Measuring Circadian Light: Impact on Health and Well-being

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Why is light so important?

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

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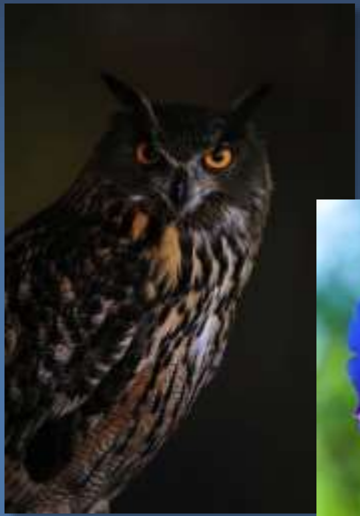
Circadian system

- 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



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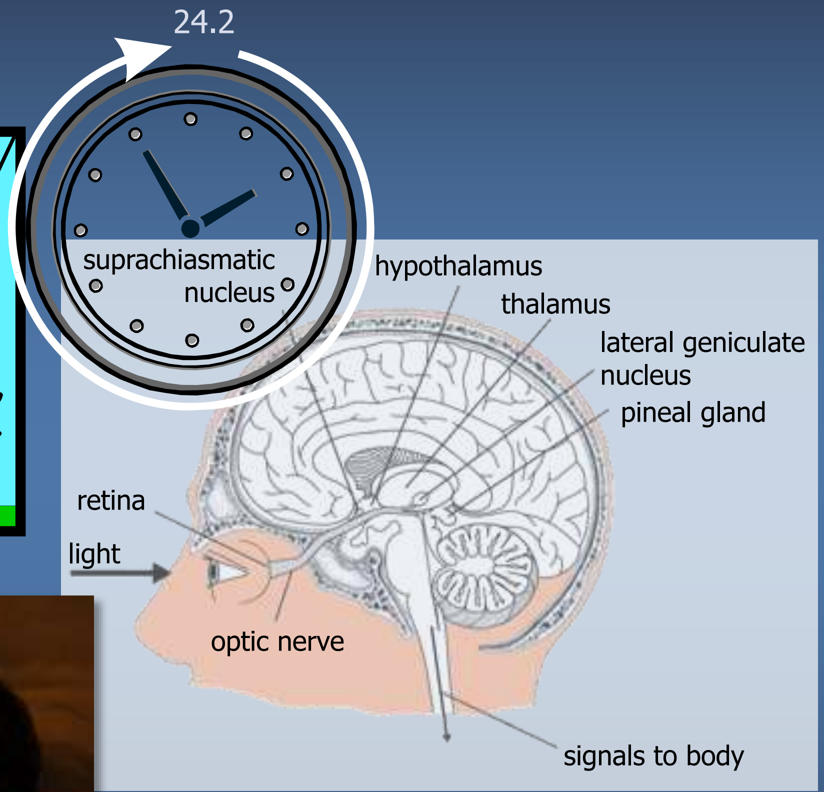
Light is the primary synchronizer of circadian rhythms to local position on Earth

The natural, 24-hour, light-dark cycle



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

…also the major disruptor

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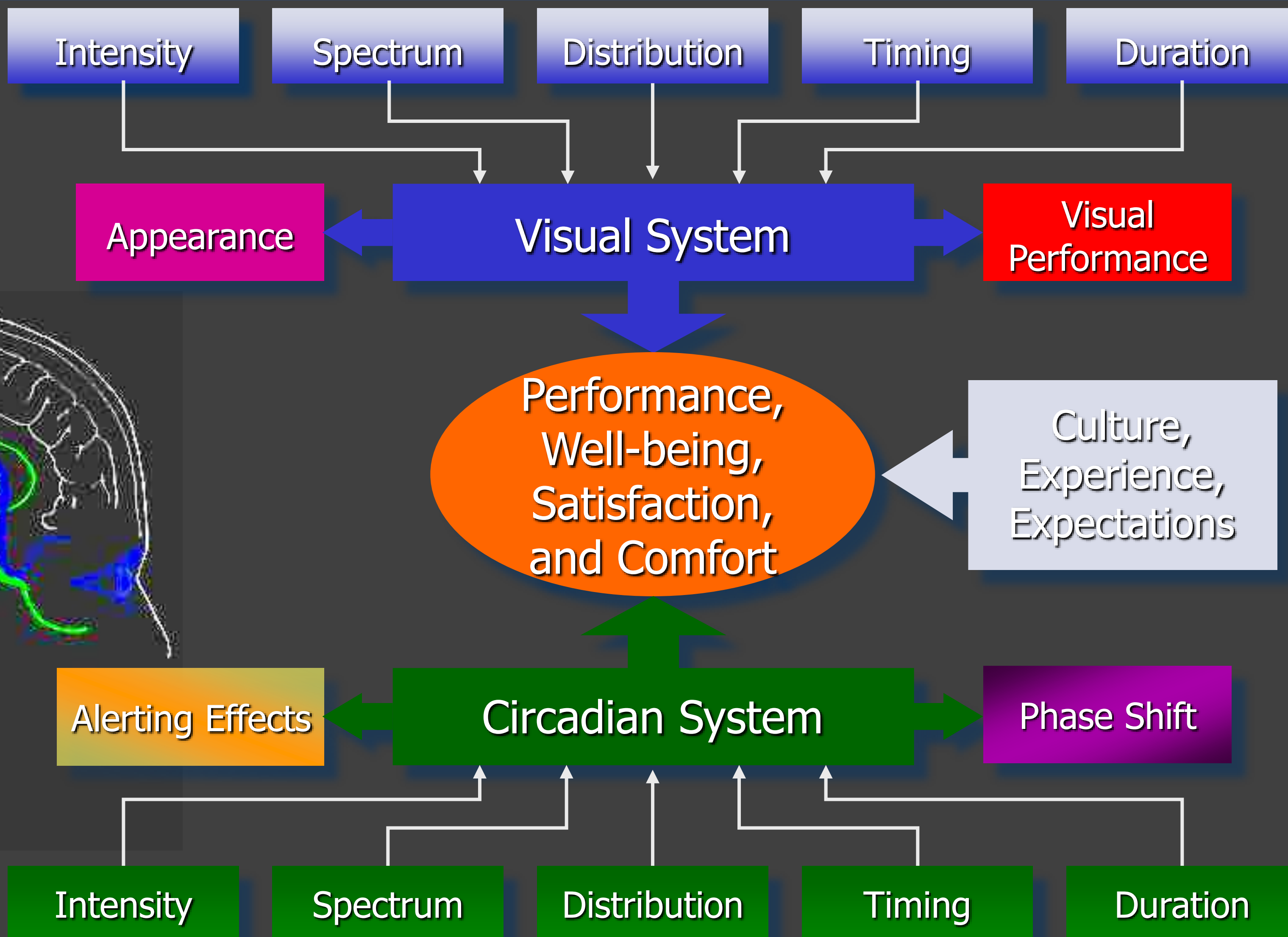
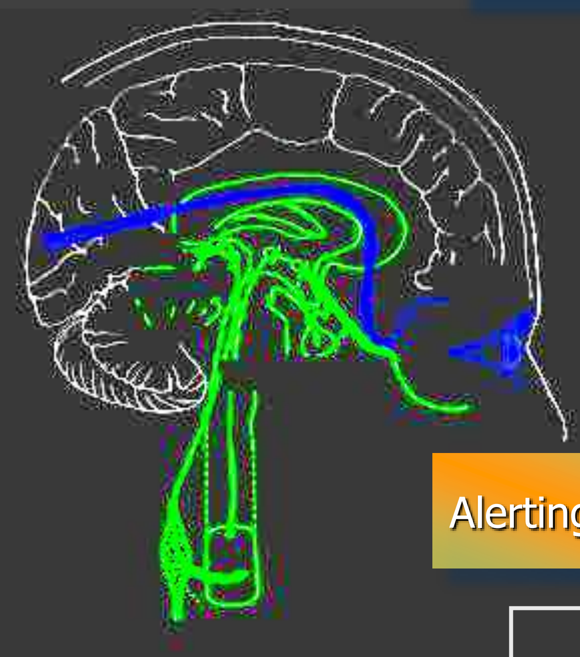
Circadian disruption

