Indoor Daylight and Circadian Functioning: Lessons from Field Research

Course Number TH114

Thursday, May 14, 2015

Speakers List

- Mariana G. Figueiro, PhD
  Lighting Research Center
  Rensselaer Polytechnic Institute

- Don Horn, FAIA, LEED Fellow
  Office of Federal High-Performance Green Buildings
  U.S. General Services Administration

- Bryan Steverson
  Office of Federal High-Performance Green Buildings
  U.S. General Services Administration

Course / Learning Objectives

- Participants will understand how daylight influences health through the circadian system and what health benefits could be provided through daylight design that maximizes circadian light exposure.

- Participants will understand how design, building operations, organizational policies, and occupant behavior influence indoor daylight experience.

- Participants will be able to implement new strategies and practices to design for daylight and health.

- Participants will have key lessons learned and communication strategies for talking with potential clients.

Agenda

- **Don Horn**, **GSA**
  - GSA perspective and why GSA is funding health research
- **Mariana Figueiro**, **RPI**
  - Overview of Circadian System and preliminary findings from GSA's daylighting research
- **Bryan Steverson, GSA**
  - What GSA is going to be doing with what it is learning
- **Questions**

GSA Asset Profile

Morse U.S. Courthouse
Eugene, OR

NPS
Omaha, NE

U.S. Census Bureau
Suitland, MD

U.S. Courthouse
Bakersfield, CA

- Portfolio of 8,721 assets housing a workforce of 1.1 million people

- 376.9 million rentable sq ft
  - 183.4 million sq ft – government-owned
  - 193.4 million sq ft – leased

- House 1.1 million federal employees

- Landlord for over 400 different federal agencies, bureaus and commissions

GSA's Health Focus

- Measurement & Metrics
- Vastly Improved Building Performance Monitoring & Control
- Changing the Focus:
  Building Operations → People's Performance
- Rapid Response
- Density Increases Value + Increases Importance of Occupants' Well Being

Circadian Lighting Research

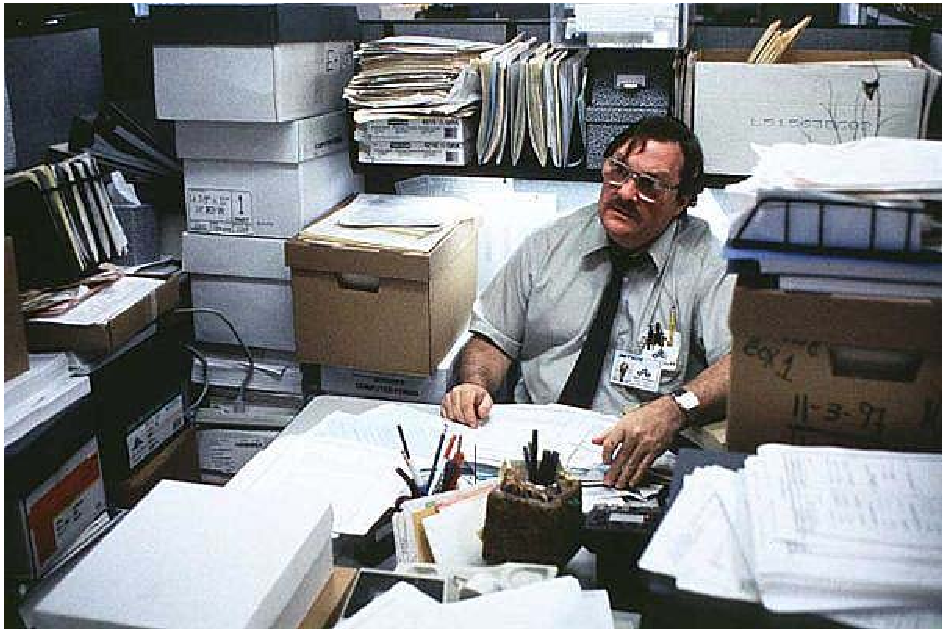
- Indoor Lighting Focus for work purposes
  - Daylight used as aesthetic enhancement and means of reducing electric energy

- Little attention paid to understand light impact on psychological and physiological systems

Purpose of GSA Research: Can daylight be a health benefit related to its importance in stimulating circadian processes

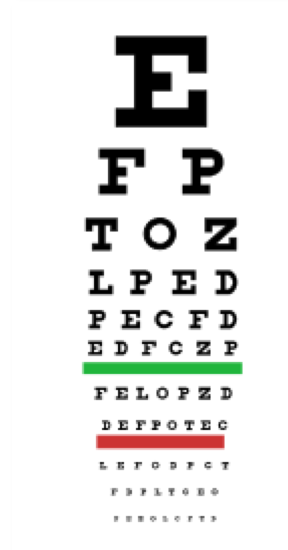
Why Is This Research Important?

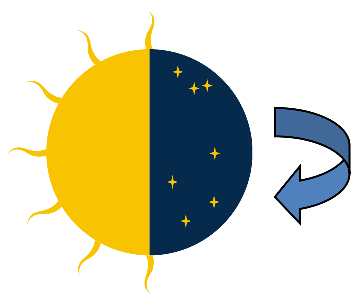
- People spend ~90% of their time Indoors
- Building research concentrated on eliminating risks—not enhancing health
- Science of energy well explored; the science of buildings' ability to improve health is not
- Need to know how to **intentionally** enhance health and well being through building design choices and **get that knowledge into professional practice**



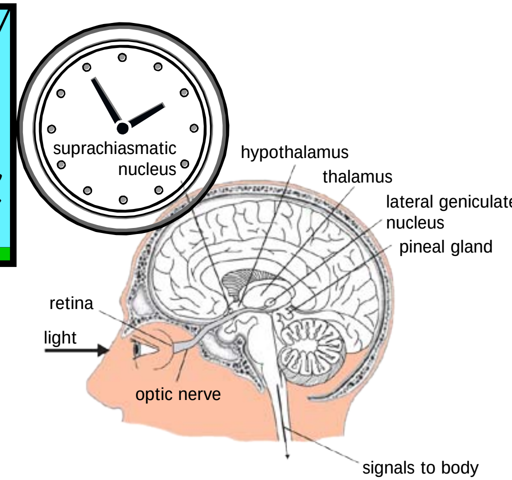
Why is light so important?

- Light reaching the retina can impact
  - Visual system – enables us to see
  - Circadian system – enables us to maintain synchronization with the solar day





The natural 24-hour light-dark cycle



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

Why is light so important?

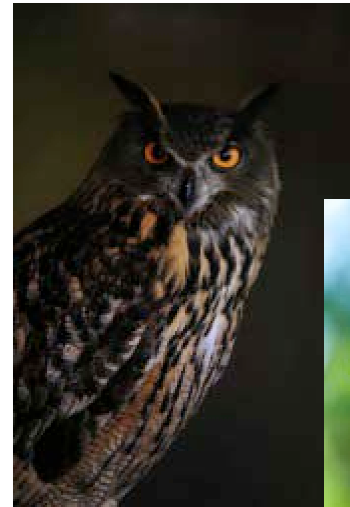
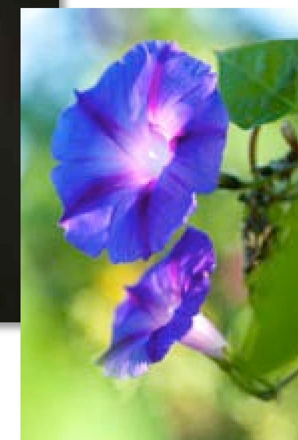
- Light reaching the retina can impact
  - Visual system – enables us to see
  - Circadian system – enables us to maintain synchronization with the solar day
  - Sensory system – conveys information

Circadian system

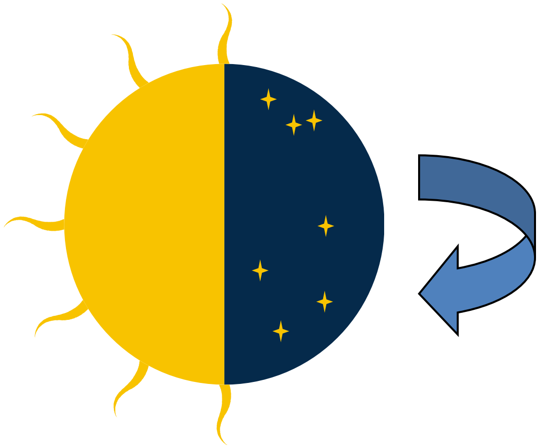
- Plants and animals exhibit patterns of behavioral and physiological changes over an approximately 24-hour cycle that repeat over successive days—these are circadian rhythms

circa = about; dies = day

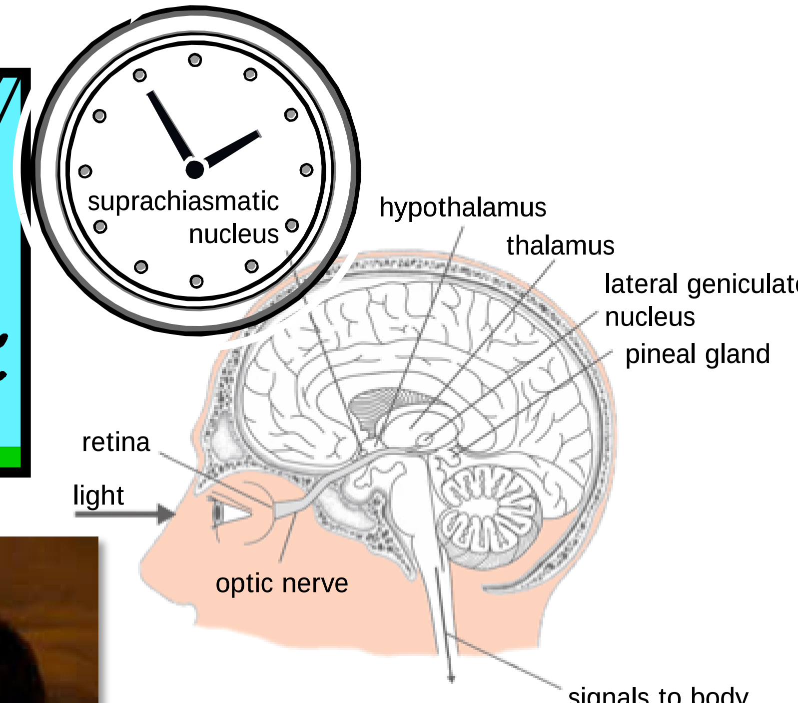
- Circadian rhythms are influenced by exogenous and endogenous rhythms

