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
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

\[ \text{circa} = \text{about; dies} = \text{day} \]

- 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

...also the major disruptor

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

Performance, Well-being, Satisfaction, and Comfort

Visual System

Appearance

Visual Performance

Circadian System

Phase Shift

Alerting Effects

Intensity
Spectrum
Distribution
Timing
Duration

Culture, Experience, Expectations

IESNA. 9th ed
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
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
Results: Spectroradiometric measurements
Edith Green-Wendell Wyatt Federal Building

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
Federal Center South
Seattle, WA

(Photo courtesy of Litecontrol, Inc.)
Results
Federal Center South (winter only)

<table>
<thead>
<tr>
<th>Deskspace Locations</th>
<th>Illuminance</th>
<th>Color Temperature</th>
<th>Circadian Stimulus (up to 0.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Photopic Lux</td>
<td>Electric (%)</td>
<td>Day (%)</td>
</tr>
<tr>
<td>A</td>
<td>598</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>B</td>
<td>203</td>
<td>65%</td>
<td>35%</td>
</tr>
<tr>
<td>C</td>
<td>404</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>D</td>
<td>168</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>E</td>
<td>389</td>
<td>19%</td>
<td>81%</td>
</tr>
<tr>
<td>F</td>
<td>2208</td>
<td>0.4%</td>
<td>99.6%</td>
</tr>
</tbody>
</table>

- 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.
GSA Central Office
Washington, D.C.
# Photometric measurements

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

<table>
<thead>
<tr>
<th>Deskspaces Locations</th>
<th>Illuminance</th>
<th>Approximate Contribution (+/- 10%)</th>
<th>Color Temperature</th>
<th>Circadian Stimulus (up to 0.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lux</td>
<td>Electric (%)</td>
<td>Day (%)</td>
<td>CCT (K)</td>
</tr>
<tr>
<td>A</td>
<td>360</td>
<td>63%</td>
<td>37%</td>
<td>4029</td>
</tr>
<tr>
<td>B</td>
<td>322</td>
<td>65%</td>
<td>35%</td>
<td>3917</td>
</tr>
</tbody>
</table>

### Orientations

<table>
<thead>
<tr>
<th></th>
<th>Lux</th>
<th>Electric (%)</th>
<th>Day (%)</th>
<th>CCT (K)</th>
<th>Average CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>457</td>
<td>69%</td>
<td>31%</td>
<td>3873</td>
<td>0.31</td>
</tr>
<tr>
<td>N</td>
<td>336</td>
<td>81%</td>
<td>19%</td>
<td>3905</td>
<td>0.23</td>
</tr>
<tr>
<td>S</td>
<td>232</td>
<td>56%</td>
<td>44%</td>
<td>4138</td>
<td>0.25</td>
</tr>
<tr>
<td>W</td>
<td>265</td>
<td>48%</td>
<td>52%</td>
<td>4054</td>
<td>0.19</td>
</tr>
</tbody>
</table>

### Floors

<table>
<thead>
<tr>
<th></th>
<th>Lux</th>
<th>Electric (%)</th>
<th>Day (%)</th>
<th>CCT (K)</th>
<th>Average CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>279</td>
<td>73%</td>
<td>27%</td>
<td>3776</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>378</td>
<td>63%</td>
<td>37%</td>
<td>3984</td>
<td>0.29</td>
</tr>
<tr>
<td>7</td>
<td>391</td>
<td>56%</td>
<td>44%</td>
<td>4151</td>
<td>0.29</td>
</tr>
</tbody>
</table>

- 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
Subjective evaluation

Compared to other offices, this lighting is...

<table>
<thead>
<tr>
<th>Office</th>
<th>Better or Much Better</th>
<th>About the same</th>
<th>Worse</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSA Washington DC (Winter 2014)</td>
<td>50%</td>
<td>38%</td>
<td>6%</td>
<td>6%</td>
</tr>
<tr>
<td>Portland EGWW (Winter 2014)</td>
<td>49.3%</td>
<td>33.3%</td>
<td>17.3%</td>
<td></td>
</tr>
<tr>
<td>Portland EGWW (Late Spring 2014)</td>
<td>56%</td>
<td>32%</td>
<td>8%</td>
<td>2%</td>
</tr>
<tr>
<td>Grand Junction (Winter 2014)</td>
<td>37.5%</td>
<td>50%</td>
<td>12.5%</td>
<td></td>
</tr>
<tr>
<td>Grand Junction (Summer 2014)</td>
<td>46%</td>
<td>23%</td>
<td>23%</td>
<td>8%</td>
</tr>
<tr>
<td>DELTA Siena College (2014)</td>
<td>85.7%</td>
<td>9.5%</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>DELTA SMUD (1997)</td>
<td>54%</td>
<td>35%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>DELTA Sony (1997)</td>
<td>42%</td>
<td>56%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>DELTA Prudential (1996)</td>
<td>38%</td>
<td>56.7%</td>
<td>5.3%</td>
<td></td>
</tr>
<tr>
<td>DELTA Salina (1995)</td>
<td>44.5%</td>
<td>49.5%</td>
<td>4%</td>
<td></td>
</tr>
</tbody>
</table>
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
Personal light exposures
Wayne N. Aspinall Federal Building