- 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



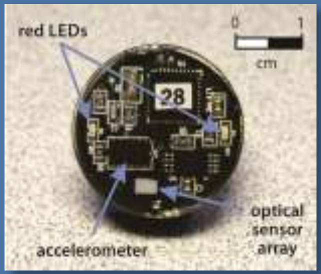


IESNA. 9th ed

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

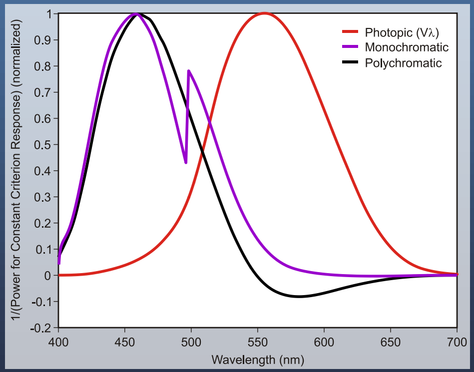


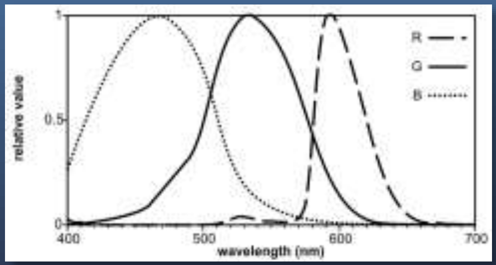
Further developed to be used in Alzheimer's disease (AD) patients under an R01 from the National Institute on Aging

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



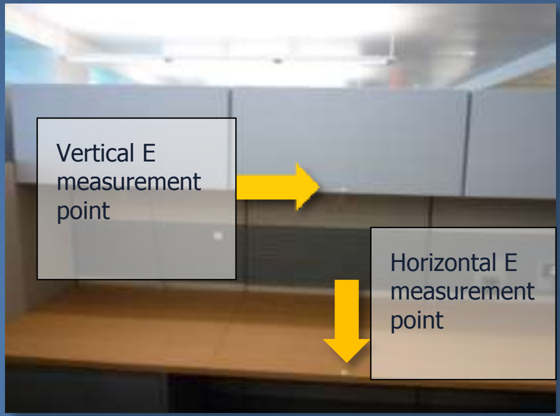


Project overview

- Proposed tasks
  - Perform building measurements (summer and winter)
    - Wayne N. Aspinall Federal Building, Grand Junction, CO
    - Edith Green-Wendell Wyatt Federal Building, Portland, OR
    - Federal Center South Building, Seattle, WA (winter only)
    - GSA Central Office, Washington, DC
  - 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

Methodology
Building measurements

- Performed morning, midday, afternoon and evening spot photometric measurements during winter and summer months
  - Illuminance measurements
  - Luminance measurements
  - Spectroradiometer measurements
- Performed lighting experience survey



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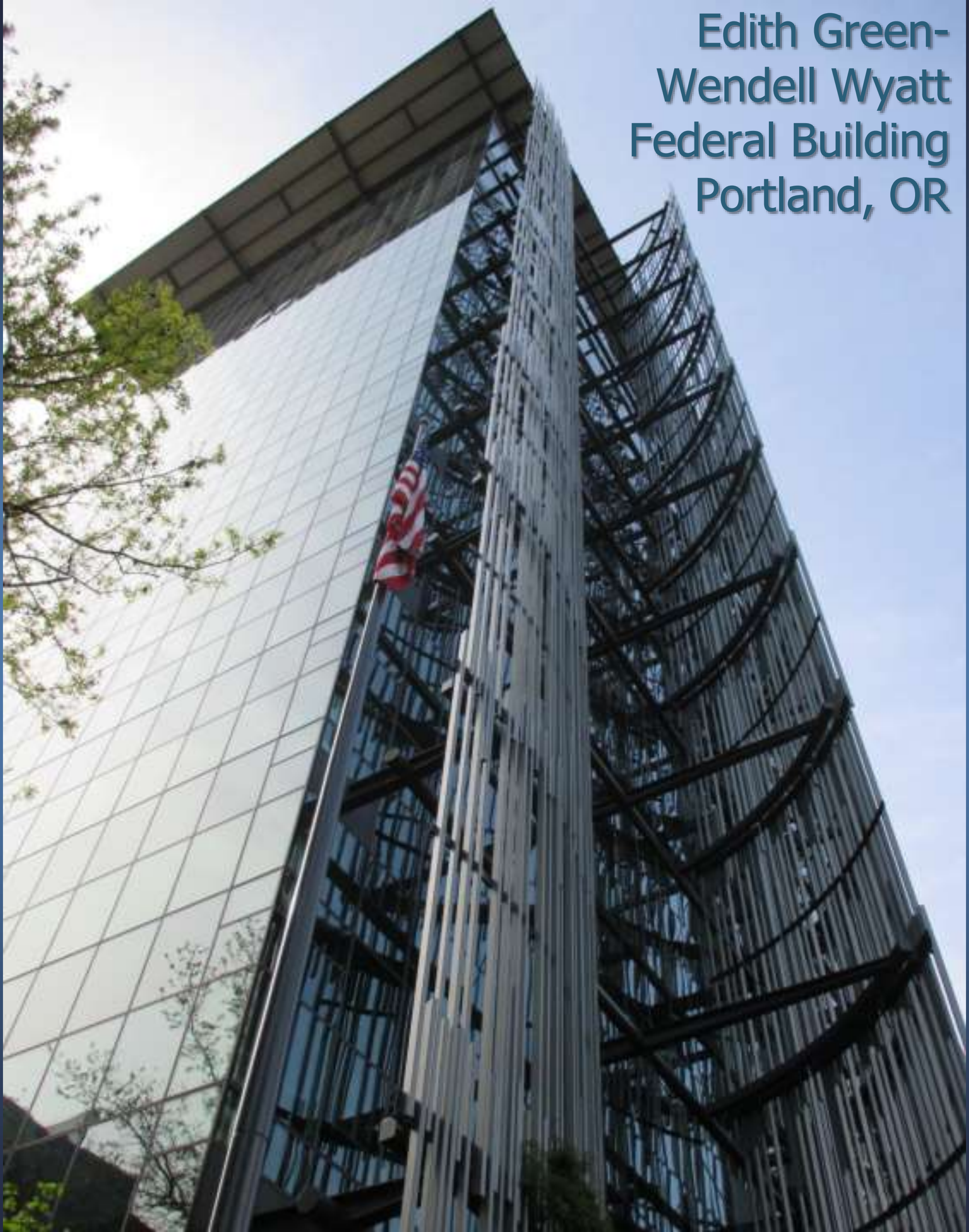
Methodology
Building measurements