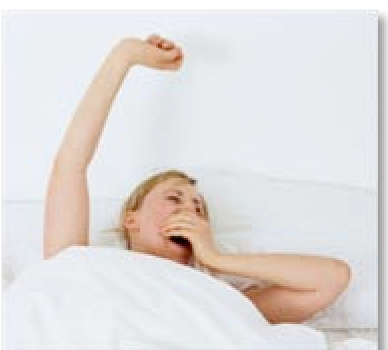
Light is the primary synchronizer of circadian rhythms to local position on Earth



The natural, 24-hour, light-dark cycle



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



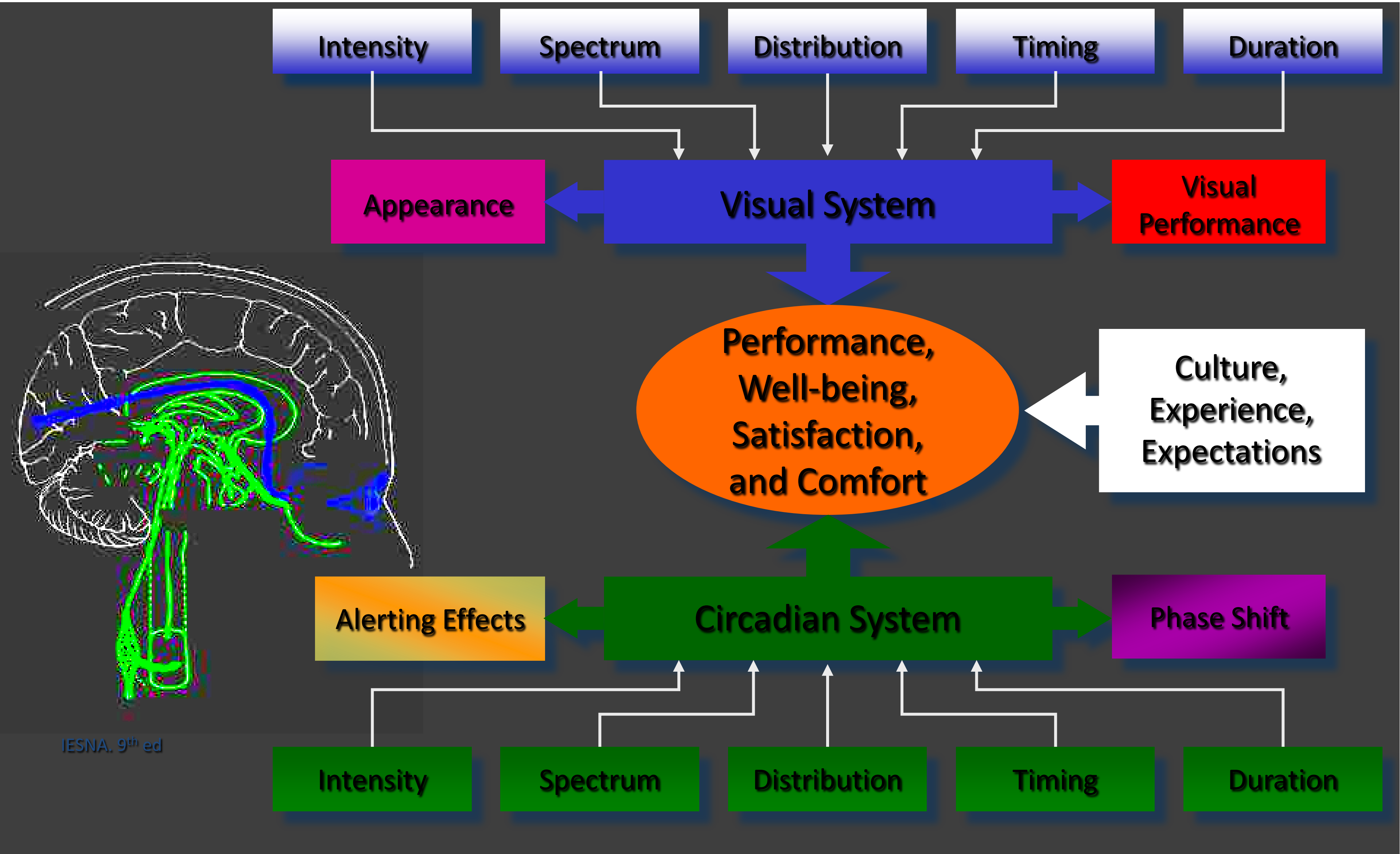
…also the major disruptor

Circadian disruption

- Circadian disruption has been associated with:
  - Poor sleep and higher stress
    - Eismann et al., 2010
  - Increased anxiety and depression
    - Du-Quiton et al., 2009
  - Increased smoking
    - Kageyama et al., 2005
  - Cardiovascular disease
    - Young et al., 2007; Maemura et al., 2007
  - Type 2 diabetes
    - Kreier et al., 2007
  - Higher incidence of breast cancer
    - Schernhammer et al., 2001, Hansen, 2006

