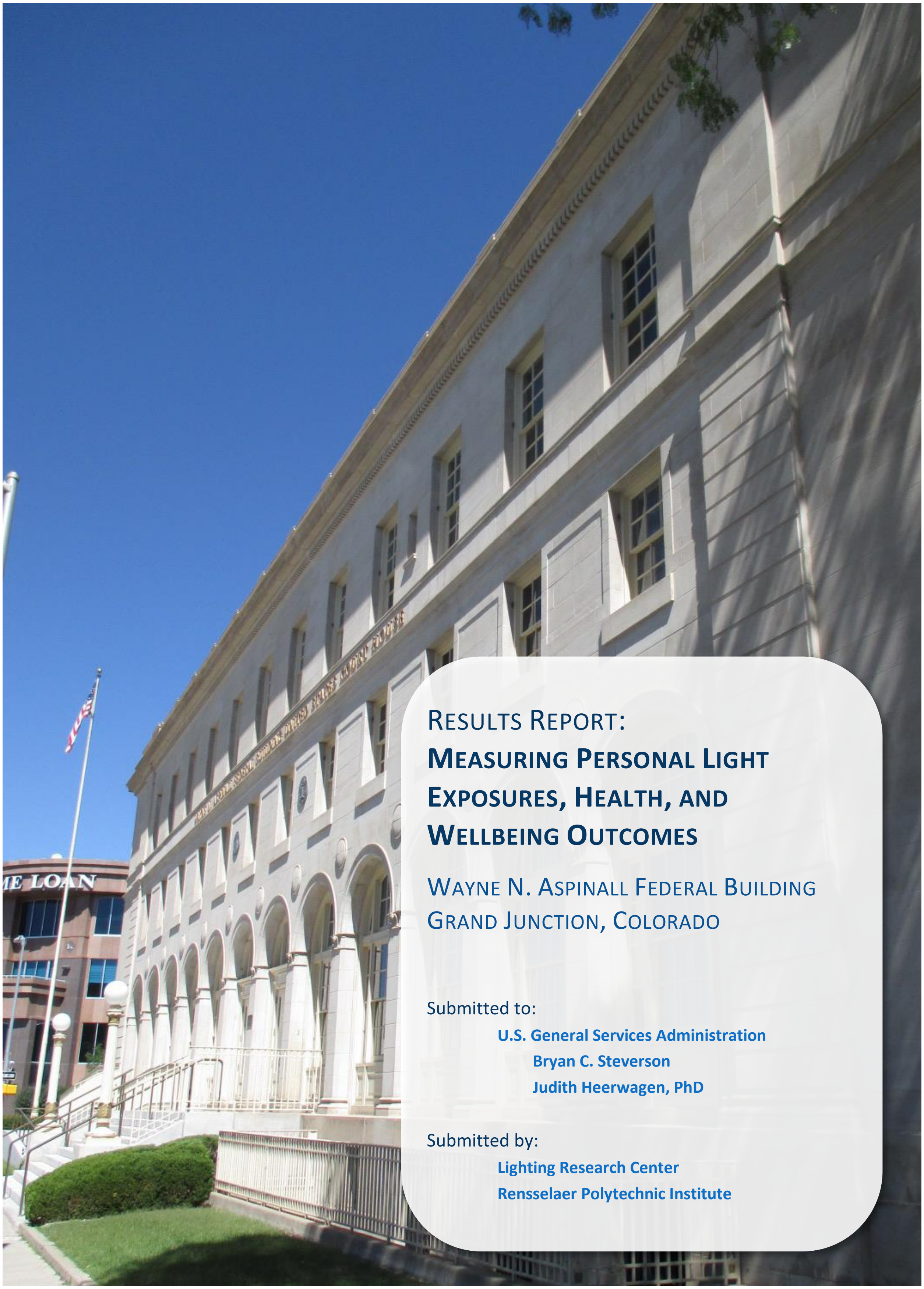


RESULTS REPORT:

MEASURING PERSONAL LIGHT EXPOSURES, HEALTH, AND WELLBEING OUTCOMES

WAYNE N. ASPINALL FEDERAL BUILDING GRAND JUNCTION, COLORADO

Submitted to:

U.S. General Services Administration

Bryan C. Steverson

Judith Heerwagen, PhD

Submitted by:

Lighting Research Center

Rensselaer Polytechnic Institute

RESULTS REPORT: MEASURING PERSONAL LIGHT EXPOSURES, HEALTH, AND WELLBEING OUTCOMES

WAYNE N. ASPINALL FEDERAL BUILDING
GRAND JUNCTION, COLORADO

SUBMITTED MARCH 14, 2014

REVISED/UPDATED JULY 31, 2014

V2: REVISED/UPDATED MAY 18, 2016

LIGHTING RESEARCH CENTER
21 UNION STREET
TROY, NY 12180

WWW.LRC.RPI.EDU

EXECUTIVE SUMMARY

Lighting design for office buildings has focused largely on the amount of light needed for work, strategies to reduce visual discomfort, and the use of daylight as a means to reduce energy in buildings. However, the lighting characteristics affecting the biological clock are different than those affecting the visual system. Little attention has been given to understanding how light affects occupants' psychological and physiological systems, including circadian functions that regulate sleep, mood, and alertness. Daylight is an ideal light source for the circadian system, but it is not known whether those who work in spaces that have daylight are indeed receiving enough light to promote circadian entrainment while in their office spaces.

Researchers from the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, together with U.S. General Services Administration (GSA) staff assessed office occupants' experience of light to identify health outcomes linked to measured light exposure. If health benefits are identified, this could have far-reaching effects on sustainable lighting design as not just a means to achieve energy efficiency goals but a means to enhance the health and wellbeing of federal workers, improve overall work effectiveness, and reduce long term health problems associated with circadian disruption (including sleep problems, mood disorders, and cardiovascular impacts). Furthermore, new technologies such as LED lighting could enable greater control over both the amount of light and its spectral characteristics, both of which are known to influence circadian processes and health outcomes in experimental settings.

Presented here are data from office workers at the Wayne N. Aspinall Federal Building in Grand Junction, Colorado. Data are from 11 participants who agreed to wear the Daysimeter in the winter months and 8 participants who agreed to repeat the study during the summer months. The Daysimeter is a calibrated light and activity meter that collects data for 7 consecutive days. In addition to wearing the device while awake (as a pendant) and during sleep (on the wrist), participants filled out a series of self-reports probing their sleep quality and mood. All participants in the building were invited to participate in the study and those who demonstrated interest received additional information about how to enroll in the study.

During the winter months, results showed that the circadian stimulus (CS) experienced by participants was low irrespective of desk locations in the building. Even though CS in the building was low, it was certainly higher than what they were experiencing at home (early morning and evenings). In order to verify the amount of circadian light participants were experiencing at work, LRC researchers calculated the CS values between 8 a.m. and 5 p.m.; the mean CS went from approximately 0.1 (total light exposure while awake) to approximately 0.2 (geometric mean lux level on the devices was 40 lux). A CS value of 0.1 is representative of a stimulus that would result in 10% melatonin suppression if that light were presented at night for 1 hour. It is a surrogate for how much that light stimulus is activating the circadian system. Values above 0.3-0.4 for one hour duration are believed to be a strong stimulation of the circadian system. A few participants reported feeling depressed and having sleep problems. Sleep efficiency was low in this group of people and actual sleep (in minutes) was less than 6 hours.

During the summer months, CS values were greater than in the winter months during working hours and outside working hours, especially in the evening. On average, CS values were at 0.25 (geometric mean lux level on the devices was 106 lux). Self-reports of sleep, depression and mood also improved, even though some participants still reported being depressed and not sleeping well. Sleep efficiency was also higher and participants reported sleeping about 30 minutes longer in summer than in winter.

Some of the mood and sleep disturbances shown in the self-report data during the winter months may have been associated with life events that are independent of the amount of daytime exposure a participant was receiving. Window shades and furniture positions may be the reason why not enough daylight is reaching the workers' eyes, but this hypothesis needs to be further investigated. It is also not known whether the circadian system will adapt to lower light levels and whether this stimulus, given that it was the strongest they received during the day, would be sufficient to maintain entrainment to the 24-hour solar day. Overall, however, participants were exposed to higher light levels during working hours and outside working hours in the summer than in the winter. Self-reports of sleep and mood as well as objective measures of sleep were also much improved in summer than in winter.

BACKGROUND

Lighting design for office buildings has focused largely on the amount of light for work, strategies to reduce visual discomfort, and the use of daylight as a means to reduce energy in buildings. Little attention has been given to understanding the experience of light, especially how it affects occupants' psychological and physiological systems, including circadian functions that regulate sleep, mood, alertness, and seasonal affective disorder (SAD).

It is well known that people like daylight in their work environment (Boyce et al. 2003; Cuttle 1983; Heerwagen & Heerwagen 1986; Hopkinson & Kay 1969). It has been argued that daylight also positively affects performance (Heschong Mahone Group 1999, 2003a, 2003b), but a cause-and-effect mechanism relating daylight to good performance has never been shown. Daylight is certainly not a special light source for vision, and the link between improved psychological wellbeing and improved performance cannot be reliably shown (Boyce 2004; Boyce & Rea 2001). But another line of research has emerged in the last 30 years, one potentially providing a physiological foundation for the widely accepted, yet again, undocumented belief that daylight improves productivity.

Basic research in circadian photobiology (Arendt 1995; Klein 1993; Moore 1997; Turek & Zee 1999) suggests that light plays a very important role in regulating the circadian (approximately 24-hour) patterns of human behavior by directly affecting the internal timing mechanisms of the body (Jewett et al. 1997; Lewy et al. 1982; Turek & Zee 1999; Van Someren et al. 1997). In contrast to the visual system, however, the circadian system requires higher light levels and shorter wavelength (i.e., blue) light to be activated (Brainard et al. 2001; McIntyre et al. 1989; Thapan et al. 2001). Moreover, since humans evolved under patterns of daylight and darkness, it is conceivable that the physical characteristics of daylight (i.e., quantity, spectrum, distribution, timing, and duration) might be fundamentally important to the regulation of human performance through the circadian system (Rea et al. 2002).

Light exposure through retinal non-visual pathways is an important regulator of circadian functions. Via the retinohypothalamic tract (RHT), neural signals are sent to the biological clock located in the suprachiasmatic nuclei (SCN). To regulate circadian functions such as body temperature, melatonin production, sleep, and activity-rest behavior, the SCN sends neural signals to other regulatory neural structures in the brain, most notably the pineal gland that stops production of the hormone melatonin when the retina is exposed to sufficient light at night. Light is the primary stimulus for regulating, through the SCN, the timing and the amount of melatonin produced by the pineal gland at night and, presumably, its effects on integrated behaviors such as subjective alertness and performance. When considering the importance of light to the circadian system and the lighting characteristics affecting it, daylight is a remarkably ideal light source for the circadian system.

Since light plays an important role in regulating human behavior through this circadian clock, daylight acting on the circadian system could conceivably positively affect performance. Present-day electric lighting is manufactured, designed and specified only to meet visual requirements, so daylight in buildings may indeed provide a special light source for driving and regulating human circadian behavior because it is dominated by short-wavelength radiation and has a high intensity. Furthermore, the use of new technologies such as LED lighting can enable greater control over both the amount of light and its spectral characteristics, both of which are known to influence circadian processes and health outcomes in experimental settings. Thus, it is reasonable to pursue the hypothesis that daylight might improve health and wellbeing through the circadian system, or, conversely, that chronic lack of daylight exposure during daytime hours may be promoting circadian disruption and negatively affecting health and mood.

However, there are no data currently available on the light-dark exposure patterns in people working in buildings that were designed to utilize daylight. Therefore, the overarching goal of this research is to assess occupant experience of light and to identify health outcomes linked to measured light exposure. If health benefits are identified, this could have far-reaching effects on sustainable lighting design as a means to achieve energy goals as well as to enhance the health and wellbeing of federal workers, improve overall work effectiveness, and reduce long term health problems associated with circadian disruption (including sleep problems, mood disorders, and cardiovascular impacts).

METHODS

PARTICIPANT RECRUITMENT

All participant recruitment was performed by U.S. General Services Administration (GSA) staff that did not have a direct working relationship with the employees and did not work in the building. The GSA staff running this project prepared an invitation letter to send to the building's tenants; there were no exclusion criteria to participate in this study. Email notices were sent out to employees.

An informational session with GSA staff and Lighting Research Center (LRC) researchers was held on September 25, 2013. All of the interested parties were invited to come and ask questions about the research protocol. LRC researchers recruited 11 participants for the winter portion of the study. Of these, 8 participants agreed to repeat the study in the summer months.

MEASUREMENT PROCEDURES

DEVICES

The Daysimeter, a calibrated light measuring device, was used to collect personal light and activity data. The physical characteristics of the Daysimeter and its calibration have been previously documented (Figueiro et al. 2012). Briefly, light sensing by the Daysimeter is performed with an integrated circuit sensor array (Hamamatsu model S11059-78HT) that includes optical filters for four measurement channels: red (R), green (G), blue (B), and infrared (IR). The R, G, B, and IR photo-elements have peak spectral responses at 615 nanometers (nm), 530 nm, 460 nm, and 855 nm, respectively. The Daysimeter is calibrated in terms of orthodox photopic illuminance (lux) and of circadian illuminance (CL_A). CL_A calibration is based upon the spectral sensitivity of the human circadian system. From the recorded CL_A values, it is then possible to determine the circadian stimulus (CS) magnitude, which represents the input-output operating characteristics of the human circadian system from threshold to saturation.

The goal of collecting personal light exposures from the workers is related to the effects of light on circadian rhythms. Circadian rhythms are every rhythm in the human body that oscillates with a period close to 24 hours, and this 24-hour oscillation repeats daily. An example of a robust circadian rhythm is the production of the hormone melatonin by the pineal gland. Melatonin is always released in the bloodstream at night and under conditions of darkness, and signals darkness to the body. Peak melatonin levels occur in the middle of the night, while the trough occurs in the middle of the day. In the absence of external cues, such as light-dark patterns, circadian rhythms will run with an average period of 24.2 hours; as a consequence, the peak and trough of melatonin would occur 10-15 minutes later every day. Morning light resets our biological clock daily and entrains us to the 24-hour solar day. Lack of entrainment has been associated with circadian disruption, which means that the peaks and troughs of various circadian rhythms are occurring at times in which it should not be occurring (e.g., melatonin levels are at peak during the daytime).