- Placed stick Daysimeters to collect continuous light measurements
  - Deskspaces located on all four façade orientations
  - Windows located on all four façade orientations
    - Circadian stimulus and photopic lux estimated at each deskspace and compared to how much it reached the window

Edith Green-Wendell Wyatt Federal Building Portland, OR



Results: Spectroradiometric measurements

Edith Green-Wendell Wyatt Federal Building

Winter

Deskspace Locations	Illuminance	Approximate Contribution (+/- 10%)		Color Temperature	Circadian Stimulus (up to 0.7)
	Lux	Electric (%)	Day (%)	CCT (K)	Average CS
A	678	33%	67%	5031	0.39
B	335	86%	14%	3296	0.32
Orientations					
E	456	62%	38%	4180	0.36
N	393	66%	34%	4012	0.34
S	766	50%	50%	4183	0.40
W	412	59%	41%	4279	0.35
Floors					
4	379	71%	29%	3685	0.31
12	571	50%	50%	4498	0.41
17	570	57%	44%	4308	0.37

Late Spring

Deskspace Locations	Illuminance	Approximate Contribution (+/- 10%)		Color Temperature	Circadian Stimulus (up to 0.7)
	Lux	Electric (%)	Day (%)	CCT (K)	Average CS
A	865	30%	70%	5321	0.45
B	344	81%	19%	3632	0.29
Orientations					
E	675	59%	41%	4272	0.36
N	1001	40%	60%	5017	0.49
S	302	65%	35%	4170	0.29
W	413	57%	43%	4396	0.32
Floors					
4	415	68%	32%	3968	0.33
12	487	63%	37%	4242	0.34
17	896	35%	65%	5175	0.43

Overall, building receives good circadian stimulation, especially in higher floors and on deskspaces close to windows

- Deskspaces located near the window receive more light
- North and East façades receive more daylight contribution
- Daylight contribution increases with floor heights

There is a seasonal difference in the contribution of daylight into the space

- Greater contribution of daylight in the North façade during late spring
- Increased daylight contribution in the South façade during winter

(Photo courtesy of Litecontrol, Inc.)

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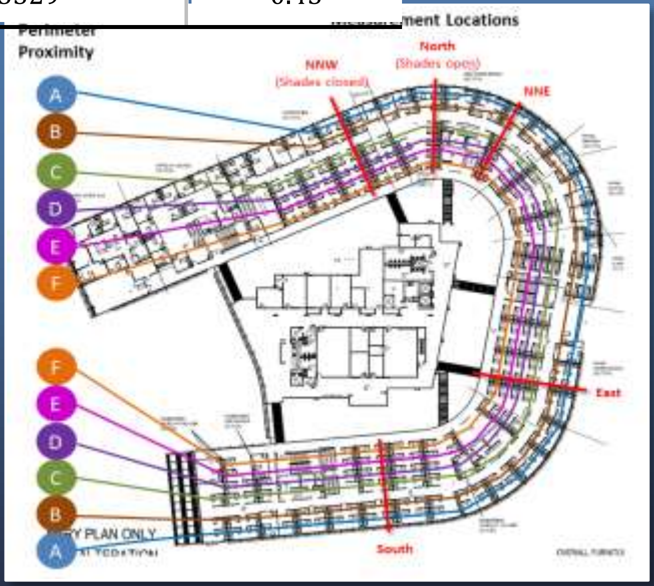
Results

Federal Center South (winter only)

Deskspace Locations	Illuminance			Color Temperature	Circadian Stimulus (up to 0.7)
	Photopic Lux	Electric (%)	Day (%)	CCT (K)	Average CS
A	598	11%	89%	4558	0.29
B	203	65%	35%	3594	0.21
C	404	11%	89%	5492	0.38
D	168	69%	31%	3659	0.15
E	389	19%	81%	4663	0.30
F	2208	0.4%	99.6%	5329	0.43

- Deskspaces located close to windows (A) and below skylights (C) are the ones with the greatest CS/daylight contributions
- Deskspaces located near the atrium has the highest CS/daylight contribution, but glare is also an issue



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Photometric measurements

GSA Central Office (1800 F Street, Washington, D.C.)

Deskspace Locations	Illuminance Lux	Approximate Contribution (+/- 10%) Electric (%)	Approximate Contribution (+/- 10%) Day (%)	Color Temperature CCT (K)	Circadian Stimulus (up to 0.7) Average CS
A	360	63%	37%	4029	0.26
B	322	65%	35%	3917	0.23
Orientations					
E	457	69%	31%	3873	0.31
N	336	81%	19%	3905	0.23
S	232	56%	44%	4138	0.25
W	265	48%	52%	4054	0.19
Floors					
G	279	73%	27%	3776	0.19
2	378	63%	37%	3984	0.29
7	391	56%	44%	4151	0.29

- Deskspaces are parallel to windows, so there is not much difference in CS measurements between deskspaces A and B
- Building orientation may not reflect seating arrangements
- Ground floor has the lowest CS values and the least contribution from daylight