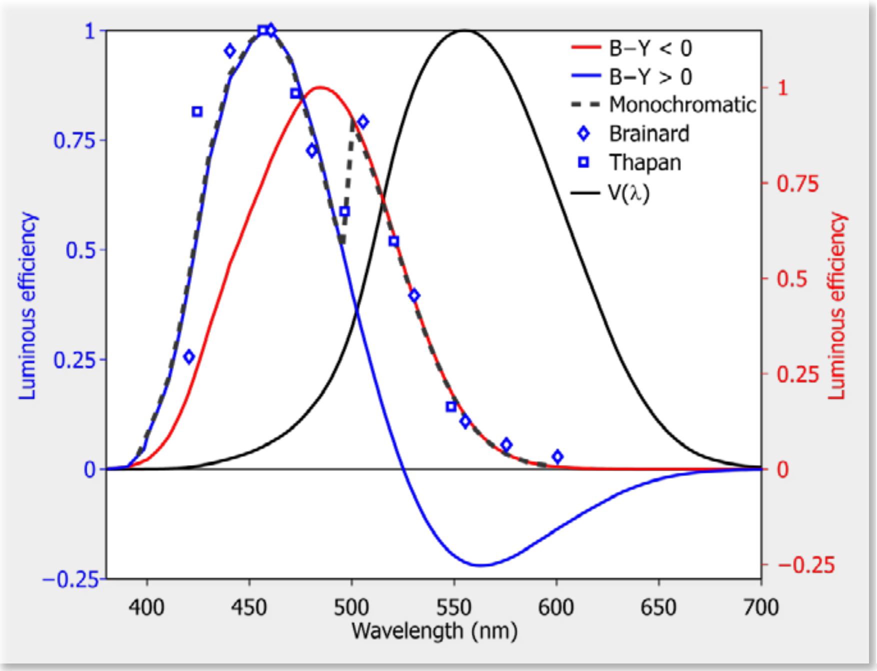
Light and human performance

Vision + Circadian + Message

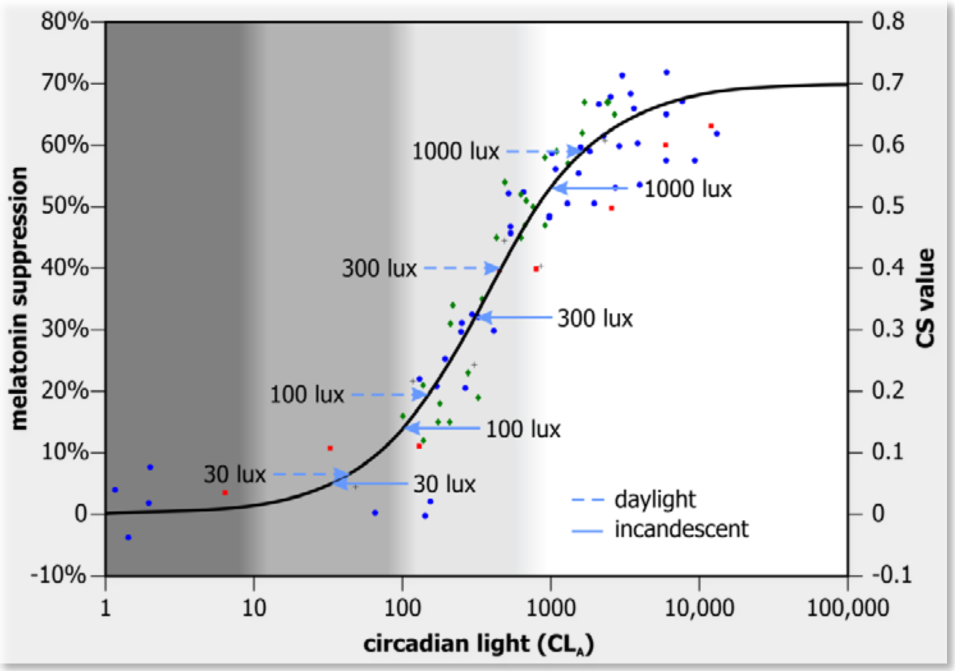


Circadian rhythms and light

Spectral sensitivity



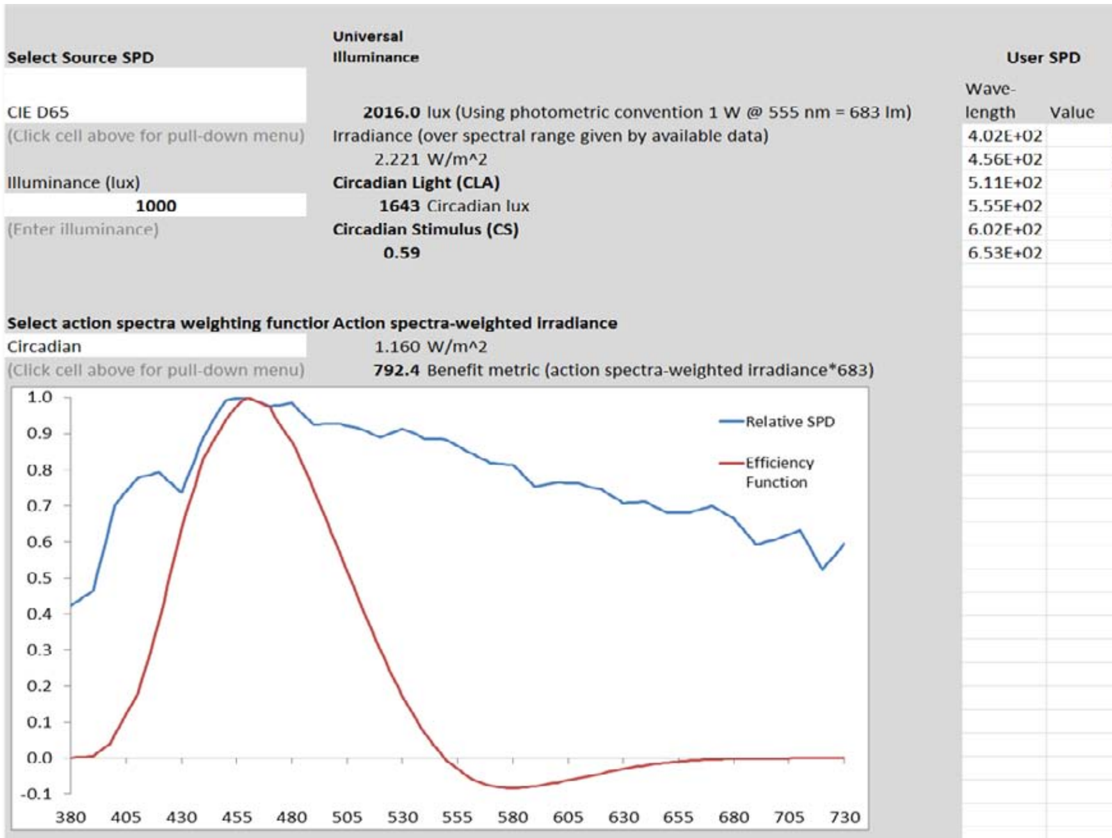
Absolute sensitivity



ATLAIANTA!

AIA Convention 2015
May 14–16, Atlanta

Circadian Stimulus Calculator



Daysimeter

Daysimeter was developed under a G x E an U01 from the National Institute on Drug Abuse

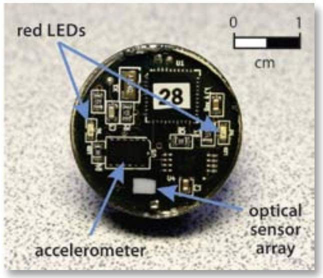
Measures circadian light/dark and activity/rest
Used to calculate circadian entrainment disruption and sleep quality

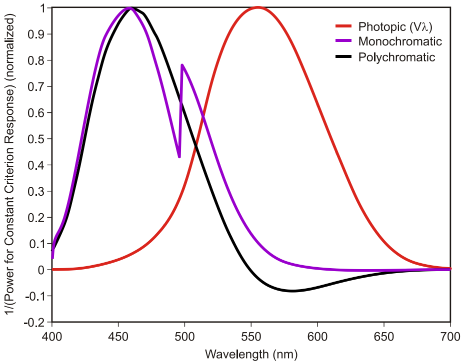
Further developed to be used in Alzheimer's disease (AD) patients under an R01 from the National Institute on Aging

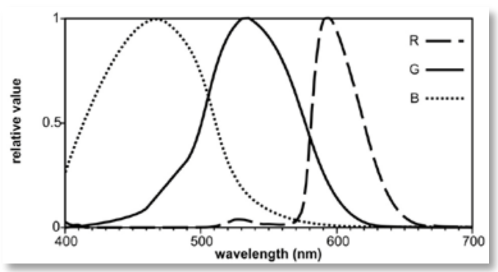
Won the 2010 The Scientist's annual Top 10 Innovations contest

Have been worn by dayshift and rotating shift nurses, 8th graders, Veterans with PTSD, older adults with early sleep onset

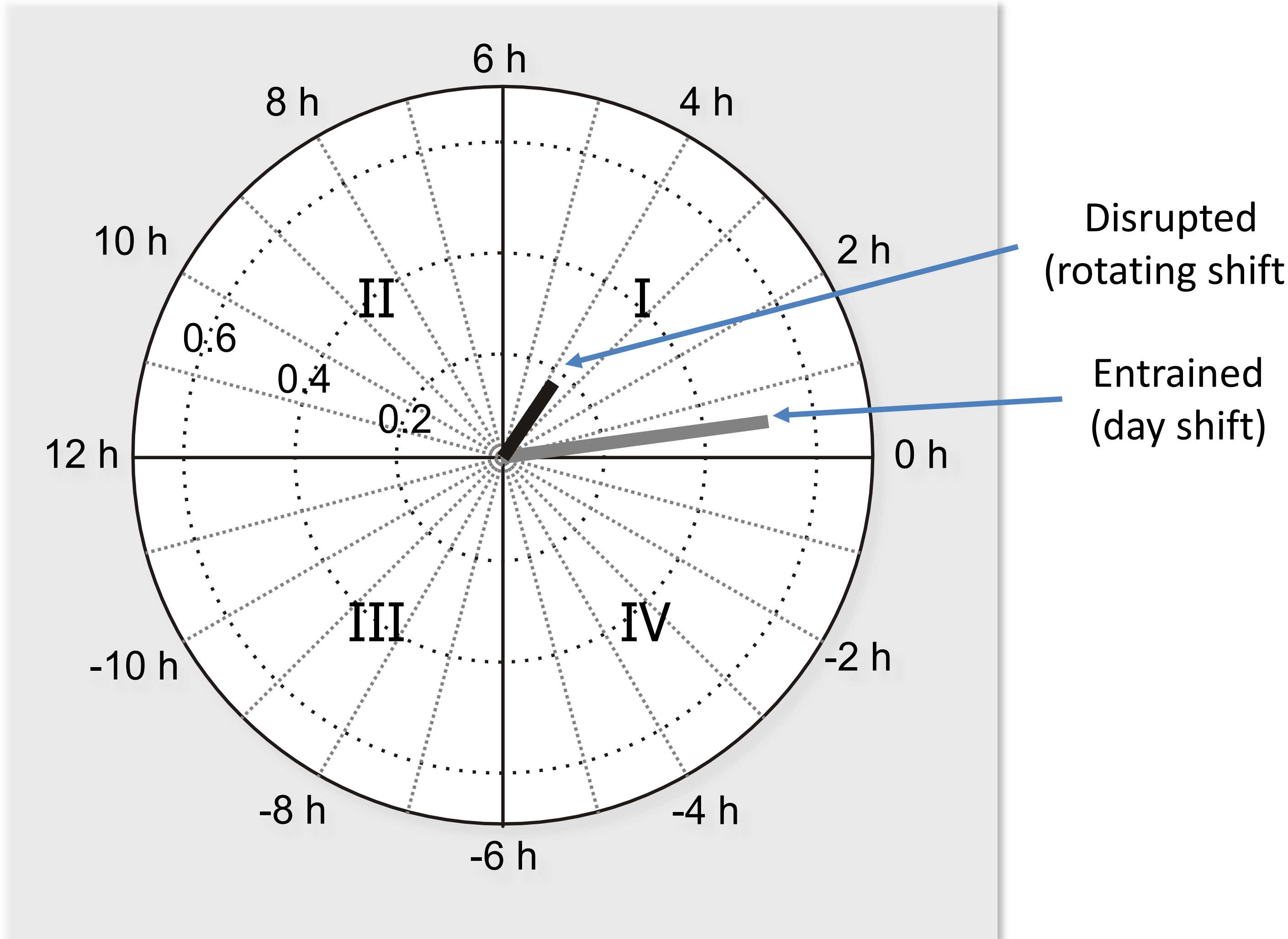
Currently being worn by AD patients to measure the impact of a tailored light treatment on sleep and behavior of this population