Furthermore, the lighting characteristics affecting our biological clock are different than those affecting our visual system. In brief, we need at least 10 times more light to activate our circadian system than to see. Light levels used in offices [e.g., 500 lux (approx. 50 fc) on the work plane; about 100-200 lux (approx. 10-20 fc) at the cornea] are sufficient for one to read black fonts on white paper, but are only slightly affecting the biological clock. The biological clock is sensitive to blue light (460 nm), while one aspect of the visual system (acuity) is maximally sensitive to yellow-green (555 nm). Biological clocks care about when the body is exposed to light over the course of the 24-hour day. Morning light will help us go to bed earlier and wake up earlier while evening light will help us go to bed later and wake up later. Therefore, being able to measure light that affects the circadian system using a calibrated device, and more importantly, being able to know when a person is exposed to circadian light over the course of the 24-hour period is important. The Daysimeter serves this purpose.

Daylight is an ideal light source for the circadian system, but it is not known whether those who work in spaces that have daylight are indeed receiving enough light to promote circadian entrainment while in their office spaces. More importantly, the amount of evening light may cancel out the effect of morning light; therefore, being able to measure light over the course of the waking period is imperative to understand the possible effects of light on health, mood and wellbeing. The goal of this project was to investigate, in buildings where daylight is prominent, the amount of circadian light one is being exposed to at work and outside working hours. This study complements the photometric measurements that are being performed in the same buildings and can help us understand how occupant behavior and/or design modifications affect personal light exposures in the building.

QUESTIONNAIRES

Participants completed several subjective questionnaires about mood and sleep habits once at the start of the study: Pittsburgh Sleep Quality Index, Karolinska Sleepiness Scale, PROMIS sleep disturbance, Positive and Negative Affect Schedule, and Center for Epidemiologic Studies Depression Scale.

The Pittsburgh Sleep Quality Index (PSQI): A subjective measure of sleep quality and patterns. It differentiates poor from good sleep by measuring 7 areas: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction. Scoring is based on a 0 to 3 scale and yields one global score; score of 5 or greater indicates a poor sleeper. (Buysse et al. 1989)

Karolinska Sleepiness Scale (KSS): A self-assessment of subjective sleepiness. The scale ranges from 1 to 9, with 1 = *most alert,* and 9 = *fighting sleep*. (Åkerstedt and Gillberg 1990)

PROMIS Sleep Disturbance-Short Form 8a: Eight questions regarding sleep quality (e.g., *my sleep was refreshing, I had difficulty falling asleep, my sleep was restless*…) on a scale of 1 – 5 (1 = *very much*, 2 = *quite a bit*, 3 = *somewhat*, 4 = *a little bit*, 5 = *not at all*). (Cella et al. 2010)

Positive and Negative Affect Schedule (PANAS): Consists of 10 positive effects (interested, excited, strong, enthusiastic, proud, alert, inspired, determined, attentive, and active) and 10 negative effects (distressed, upset, guilty, scared, hostile, irritable, ashamed, nervous, jittery, and afraid). Participants were asked to rate items on a scale from 1 to 5, based on the strength of emotion where 1 = *very slightly or not at all*, and 5 = *extremely*. (Watson et al. 1988)

Depression Scale (CES-D): A self-report designed to measure depressive symptoms consisting of a 20-item measure that asks how often over the past week subjects experienced symptoms associated with depression, such as restless sleep, poor appetite, and feeling lonely. Response options range from 0 to 3 for each item (0 = *rarely or none of the time*, 1 = *some or little of the time*, 2 = *moderately or much of the time*, 3 = *most or almost all the time*). Scores range from 0 to 60, with high scores (greater than 16) indicating greater depressive symptoms. (Radloff 1977)

Protocol

Participants signed a consent form approved by the Institute Review Board at Rensselaer Polytechnic Institute (IRB). Once enrolled in the study, participants were asked to wear a Daysimeter as a pendant for 7 consecutive days in the winter months (December 2013 and January 2014) and again in the summer months (May and June 2014). Participants were asked to wear the device on their wrist while sleeping at night to monitor their sleep/wake activity patterns.

During the 7-day data collection period, participants were asked to keep a sleep log of bedtime and wake time, sleep latency, quality of sleep, and naps. KSS was collected 4 times per day: wake, noon, dinner, bedtime.

The Daysimeter devices were mailed to participants, who were asked to return them in a pre-paid envelope after the 7-day period. No issues were reported with this method of delivering/returning the devices to the LRC.

Data Analyses

The Daysimeter data were analyzed and the following outcome measures were obtained:

Phasor Magnitude and Phasor Angle

Rea et al. (2008) proposed a quantitative technique to measure circadian disruption known as phasor analysis, which quantifies circadian disruption in terms of the phase and the amplitude relationships between the environmental light-dark pattern and behavioral response patterns. Phasor analysis makes it possible to interpret the light and activity data, sampled together over consecutive multiple days. To quantify circadian disruption using the Daysimeter data, we use the measured circadian light-dark pattern and activity-rest pattern. The relationship between these two sets of time-series data is quantified through phasor analysis, which incorporates a fast Fourier transform (FFT) power and phase analysis of the circular correlation function computed from the two data sets. Conceptually, each data set is joined end-to-end in a continuous loop. Correlation values (r) between the patterns of light-dark and activity-rest are then computed (e.g., every 5 minutes) as one set of data is rotated with respect to the other. An FFT analysis is then applied to the circular correlation function to determine the 24-hour amplitude and phase relationships between the light-dark data and the activity-rest data. The resulting vector, or phasor, quantifies, in terms of the 24-hour frequency, how closely tied the light and activity patterns are to a 24-hour pattern (phasor magnitude) as well as their relative temporal relationship (phasor angle). Phasor analysis is used to characterize the resonance between the 24-hour light-dark pattern and the 24-hour activity-rest pattern. The overall light level exposures are calculated by creating a mean 24-hour light-dark pattern from the hourly mean values for each participant. Since CS is a measure of the effectiveness of optical radiation on the retina for stimulating the human circadian system, the daily patterns of CS were used in the phasor analyses; the larger the phasor magnitude, the greater the resonance between these two rhythms.

Activity-rest Rhythms

Two other measures of activity-rest rhythms consolidation were computed: 1) inter-daily stability (IS), a ratio indicating the strength of coupling between the light-dark cycle and activity-rest rhythm over a 24-hour period; 2) intra-daily variability (IV), an indication of the fragmentation of the activity-rest rhythm (Van Someren et al. 1997).

Sleep Analyses

The sleep algorithm is based on the sleep analyses used by the Actiwatch Algorithm (Actiware-Sleep Version 3.4; Mini Mitter Co., Inc., now Philips Respironics). The algorithm developed for the Daysimeter data scores each data sample as “sleep” or “wake” based on the AI, the delta of the root mean square of acceleration recorded by the Daysimeter averaged over the sampling interval or epoch of 90 seconds. All of the following sleep measures using the Daysimeter data were based upon this binary sleep-wake score.

The following sleep parameters were calculated from the activity-rest data obtained with the Daysimeter at night:

- Time in bed is defined as the difference between wake time and bed time.
- Sleep start time is defined as the first 10-minute interval within the analysis period with one or fewer epochs scored as wake.
- Sleep end time is defined as the last 10-minute interval within the analysis period with one or fewer epochs scored as wake.
- Assumed sleep time is then found to be the difference between sleep end time and sleep start time.
- Actual sleep time is defined as the sum of epochs scored as sleep multiplied by the epoch length.
- Actual sleep time percent is simply the actual sleep time divided by the assumed sleep time.
- Actual wake time is calculated as the sum of epochs scored as wake multiplied by the epoch length.
- Actual wake time percent is the actual wake time divided by the assumed sleep time.
- Sleep efficiency is the percentage of time in bed that is spent sleeping, or actual sleep time divided by time in bed.
- Sleep onset latency is the period of time required for sleep onset after going to bed, it is calculated as the difference between sleep start and bed time.
- Sleep bouts are the number of continuous blocks of epochs scored as sleep.
- Wake bouts are the number of continuous blocks of epochs scored as wake.

- Mean sleep bout duration is the average length of the blocks of continuous sleep, calculated as actual sleep time divided by sleep bouts.
- Mean wake bout duration is the average length of blocks of continuous wake, calculated as actual wake time divided by wake bouts.

RESULTS

PARTICIPANTS' SEATING LOCATIONS

Table 1 shows the participants' seating locations and window orientations. Participants' seating locations in their offices did not change from when the study was conducted in the winter months to the summer months.

Table 1. All study participants' seating locations, window orientations, and type of office.

Participant No.	Dates	Floor	Window Orientation	Window Proximity	Type
1	December 2 – 8, June 9 – 16	3	North	1st row (close)	Open Plan Cubicle
2	December 9 – 15	2	South	Private	Private Office
3	December 9 – 15, June 9 – 16	2	South	1st row (close)	Open Plan Cubicle
4	December 9 - 15	2	South	1st row (close)	Open Plan Cubicle
5	December 9 – 15, June 9 – 14	3	South	1st row (close)	Open Plan Cubicle
6	December 9 – 15, June 16 – 22	1	North	1st row (close)	Open Plan Cubicle
7	December 9 – 15, June 16 – 21	1	West	1st row (close)	Open Plan Cubicle
8	December 9 – 15, June 9 – 16	2	East	1st row (close)	Private Office
9	January 6 – 12, June 16 – 23	3	NE corner	1st row (close)	Private Office
10	January 6 – 12	1	West	1st row (close)	Open Plan Cubicle
11	January 6 – 12	1	North	Private	Private Office

Sleep Analyses, Phasor Analyses and Self-Reports of Sleep and Mood (Winter Months)

Tables 2 – 6 show the individual results together with the mean, median, and standard error of the mean (SEM) of the sleep and phasor analyses from the Daysimeter data and the self-reports of sleep and mood questionnaires. Some interesting observations from the data follow.

- Based on the actigraphy data from the Daysimeter, it seems like the average sleep amount in this group of workers is, in general, low (close to 6 hours per night). Sleep efficiency is also low in this group.
- Sleep scores from self-reports are mixed. One scale (PSQI) suggests that 7 of 11 participants have sleep disturbances (scores above 5 signify sleep disturbances), while the PROMIS Global Score suggests that only two participants have moderate sleep disturbances (scores above 25 signify sleep disturbances).
- Notwithstanding the small sample size, the mean CS values (mean of 0.14) experienced by participants during their waking period were very low. The CS of 0.14 is equivalent to 14% melatonin suppression if that light was applied for one hour in the middle of the night, when melatonin levels are high. This suggests that the amount of light that participants were exposed to is likely not strongly stimulating the circadian system. While entrainment of the circadian system is not the same as acute melatonin suppression, there is no strong reason to believe that acute melatonin suppression and circadian entrainment have different sensitivity to light. On the other hand, it is important to keep in mind that the duration of exposure during working hours is much higher than one hour, and perhaps this amount of circadian stimulation is sufficient to maintain entrainment.
- Participants who were exposed to lower CS values tended to report sleeping worse and having more mood issues. Correlations were not statistically significant, however, most likely given the reduced sample size.
- Phasor magnitude was reasonably low in this population (mean of 0.26). A high phasor magnitude suggests entrainment to the 24-hour day/night cycle. For comparison, other data sets show that the mean phasor magnitude in school teachers and dayshift nurses (both very regular groups of people) was 0.52 and 0.46 respectively (Rea et al. 2011; Miller et al. 2010).
- Phasor angles (mean of 1.05) were within the normal population. The phasor angles for school teachers and dayshift nurses were 0.94 and 0.68.
- Depression scores were high in three participants. Two of the participants had the lowest CS values, which may explain their symptoms, but one of them received CS values similar to other participants. It is possible that life events of the three participants who reported feeling depressed are more likely affecting their scores more than the lighting.
- The same three participants who reported feeling depressed also reported high negative scores and low positive scores in the PANAS.

Some limitations of the data set include:

- A small sample size. Data needs to be collected on a larger sample population to make more definitive conclusions about the impact of daylight on health and wellbeing.
- A few of the participants, but one in particular, likely reported feeling more depressed than usual because of their life events; it is possible that the lighting in their environment may not have played a role in these self-report ratings.
- Research questions still unanswered are whether humans adapt to lower levels of light for the circadian system and whether a CS value of 0.1 or larger may be enough to maintain entrainment.

Table 2. Sleep analysis (winter).

Participant No.	Nights averaged	Actual sleep (min.)	Actual sleep (%)	Actual wake (min.)	Actual wake (%)	Sleep efficiency (%)	Latency (min.)
1	5	249	83%	50	17%	58%	107
2	5	363	91%	45	9%	67%	105
3	5	337	91%	36	9%	73%	84
4	5	313	88%	41	12%	70%	59
5	5	360	93%	30	7%	69%	121
6	5	365	85%	71	15%	69%	71
7	5	328	96%	14	4%	69%	116
8	5	361	86%	61	14%	71%	87
9	4	334	93%	25	7%	72%	90
10	5	307	89%	41	11%	62%	117
11	5	449	90%	49	10%	86%	19
Mean		342	90%	42	10%	70%	89
Median		337	90%	41	10%	69%	90
SEM		14.1	1.1%	4.6	1.1%	2.0%	8.8

Table 3. Phasor analysis (winter).

Participant No.	Phasor magnitude	Phasor angle	IS	IV	Daytime CS	Daytime lux Mean	Daytime lux Geo mean	Daytime lux Median
1	0.26	1.18	0.77	0.52	0.14	303	37	55
2	0.33	0.71	0.87	0.50	0.13	375	43	55
3*	0.36	2.34	0.72	0.59	0.22	1103	70	81
4	0.27	1.33	0.85	0.44	0.11	399	30	36
5	0.30	0.46	0.90	0.39	0.16	1900	51	95
6	0.26	1.06	0.85	0.71	0.10	318	25	32
7	0.21	0.28	0.73	0.76	0.15	966	0	67
8	0.17	2.25	0.83	0.56	0.13	955	38	42
9	0.26	0.31	0.58	0.86	0.19	2497	55	57
10	0.24	0.51	0.86	0.46	0.09	271	24	27
11	0.26	1.12	0.86	0.63	0.17	520	70	105
Mean	0.26	1.05	0.80	0.58	0.14	874	40	59
Median	0.26	1.06	0.85	0.56	0.14	520	38	55
SEM	0.02	0.22	0.03	0.04	0.01	221	6	8

Table 4. Self-reported sleep analysis (winter).

Participant No.	PSQI global score	PROMIS global score	PROMIS T-score
1	5	10	38.1
2	10	20	52.4
3	10	21	53.4
4	9	33	65.1
5	11	32	64
6	5	14	45.3
7	3	11	40.4
8	12	21	53.4
9	3	11	40.4
10	6	12	42.2
11	7	23	55.3
Mean	7.36	18.91	50
Median	7	20	52.4
SEM	0.97	2.47	2.84

Note: PSQI > 5 and PROMIS > 25 indicate sleep disturbances

Table 5. Self-reported mood (winter).

Participant No.	PANAS total positive	PANAS total negative	CES-D total score
1	36	14	0
2	35	13	10
3	29	26	13
4	13	27	18
5	24	11	6
6	33	13	4
7	41	13	1
8	18	30	23
9	32	12	2
10	23	15	7
11	14	24	19
Mean	27.09	18.00	9.36
Median	29.00	14.00	7.00
SEM	2.82	2.15	2.38

Note: CES-D > 16 indicates depression symptoms; PANAS pos (higher = better); PANAS neg (lower = better)

Table 6. Self-reported sleepiness (winter).

