38	39	40	42
EML	87	112	133	160	196	255
M/P	0.43	0.52	0.60	0.70	0.82	1.03

500 lux horizontal

CCT	2700 K	3000 K	3500 K	4000 K	5000 K	6500 K
E_H	48[illegible]	519	530	5[illegible]5	571	592
E_V	3[illegible]5	3[illegible]6	3[illegible]3	3[illegible]4	3[illegible]2	4[illegible]
CL_A	273	357	182	285	420	612
CS	**0.30**	**0.35**	0.23	**0.31**	**0.38**	**0.45**
CS/LPD	0.59	0.69	0.45	0.61	0.75	0.89
Melanopsin	17	22	26	32	39	50
Rod	26	31	35	41	48	59
S-Cone	6	10	14	19	25	30
M-Cone	43	48	51	55	60	66
L-Cone	57	61	62	63	66	69
EML	143	183	218	263	321	418
M/P	0.43	0.52	0.60	0.70	0.82	1.03

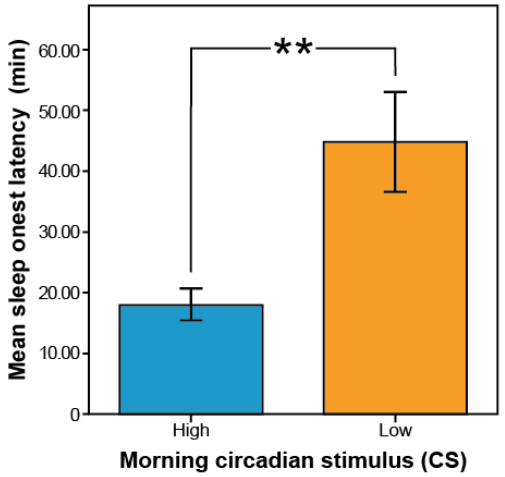


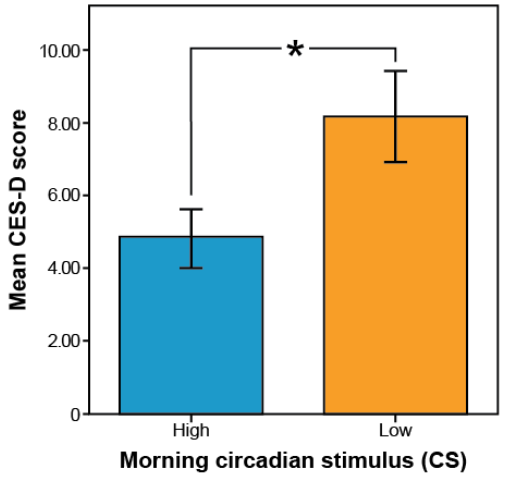
Sponsors: Natural Resources Canada, LRC Light and Health Alliance , LRC Lighting Energy Alliance

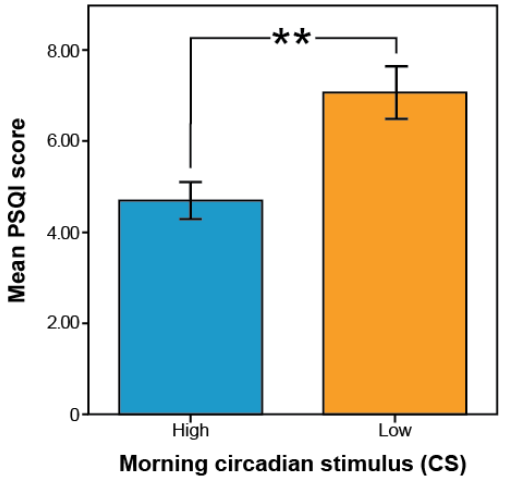
Jarboe et al., 2019

Circadian Entrainment in Office Workers

Those exposed to higher (CS > 0.3) morning (08:00 a.m. to noon) CS 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)







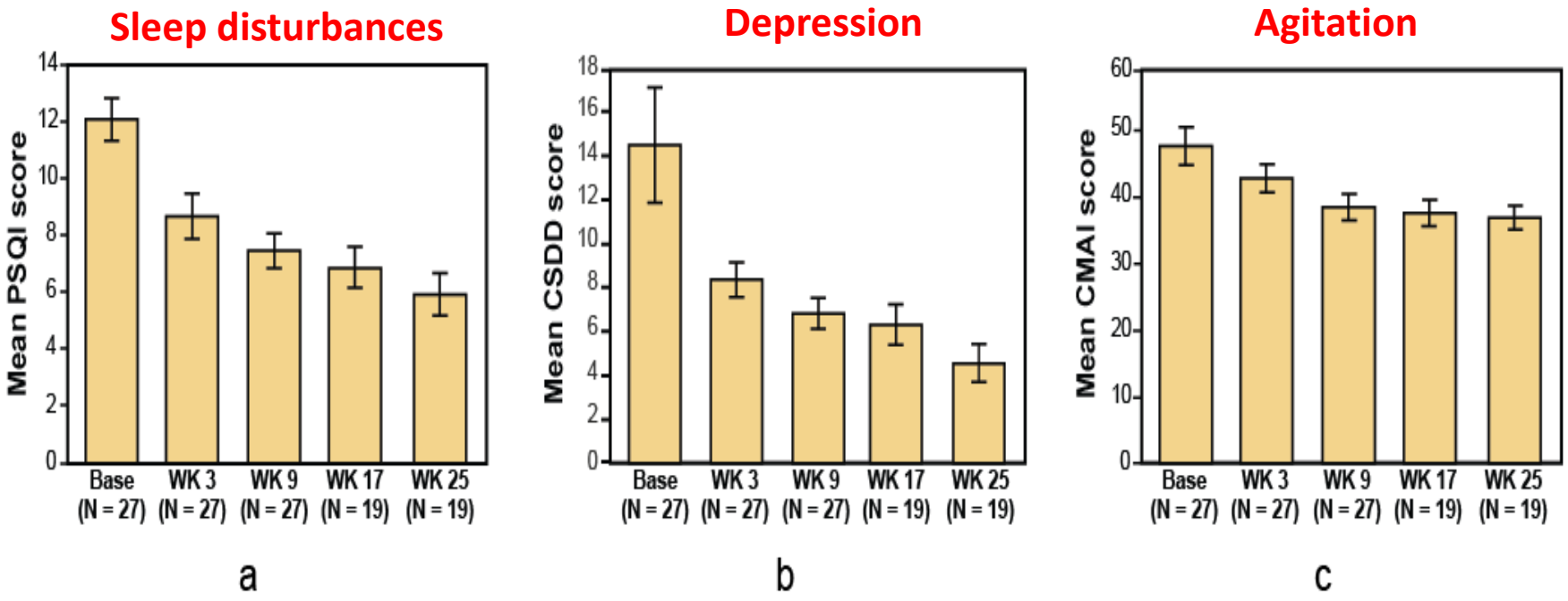
Figueiro M.G., Steverson B., Heerwagen J., Kampschroer K., Hunter C.M., Gonzales K., Rea, M.S. (2017). The impact of daytime light exposures on sleep and mood in office workers. *Sleep Health*, 3(3):204-215.

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

Sponsor: U.S. General Services Administration

Circadian entrainment in persons with dementia

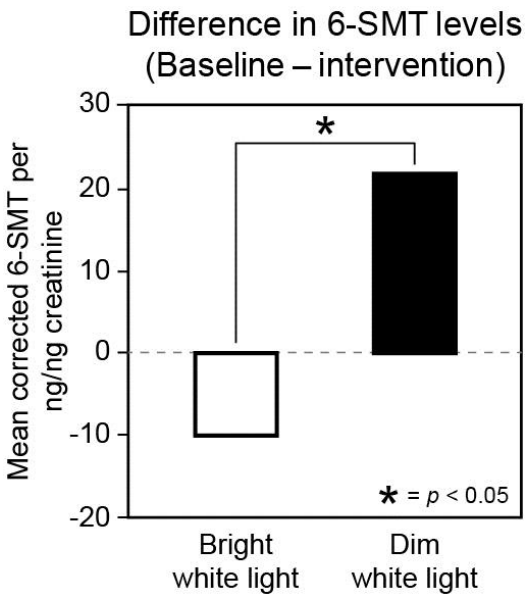
CS > 0.3 all day (waking till 6 pm) reduced sleep disturbances, depression and agitation in dementia patients over the course of 6 months



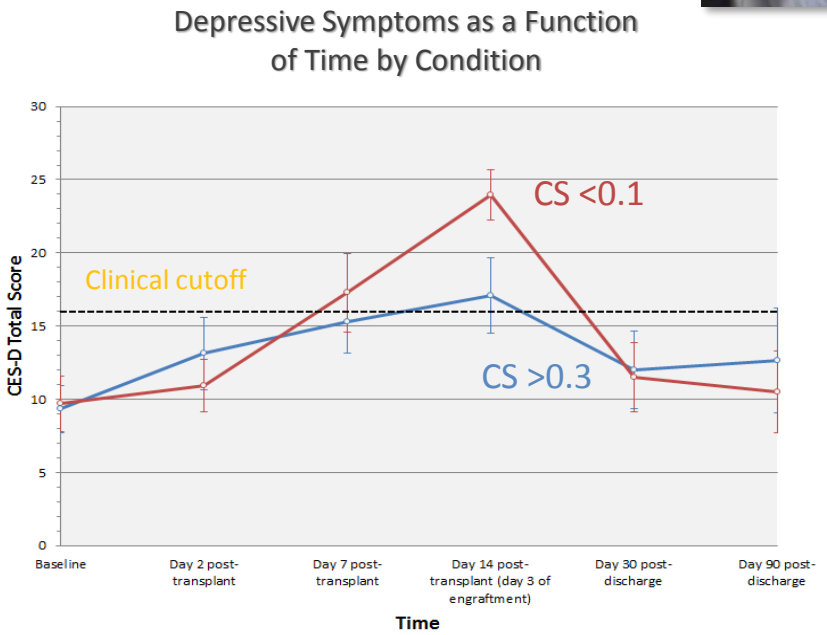
Sponsor: National Institute on Aging (R01AG034157)

Circadian Entrainment in Myeloma Transplant Patients

- In collaboration with Dr. William Redd (Icahn School of Medicine at Mt. Sinai, NYC), we are investigating the impact of a CS of 0.3 (1000 lux at pillow, 3000 K light source) between 7 a.m. and 10 a.m.