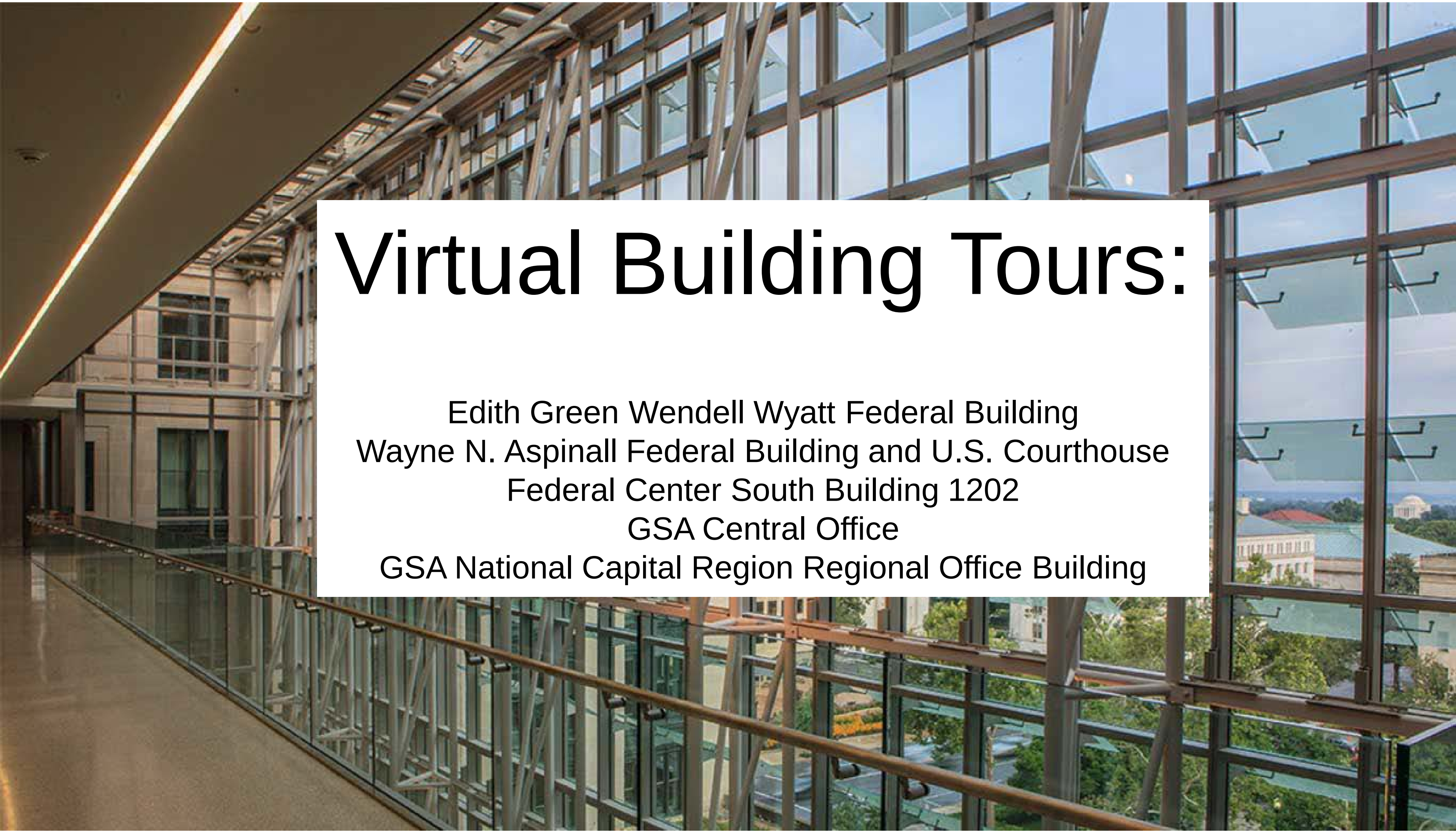


Measuring circadian disruption in the field: Phasor diagram for day- and rotating-shift nurse



GSA Field Measurements

- Proposed tasks
  - Perform photometric measurements
  - Collect personal light exposure with the Daysimeter
- Hypothesis
  - Buildings with more access to daylight would provide more circadian stimulation to workers
    - Better sleep quality and mood, especially in summer months, when there is more daylight availability



Virtual Building Tours:

Edith Green Wendell Wyatt Federal Building
Wayne N. Aspinall Federal Building and U.S. Courthouse
Federal Center South Building 1202
GSA Central Office
GSA National Capital Region Regional Office Building

Edith Green Wendell Wyatt Federal Building
Portland, Oregon

Before

After

Photo: Nic Lehoux

Edith Green Wendell Wyatt Federal Building
Portland, Oregon

Image: SERA Architects

Edith Green Wendell Wyatt Federal Building

Portland, Oregon

Image: SERA Architects

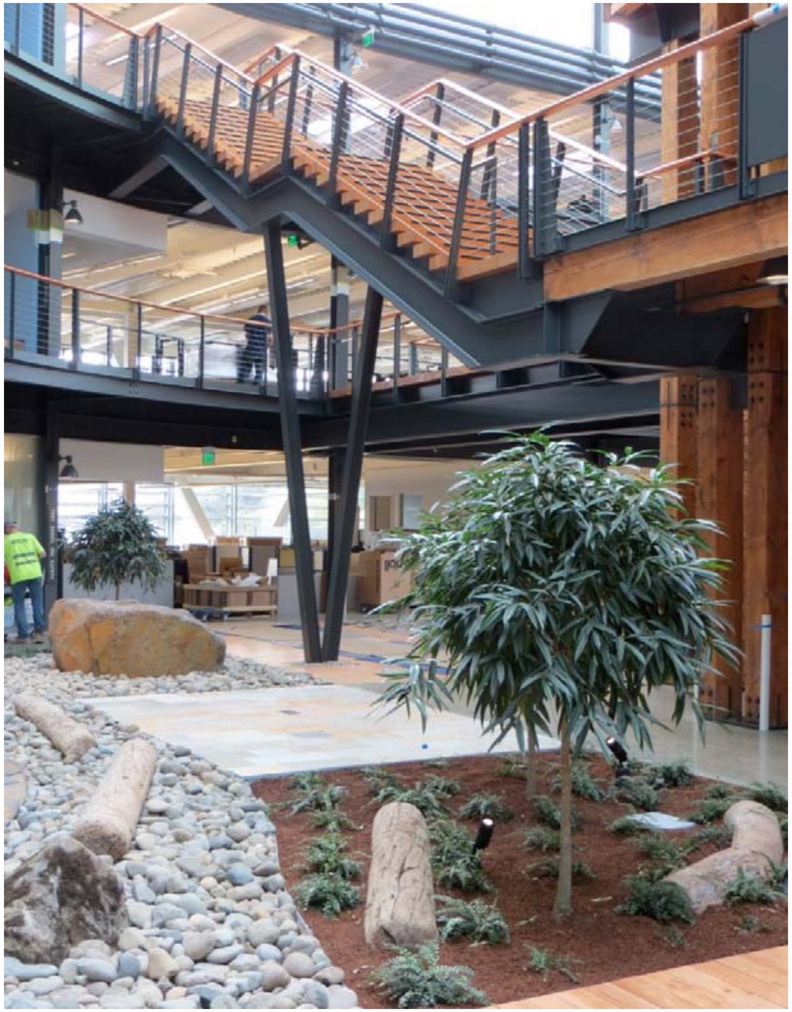
Wayne N. Aspinall Federal Building and U.S. Courthouse
Grand Junction, Colorado

Wayne N. Aspinall Federal Building and U.S. Courthouse
Grand Junction, Colorado

Federal Center South Building 1202
Seattle, Washington

Photos: Benjamin Benschneider

Federal Center South Building 1202
Seattle, Washington



GSA Central Office
Washington, DC

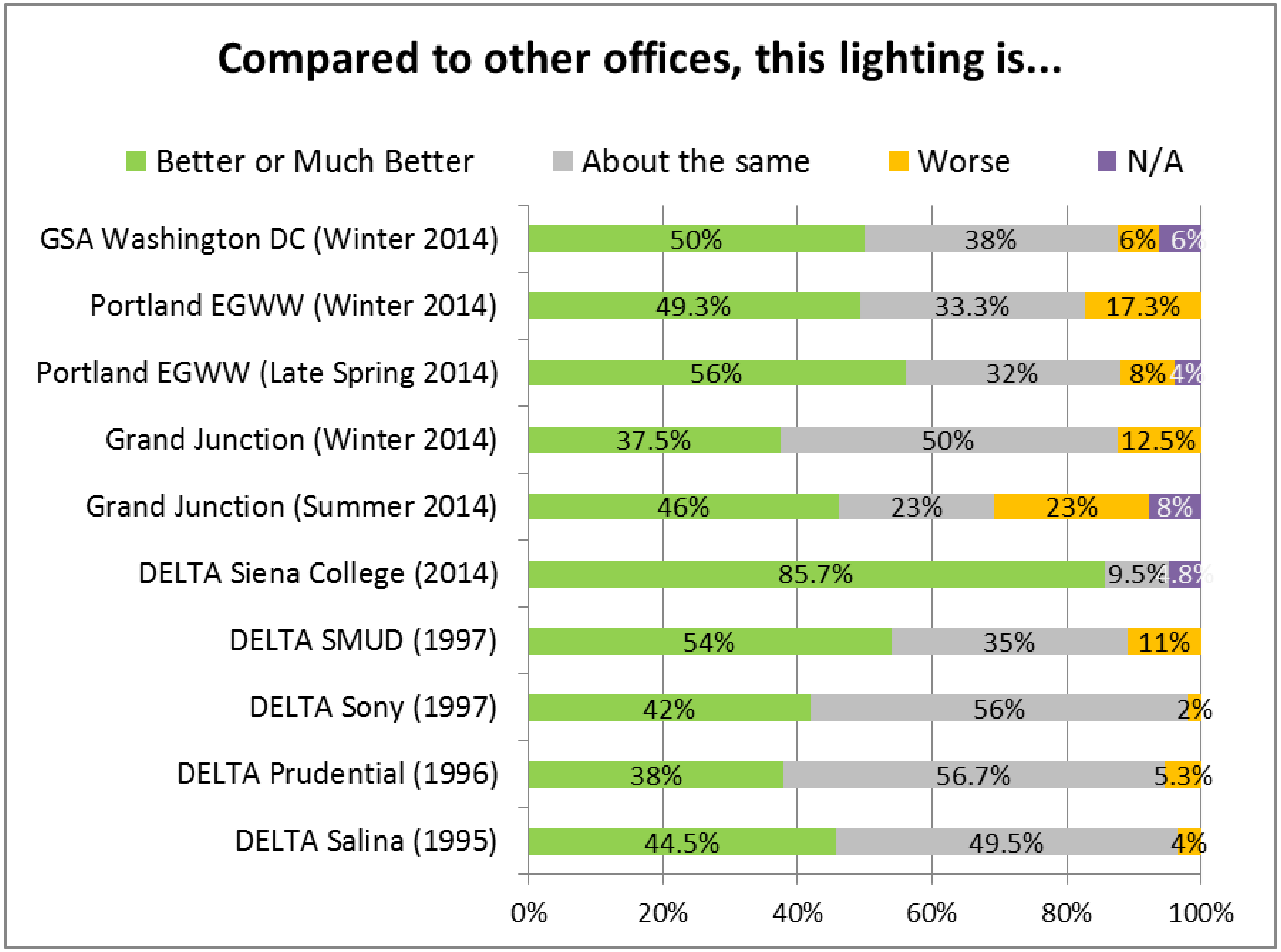
GSA National Capital Region Regional Office Building
Washington, DC