Participant No.	Day 1				Day 2				Day 3				Day 4				Day 5				Day 6				Day 7			
	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B
1	5	3	3	7	4	3	3	7	3	2	2	7	3	2	1	8	3	2	1	8	3	2	1	8	3	2	3	8
2	6	3	6	3	7.5	7	3	4	6	5	3	5	6	3	4	6	5	6	3	2	5	3	3	8	4	3	3	3
3	4	2	6	8	7	6	7	9	6	4	6	8	6	3	6	9	4	2	4	6	3	3	2	7	6	2	3	9
4	6	8	9	7	7	5	7	7	8	8	7	7	6	8	8	8	8	5	4	5	7	5	7	9	7	5	6	8
5	7	6	7	8	7	6	7	8	6	6	7	7	6	6	8	7	6	7	6	7	7	3	7	7	7	3	8	7
6	6	3	3	8	5	3	5	6	6	3	5	7	6	3	5	7	5	3	6	8	6	3	7	9	5	3	5	8
7	3	6	6	8	3	3	3	8	3	2	5	8	6	3	4	7	5	6	4	7	4	4	7	9	6	3	6	8
8	3	4	5	4	2	5	5	6	4	5	4	3	3	4	5	4	6	5	5	6	6	4	4	8	6	3	5	6
9	2	2	2	6	4	6	2	2	6	3	2	5	2	1	5	8	6	2	3	4	2	1	3	4	2	2	3	4
10	7	5	2	6	9	5	5	7	8	6	7	6	5	3	2	6	7	5	6	6	5	3	3	6	5	4	4	6
11	6	3	3	5	5	3	4	7	6	3	4	7	6	3	5	7	3	3	3	6	3	3	4	5	5	5	9	8
Mean	5.0	4.1	4.7	6.4	5.5	4.7	4.6	6.5	5.6	4.3	4.7	6.4	5.0	3.5	4.8	7.0	5.3	4.2	4.1	5.9	4.6	3.1	4.4	7.3	5.1	3.2	5.0	6.8
Median	6	3	5	7	5	5	5	7	6	4	5	7	6	3	5	7	5	5	4	6	5	3	4	8	5	3	5	8
SEM	0.5	0.6	0.7	0.5	0.7	0.4	0.5	0.6	0.5	0.6	0.6	0.5	0.5	0.6	0.6	0.4	0.5	0.6	0.5	0.5	0.5	0.3	0.7	0.5	0.5	0.3	0.6	0.6

Note: W: Wake, N: Noon, D: Dinner, B: Bedtime

Appendix 1 shows the average CS and activity over the course of the 7 days for each of the winter participants. Appendix 2 shows the daily patterns of CS and activity over the course of the week for each of the participants. While the devices were worn on the wrist during the nighttime, only the daytime (pendant) data were included in the phasor analyses. The reason for this is because the activity patterns while devices are being worn as pendants is different than activity patterns while they are being worn on the wrist; therefore, to avoid bias in the data and to allow comparison of the phasor analyses from these participants to other data already collected, researchers assumed close to zero activity and light during the times in which participants reported being asleep. As shown in these figures, participants were regular and exposed to similar lighting conditions over the course of 7 days. Some participants received a higher amount of light around lunchtime, suggesting possibly that they went outdoors during that time. These figures can be seen as a *sketch* of the participants' CS and activity over the course of 24 hours. As with other populations, activity levels are higher during the daytime and evening hours (black traces on graphs), while light exposures tend to be higher around the middle of the day and lower in the early morning and evening hours. This clearly suggests that participants were exposed to the highest CS values during their working hours, rather than while at home.

Sleep Analyses, Phasor Analyses and Self-Reports of Sleep and Mood (Summer Months)

Tables 7 – 11 show the individual results together with the mean, median and SEM of the sleep and phasor analyses from the Daysimeter data and the self-reports of sleep and mood questionnaires for the 8 participants who agreed to repeat the study during the summer months and had usable Daysimeter data. Daysimeter data from Participant 4 were not usable because of low compliance, so only the self-report data for this participant are included in the analyses. A few interesting observations from the data:

- Based on the actigraphy data from the Daysimeter, it seems like the average sleep amount in this group of workers is, in general, low (close to 6 hours per night). Sleep efficiency, while higher in summer than in winter months, is still low compared to other groups of people.
- Sleep scores from self-reports are mixed. One scale (PSQI) suggests that 4 out of 8 participants have sleep disturbances (scores above 5 signify sleep disturbances), while the PROMIS Global Score showed that only one participant had sleep disturbances.
- Notwithstanding the small sample size, the mean CS values experienced by participants during their working hours were almost twice as high as experienced during their working hours in the winter months, but it was still low (mean = 0.25). Except for one participant, CS values during working hours were below 0.3. The CS of 0.3 is equivalent to 30% melatonin suppression if that light was applied for one hour in the middle of the night when melatonin levels are high.
- Participants who were exposed to the highest CS values tended to report sleeping better and having less depression. Correlations were not statistically significant, however, most likely given the reduced sample size.
- Phasor magnitude was still low (mean of 0.31), although it was higher in the summer than in the winter months. A high phasor magnitude suggests entrainment to the 24-hour day/night cycle. For comparison, other data sets show that the mean phasor magnitude in school teachers and dayshift nurses (both very regular groups of people) was 0.52 and 0.46 respectively (Rea et al. 2011; Miller et al. 2010).
- Phasor angles were closer to zero in the summer than in the winter (mean of 0.27), suggesting that this population is more active with sunrise and less active after sunset. The phasor angles for school teachers and dayshift nurses were 0.94 and 0.68.
- Depression score was high in one participant. This participant did not comply with usage for the Daysimeter device, so light data for this participant is not available.

Some limitations of the data set include:

- A small sample size. Data needs collection on a larger sample population to make more definitive conclusions about the impact of daylight on health and wellbeing.
- A few of the participants, but one in particular, likely reported feeling more depressed than usual because of their life events; it is possible that the lighting in their environment may not have played a role in these self-report ratings.
- Research questions still unanswered are whether humans adapt to lower levels of light for the circadian system and whether a CS value of 0.1 or larger may be enough to maintain entrainment.

Table 7. Sleep analysis (summer).

Participant No.	Nights averaged	Actual sleep (min.)	Actual sleep (%)	Actual wake (min.)	Actual wake (%)	Sleep efficiency (%)
1	4	271	81%	62	19%	72%
3	4	378	96%	16	4%	89%
5	5	386	85%	67	15%	77%
6	3	349	93%	25	7%	83%
7	4	396	87%	62	13%	74%
8	5	388	81%	90	19%	73%
9	5	397	96%	15	4%	86%
Mean		366	88%	48	12%	79%
Median		386	87%	62	13%	77%
SEM		15.75	2.36%	10.28	2.36%	2.38%

Table 8. Phasor analysis (summer).

						Daytime lux		
Participant No.	Phasor magnitude	Phasor angle	IS	IV	Daytime CS	Mean	Geo mean	Median
1	0.21	0.43	0.57	0.55	0.24	2103	116	97
3*	0.36	0.72	0.61	0.51	0.29	1390	0	235
5	0.44	-0.64	0.84	0.32	0.27	1314	164	190
6	0.30	0.49	0.87	0.71	0.25	1338	127	99
7	0.25	0.45	0.87	0.39	0.22	756	103	107
8	0.27	0.95	0.70	0.65	0.14	451	47	59
9	0.32	1.57	0.76	0.63	0.31	3201	183	100
Mean	0.31	0.57	0.74	0.54	0.25	1508	106	127
Median	0.30	0.49	0.76	0.55	0.25	1338	116	100
SEM	0.03	0.25	0.04	0.05	0.02	344.43	24	24

Table 9. Self-reported sleep analysis (summer).

Participant No.	PSQI global score	PROMIS global score	PROMIS T-score
1	2	11	40.4
3	7	14	45.3
4	10	33	65.1
5	8	21	53.4
6	5	18	50.2
7	4	17	49.1
8	9	15	46.7
9	3	10	38.1
Mean	6	17.4	48.5
Median	6	16	48
SEM	1.04	2.57	2.96

Note: PSQI>5 and PROMIS > 25 – sleep disturbances

Table 10. Self-reported mood (summer).

Participant No.	PANAS total positive	PANAS total negative	CES-D total score
1	36	13	0
3	37	14	4
4	11	27	22
5	20	14	9
6	32	14	5
7	35	12	2
8	26	26	14
9	36	14	2
Mean	29	17	7
Median	34	14	5
SEM	3.33	2.14	2.64

Note: CES-D > 16 indicates depression symptoms; PANAS pos (higher = better); PANAS neg (lower = better)

Table 11. Self-reported sleepiness (summer)

Participant No.	Day 1				Day 2				Day 3				Day 4				Day 5				Day 6				Day 7			
	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B	W	N	D	B
1	5	3	3	8	4	3	3	8	5	3	3	8	5	2	3	9	4	3	4	8	3	3	4	9	3	3	3	8
2	6	2	4	7	6	2	4	7	7	3	3	8	8	2	2	6	7	2	4	7	6	2	3	7	6	2	2	7
3	8	7	6	7	8	7	6	7	9	7	6	7	8	7	6	7	8	5	5	7	8	5	5	7	8	5	5	7
4	3	4	5	6	3	4	5	6	3	4	5	6	3	4	6	7	3	4	5	8	3	4	5	6	3	4	5	5
5	8	5	6	8	7	6	5	7	8	6	6	8	6	4	4	7	7	6	4	5	6	4	4	6	6	6	6	8
6	6	4	5	6	4	4	5	6	6	5	4	7	5	5	6	7	3	6	6	7	3	3	5	6	5	5	6	6
7	5	5	5	6	4	4	4	6	4	3	4	4	3	3	5	5	3	3	4	6	5	4	4	5	5	4	4	6
8	1	2	2	4	3	2	3	7	6	3	2	7	7	4	9	8	4	3	2	6	2	3	5	7	2	3	4	7
9	5	3	3	8	4	3	3	8	5	3	3	8	5	2	3	9	4	3	4	8	3	3	4	9	3	3	3	8
Mean	5.3	4.0	4.5	6.5	4.9	4.0	4.4	6.8	6.0	4.3	4.1	6.9	5.6	3.9	5.1	7.0	4.9	4.0	4.3	6.8	4.5	3.5	4.4	6.6	4.8	4.0	4.4	6.8
Median	6	4	5	7	4	4	5	7	6	4	4	7	6	4	6	7	4	4	4	7	4	4	5	7	5	4	5	7
SEM	0.8	0.6	0.5	0.5	0.7	0.6	0.4	0.3	0.7	0.6	0.5	0.5	0.7	0.6	0.8	0.4	0.7	0.5	0.4	0.4	0.7	0.3	0.3	0.4	0.7	0.5	0.5	0.4

Note: W: Wake, N: Noon, D: Dinner, B: Bedtime

Appendix 3 shows the daily patterns of CS and activity over the course of the week for each of the participants who had usable data collected during the summer months. Appendix 4 shows the average CS and activity over the course of the 7 days for each of the participants who had usable data. While the devices were worn on the wrist during the nighttime, only the daytime (pendant) data were included in the phasor analyses. The reason for this is because the activity patterns while devices are being worn as pendants is different than activity patterns while they are being worn on the wrist; therefore, to avoid bias in the data and to allow comparison of the phasor analyses from these participants to other data collected, researchers assumed close to zero activity and light during the times in which participants reported being asleep. As shown in these figures, participants were regular and exposed to similar lighting conditions over the course of 7 days. Some participants receive a higher amount of light around lunchtime, possibly suggesting a trip outdoors during that time. What was very interesting about the summer data is the fact that participants had much higher exposures to circadian light after working hours due to the longer daylight availability. These figures can be seen as a *sketch* of the participants' CS and activity over the course of 24 hours. As with other populations (e.g., dayshift nurses, school teachers, and healthy older adults), activity levels are higher during the daytime and evening hours, while light exposures tend to be higher around the middle of the day and lower in the early morning and evening hours, even though evening light during the summer was much greater than exposure experienced during the winter months.

Discussion

Daylight is a remarkably ideal light source for the circadian system. Thus, it is reasonable to pursue the hypothesis that daylight might improve health and wellbeing through the circadian system, or, conversely, that chronic lack of daylight exposure during daytime hours may be promoting circadian disruption and negatively affecting health and mood. The first step toward forging a link between daylight exposure in buildings and health outcomes is to measure patterns of circadian light and dark experienced by workers in the building. This can help quantify how occupant behavior or design modifications affect personal light exposures at work. The present study is the first to obtain circadian light-dark and activity patterns in office workers in a Federal building designed to increase daylight availability in the space.

Given that all the current lighting standards are designed to meet the needs of the visual system, and that the human visual system is much more sensitive to light than the human circadian system, it was important to use a calibrated light meter that would provide measurements of circadian stimulation from occupants of the buildings. The fact that a person can see in the environment does not necessarily mean that the circadian system is being stimulated. Moreover, the spectral sensitivity of the circadian system peaks at short wavelengths (i.e., blue light: close to 460 nm) while the peak sensitivity of the human visual system is close to 555 nm.

Based on the measurements, despite the availability of daylight in the space, participants are being exposed to low average CS levels during the day. As expected, this amount of light is even less during the winter months than in the summer months. It is important to note, however, that the highest amount of light that participants received was during the times in which they were at work, and this was particularly true in winter months. Light levels at times when they were likely at home (early morning and evening) were much lower, even though post-work light exposures in the summer months were close to those that they were exposed to during work hours. Appendix 5 shows the adjusted analyses among participants who repeated the study in both winter and summer months, along with two-tailed Student's *t*-tests.

The authors can speculate on a few reasons why the amount of circadian light in the building was low. One is due to occupant behavior, as workers tend to pull the shades closed whenever sunlight hits their face or deskspace. While this behavior is well-documented in the literature, it may not be the only explanation for our results. In winter months, three participants who were sitting by north-facing windows (Participants 1, 6 and 11), where shades were not pulled because there is not direct sunlight, were not receiving higher amounts of CS. In fact, the lowest CS values that were measured during working hours were from participants that were sitting in north-facing windows. This might be because of the furniture placement. The workers' sitting position in this building is such that they have their backs to the window, reducing the amount of eye-level light they might be receiving. As expected, some of the workers sitting at the south and west façades were also receiving low amounts of light, most likely due to shades being used to protect against sunlight penetration in the space.