A negative number = better outcome because it reflects greater melatonin levels with intervention

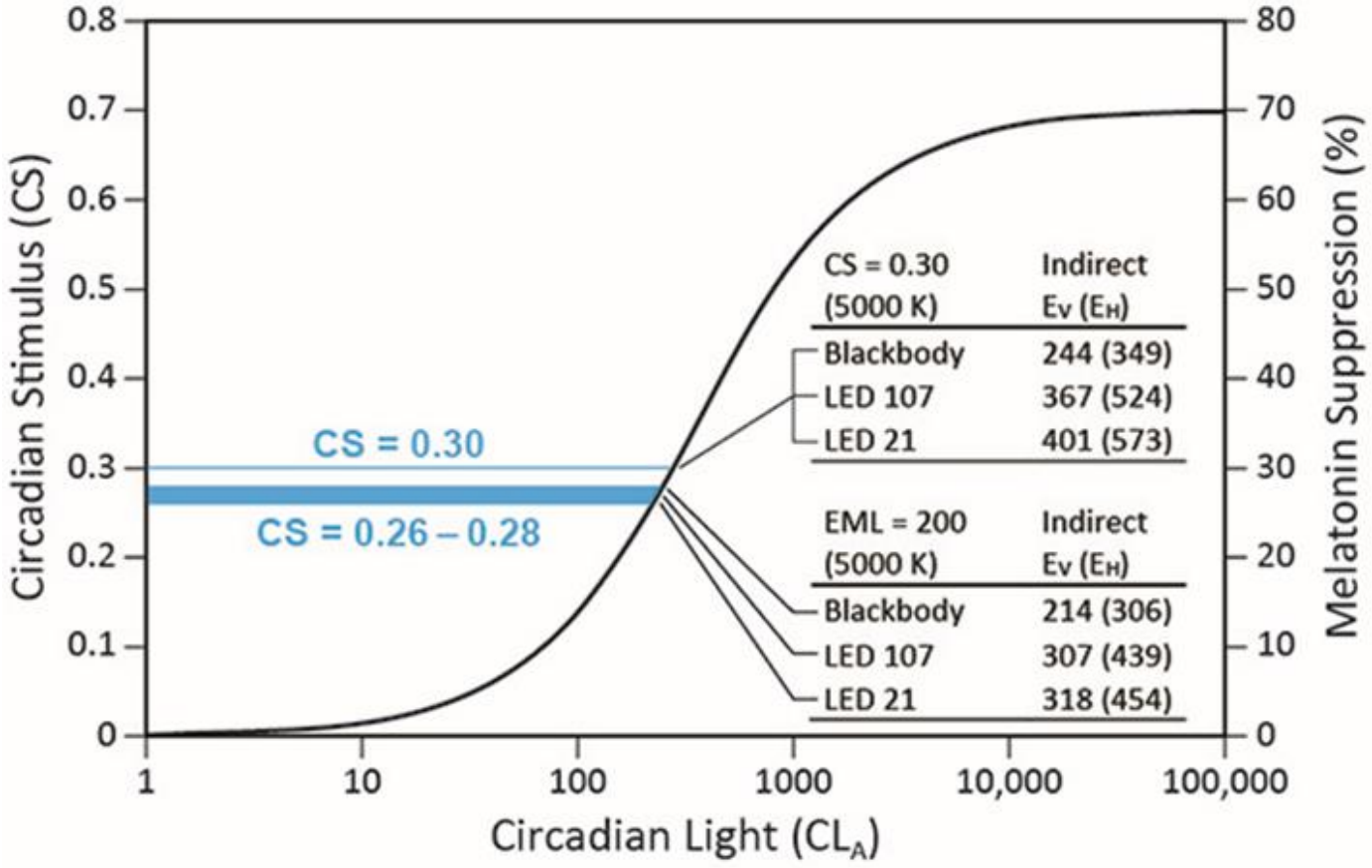


Sponsor: National Cancer Institute and Acuity Brands

UL Recommended Practice

Goal: Promote circadian entrainment in day active people

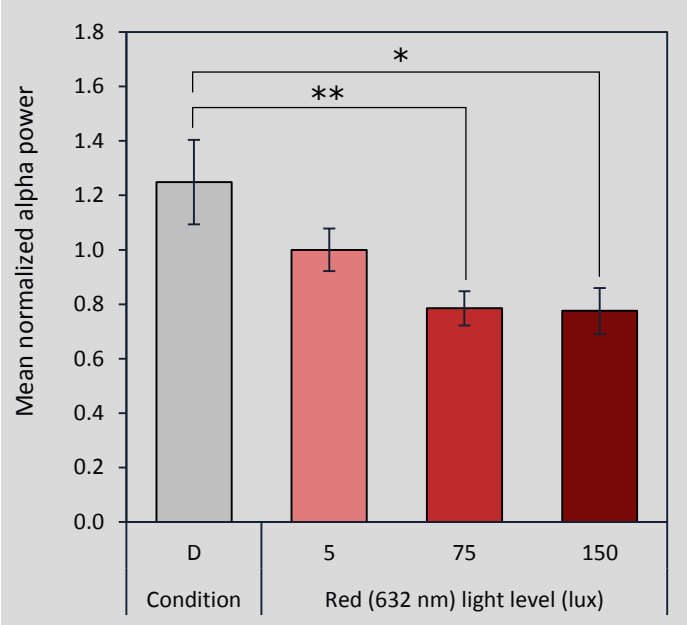
A general method: Specifying E_V and SPD will provide an estimate of CS

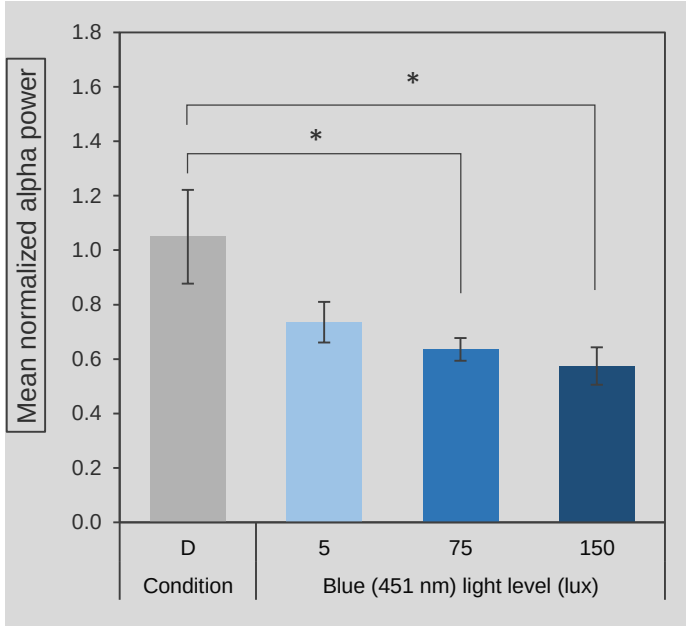


Direct (acute) effects of light

Less sleepy ↓ ▪ Alpha

- Light can also have a direct (acute effect) on people
  - Suppress melatonin
  - Increase morning cortisol levels
  - Increase brain activities
  - Reduce subjective sleepiness





Less sleepy

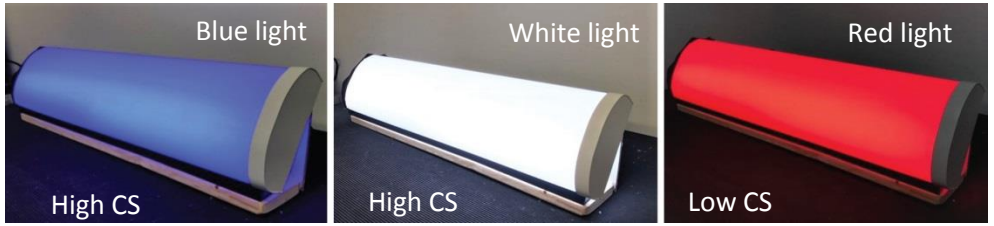
BUT, IT DOESN'T HAVE TO BE BLUE LIGHT!