GSA National Capital Region Regional Office Building
Washington, DC

Photometric measurements Summary of findings

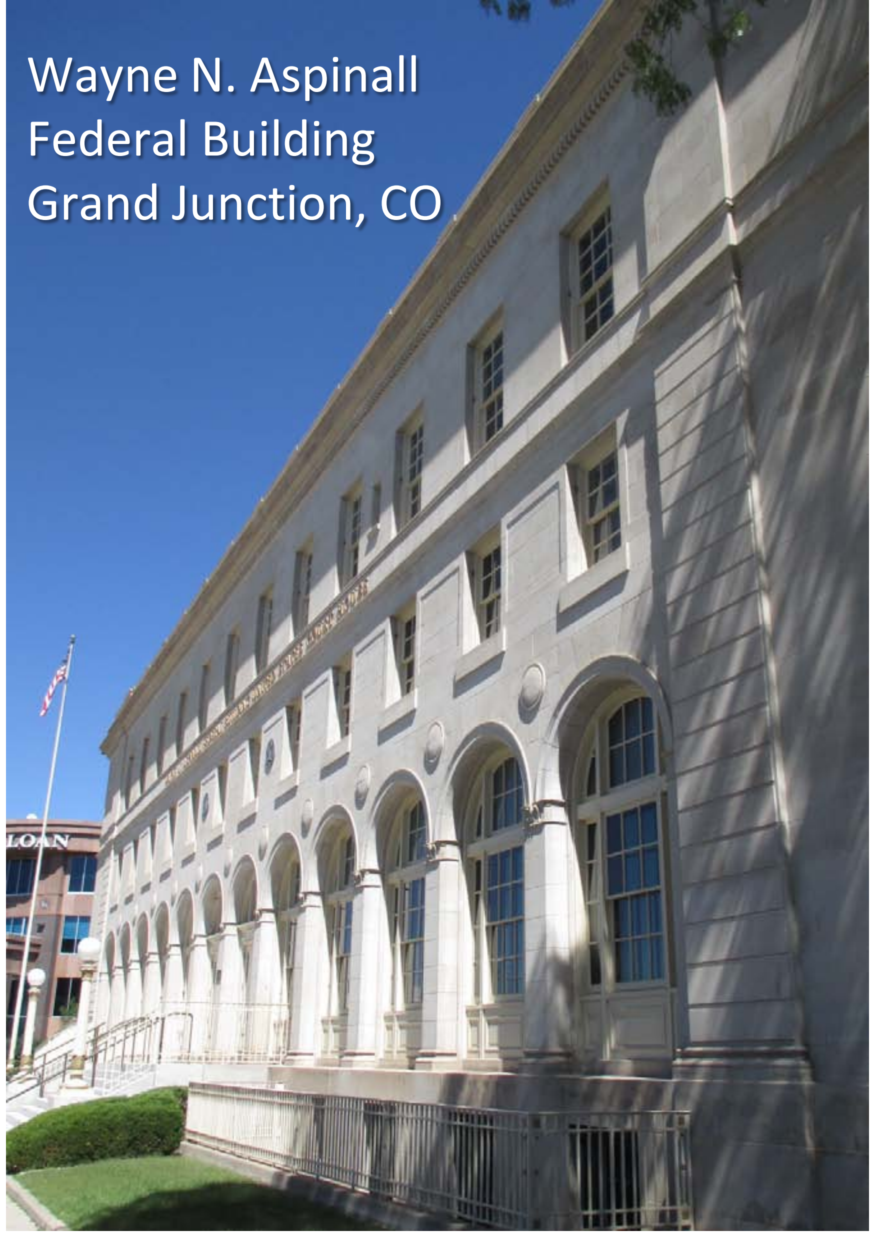
- Building orientation, deskspace location and floor height, influenced the amount of circadian stimulation received by workers
  - In general, North façade, higher floors, and deskspaces closer to windows received the highest amount of daylight
  - In winter, south and east façades received more light than in summer months
- Furniture layout, shades positions, placement of luminaires need to be taken into consideration if we want to increase daylight penetration in the building
  - Care should be taken to avoid direct and reflected glare
  - Electric lighting will play an important role in deskspaces located in the south, west and perhaps east façades and in deskspaces located away from windows

Subjective evaluation
Summary of findings



Personal light exposures

- We collected personal light exposures using the Daysimeter and related these measurements to health and sleep outcomes
  - Subjects were invited to participate in the 7 day study during winter and summer months
  - Subjects were asked to fill out sleep quality and mood questionnaires once at start of the study


Wayne N. Aspinall
Federal Building
Grand Junction, CO
LOAN

Personal light exposures

		Waking Average			Work Average			Post-Work Average		
		Ari-mean (CS)	Illuminance Ari-mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)
Winter	Mean	0.19	824	36	0.21	834	84	0.12	1000	24
	Median	0.18	728	32	0.21	418	76	0.11	75	19
	Std Dev	0.04	559	15	0.04	826	29	0.03	1900	11
Summer	Mean	0.28	1308	111	0.26	1197	178	0.28	1247	64
	Median	0.29	1036	112	0.23	916	122	0.30	1359	74
	Std Dev	0.06	864	42	0.06	962	94	0.07	502	22
	p value	0.004*	0.21	0.005*	0.007*	0.03*	0.02*	<0.001*	0.76	0.003*

Asterisks (*) indicate statistically significant values.

- Workers were exposed to the highest CS during working hours
- CS values were significantly higher in summer than winter months
  - CS values in winter months were at threshold for activation of circadian system (0.1)

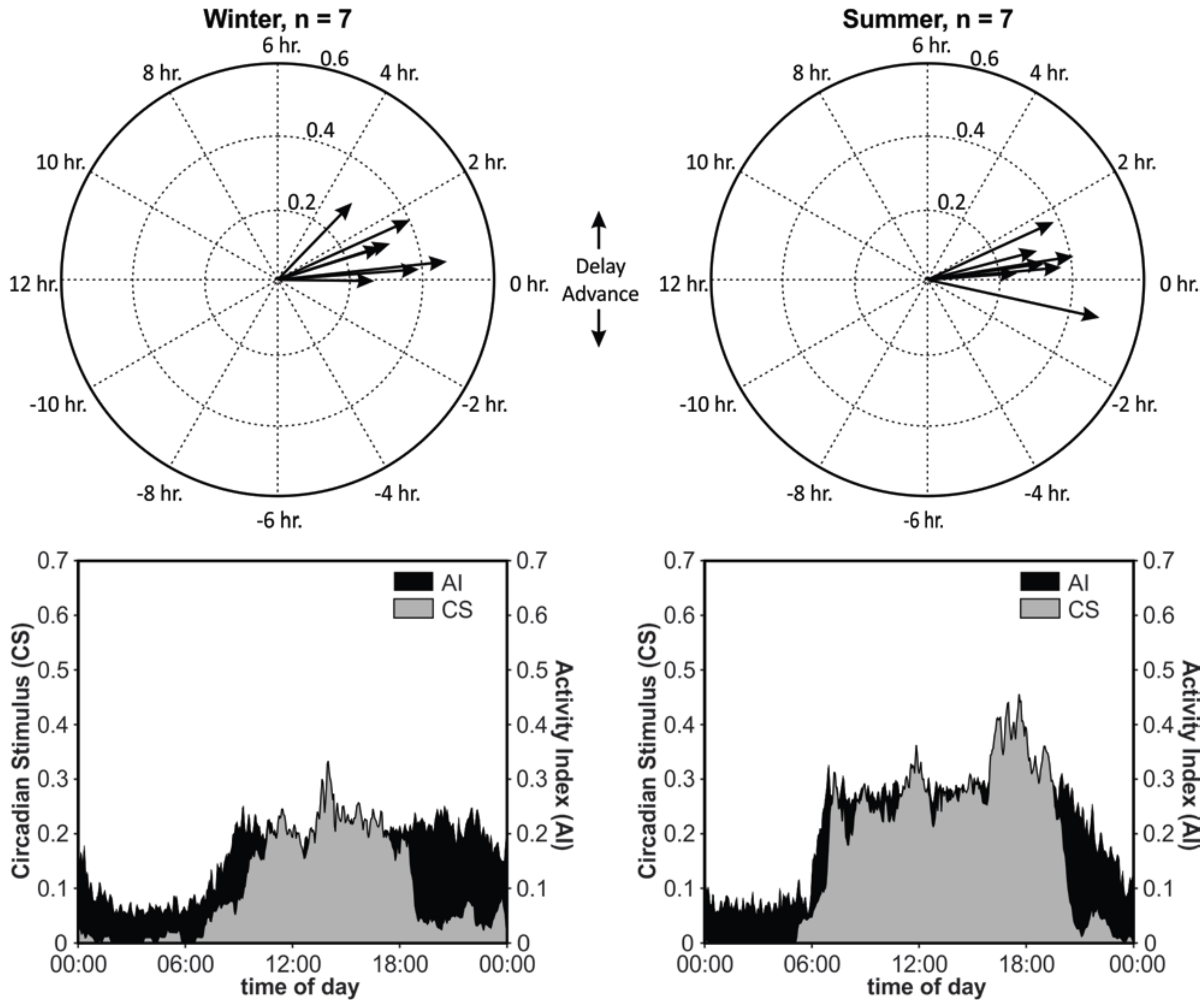
Circadian entrainment and sleep quality

		Phasor		Sleep		
		Magnitude	Angle (hours)	Actual Sleep Time (min)	Sleep Efficiency (%)	Sleep Onset Latency (min)
Winter	Mean	0.35	1.10	341	70%	93
	Median	0.33	1.16	357	70%	84
	St Dev	0.07	1.05	42	6%	22
Summer	Mean	0.36	0.51	373	79%	18
	Median	0.37	0.53	386	77%	16
	St Dev	0.08	0.75	48	7%	13
	p value	0.53	0.23	0.014*	<0.001*	<0.001*