There was a clear effect of season on both light exposures and self-reports of mood and sleep. On average, in the summer months, participants received significantly more circadian light (both at work and outside work), slept significantly more, and had significantly greater efficiency and significantly lower sleep latency than in winter months. Self-reports of sleep and mood were also improved in the summer months compared to winter months. It is clear that overall light exposure has an effect on these self-reports. It will be informative if more personal light data could be collected from those working in non-daylit buildings in the same area so that a comparison between building types can be made.

REFERENCES

Åkerstedt, T. and M. Gillberg. 1990. Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience* 52(1-2): 29-37.

Arendt, J. 1995. *Melatonin and the mammalian pineal gland*. London: Chapman & Hall.

Boyce, P.R. and M.S. Rea. 2001. *Lighting and human performance II: Beyond visibility models toward a unified human factors approach to performance*, EPRI, Palo Alto, C.A.

Boyce, P.R., C. Hunter and O. Howlett. 2003. *The benefits of daylight through windows*. Capturing the Daylight Dividends Program, Rensselaer Polytechnic Institute, Troy, N.Y.

Boyce, P.R. 2004. *Reviews of technical reports on daylight and productivity*. Capturing the Daylight Dividends Program, Troy, N.Y.

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

Buysse, D.J., C.F. Reynolds, T.H. Monk, S.R. Berman and D.J. Kupfer. 1989. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research* 28(2): 193-213.

Cella, D., W. Riley, A. Stone, N. Rothrock, B. Reeve, S. Yount, D. Amtmann, R. Bode, D. Buysse and S. Choi. 2010. The Patient-Reported Outcomes Measurement Information System (PROMIS) developed and tested its first wave of adult self-reported health outcome item banks. *Journal of Clinical Epidemiology* 63(11): 1179-1194.

Cohen, S., T. Kamarck and R. Mermelstein. 1983. A global measure of perceived stress. *Journal of Health and Social Behavior*: 385-396.

Cuttle, C. 1983. People and windows in workplaces. In *Proceedings of the people and physical environment research conference*. Wellington, New Zealand.

Cuttle, C. 2002. Identifying the human values associated with windows. *International Daylightin*g 5: 3-6.

Figueiro, M.G., Hamner, R., Bierman, A., & Rea, M.S. 2013. Comparisons of three practical field devices used to measure personal light exposures and activity levels. *Lighting Research & Technology* 45(4): 421-434.

Heerwagen, J., & Heerwagen D. 1986. Lighting and psychological comfort. *Lighting Design and Application* 6: 47-51.

Heerwagen, J. 1986. “Windowscapes: The role of nature in the view from the window.” Conference Proceedings: International Daylighting Conference, November 4-7, 1986. Long Beach, C.A.

Heschong Mahone Group. 1999. *Daylighting in schools: An investigation into the relationship between daylighting and human performance*. Pacific Gas and Electric.

Heschong Mahone Group. 2003a. *Windows and offices: A study of office worker performance and the indoor environment*. California Energy Commission, Public Energy Interest Research.

Heschong Mahone Group. 2003b. *Windows and classrooms: A study of student performance and the indoor environment.* California Energy Commission, Public Energy Interest Research.

Hopkinson, R.G. and J.D. Kay. 1969. *The Lighting of Buildings*. Frederick A. Praeger: New York and Washington, D.C.

Jewett, M., D.W. Rimmer, J.F. Duffy, E.B. Klerman, R. Kronauer, and C.A. Czeisler. 1997. Human circadian pacemaker is sensitive to light throughout subjective day without evidence of transients. *American Journal of Physiology* 273: R1800-R1809.

Klein, D.C. 1993. The mammalian melatonin rhythm-generating system. In L. Wetterberg, editor. *Light and Biological Rhythms in Man.* Neuroscience. Oxford: Pergamon Press, 55-72.

Lewy, A.J., H.A. Kern, N.E. Rosenthal, and T.A. Wehr. 1982. Bright artificial light treatment of a manic-depressive patient with seasonal mood cycle. *American Journal of Psychiatry* 139: 1496-1498.

McIntyre, I.M., T.R Norman, G.D. Burrows, and S.M. Armstrong. 1989. Human melatonin suppression by light is intensity dependent. *Journal of Pineal Research* 6: 149-156.

Miller, D., M.G. Figueiro, A. Bierman, E. Schernhammer, and M.S. Rea. 2010. Ecological measurements of light exposure, activity and circadian disruption. *Lighting Research & Technology* 42: 271-284.

Moore, R.Y. 1997. Circadian rhythms: Basic neurobiology and clinical applications. *Annual Review of Medicine* 48: 253-266.

Radloff, L.S. 1977. The CES-D Scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement* 1: 385-401.

Rea, M.S., A. Bierman, M.G. Figueiro and J.D. Bullough. 2008. A new approach to understanding the impact of circadian disruption on human health. *Journal of Circadian Rhythms* 6:7.

Rea, M.S., J.A. Brons and M.G. Figueiro. 2011. Measurements of light at night (LAN) for a sample of female school teachers. *Chronobiology International* 28(8): 673-680.

Rea, M.S, M.G. Figueiro and J.D. Bullough. 2002. Circadian photobiology: An emerging framework for lighting practice and research. *Lighting Research & Technology* 34(3): 177-190.

Thapan, K., J. Arendt and D.J. Skene. 2001. An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. *Journal of Physiology* 535 (Pt. 1): 261-267.

Turek, F.W. and P.C. Zee. 1999. Introduction to sleep and circadian rhythms. In Turek FW & Zee PC (eds), *Regulation of Sleep and Circadian Rhythm*: 1-17. New York, N.Y. Marcel Dekker.

Van Someren, E.J.W., Kessler, A., Mirmirann, M., & Swaab, D.F. 1997. Indirect bright light improves circadian activity-rest rhythm disturbances in demented patients. *Biological Psychiatry* 41: 955-963.

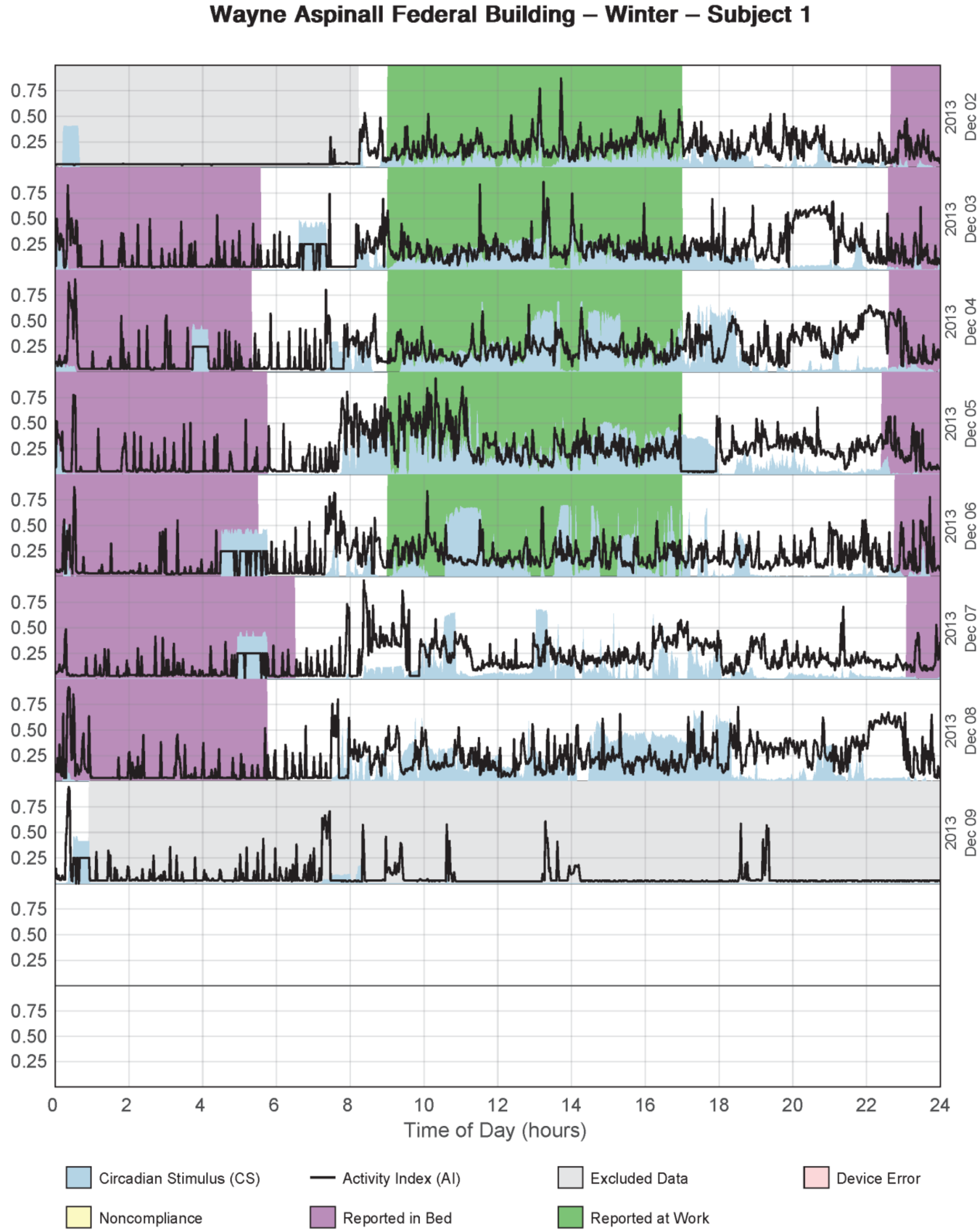
Watson, D., L.A. Clark and A. Tellegen 1988. Development and validation of brief measures of positive and negative affect: The PANAS scale. *Journal of Personality and Social Psychology* 54: 1063-1070.