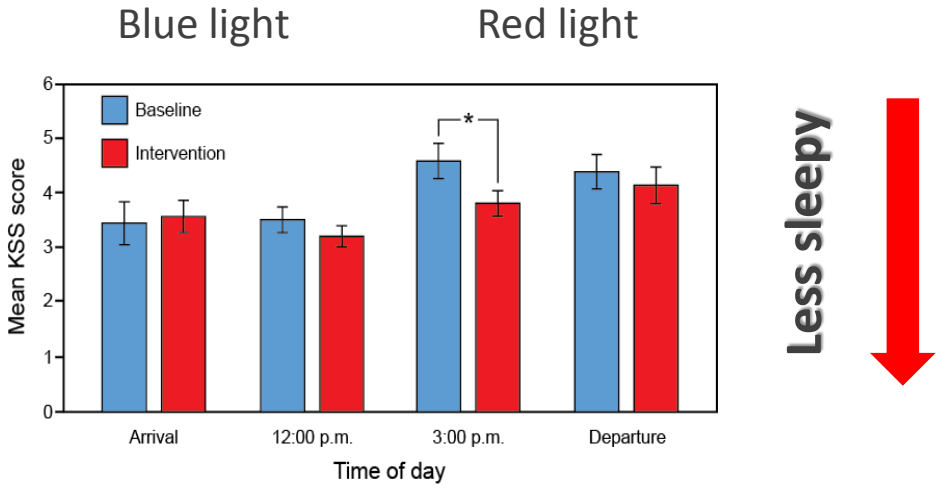
Sponsor: General Services Administration

Lighting and alertness
Daytime effects - Field study

- Field study (n=20) showed that red light during post-lunch dip reduces subjective sleepiness

Time of Day	Lighting Intervention	λ_{max} (nm)	E_V (lux)	CS
6:00 a.m. to 12:00 p.m.	blue	455	50	0.40
12:00–1:30 p.m.	white (6500 K)	n/a	200	0.30
1:30–5:00 p.m.	red	634	50	0





Not just about blue light!

Key Points

- Amount, timing, duration, and distribution must be included in any design
  - Spectrum is important, but not the whole story
  - "Human centric" lighting is not just about dynamic lighting systems
  - Think distribution! Think layers of light!
- Use the right metric!
  - We don't know it all, but we are seeing positive results of CS in the field
    - Field studies are showing promising results when CS=0.3 during the day and CS=0.1 in the evening is used
- It is not just about blue light (or blue-enriched light)
  - Long-wavelength (red, 630 nm) does not suppress melatonin but elicits an alerting response in humans (Plitnick et al., 2010; Sahin and Figueiro, 2013; Sahin et al., 2014; Figueiro et al., 2016)

Thank you!

www.lrc.rpi.edu

Email: figuem@rpi.edu

Acknowledgements: National Institute on Aging, National Cancer Institute, Office of Naval Research, McClung Foundation,

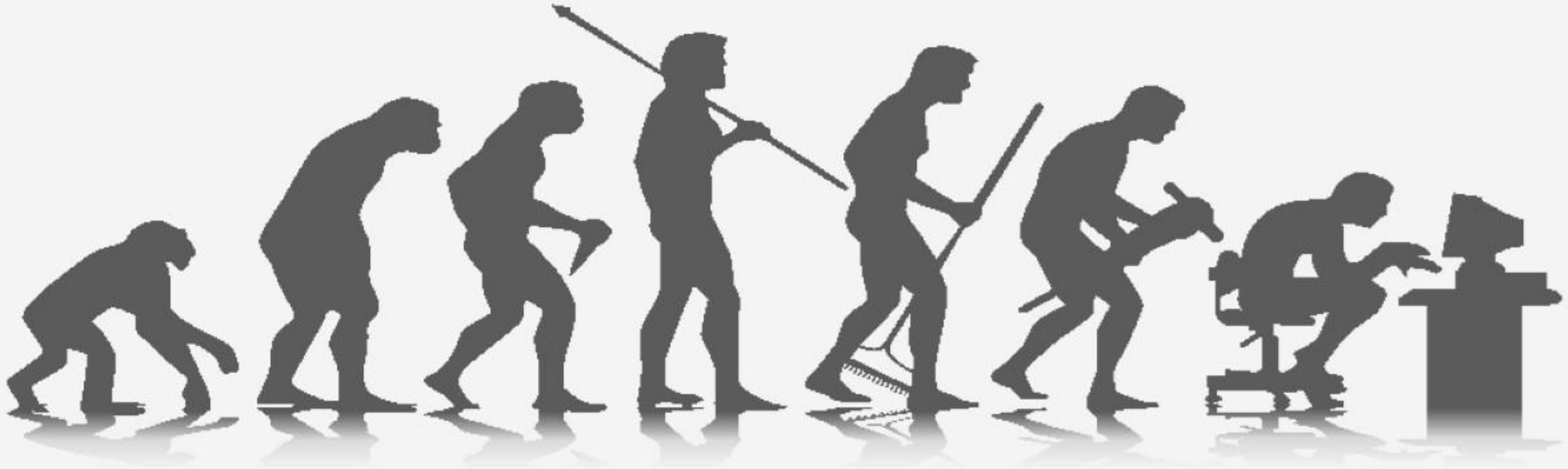
2019 DLC STAKEHOLDER MEETING

April 1 - 3 • St. Louis, MO

BUILDING FOR HEALTH

Nice to meet you…

Gayathri Unnikrishnan
Standard Development
International WELL Building Institute



OUR ENVIRONMENT IS CHANGING ALONG WITH OUR LIFESTYLE...

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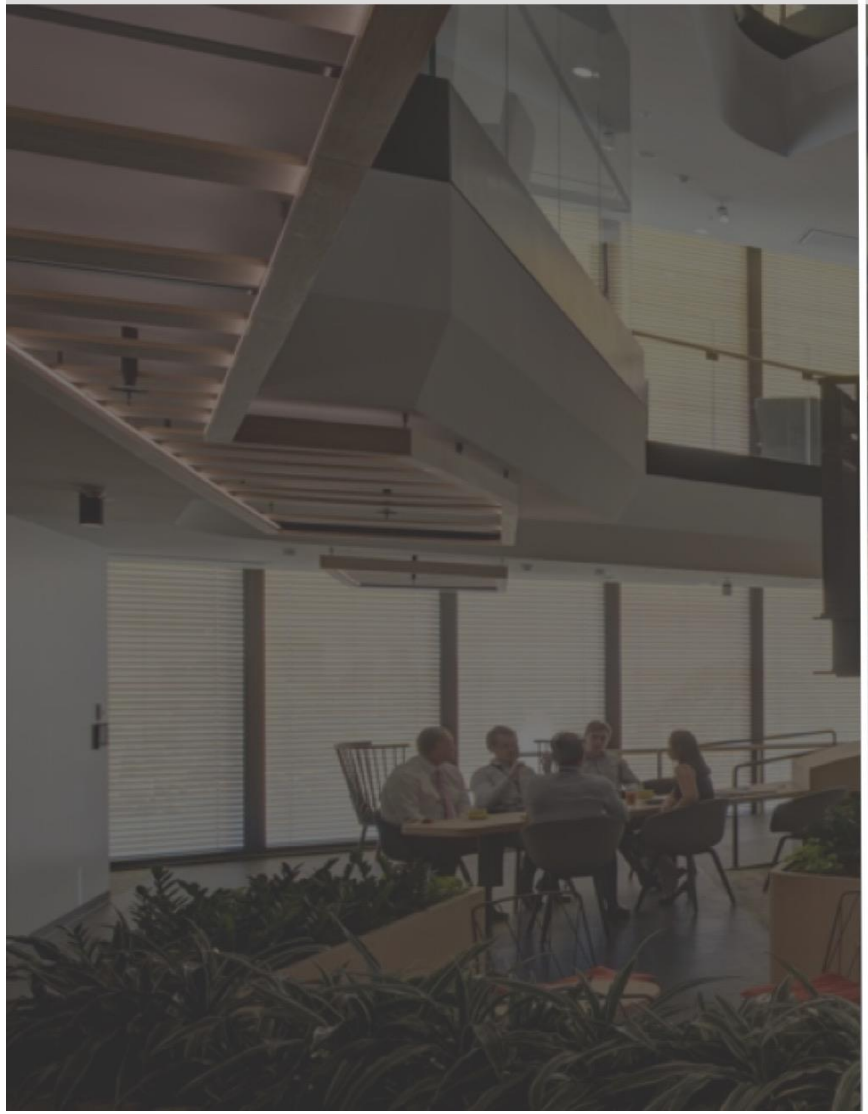
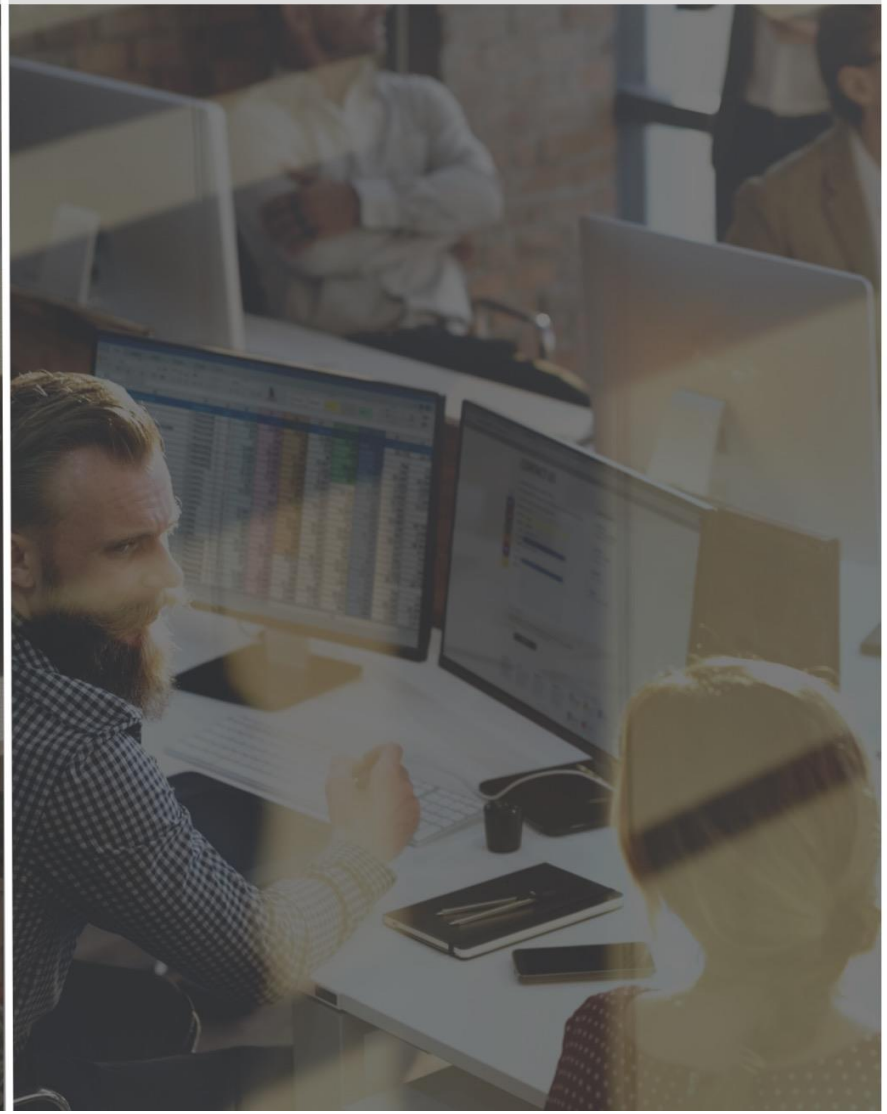
IMPROVING PERFORMANCE FOR