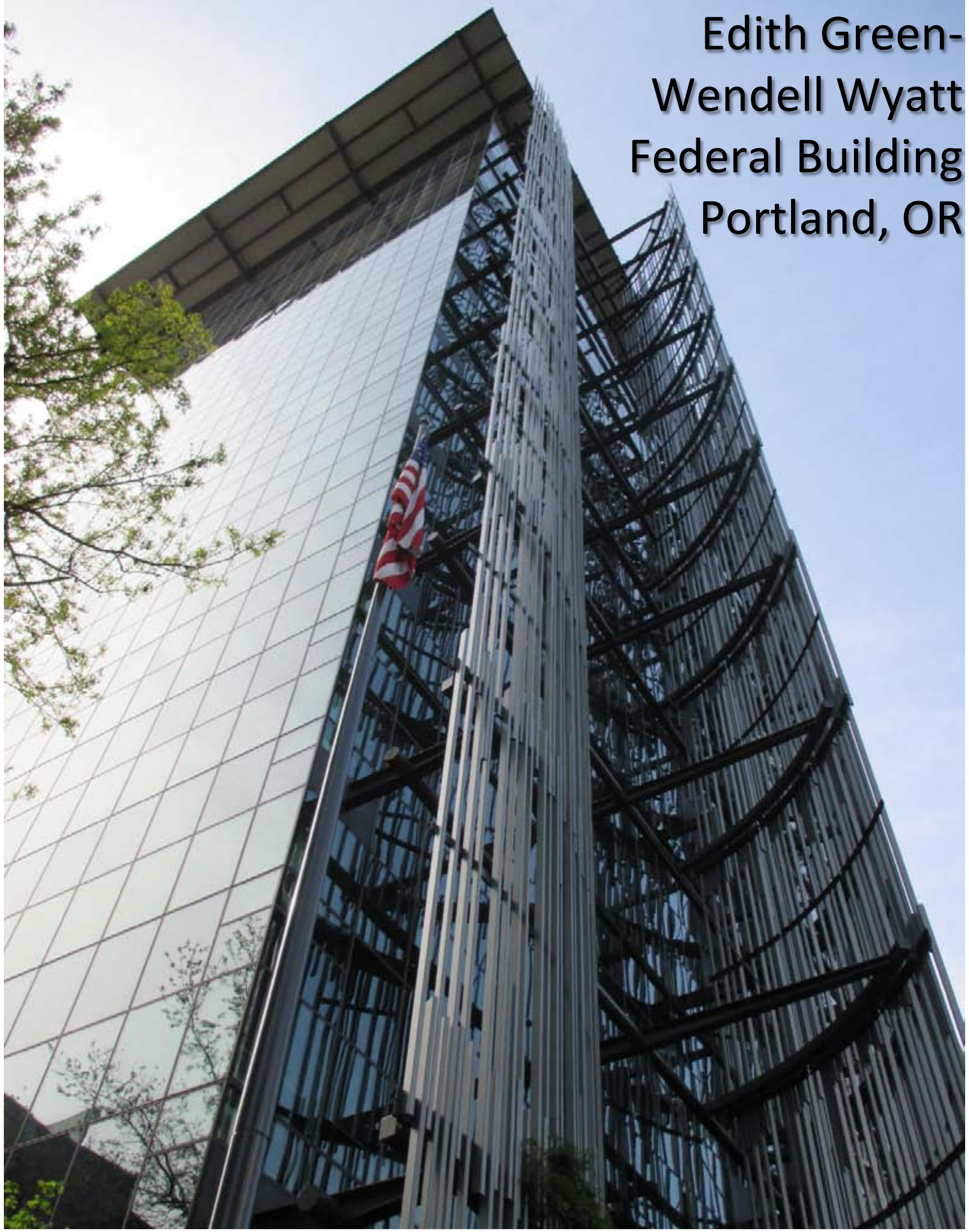
Asterisks (*) indicate statistically significant values.

- In general, phasor magnitudes were lower than in dayshift nurses and in teachers, which is between 0.4 and 0.5
- Phasor angles are higher in winter months because of the evening activity that occurs in dim light
- Sleep durations was generally short and sleep efficiency low
- Significant increase in sleep duration and sleep efficiency and significant reduction in sleep onset latency in summer than in winter

Circadian entrainment



Figueiro and Rea, in press


Edith Green-
Wendell Wyatt
Federal Building
Portland, OR

Personal light exposures

		Waking Average			Work Average			Post-Work Average		
		Ari-mean (CS)	Illuminance Ari-mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)
Winter	Mean	0.15	219	34	0.19	280	91	0.06	31	10
	Median	0.14	162	26	0.17	178	62	0.05	27	9
	Std Dev	0.05	150	20	0.06	218	79	0.03	17	4
Summer	Mean	0.26	1094	94	0.28	1277	192	0.22	743	51
	Median	0.24	838	80	0.31	952	207	0.22	754	44
	Std Dev	0.06	904	51	0.09	1483	117	0.08	451	35
	p value	<0.001*	<0.001*	<0.001*	0.01*	0.02*	0.01*	<0.001*	<0.001*	<0.001*

Asterisks (*) indicate statistically significant values.

- Workers were exposed to the highest CS during working hours
- CS values experienced by subjects were above threshold (0.1)
- CS values were significantly higher in summer than winter months

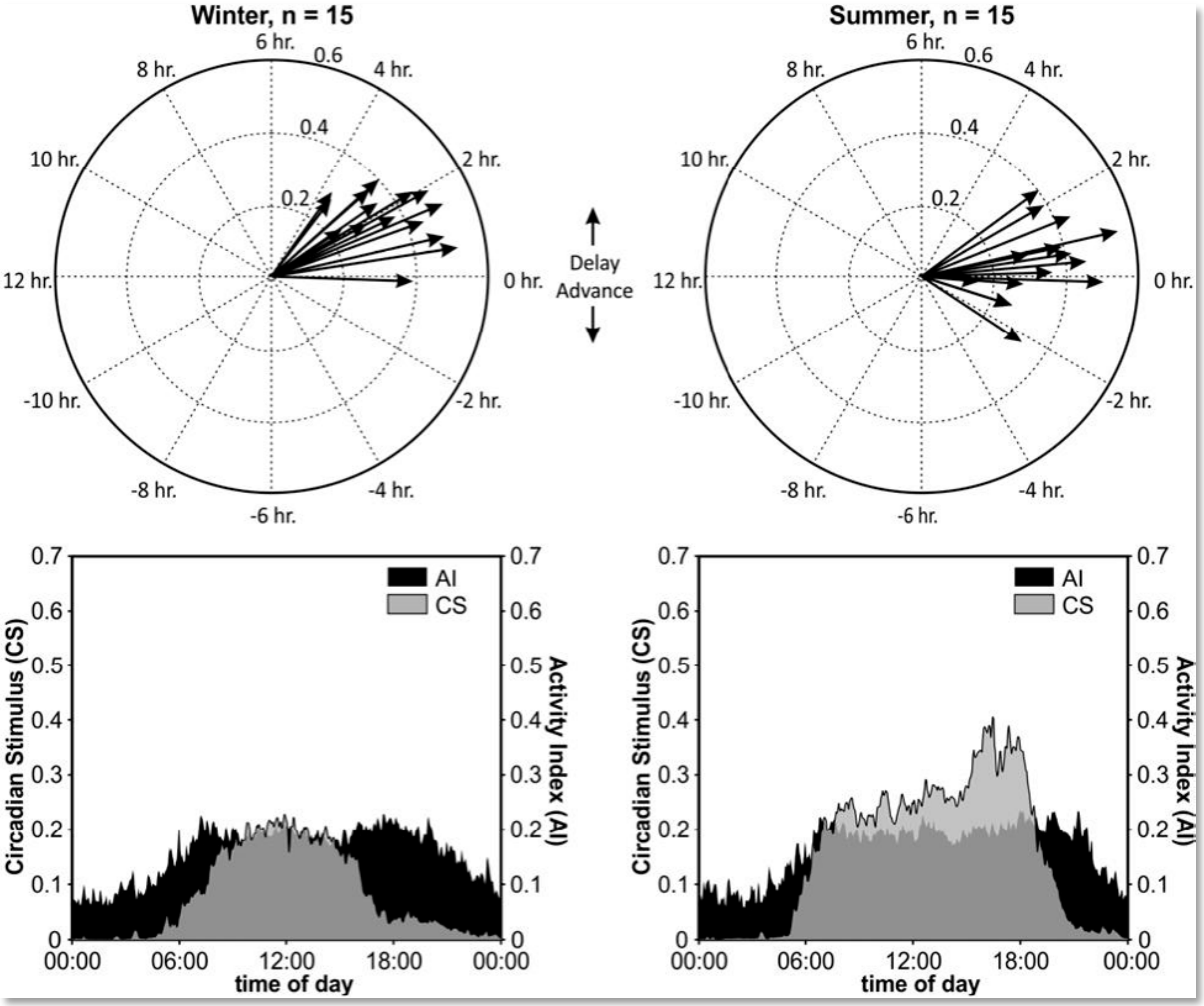
Circadian entrainment and sleep quality

		Phasor		Sleep		
		Magnitude	Angle (hours)	Actual Sleep Time (min)	Sleep Efficiency (%)	Sleep Onset Latency (min)
Winter	Mean	0.37	1.93	367	79%	19
	Median	0.37	1.92	361	80%	11
	Std Dev	0.09	1.03	42	8%	29
Summer	Mean	0.35	0.27	355	78%	22
	Median	0.37	0.35	334	79%	16
	Std Dev	0.1	1.23	59	7%	18
	p value	0.43	<0.001*	0.46	0.85	0.58