CREDITS

LRC Researchers: Dr. Mariana Figueiro, Dr. Mark Rea, Jennifer Brons

Graphic Designer: Dennis Guyon

Editors: Rebekah Mullaney, Dennis Guyon, Sarah Hulse

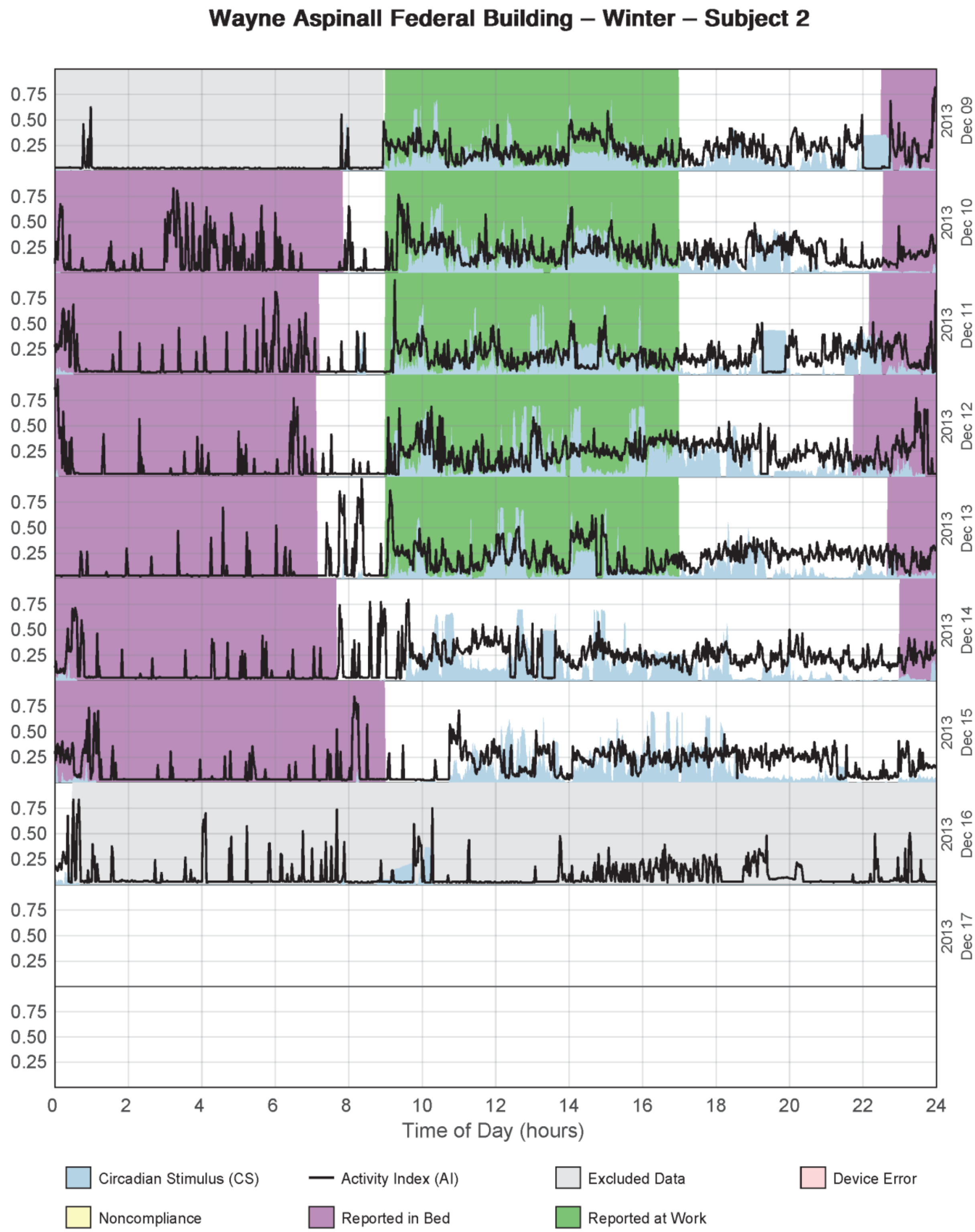


Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

Rensselaer

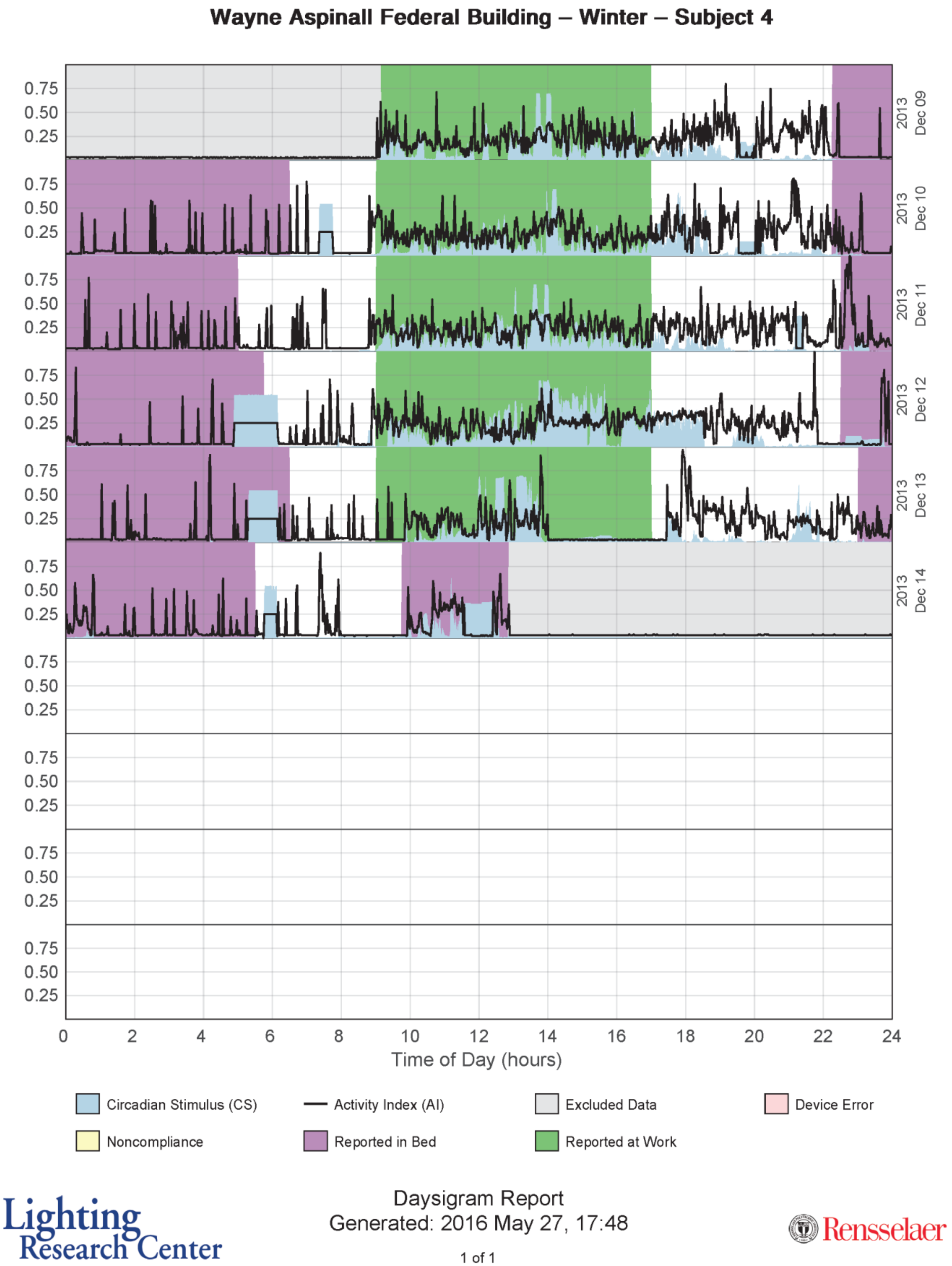


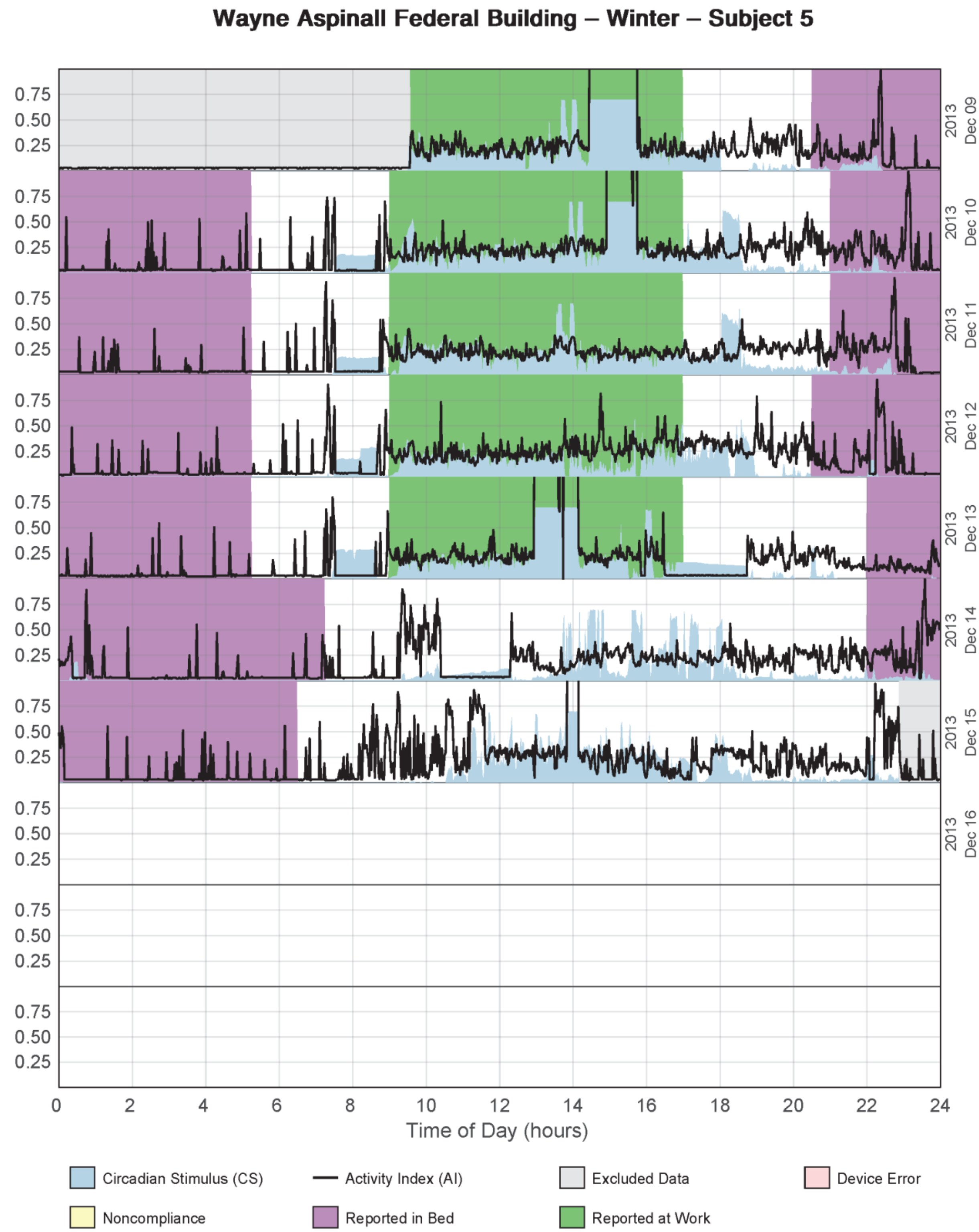
Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

Lighting Research Center

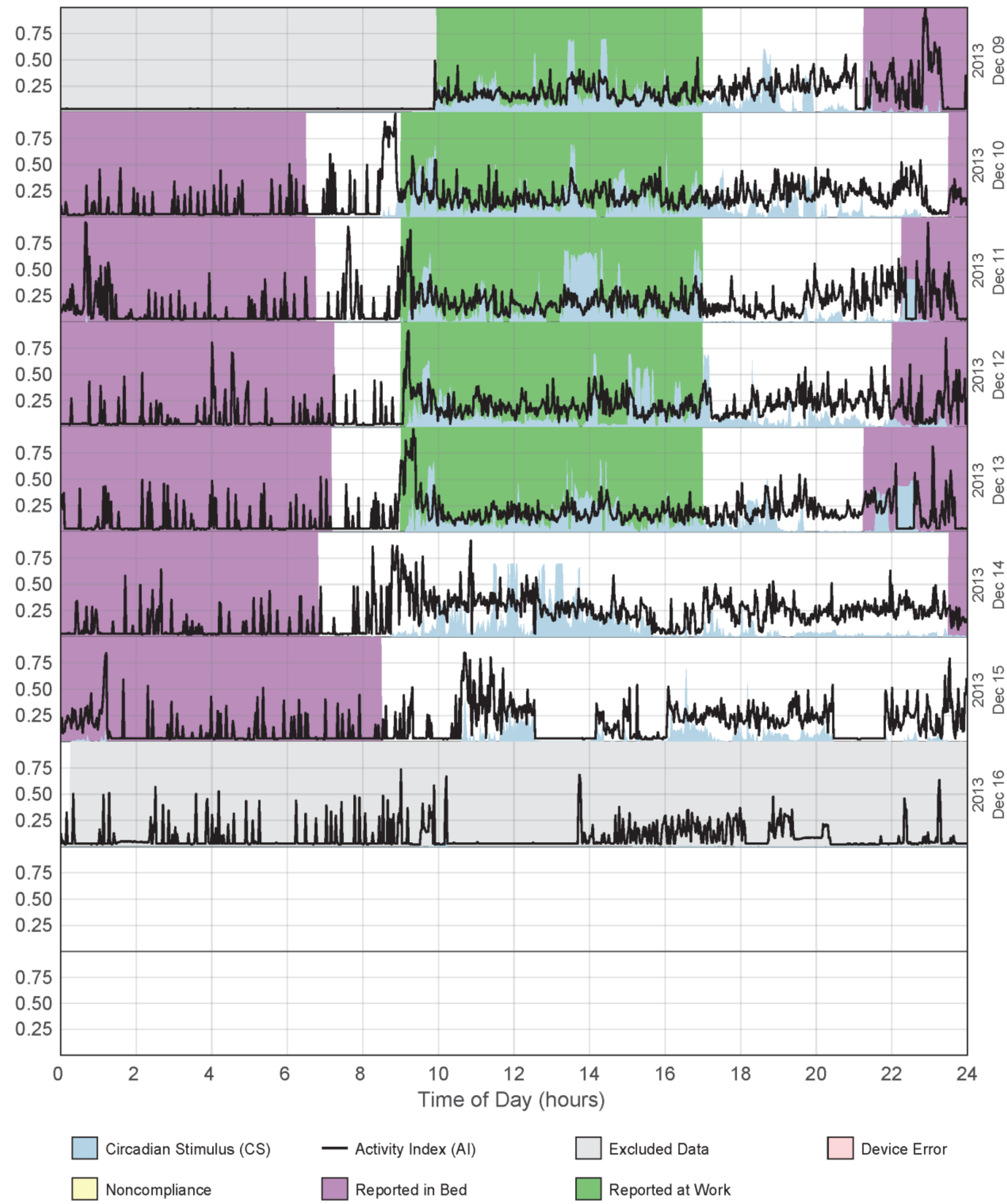
Rensselaer


Wayne Aspinall Federal Building – Winter – Subject 4
0.75
0.50
0.25
2013 Dec 09
2013 Dec 10
2013 Dec 11
2013 Dec 12
2013 Dec 13
2013 Dec 14
0
2
4
6
8
10
12
14
16
18
20
22
24
Time of Day (hours)
Circadian Stimulus (CS)
Activity Index (AI)
Excluded Data
Device Error
Noncompliance
Reported in Bed
Reported at Work
Lighting Research Center
Daysigram Report
Generated: 2016 May 27, 17:48
1 of 1
Rensselaer