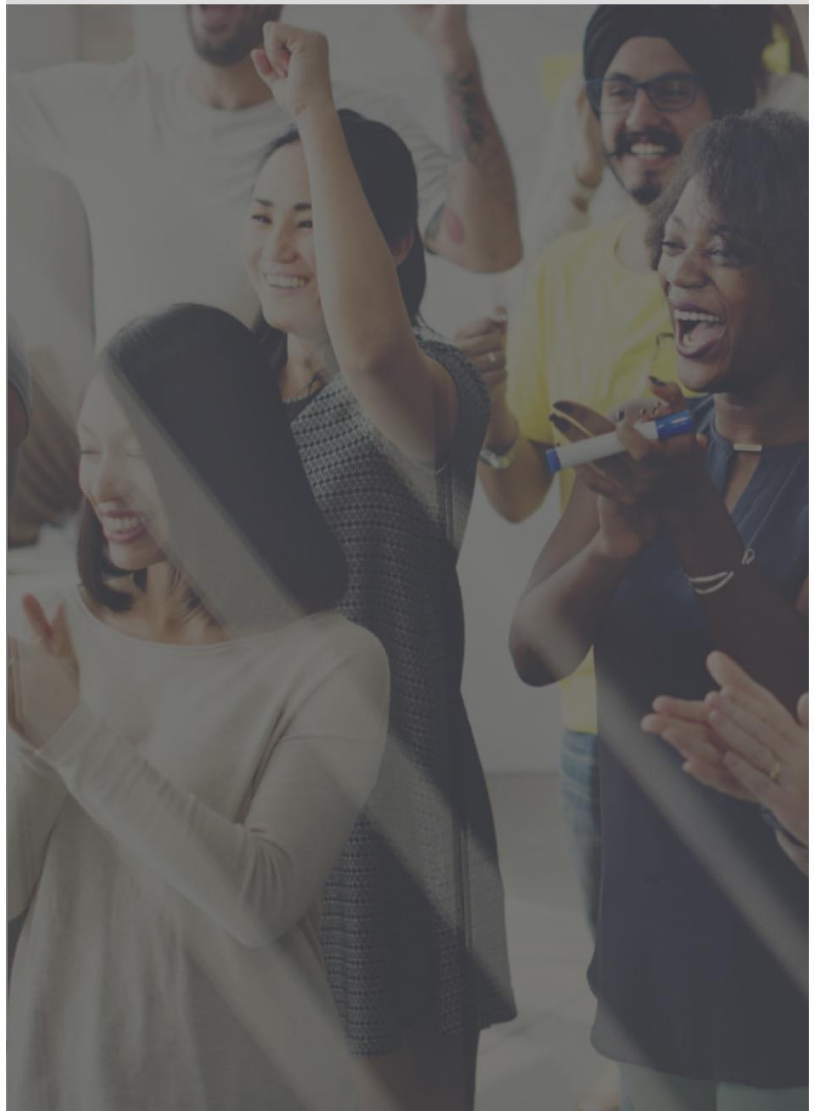
BUILDINGS

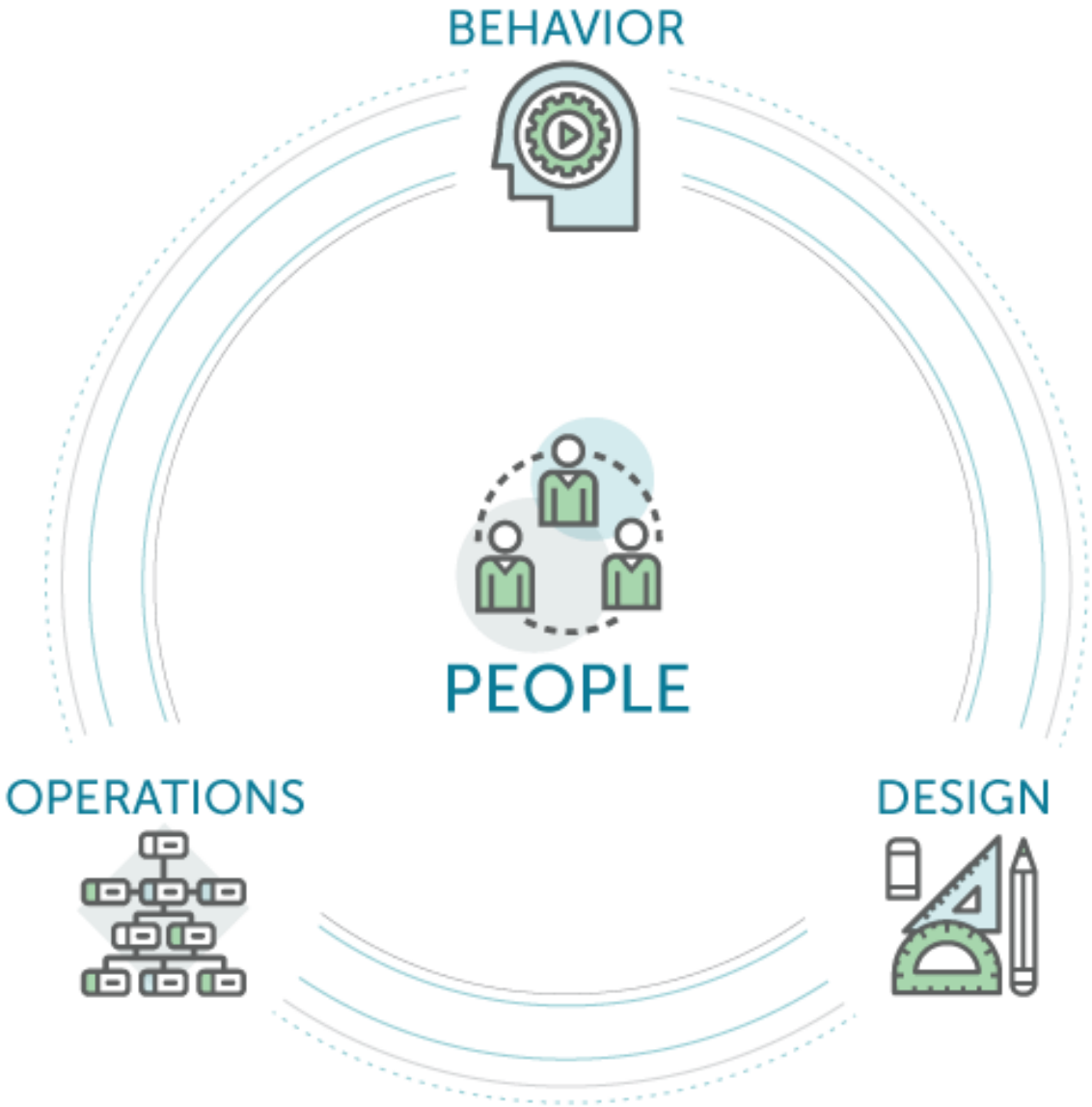


PEOPLE



BUSINESSES




BEHAVIOR
PEOPLE
OPERATIONS
DESIGN

SECOND WAVE OF

PEOPLE + PLANET

SUSTAINABILITY

THE GLOBAL WELL MOVEMENT

SINCE 2014 LAUNCH

1,603

WELL PROJECTS

345 MILLION

SQUARE FEET

50

COUNTRIES

33

U.S. STATES

AND TERRITORIES

4,290

WELL AP'S

81

COUNTRIES

569 projects in US

LEADING MARKETS

BY NUMBER OF PROJECTS

Countries	**(1) United States** (2) China (3) United Kingdom (4) Australia (5) France
U.S. Cities	**(1) Los Angeles** (2) New York (3) San Francisco (4) Chicago (5) Boston
U.S. States	**(1) California** (2) Pennsylvania (3) New York (4) Texas (5) Georgia, Masachussets

WELL IS FOR LEADERS

Real Estate
Charter Hall
Grosvenor
CBRE
Cushman & Wakefield
Ivanhoe Cambridge
Lendlease
Sino Ocean Land
Boston Properties
Colliers
IDI Gazeley
Cadillac Fairview
Hines
JLL
Oxford Properties
SL Green

Professional Services
Deloitte
Dubai Holding
Ernst & Young

Finance
AEW Capital Management
Barclays
TD Bank
Manulife
Citibank
Wells Fargo

Technology
Microsoft
Fandango
Lenovo
Symantec
Verizon
Stryker

Healthcare
Merck
Cleveland Clinic
China Life Health Management
23andMe
McKesson

Design & Construction
HKS
Structuretone
WSP Parsons Brinckerhoff
Arup
Cundall
EMSI
Perkins + Will
Glumac
AECOM
ASID
DLR Group
Gensler
HOK
Skanska