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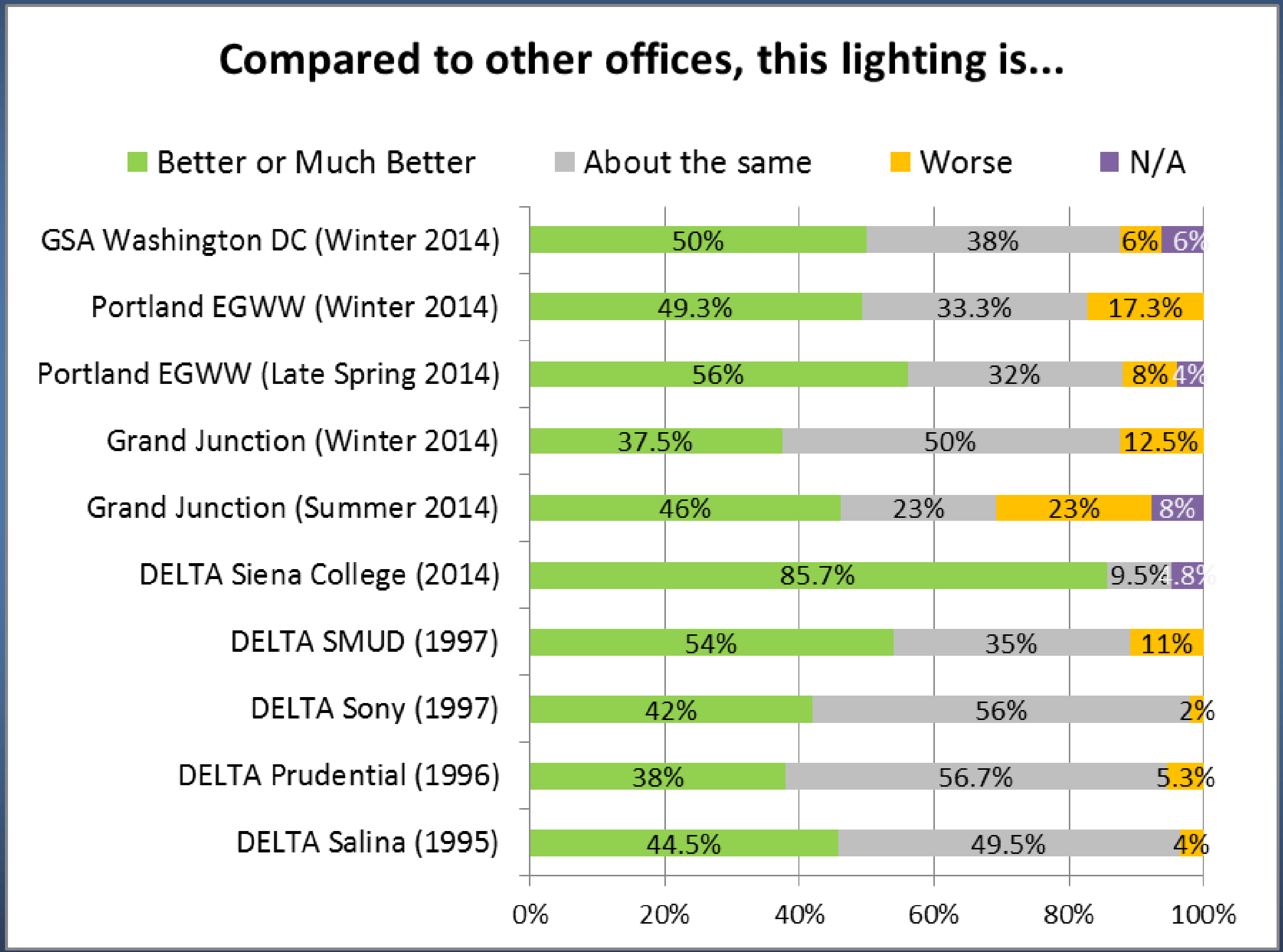
Subjective evaluation



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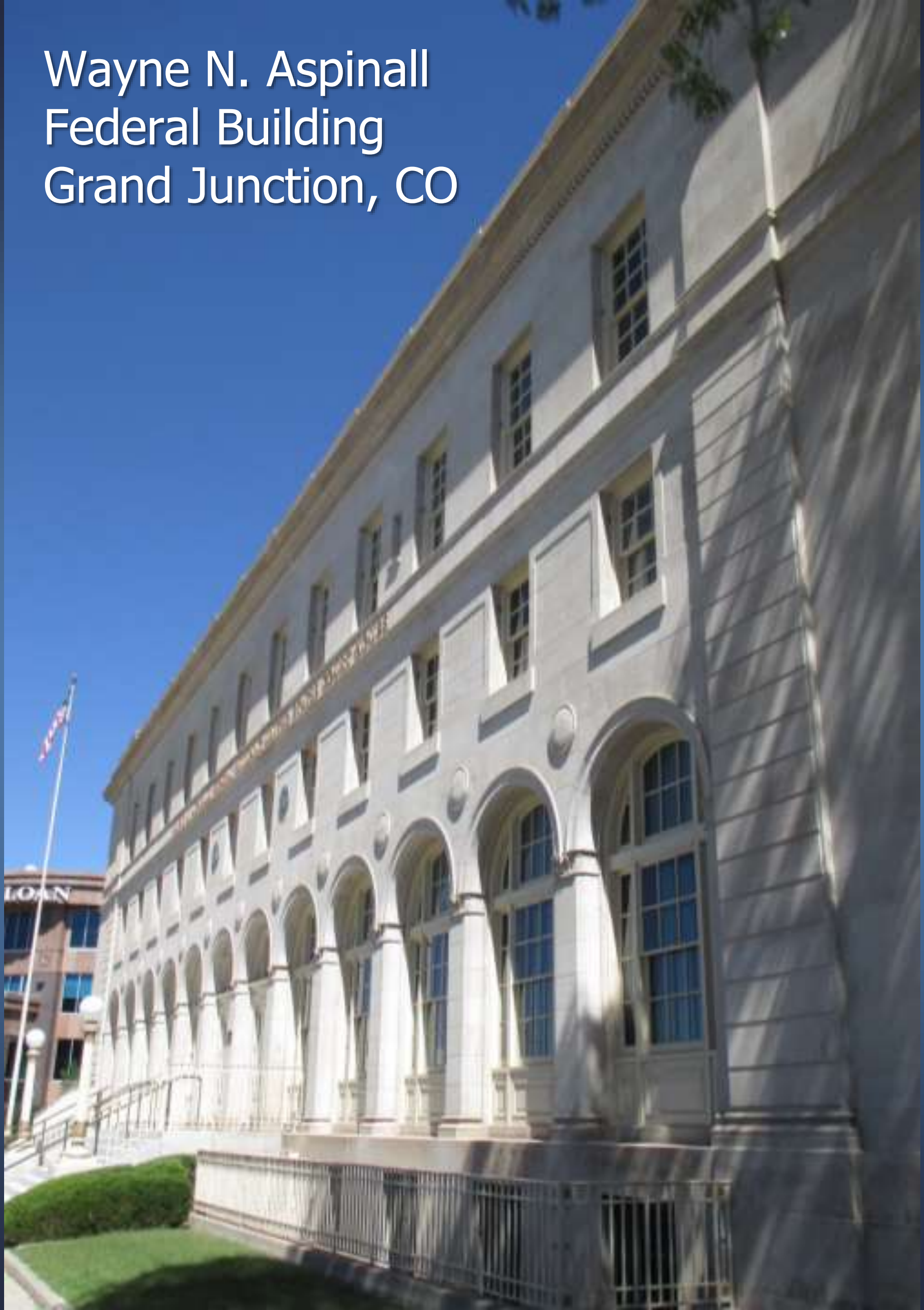
Personal light exposures