Daysigram Report
Generated: 2016 May 27, 17:48
1 of 1

Wayne Aspinall Federal Building – Winter – Subject 6

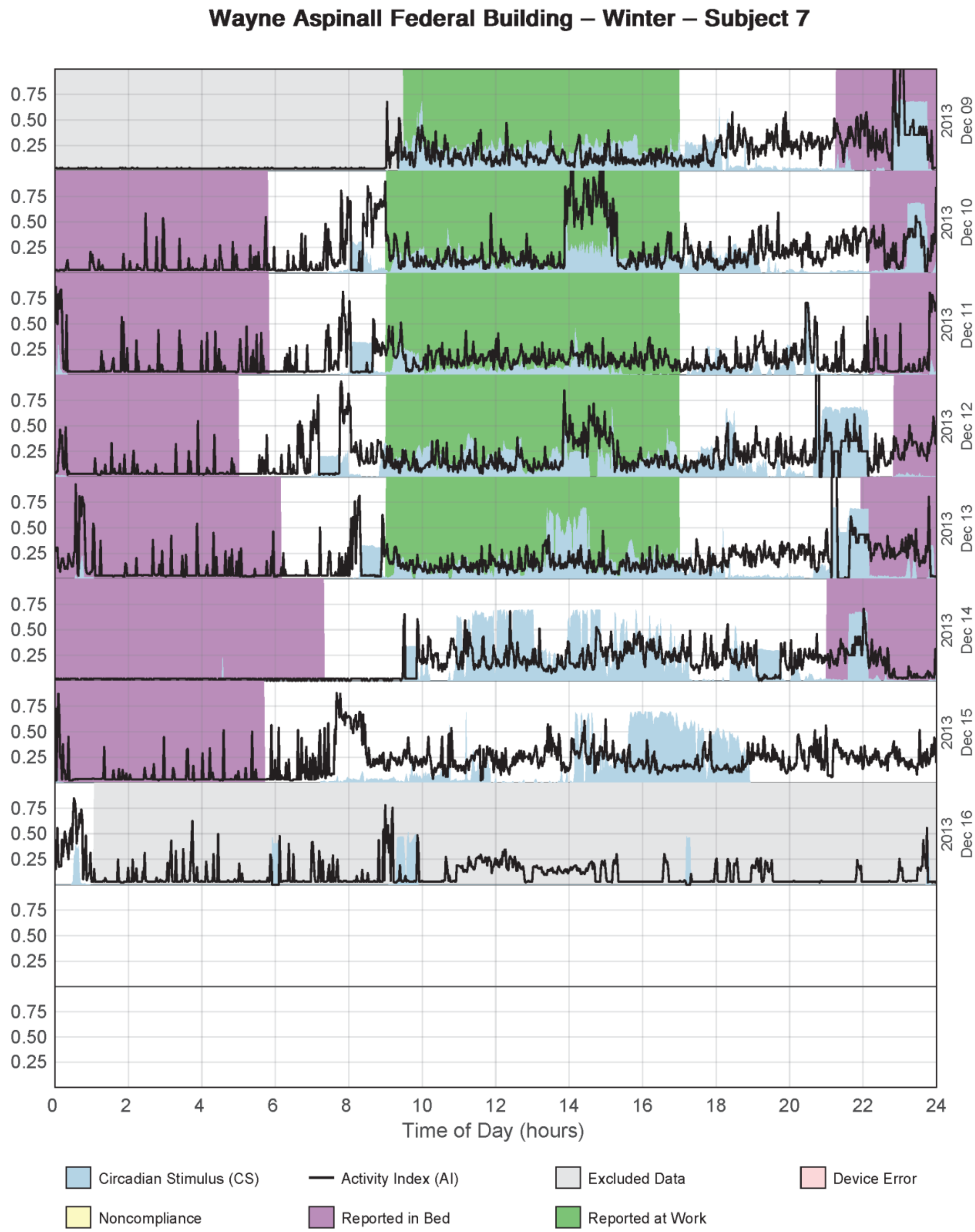


Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

Rensselaer

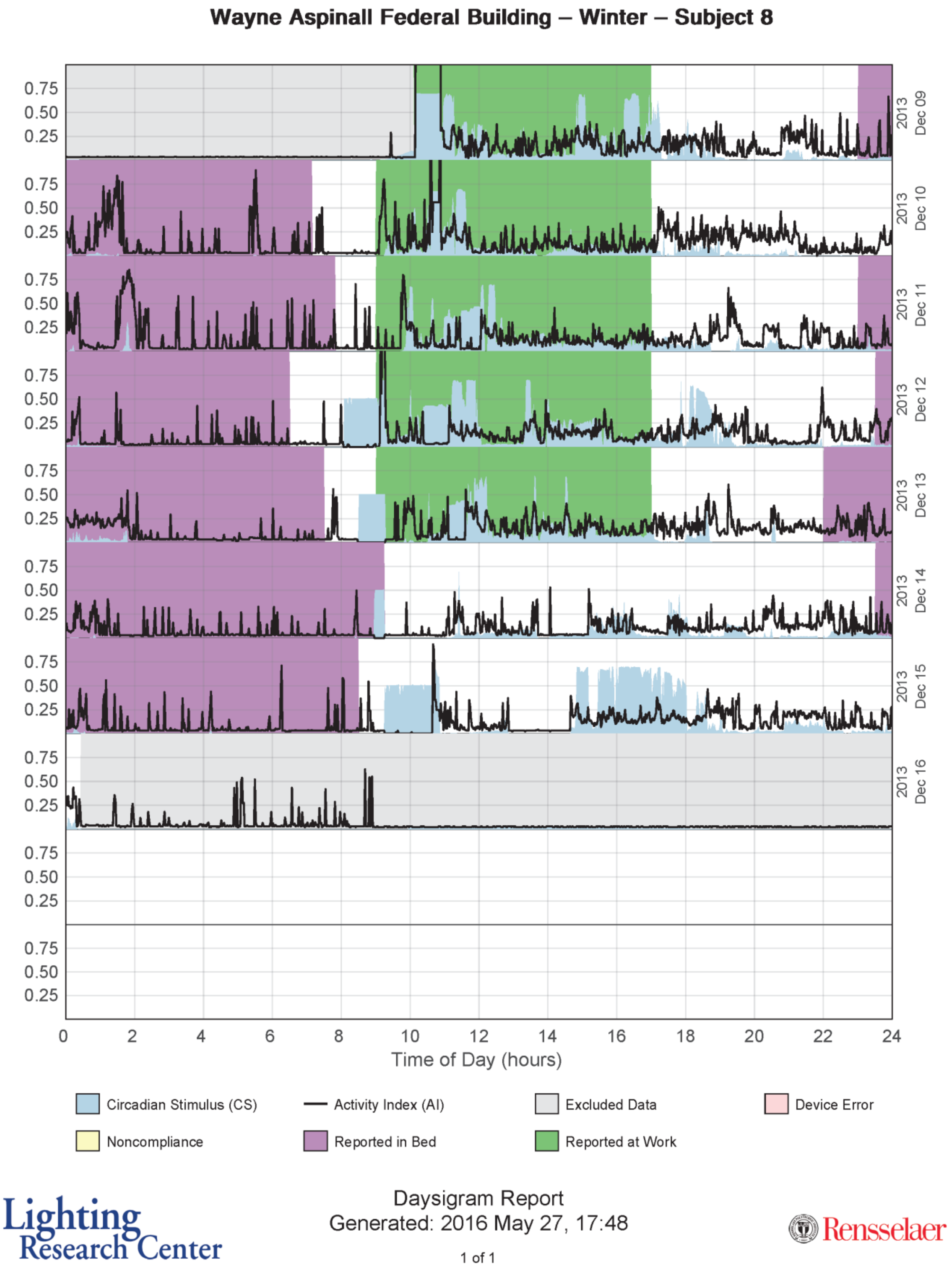


Lighting Research Center

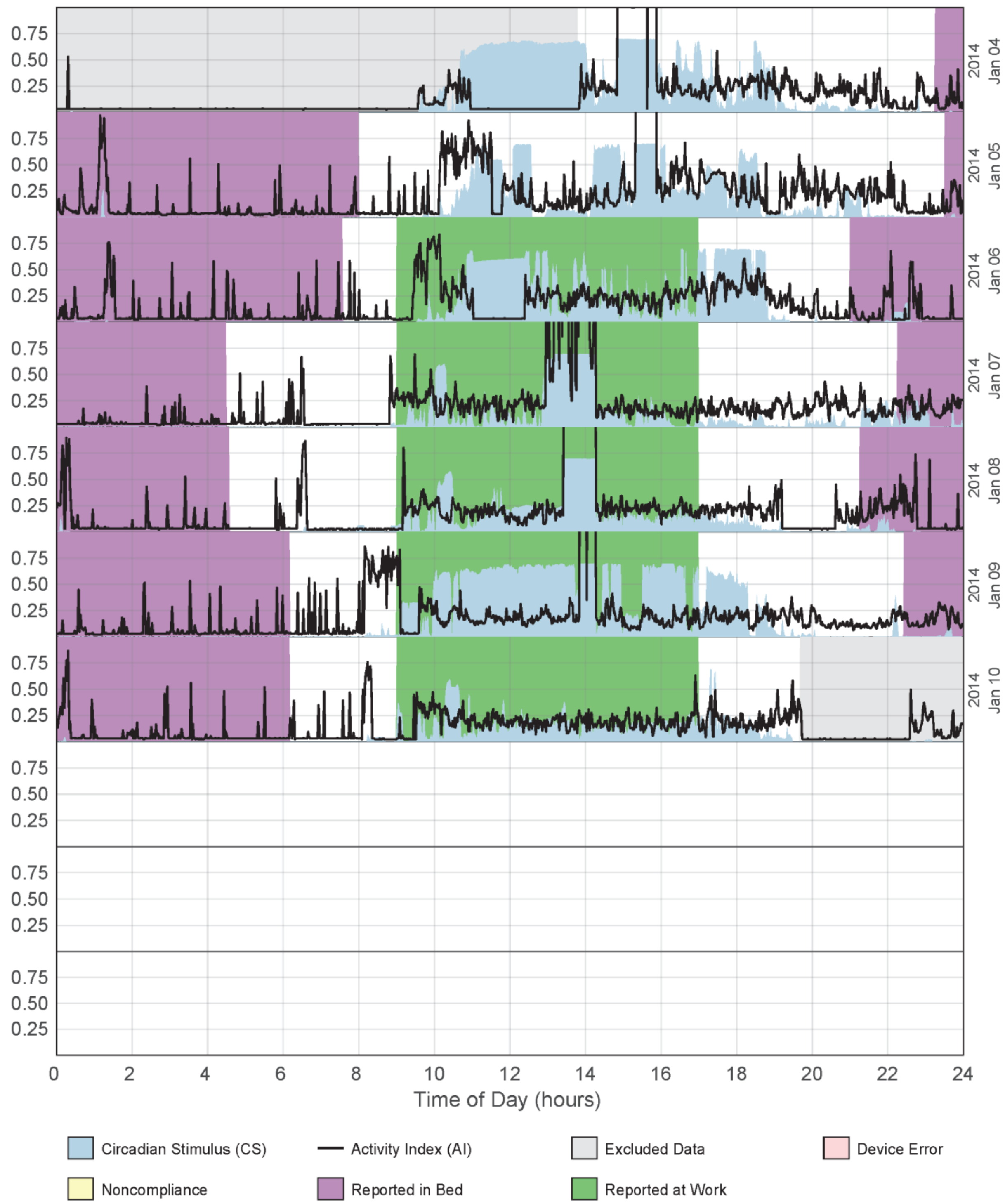
Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

Rensselaer


Wayne Aspinall Federal Building – Winter – Subject 8
0.75
0.50
0.25
2013 Dec 09
2013 Dec 10
2013 Dec 11
2013 Dec 12
2013 Dec 13
2013 Dec 14
2013 Dec 15
2013 Dec 16
0 2 4 6 8 10 12 14 16 18 20 22 24
Time of Day (hours)
Circadian Stimulus (CS)
Activity Index (AI)
Excluded Data
Device Error
Noncompliance
Reported in Bed
Reported at Work
Lighting Research Center
Daysigram Report
Generated: 2016 May 27, 17:48
1 of 1
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 9

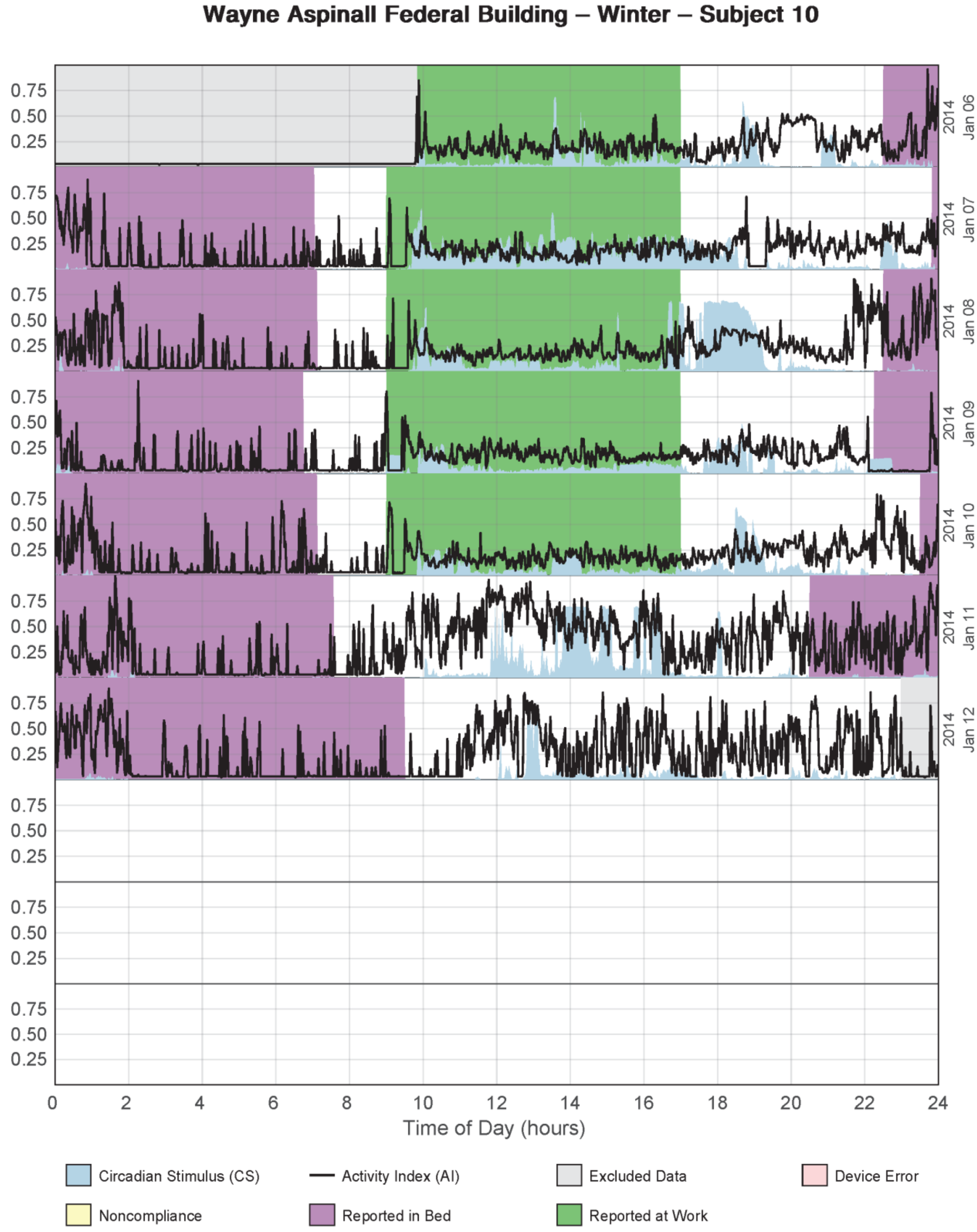


Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

Rensselaer



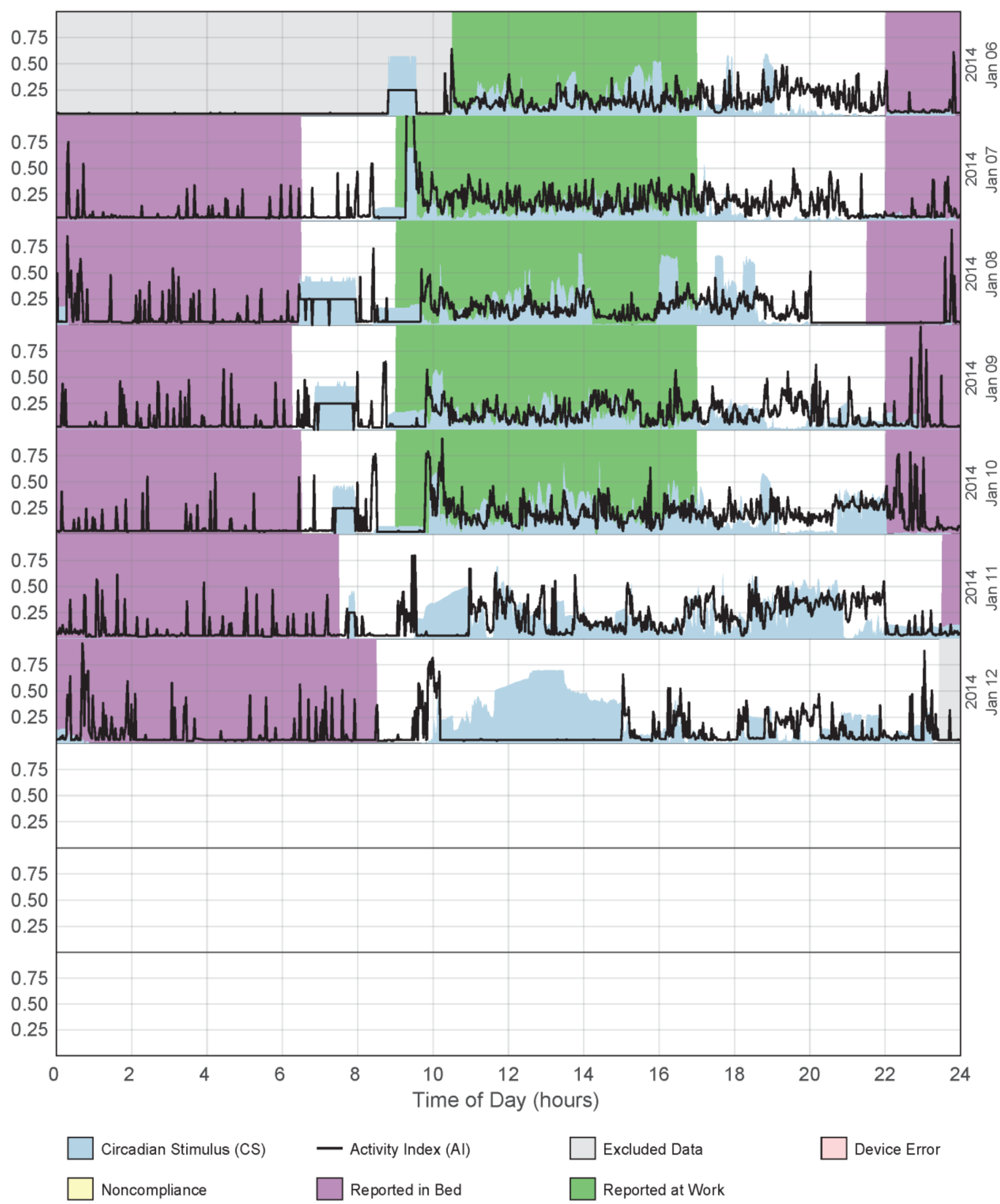
Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 11