Retail
Mohawk
Milliken
Shaw
Teknion
Unilever

ASID

PROJECT BASICS

INTERNATIONAL WELL BUILDING INSTITUTE™

WELL PLATINUM 2017

WASHINGTON D.C., USA

8,500 SQ FT

NEW & EXISTING INTERIORS

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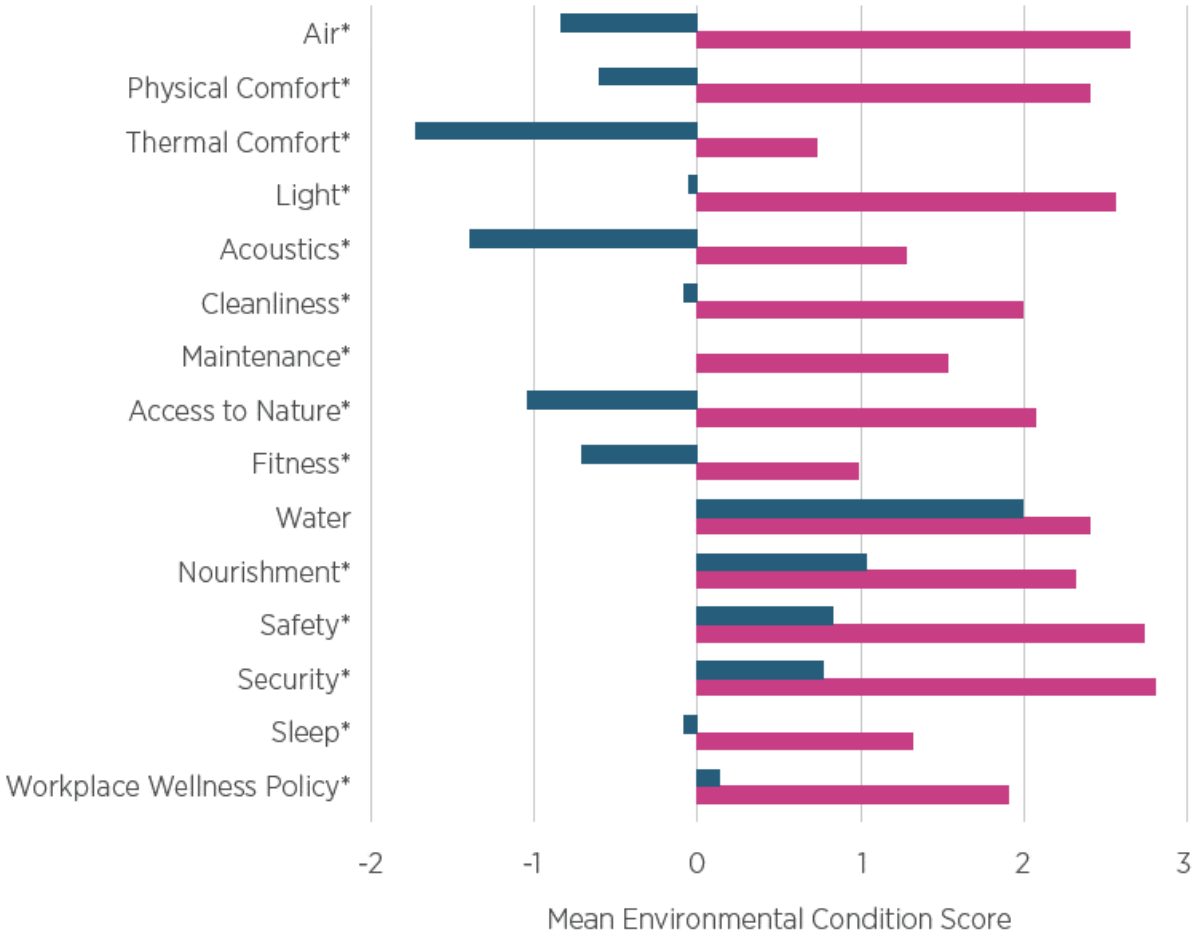
SURVEY RESULTS

AMERICAN SOCIETY OF INTERIOR DESIGNERS

PRE- AND POST-OCCUPANCY



Pre-certification

Post-certification

*Indicates a statistically significant difference (p<.05) between the pre-certification space and the post-certification space.

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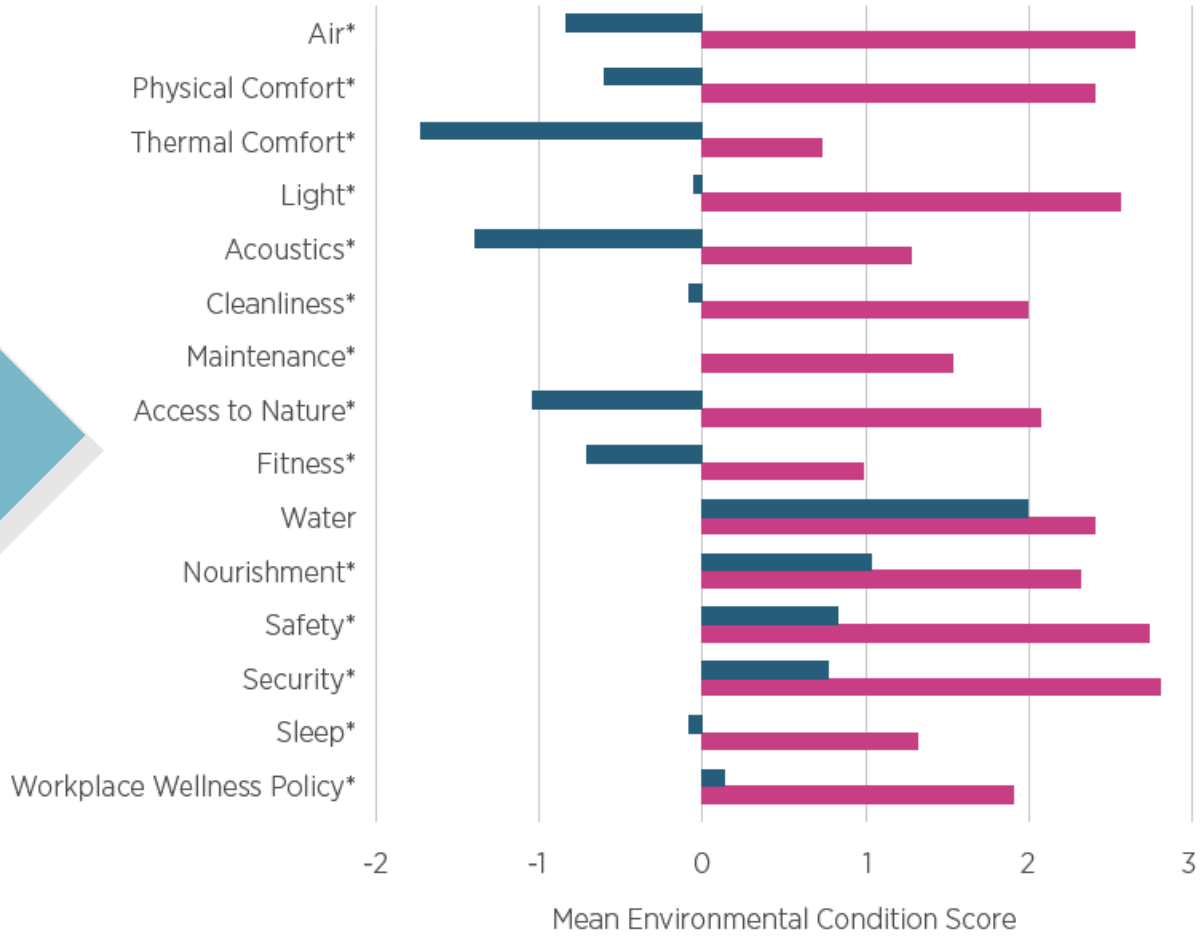
Source: American Society of Interior Designers. Design Impact Lives: ASID HQ Office Research, Pre-/Post-Occupancy Analysis. 2017.

AMERICAN SOCIETY OF INTERIOR DESIGNERS

SURVEY RESULTS

PRE- AND POST-OCCUPANCY

Significantly higher mean environmental condition scores for 14/15 variables measured in the post-certification report.



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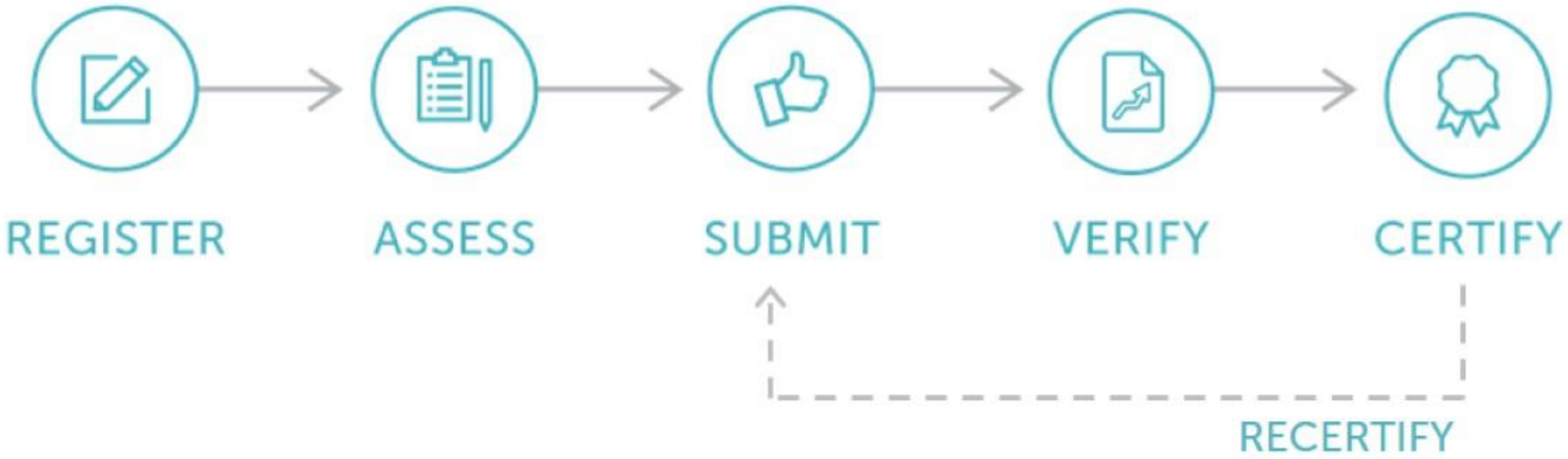
Source: American Society of Interior Designers. Design Impact Lives: ASID HQ Office Research, Pre-/Post-Occupancy Analysis. 2017.