- The LRC 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



Personal light exposures
Wayne N. Aspinall Federal Building

		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)

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Circadian entrainmnet and sleep quality

Wayne N. Aspinall Federal Building

		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

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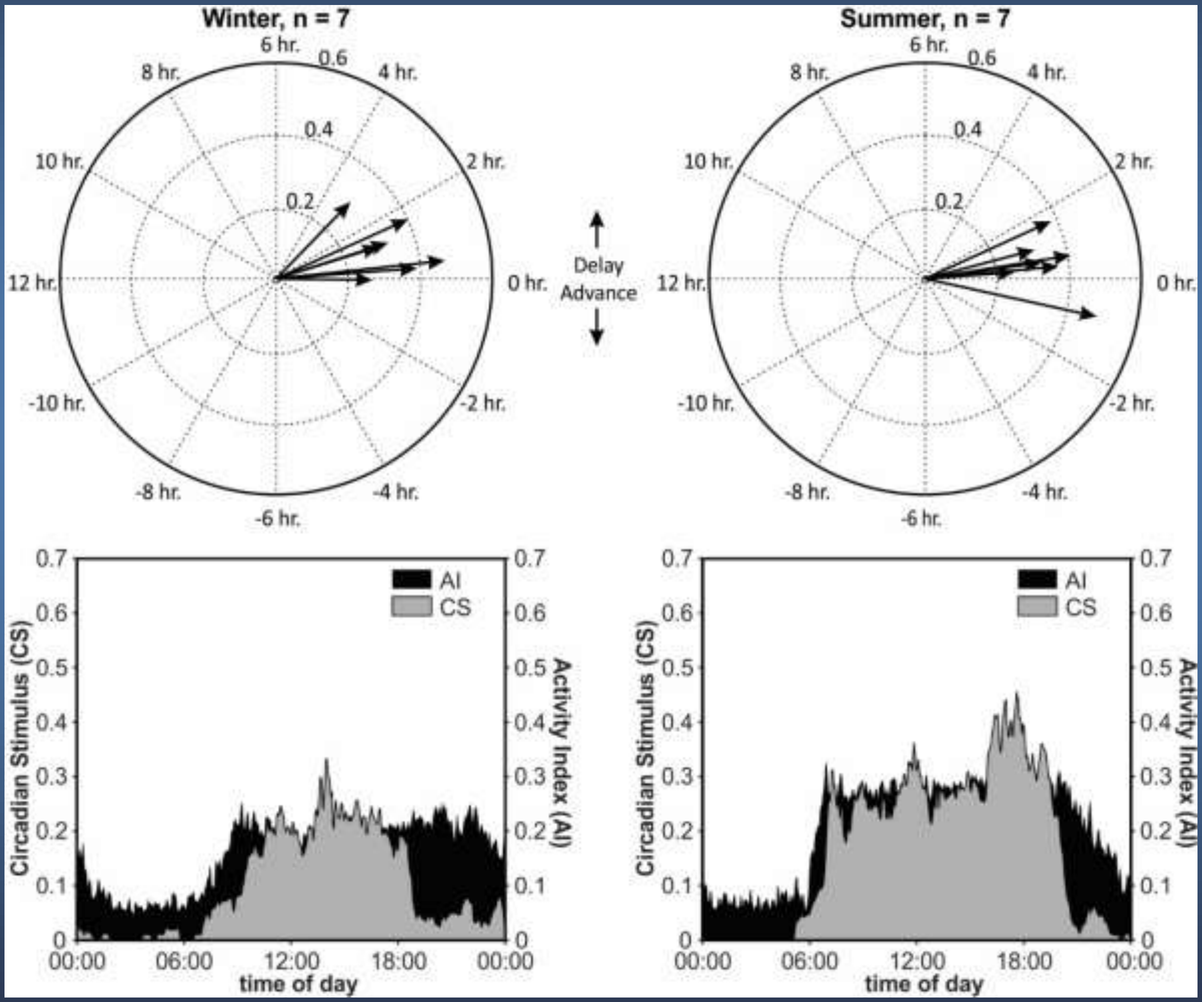
Phasor analyses
Wayne N. Aspinall Federal Building



Figueiro and Rea, in press

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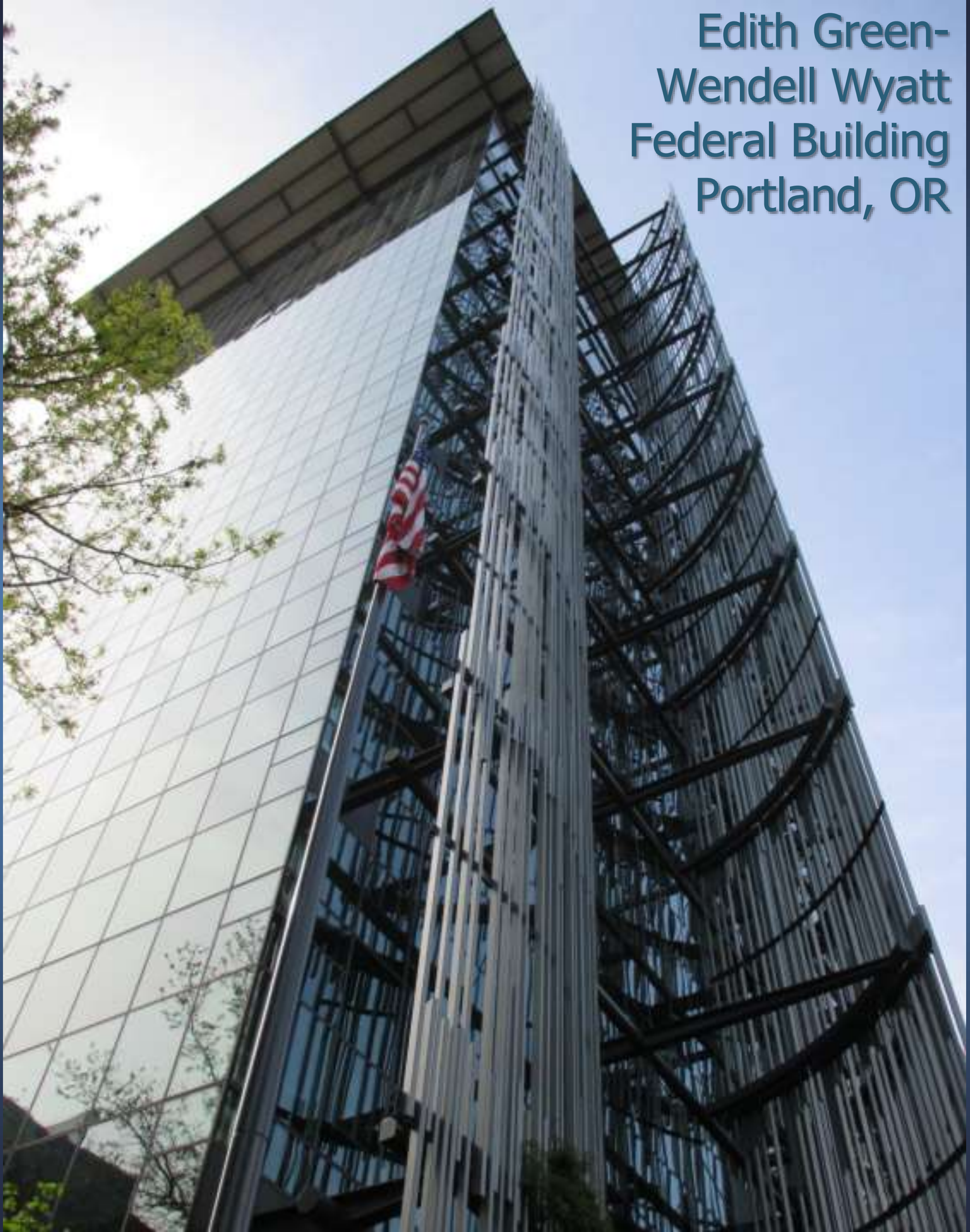
Edith Green-Wendell Wyatt Federal Building Portland, OR