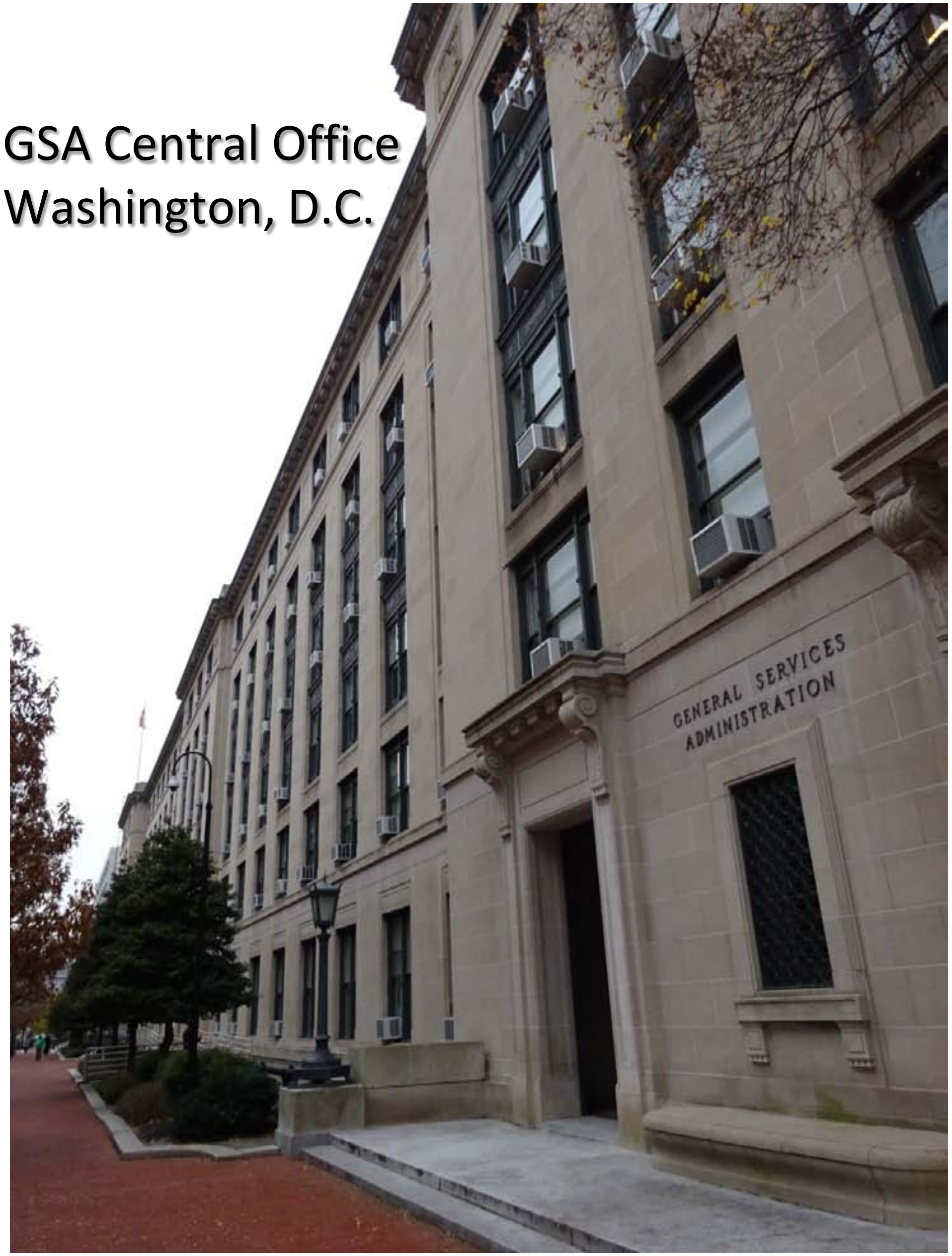
Asterisks (*) indicate statistically significant values.

- In general, phasor magnitudes were lower than in dayshift nurses and in teachers, which is between 0.4 and 0.5
- Phasor angles are higher in winter months because of the evening activity that occurs in dim light
- Sleep durations was generally short and sleep efficiency low
- No significant differences in phasor magnitudes or sleep parameters between winter and summer months

Circadian entrainment



GSA Central Office
Washington, D.C.



Personal light exposures

location		Waking Average			Work Average (out of office)			Work Average (at office)			Post-Work Average		
		Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)	Ari-Mean (CS)	Illuminance Ari-Mean (Lx)	Illuminance Geo-Mean (Lx)
All	Mean	0.10	221	31	0.09	139	26	0.15	189	85	0.05	77	14
All	Median	0.10	171	27	0.09	169	23	0.13	161	77	0.04	32	12
All	Std Dev	0.03	186	17	0.05	262	21	0.07	121	55	0.03	188	9
1800 F	Mean	0.11	222	32	0.09	131	26	0.15	204	91	0.05	82	14
1800 F	Median	0.10	169	28	0.09	169	23	0.14	172	83	0.04	33	12
1800 F	Std Dev	0.03	192	17	0.05	264	22	0.07	118	54	0.03	197	10
ROB	Mean	0.09	212	26	0.10	210	24	0.06	54	26	0.03	25	10
ROB	Median	0.09	176	20	0.09	236	21	0.06	55	29	0.02	16	8
ROB	Std Dev	0.04	145	18	0.02	262	10	0.03	15	11	0.04	25	8
	p value	0.49	0.91	0.47	0.81	0.30	0.88	0.01*	0.02*	0.02*	0.25	0.57	0.34

Asterisks (*) indicate statistically significant values.

Asterisks (*) indicate statistically significant values.

- Except for ROB (control building), participants received the highest CS during working hours
- CS exposures were significantly lower in ROB (control) building

Circadian entrainment and sleep quality

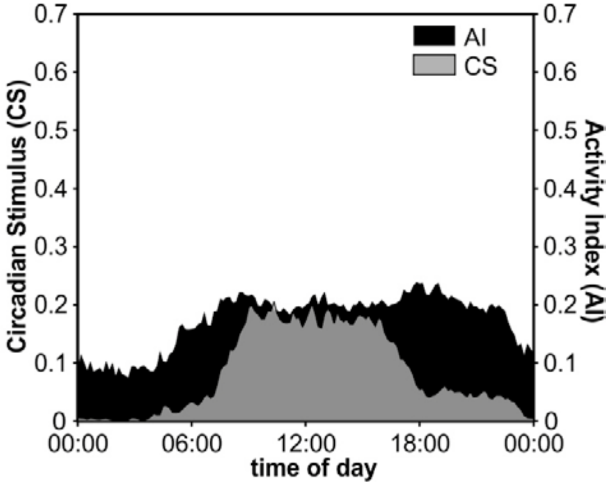
	location	Phasor		Sleep		
		Magnitude	Angle (hours)	Actual Seep Time (mins.)	Sleep Efficiency (%)	Sleep Onset Latency (mins.)
All	Mean	0.27	1.94	346	76%	27
	Median	0.27	2.02	344	77%	18
	Std Dev	0.07	1.21	43	9%	29
1800 F	Mean	0.27	1.91	345	76%	23
	Median	0.27	1.99	344	77%	17
	Std Dev	0.07	1.21	40	9%	23
ROB	Mean	0.23	2.17	355	72%	51
	Median	0.23	2.12	366	75%	35
	Std Dev	0.07	1.33	65	10%	49
	p value	0.19	0.63	0.58	0.30	0.02*

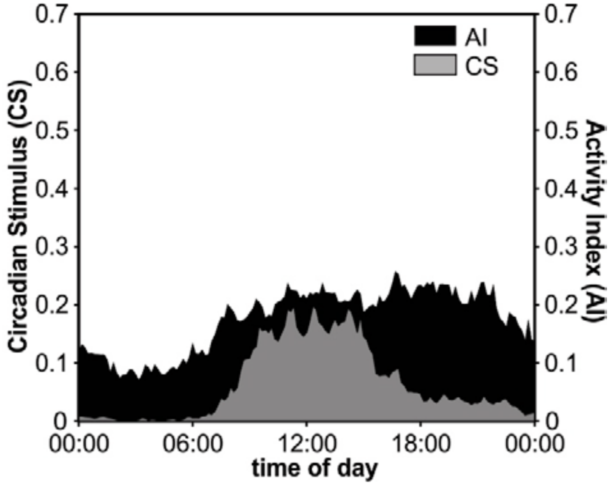
Asterisks (*) indicate statistically significant values.