WELL CERTIFICATION PROCESS



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DYNAMIC SCORECARD

- Leverage the WELL v2 digital platform to create a custom scorecard.
- Enter your project details and browse a selection of suggested features tailored to help you achieve your project's unique goals.

LIGHT: THE ISSUE

Disruption to the body's circadian rhythm are associated with chronic diseases including obesity, diabetes, and depression.[1]

1. National Institute of General Medical Sciences. Circadian Rhythms Fact Sheet. 2012; https://www.nigms.nih.gov/Education/Pages/Factsheet_CircadianRhythms.aspx.

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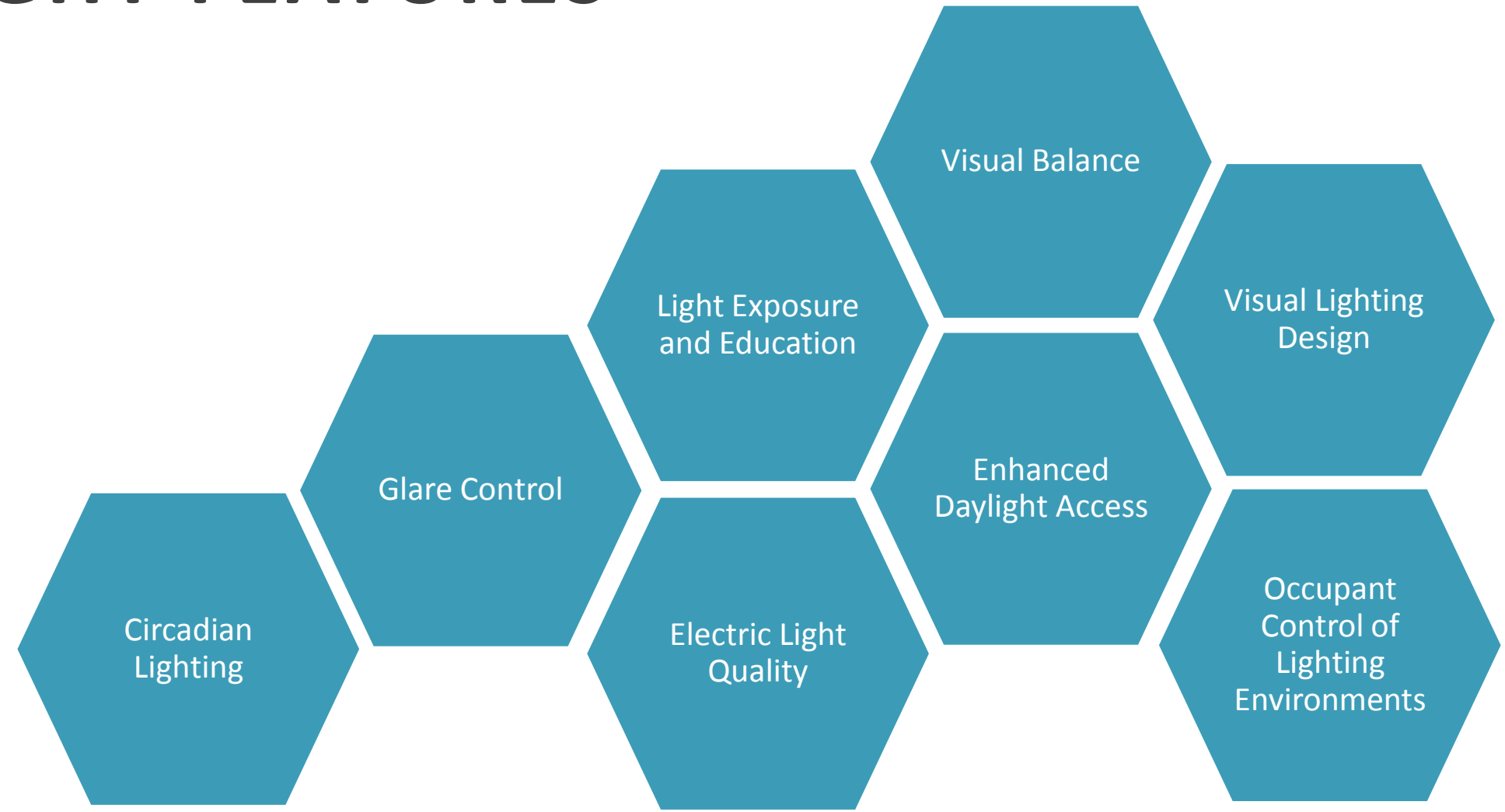
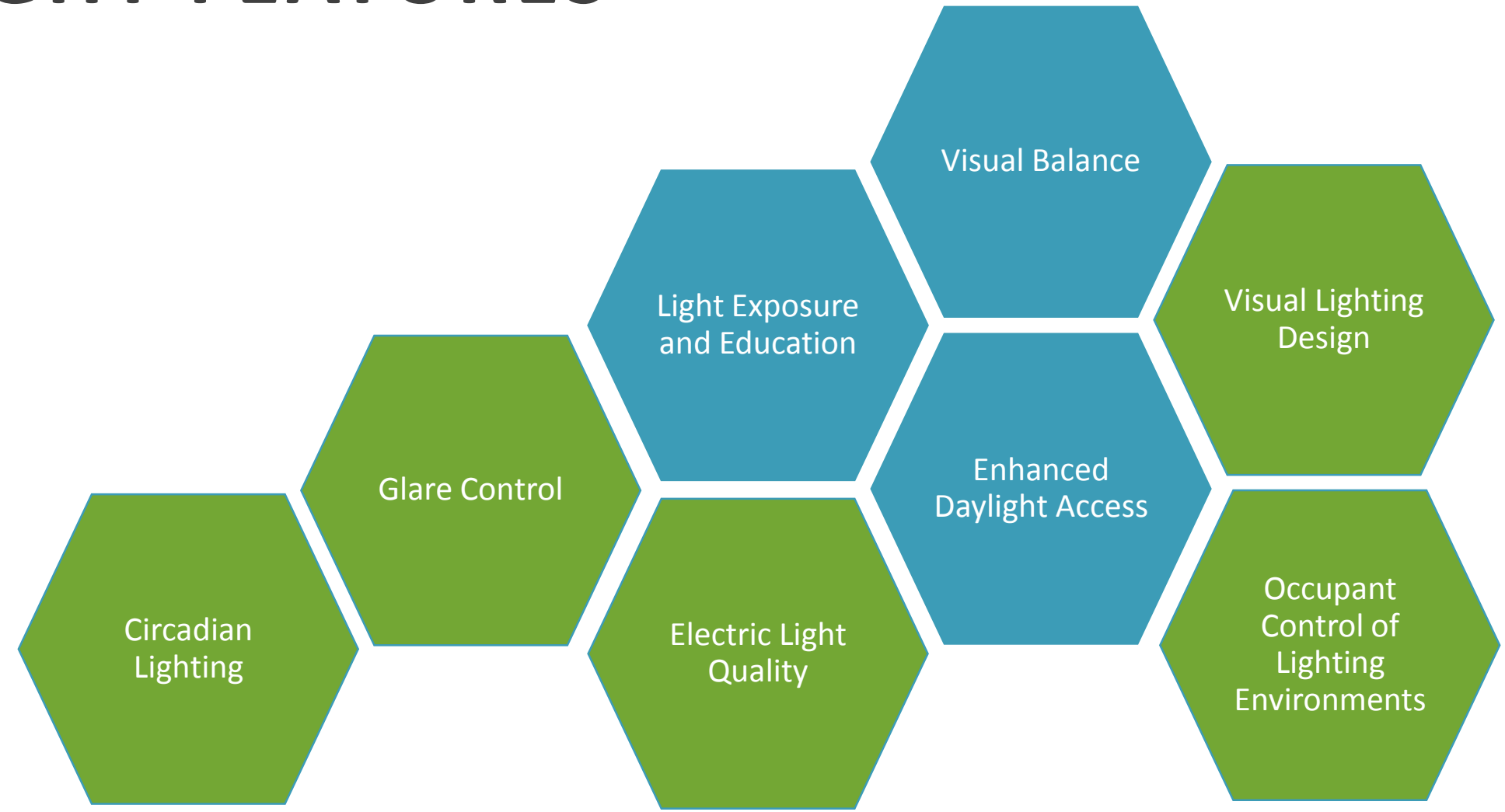
LIGHT FEATURES