Personal light exposures

Edith Green-Wendell Wyatt Federal Building

		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

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Circadian entrainment and sleep quality

Edith Green-Wendell Wyatt Federal Building

		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

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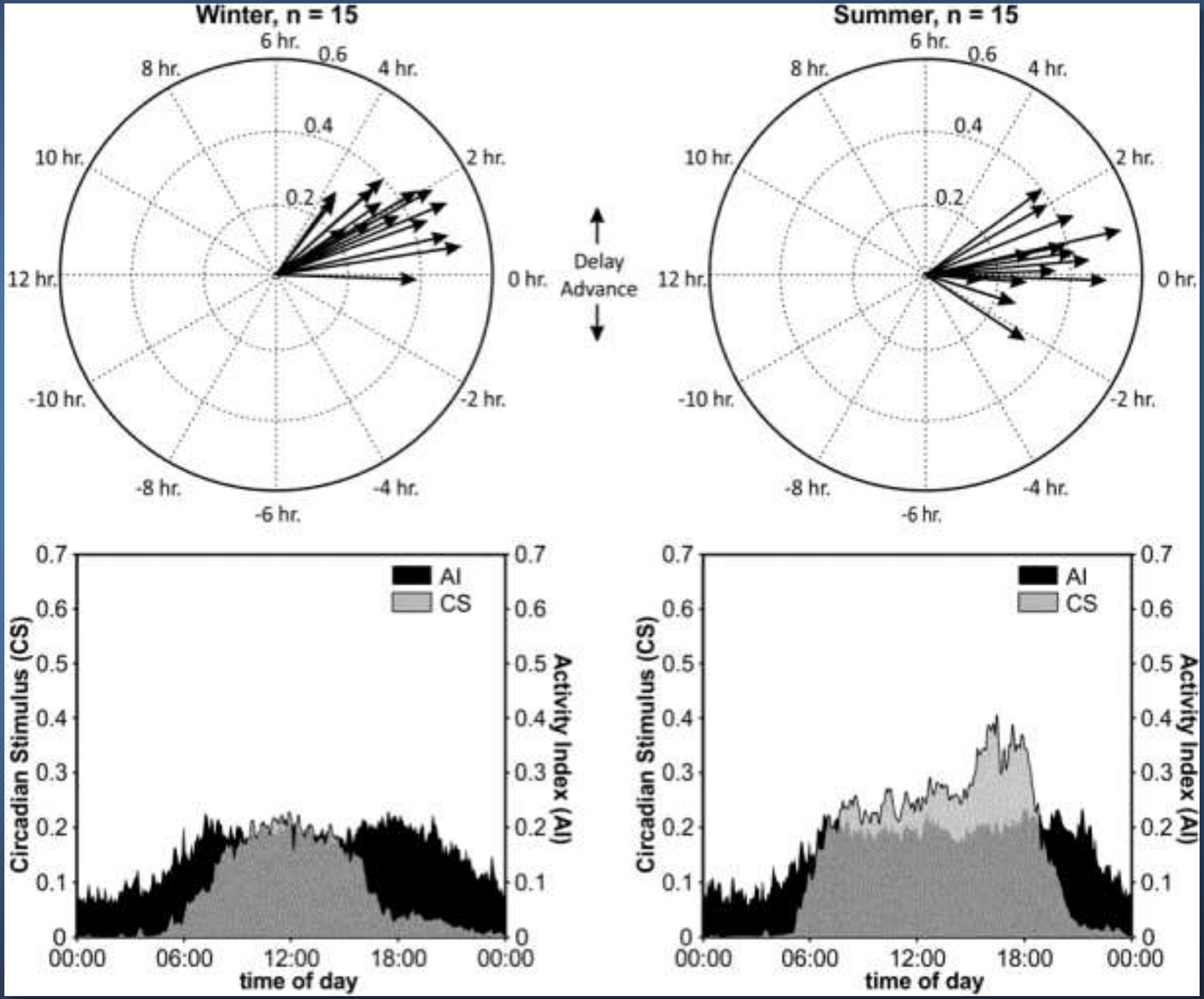
Phasor analyses
Edith Green-Wendell Wyatt Federal Building



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GSA Central Office
Washington, D.C.

Personal light exposures

GSA Central Office and Regional Office Building

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
	Median	0.10	171	27	0.09	169	23	0.13	161	77	0.04	32	12
	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
	Median	0.10	169	28	0.09	169	23	0.14	172	83	0.04	33	12
	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
	Median	0.09	176	20	0.09	236	21	0.06	55	29	0.02	16	8
	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.