<table>
<thead>
<tr>
<th></th>
<th>Waking Average</th>
<th>Work Average</th>
<th>Post-Work Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ari-mean (CS)</td>
<td>Ari-mean (Lx)</td>
<td>Ari-mean (Lx)</td>
</tr>
<tr>
<td>Winter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.19</td>
<td>824</td>
<td>0.21</td>
</tr>
<tr>
<td>Median</td>
<td>0.18</td>
<td>728</td>
<td>0.21</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.04</td>
<td>559</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>0.28</td>
<td>1308</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>0.29</td>
<td>1036</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>0.06</td>
<td>864</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>0.004*</td>
<td>0.21</td>
<td>0.007*</td>
</tr>
<tr>
<td></td>
<td>0.005*</td>
<td>0.03*</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.28</td>
<td>1308</td>
<td>0.28</td>
</tr>
<tr>
<td>Median</td>
<td>0.29</td>
<td>1036</td>
<td>0.30</td>
</tr>
<tr>
<td>Std Dev</td>
<td>0.06</td>
<td>864</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>0.004*</td>
<td>0.21</td>
<td>0.007*</td>
</tr>
<tr>
<td></td>
<td>0.005*</td>
<td>0.03*</td>
<td>0.02*</td>
</tr>
<tr>
<td></td>
<td>p value</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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)
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

Asterisks (*) indicate statistically significant values.
Phasor analyses
Wayne N. Aspinall Federal Building

Figueiro and Rea, in press
Personal light exposures
Edith Green-Wendell Wyatt Federal Building

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

<table>
<thead>
<tr>
<th></th>
<th>Waking Average</th>
<th>Work Average</th>
<th>Post-Work Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ari-mean (CS)</td>
<td>Ari-mean (Lx) Geomean (Lx)</td>
<td>Ari-mean (CS)</td>
</tr>
<tr>
<td>Winter</td>
<td>Mean</td>
<td>0.15</td>
<td>219</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.14</td>
<td>162</td>
</tr>
<tr>
<td></td>
<td>Std Dev</td>
<td>0.05</td>
<td>150</td>
</tr>
<tr>
<td>Summer</td>
<td>Mean</td>
<td>0.26</td>
<td>1094</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>0.24</td>
<td>838</td>
</tr>
<tr>
<td></td>
<td>Std Dev</td>
<td>0.06</td>
<td>904</td>
</tr>
<tr>
<td>p value</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>
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.
Phasor analyses

Edith Green-Wendell Wyatt Federal Building
### Personal light exposures

#### GSA Central Office and Regional Office Building

<table>
<thead>
<tr>
<th>Location</th>
<th>Waking Average</th>
<th>Work Average (out of office)</th>
<th>Work Average (at office)</th>
<th>Post-Work Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ari-Mean (CS)</td>
<td>Illuminance (Lx)</td>
<td>Ari-Mean (CS)</td>
<td>Illuminance (Lx)</td>
</tr>
<tr>
<td>All</td>
<td>0.10</td>
<td>221</td>
<td>31</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>171</td>
<td>27</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>186</td>
<td>17</td>
<td>0.05</td>
</tr>
<tr>
<td>1800 F</td>
<td>0.11</td>
<td>222</td>
<td>32</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>169</td>
<td>28</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>192</td>
<td>17</td>
<td>0.05</td>
</tr>
<tr>
<td>ROB</td>
<td>0.09</td>
<td>212</td>
<td>26</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>0.09</td>
<td>176</td>
<td>20</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>0.04</td>
<td>145</td>
<td>18</td>
<td>0.02</td>
</tr>
<tr>
<td>p value</td>
<td>0.49</td>
<td>0.91</td>
<td>0.47</td>
<td>0.81</td>
</tr>
</tbody>
</table>

* 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
GSA Central Office and Regional Office Building

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
Phasor analyses (working days)
GSA Central Office

1800 F
CS = 0.15

ROB
CS = 0.06

1800 F
CS = 0.09

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, desk space 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
How can this information change practice?
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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www.lrc.rpi.edu

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