LIGHT FEATURES



WE ARE WELL

WELLCERTIFIED.COM

INTERNATIONAL WELL BUILDING INSTITUTE™

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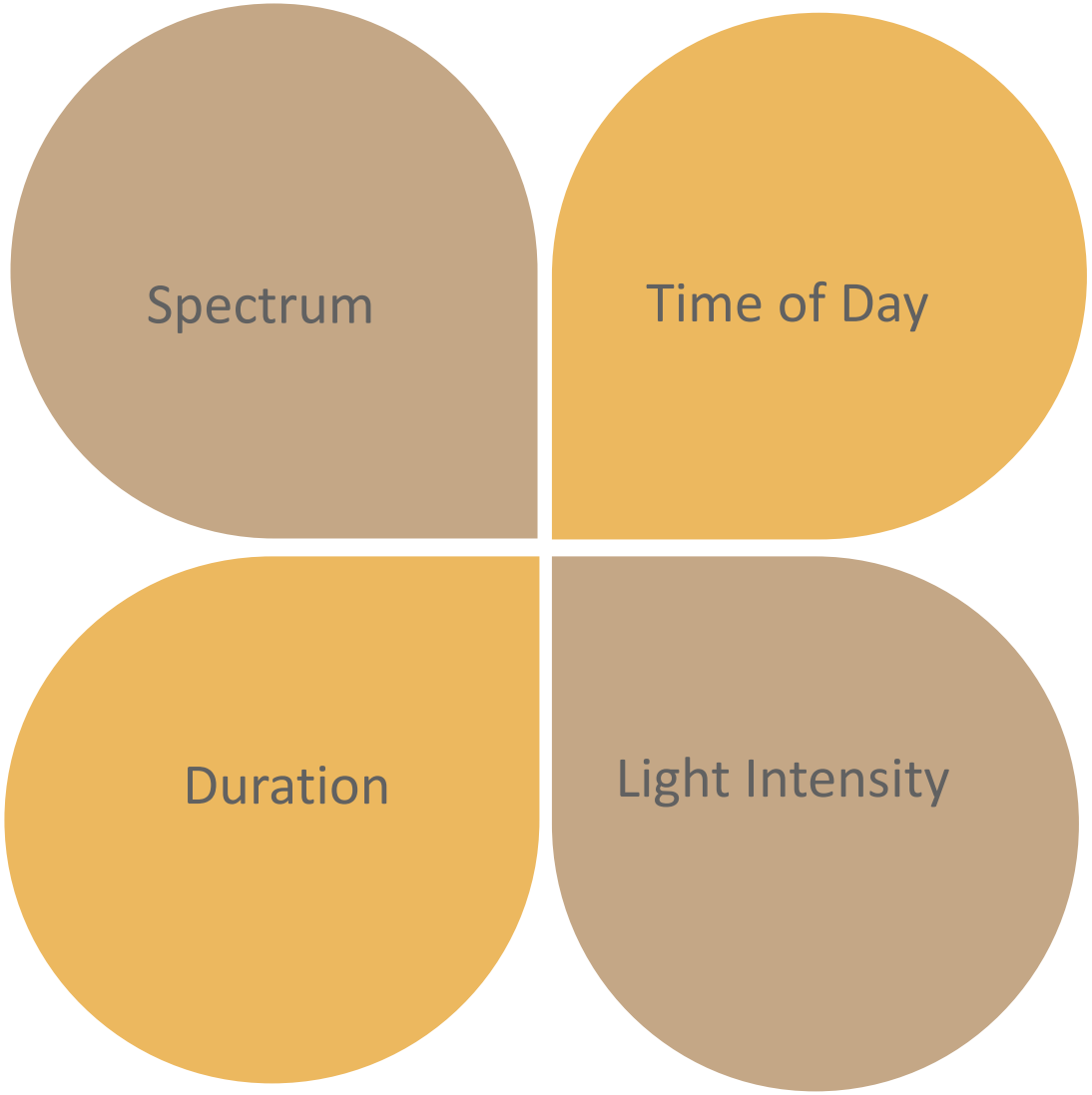
Spectrum

Excel Files

On site measurements



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Light, Health and Energy

Design Implementation Experience

James R Benya, PE, FIES, FIALD

BENYA BURNETT CONSULTANCY

DLC Advisory Council Member

Question #1: Does this Health and Light stuff really work?

- For what building types?
- For what situation?
- For what population?
- How well does it work?
- How can it be measured?
- What are the risks?
- What are the benefits?

Question #2: Are there standards to follow, and who developed them?

LEED is the dominant sustainability standard, developed by USGBC. Green Globes is also prominent. ASHRAE/IES/USGBC 189.1 is a normative standard intended for code use. The Living Building Challenge, NZEB, and PassiveHouse are alternative programs. Similar programs exist internationally such as BREEAM and CASBEE.

Two current wellness building standards in the US are:

- WELL
- Fitwel

Their standards were developed by

- Delos Wellness
- The Center for Active Design

Question #3 – Are these standards certified under ANSI or CIE?

Like LEED, these standards are based on many principles of illuminating engineering published by IES, but IES was not directly involved with the standards.

GBCI credentials are ANSI recognized, but LEED standards are not ANSI certified.

WELL and FitWel Standards are not ANSI certified.

CIE committees are still working on standards.

Question #4: Can WELL/Fitwel Coexist with LEED and/or the Energy Code?

Conflict

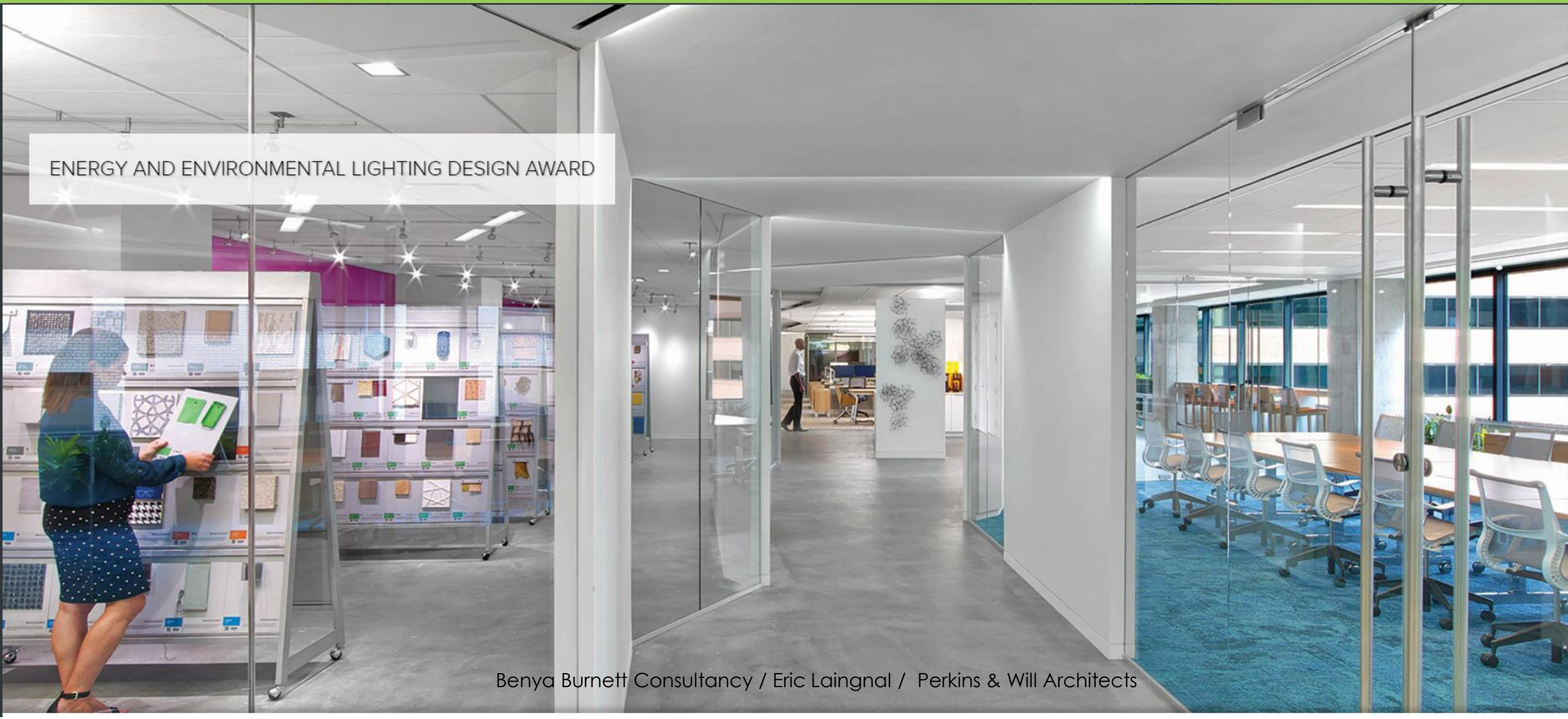
- High light levels ≠ energy efficient
- High CRI/high R9 lighting less energy efficient than ordinary
- Daylight and view = solar heat gain
- Fenestration = winter heat loss, possible impact on light quality
- May require automatic lighting controls that may not directly coincide with energy code controls

Converge

- Glare-free daylight is good
- Light spectral qualities reinforce diurnal workplaces

Question #5: How To Design a Project?

- Set priorities: code, sustainability, wellness
- Set a realistic budget
- Set realistic expectations
- Daylight is the critical component – opportunities diminish without it
- Controls play an enormous role – NLC will probably be needed
- Color tuning – maybe yes, maybe no
- Be prepared for issues with reviews by the standards-setting groups



ASID Headquarters, Washington - IESNA Award of Excellence 2018 – World's First and Only LEED Platinum/WELL Platinum Project

Final Question: A Role for DLC?

- Stay on top of the color tuning issue; support innovation
  - CCT tuning
  - Part-spectral tuning
  - Questions of intensity, direction need to be considered
- Ensure NLC standards support the alternative technologies
- Consider listing automatic daylighting controls?