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

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Circadian entrainment and sleep quality

GSA Central Office and Regional Office Building

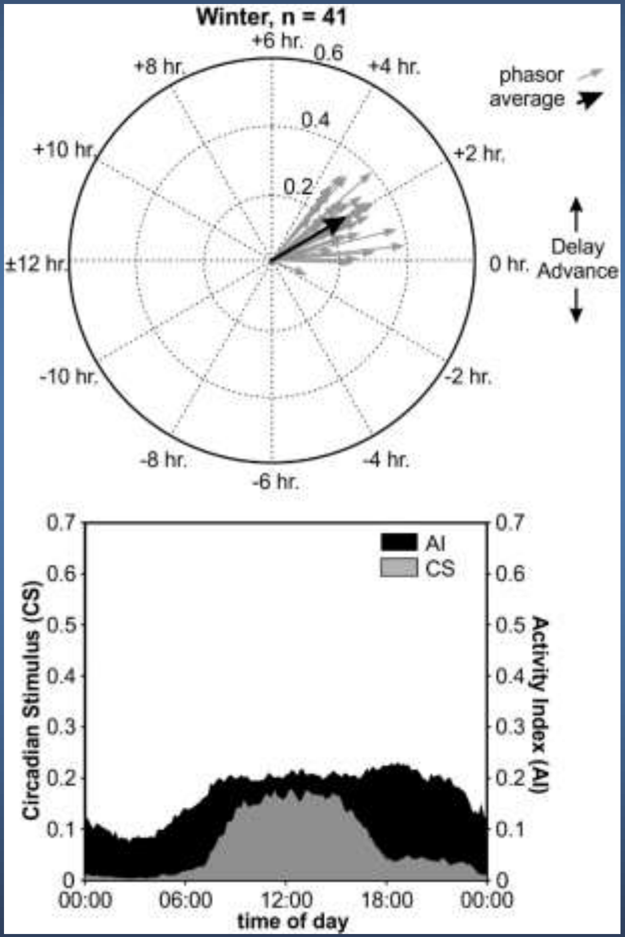
	location	Phasor		Sleep		
		Magnitude	Angle (hours)	Actual Sleep Time (mins.)	Sleep Efficiency (%)	Sleep Onset Latency (mins.)
All	Mean	0.27	1.94	346	76%	27
	Median	0.27	2.02	344	77%	18
	Std Dev	0.07	1.21	43	9%	29
1800 F	Mean	0.27	1.91	345	76%	23
	Median	0.27	1.99	344	77%	17
	Std Dev	0.07	1.21	40	9%	23
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*

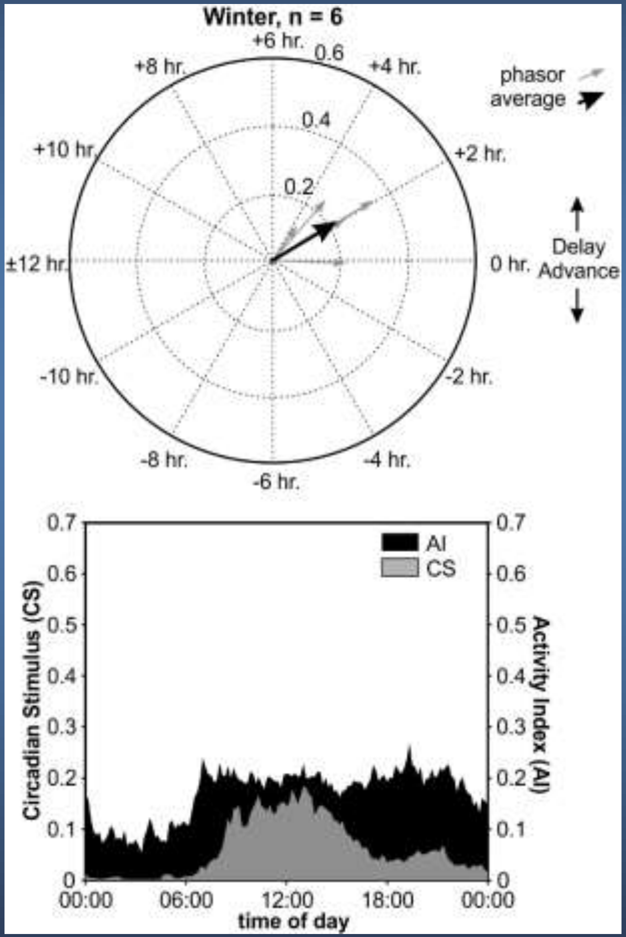
Asterisks (*) indicate statistically significant values.

- 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

Phasor analysis (all days)

GSA Central Office





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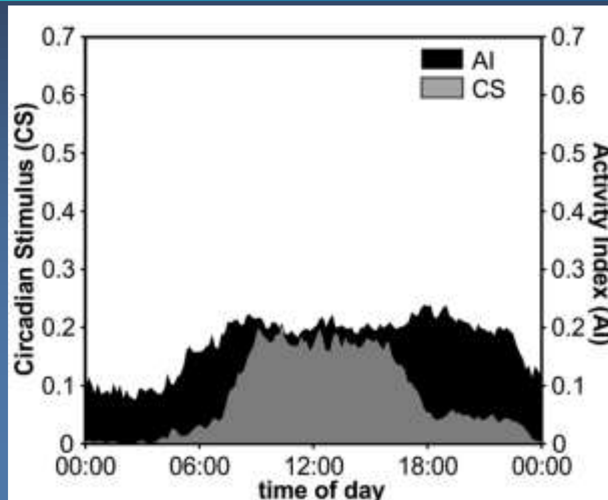
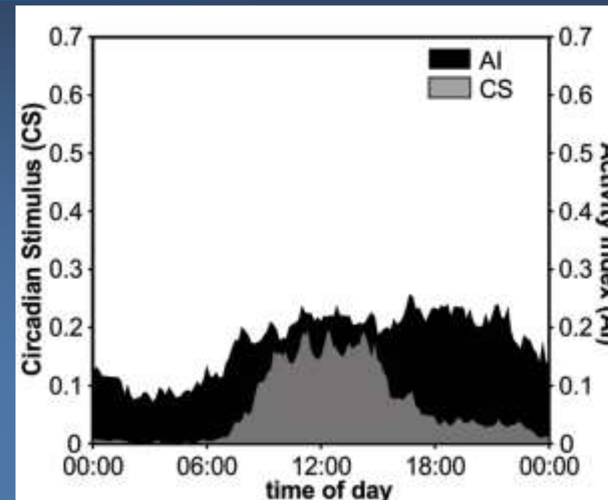
Phasor analyses (working days)