Lighting Research Center

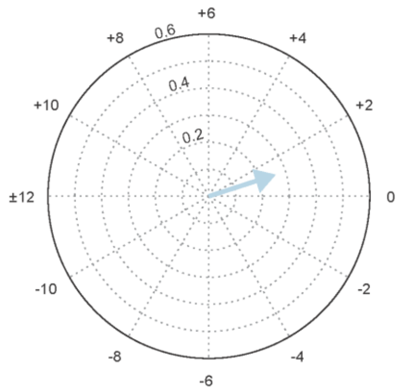
Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

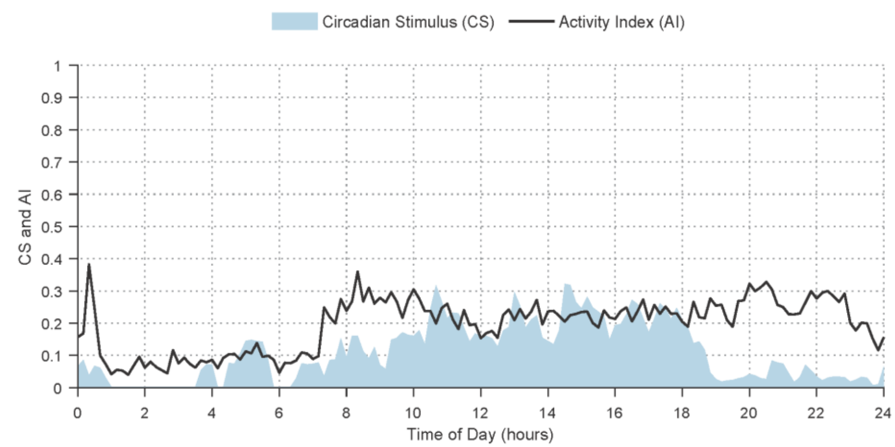
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 1

Phasor



Average Day



Phasor Magnitude: 0.26
Phasor Angle: 1.18 hours

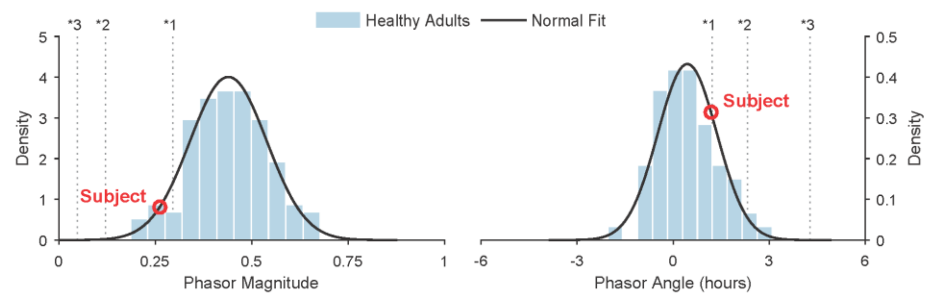
Interdaily Stability (IS): 0.52
Intradaily Variability (IV): 0.83

Mean Waking Activity Index (AI): 0.23

Mean Waking Circadian Stimulus (CS): 0.14

Geometric Mean Waking Photopic Illuminance: 303.44 lux

Normal Probability Distribution



*Rotating shift nurses working 1, 2, & 3 nights per week.

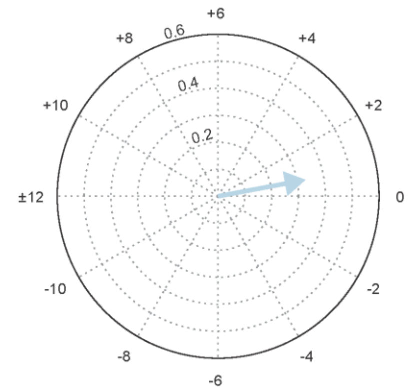
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 2

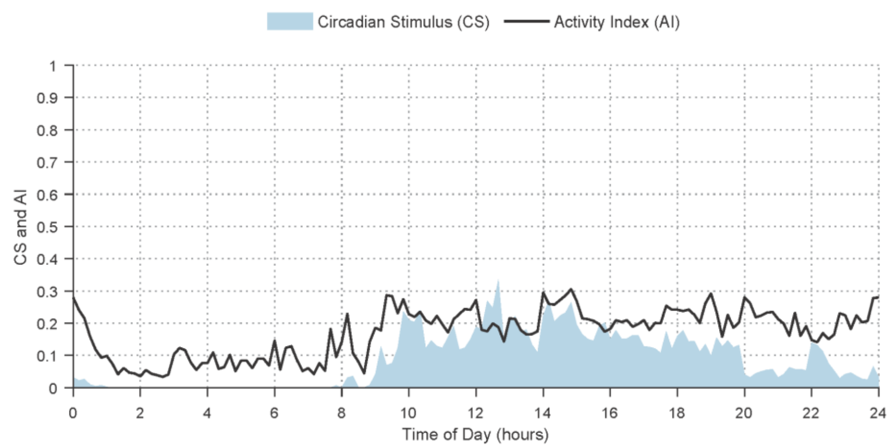
Phasor



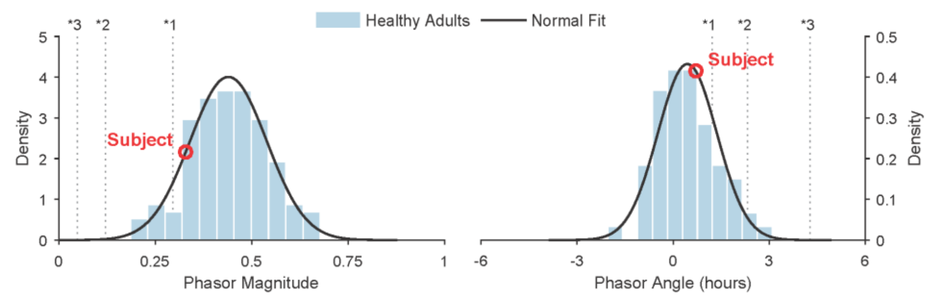
Phasor Magnitude:	0.33
Phasor Angle:	0.71 hours
Interdaily Stability (IS):	0.60
Intradaily Variability (IV):	0.99
Mean Waking Activity Index (AI):	0.21
Mean Waking Circadian Stimulus (CS):	0.13
Geometric Mean Waking Photopic Illuminance:	375.45 lux

Lighting Research Center

Average Day



Normal Probability Distribution



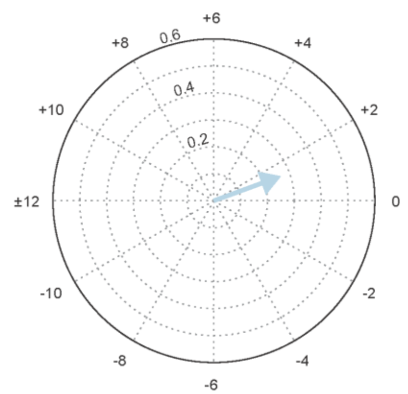
*Rotating shift nurses working 1, 2, & 3 nights per week.

Composite Report
Generated: 2016 June 06, 17:06

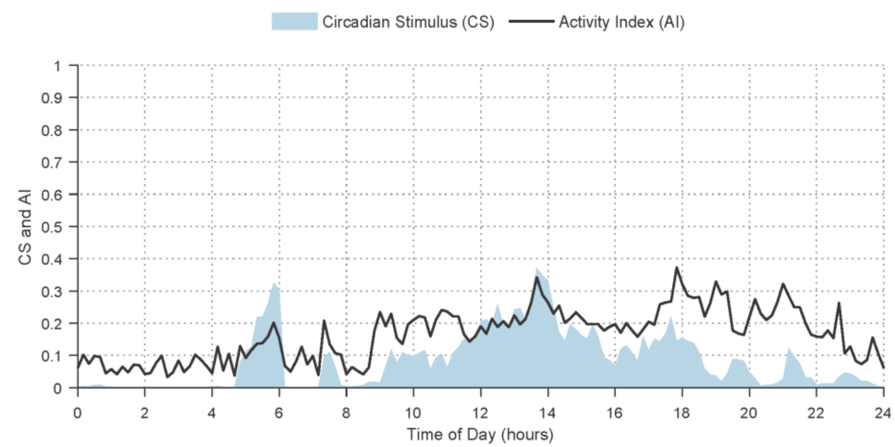
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 4

Phasor

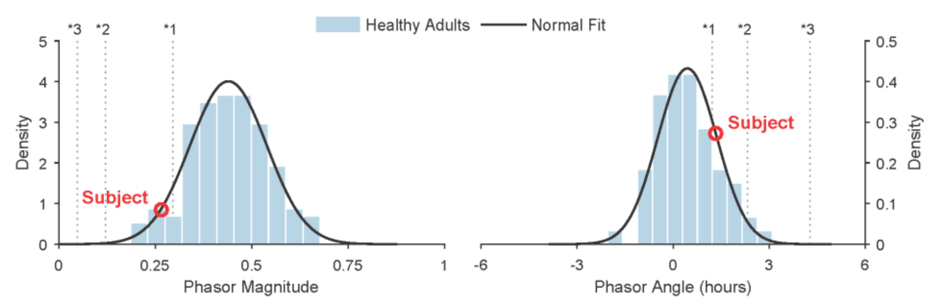


Average Day



Phasor Magnitude:	0.27
Phasor Angle:	1.33 hours
Interdaily Stability (IS):	0.64
Intradaily Variability (IV):	0.80
Mean Waking Activity Index (AI):	0.20
Mean Waking Circadian Stimulus (CS):	0.11
Geometric Mean Waking Photopic Illuminance:	399.29 lux

Normal Probability Distribution



*Rotating shift nurses working 1, 2, & 3 nights per week.

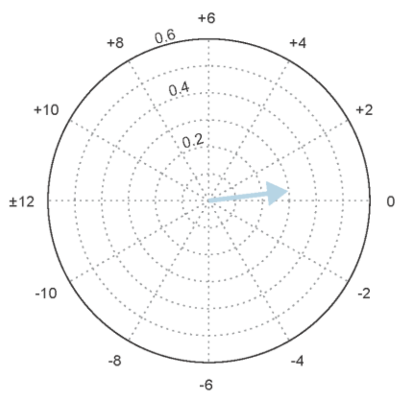
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

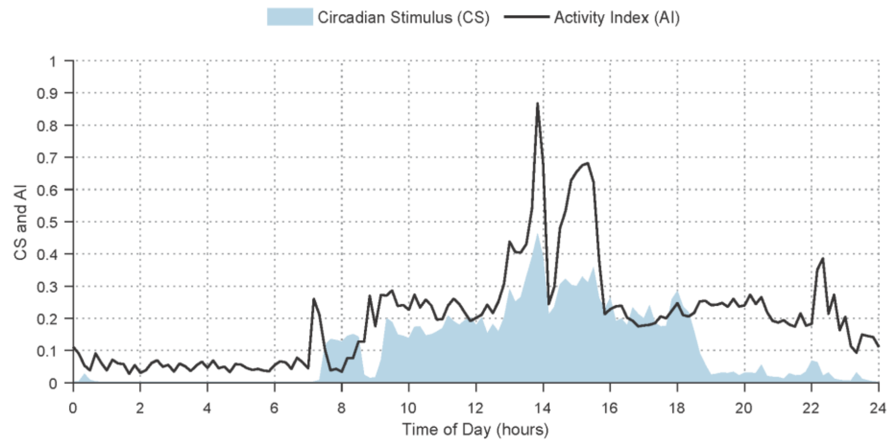
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 5

Phasor

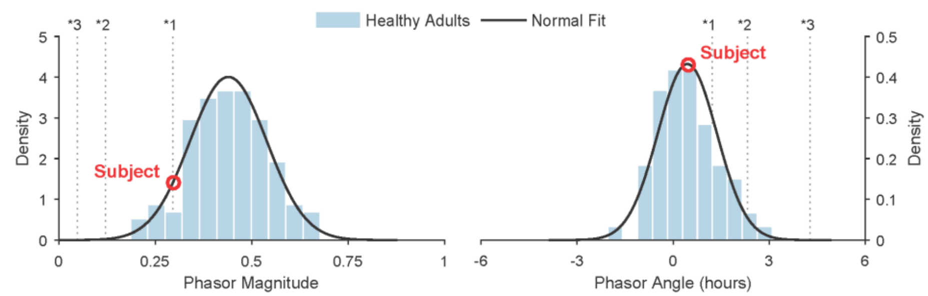


Average Day



Phasor Magnitude:	0.30	
Phasor Angle:	0.46	hours
Interdaily Stability (IS):	0.41	
Intradaily Variability (IV):	1.13	
Mean Waking Activity Index (AI):	0.26	
Mean Waking Circadian Stimulus (CS):	0.16	
Geometric Mean Waking Photopic Illuminance:	1900.49	lux

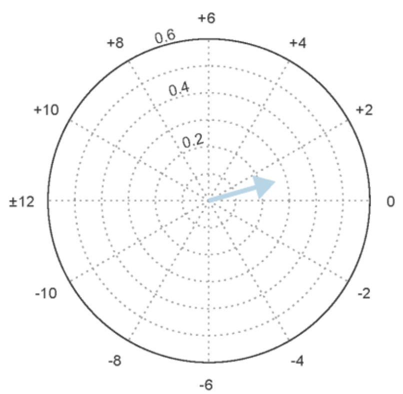
Normal Probability Distribution

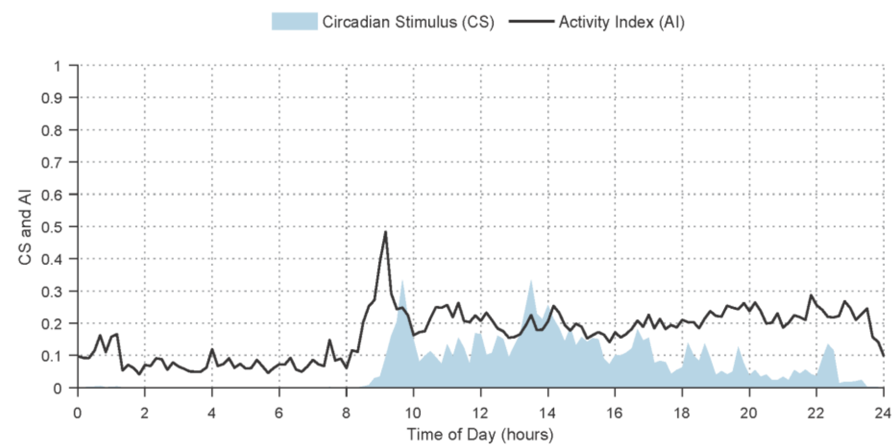


*Rotating shift nurses working 1, 2, & 3 nights per week.