Panel Discussion

Panel Question:

How does
lighting for wellness
relate to
energy usage?

Is more light, and therefore more energy needed to support wellness?

Panel Question:

What role does **fixture distribution** play in increasing vertical illuminance?

Panel Question:

How quick is this growing, and in what **market segments**?

Are there any industry practices that **threaten the growth** of this area?

Panel Question:

What role do **controls** play?
How can they help
offset the energy use?

What needs to be controlled
and why:

- **Intensity?**
- **Spectrum?**
- **Distribution**?

Panel Question:

What **tools and resources** are available to predict non-visual impacts of lighting in a project? Is that information accessible?

CS Calculator

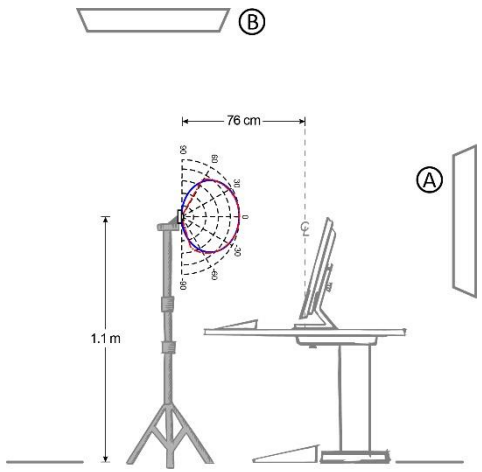
http://www.lrc.rpi.edu/cscalculator/

CS calculator

- SPD of the light source
- Average photopic light level at the eye (vertical illuminance)
  - Use computer simulation (e.g., AGI) to estimate the impact of reflectances, furniture, shadows)
- Plug in the values in the calculator
- Note: Not the actual installation
- Strongly urge designers to check light levels after construction

Instruments and tools

- Spectroradiometers (large and small, expensive and not so expensive)
- Light meters (place them at eye level)
- Request SPD from manufacturers

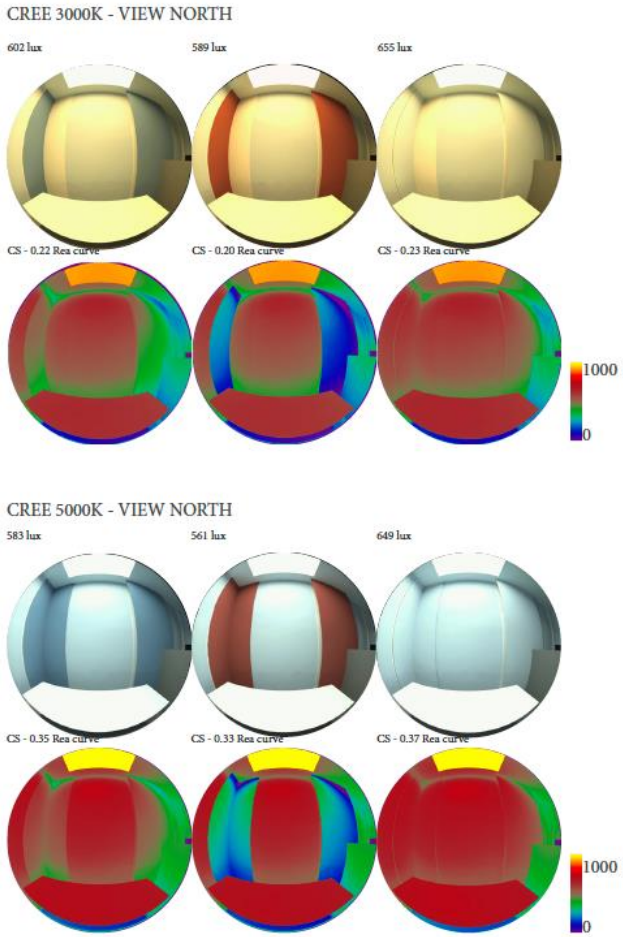


LARK

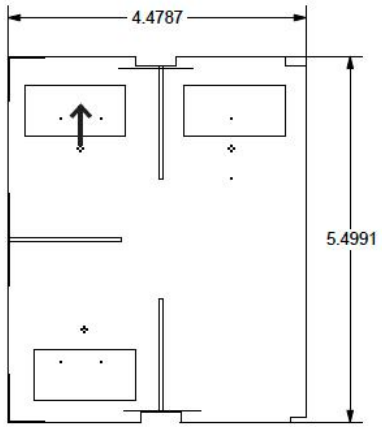
LARK
SPECTRAL LIGHTING

http://faculty.washington.edu/inanici/Lark/Lark_home_page.html

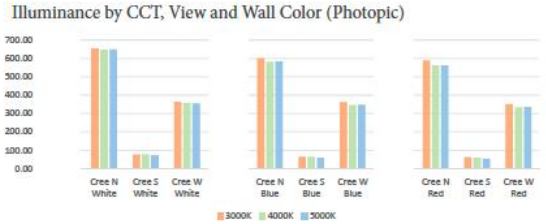
https://www.food4rhino.com/app/lark-spectral-lighting

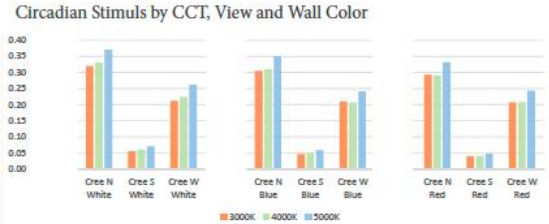


(top sets) Tone Mapped (Rendered) Images based upon the photopic response curve. (bottom sets) False color images based upon the Circadian Stimulus (CS) action spectra.



Simulation results show consistent photopic illuminance based on CCT with modest differences based on wall reflectance levels. North viewing angles receive the highest illuminance with the luminaire in the field of view. Circadian stimulus (CS) results are similar between 3000K & 4000K. However, there is a consistent increase in CS with 5000K sources. White walls reflect the most light and therefore show the highest CS values. There is a modest increase in CS between blue walls and red walls. The impact of wall color increases as the occupant's view of the source decreases within the field of view and interior surfaces become dominate luminous sources.





Comparison of simulation outputs by CCT and view

Circadian Stimulus Prediction from Simulation

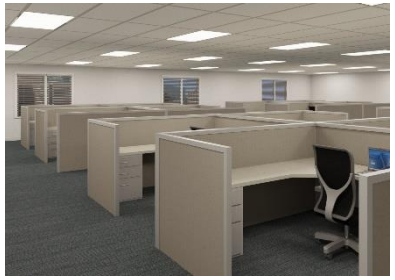
ZGF

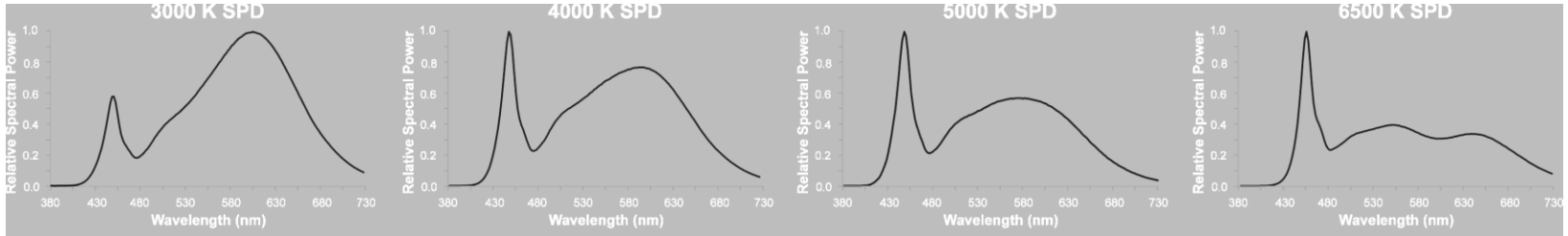
Lighting Patterns Website

http://lightingpatternsforhealthybuildings.org/

Select your CCT to create your schedule and find your target illuminance levels

Time	CS	3000 K			4000 K			5000 K			6500 K		
		E_V (lux)	E_H (lux)	LPD (W/ft²)	E_V (lux)	E_H (lux)	LPD (W/ft²)	E_V (lux)	E_H (lux)	LPD (W/ft²)	E_V (lux)	E_H (lux)	LPD (W/ft²)
7:00 AM - 4:00 PM	0.3	275	483		375	659		265	466		200	351	
4:00 - 5:00 PM	0.3 >> 0.2												
5:00 - 7:00 PM	0.2	175	307	0.52	225	395	0.74	175	307	0.55	125	220	0.43
7:00 - 8:00 PM	0.2 >> 0.1												
8:00 PM - EOB	0.1	75	132		100	176		105	184		50	88	





Please note that calculations are based on average SPDs and distributions. Different spectra and distributions may result in different illuminance and CS values.

Educational Videos

- file:///Users/mariana/Library/Mobile%20Documents/com~apple~CloudDocs/Light%20and%20health%20-%20YouTube.html

Resources

- http://lightingpatternsforhealthybuildings.org/
- http://www.lrc.rpi.edu/cscalculator/
- http://faculty.washington.edu/inanici/Lark/Lark_home_page.html
- https://www.food4rhino.com/app/lark-spectral-lighting
- https://www.youtube.com/playlist?list=PL_X9RKGy9RIZmgzoJwHZsQmpPW6O1fLu3
-

Additional Resources

- https://www.solemma.com/Alfa.html
- https://www.solemma.com/Diva.html
- https://fluxometer.com/
- https://fluxometer.com/rainbow/#!id=BIOS%20Lighting/BIOS%20Puck%204000K

Panel Question:

Challenges for users and industry?

Differentiation of products – **what is needed**?

Thank you all!