GSA Central Office

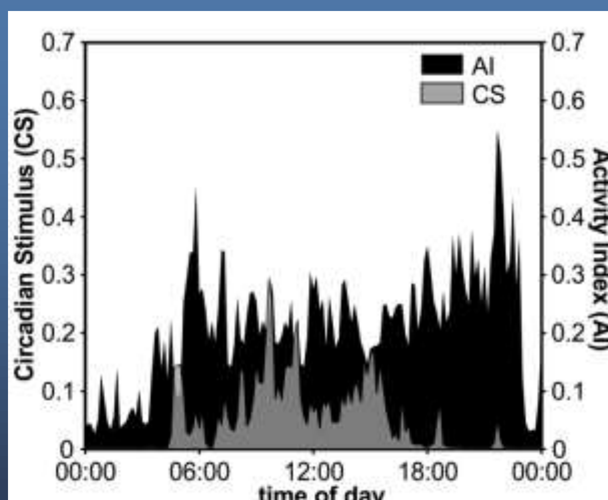
1800 F
CS = 0.15

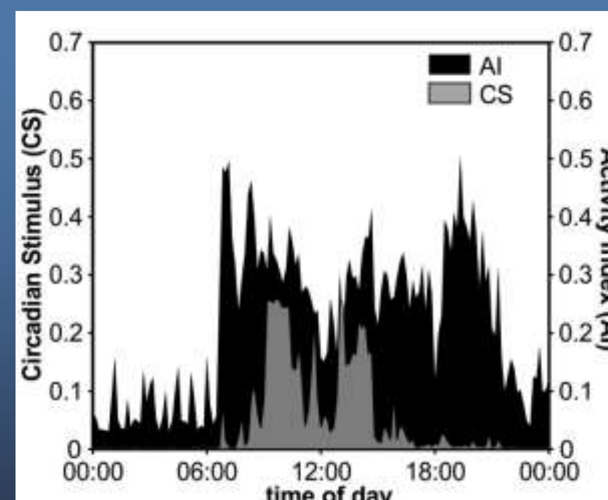




1800 F
CS = 0.09

ROB
CS = 0.06





ROB
CS = 0.10

Office

Not in office

Discussion

- 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

Discussion

- 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

Limitations and future work

- Lack of a larger sample size in control building
- Workers will not stay in a single place in office
  - Pendant measurements may be underestimating circadian light exposures
- Telecommute may reduce overall light exposure
  - Workers receive the greatest amount of light at work (except for the control building)
- Individual differences may play a role
  - It is not known how people cope with dark winters, especially in the NW (coffee intake?)
- CS threshold is not known; neither is the relationship between amount and duration of exposure
  - A CS of 0.1 seems to be the threshold, but further studies are needed to test this hypothesis

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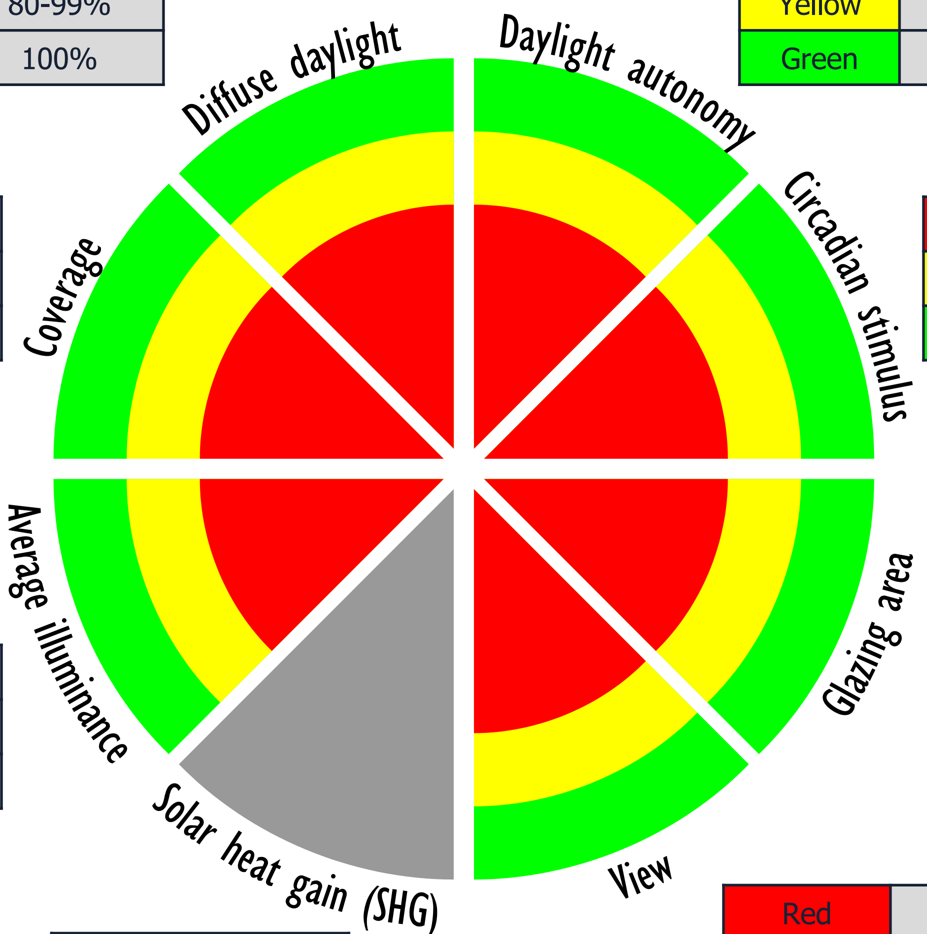
How can this information change practice?

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%

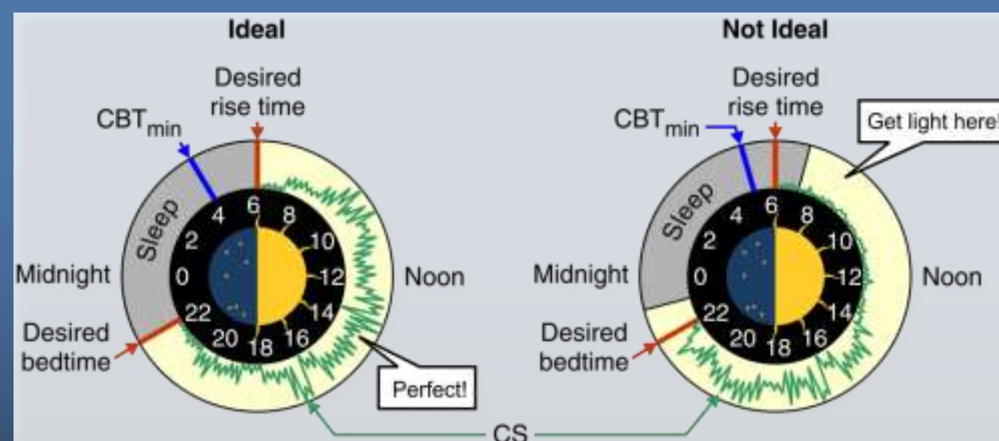
Red	Below 10 fc
Yellow	10-49 fc; > 500 fc
Green	50-500 fc

Expressed in btu/ft²/day

Red	No view
Yellow	Sky
Green	Ground & sky

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



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Office of Naval Research (N00014-11-1-0572)
Army Research Office

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Thank you!
www.lrc.rpi.edu

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