- Phasor magnitudes were lower than in dayshift nurses and in teachers, which is between 0.4 and 0.5
- Sleep durations was generally short and sleep efficiency low
- In the control building, participants had
  - Shorter phasor magnitudes, suggesting more circadian disruption
  - Lower sleep efficiency
  - Significantly greater sleep onset latency
- Sample size in control building is small

Light exposures (working days)

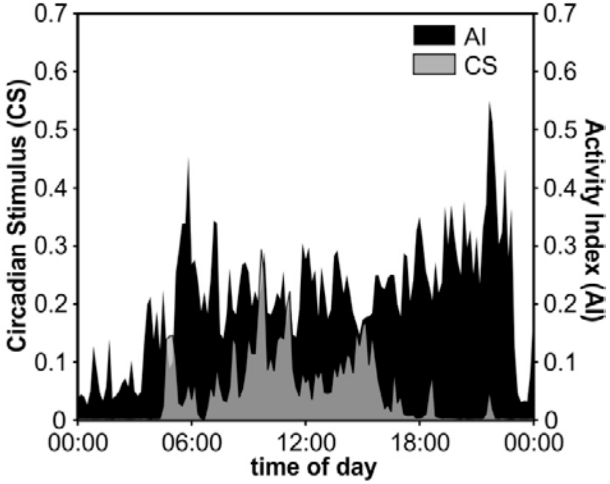
1800 F
CS = 0.15

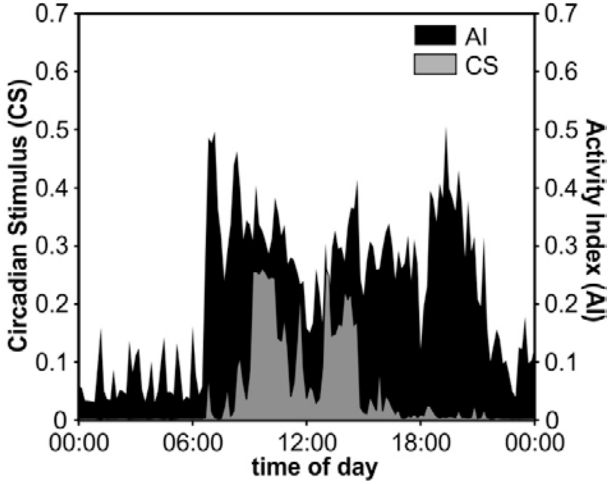




1800 F
CS = 0.09

ROB (control)
CS = 0.06





ROB (control)
CS = 0.1

Office

Not in office

Personal light exposures and self reports

location		total CES-D (winter)	PSQI (winter)	PSS-10 (winter)	sleep disturbance t-score (winter)	PANAS total positive (winter)	PANAS total negative (winter)
All	Mean	6.5	6.1	13.5	47.6	33.0	15.6
	Median	5.0	5.0	13.0	46.7	33.0	15.0
	SEM	0.8	0.4	0.9	1.2	1.1	0.8
1800 F	Mean	6.4	5.9	13.4	46.8	33.3	15.4
	Median	5.0	5.0	12.0	45.3	33.5	15.0
	SEM	0.9	0.4	1.0	1.2	1.1	0.8
ROB	Mean	7.2	7.8	14.2	53.1	30.8	17.0
	Median	9.0	9.0	15.0	53.7	30.0	16.0
	SEM	2.3	1.6	2.5	3.5	3.6	2.1
	p value	0.76	0.11	0.79	0.09	0.47	0.52

- PSQI scores suggest sleep disturbances in those working in ROB (control), while the Sleep Disturbance t-score does not
- None of the subjects reported suffering from depression
- The data suggest that ROB participants sleep worse and have worse mood
    - Need to increase sample size in control group

Personal light exposures
Summary of findings

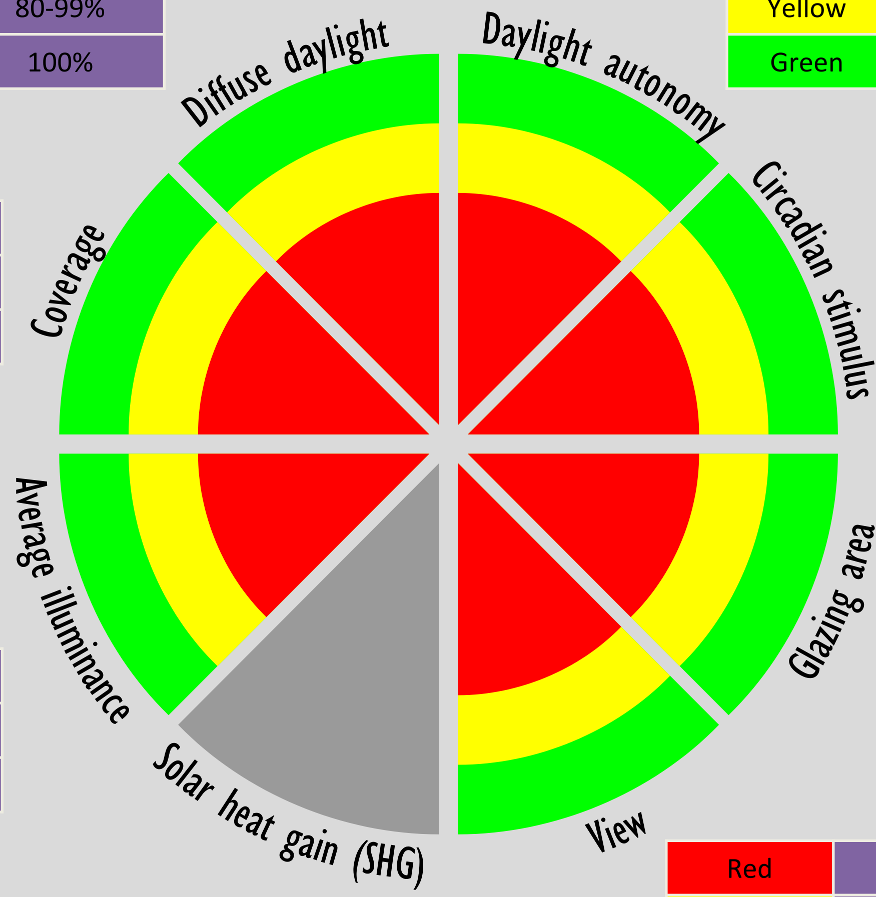
- Amount of circadian stimulation was significantly higher in summer than in winter months
  - Highest amount of light was received during work hours, except for the control building
- Sleep efficiency and sleep duration was low in this population
  - But, sleep efficiency was significantly improved in summer compared to winter months in Grand Junction, Colorado, but not in Portland, Oregon
  - Sleep onset latency was greater in participants in ROB building compared to 1800 F street building
- We were not able to show a relationship between light exposure and mood outcomes
  - Sample size is small
  - Need larger sample size in the control building without daylight

How can this information change practice?

Red	< 80%
Yellow	80-99%
Green	100%

Red	Below 50%
Yellow	50-79%
Green	80-100%

Red	< 80% above 10 fc
Yellow	80-99% above 10 fc
Green	100% above 10 fc



Red	Below 50%
Yellow	50-79%
Green	80-100%

Red	Above 20%
Yellow	10-20%
Green	Below 10%

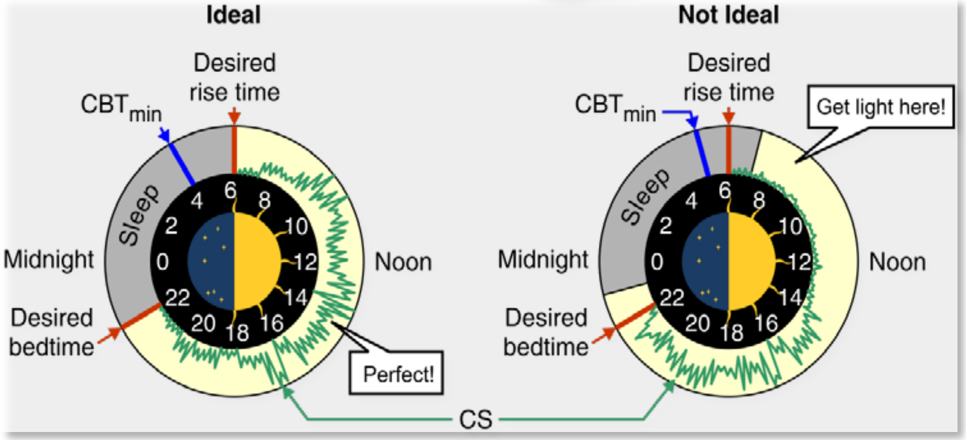
Red	Below 10 fc
Yellow	10-49 fc; > 500 fc
Green	50-500 fc

Red	No view
Yellow	Sky
Green	Ground & sky

Expressed in btu/ft²/day

How can this information change practice?

- Development of the Daysimeter and a model of the SCN's limit cycle oscillator helps the LRC to "write a prescription" so that a person can receive a light-dark pattern that matches their desired rise and sleep times
  - A biological watch may track a person's circadian time and provide a recommendation for when to receive or avoid light



Sponsors:
National Institute on Aging (R01AG034157)
National Institute on Drug Abuse (U01DA023822)
Office of Naval Research (N00014-11-1-0572)
Army Research Office

Translating Research into Practice

Multi-step process:

1. Conduct research, analyze data
2. Create best practices
3. Implement practices, impact analysis

Optimizing the Daylighting Ecosystem in Buildings

Workshop

- April 21-22, 2015
- Interdisciplinary mix of experts
- How can GSA optimize the daylighting ecosystem in buildings?
- Outcomes / Next Steps

Contact Information

Mariana Figueiro, PhD
figuem@rpi.edu

Don Horn, FAIA, LEED Fellow
donald.horn@gsa.gov

Bryan Steverson
bryan.steverson@gsa.gov

Session Evaluation

Please be sure to complete the session evaluation. Your feedback will help us develop future education sessions at AIA Convention. Your opinion matters. Share it!

ATL AIA NTA!

Evaluations are available through the official Convention App: AIA 2015