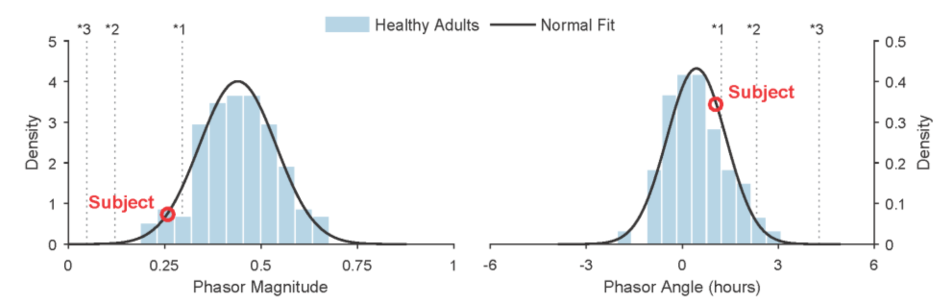
Composite Report
Generated: 2016 June 06, 17:06

Wayne Aspinall Federal Building – Winter – Subject 6





Phasor Magnitude:	0.26
Phasor Angle:	1.06 hours
Interdaily Stability (IS):	0.63
Intradaily Variability (IV):	0.93
Mean Waking Activity Index (AI):	0.20
Mean Waking Circadian Stimulus (CS):	0.10
Geometric Mean Waking Photopic Illuminance:	318.44 lux



*Rotating shift nurses working 1, 2, & 3 nights per week.

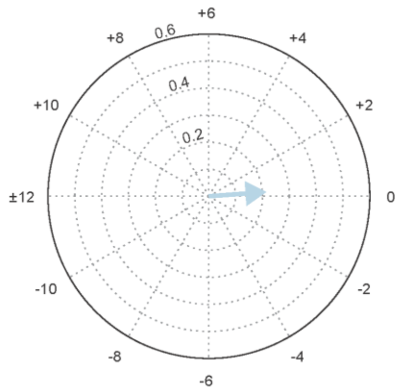
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

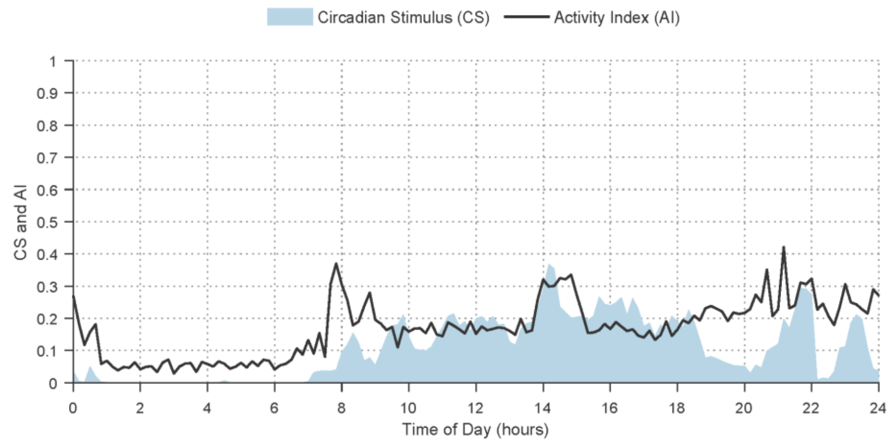
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 7

Phasor



Average Day



Phasor Magnitude: 0.21
Phasor Angle: 0.28 hours

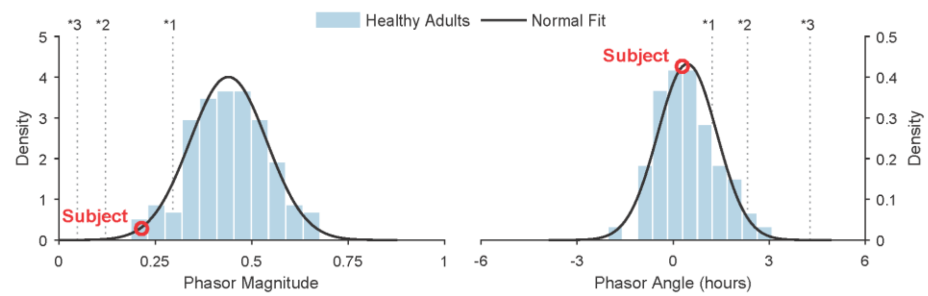
Interdaily Stability (IS): 0.49
Intradaily Variability (IV): 0.96

Mean Waking Activity Index (AI): 0.20

Mean Waking Circadian Stimulus (CS): 0.15

Geometric Mean Waking Photopic Illuminance: 965.82 lux

Normal Probability Distribution



*Rotating shift nurses working 1, 2, & 3 nights per week.

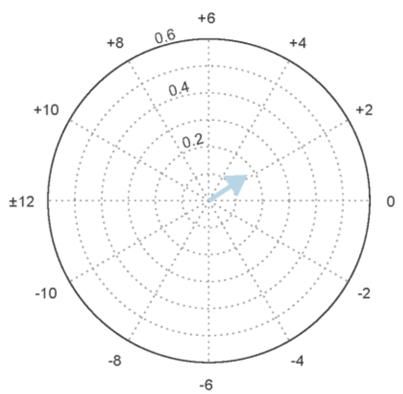
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

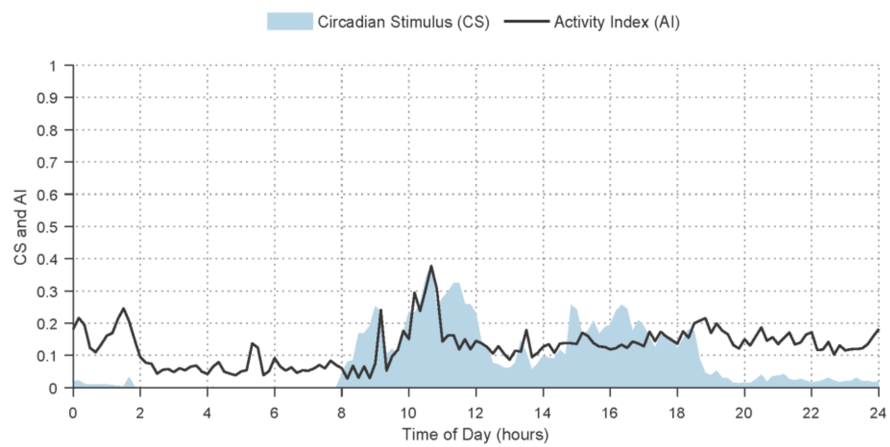
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 8

Phasor

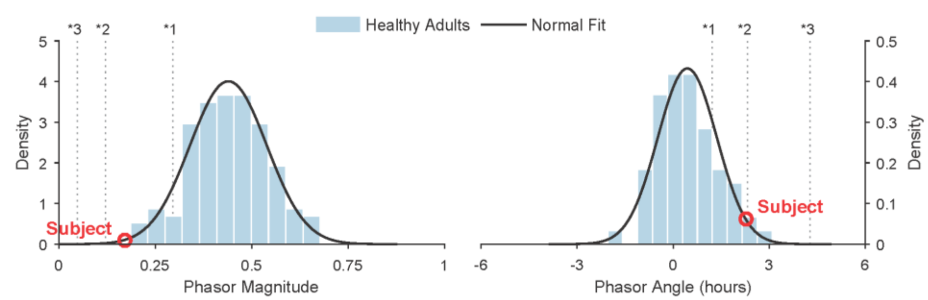


Average Day



Phasor Magnitude:	0.17
Phasor Angle:	2.25 hours
Interdaily Stability (IS):	0.27
Intradaily Variability (IV):	1.02
Mean Waking Activity Index (AI):	0.14
Mean Waking Circadian Stimulus (CS):	0.13
Geometric Mean Waking Photopic Illuminance:	955.09 lux

Normal Probability Distribution



*Rotating shift nurses working 1, 2, & 3 nights per week.

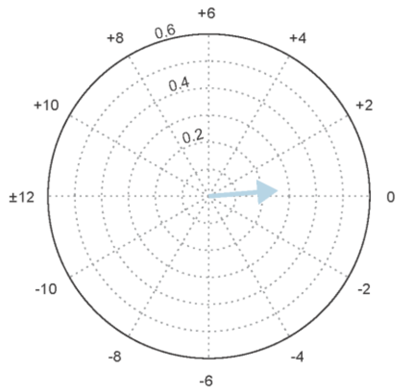
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

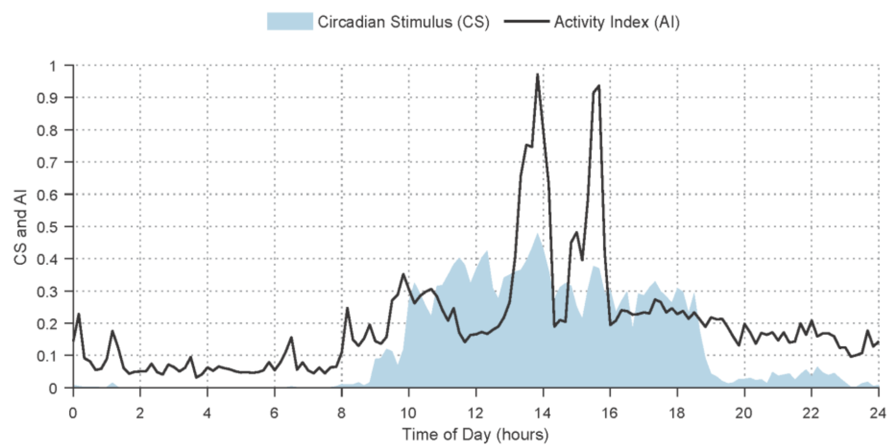
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 9

Phasor

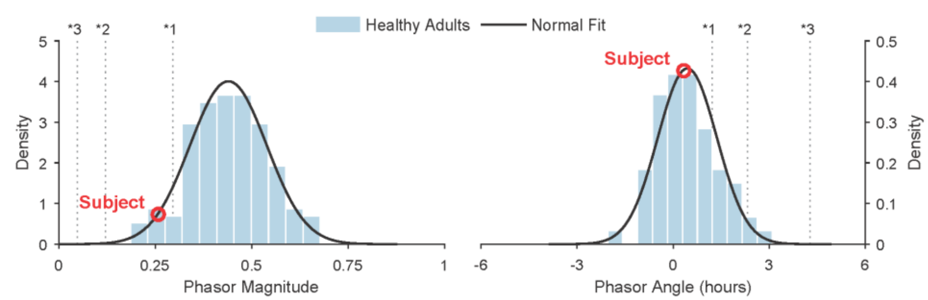


Average Day



Phasor Magnitude:	0.26
Phasor Angle:	0.31 hours
Interdaily Stability (IS):	0.40
Intradaily Variability (IV):	1.37
Mean Waking Activity Index (AI):	0.26
Mean Waking Circadian Stimulus (CS):	0.19
Geometric Mean Waking Photopic Illuminance:	2497.35 lux

Normal Probability Distribution



*Rotating shift nurses working 1, 2, & 3 nights per week.

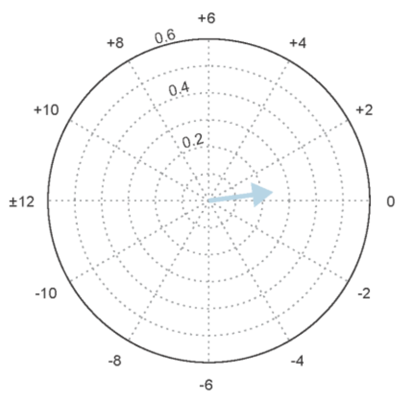
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

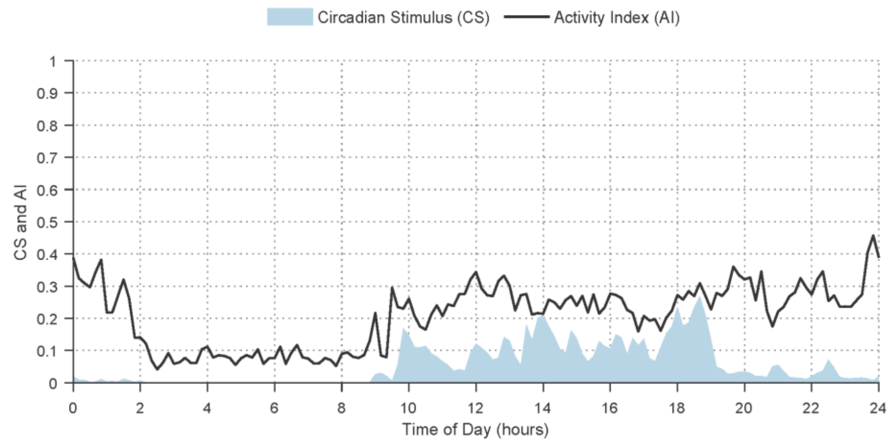
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 10

Phasor

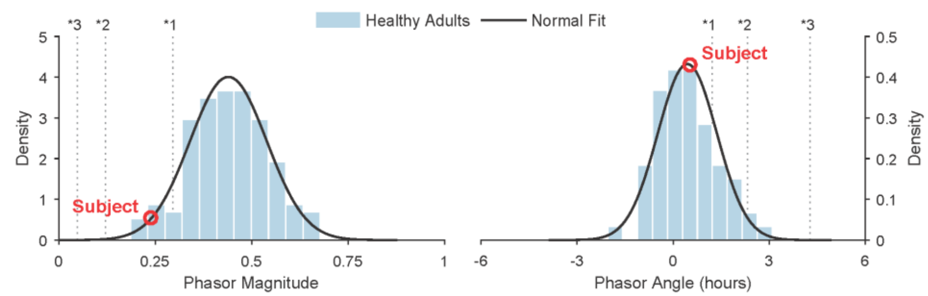


Average Day



Phasor Magnitude:	0.24
Phasor Angle:	0.51 hours
Interdaily Stability (IS):	0.44
Intradaily Variability (IV):	0.58
Mean Waking Activity Index (AI):	0.24
Mean Waking Circadian Stimulus (CS):	0.09
Geometric Mean Waking Photopic Illuminance:	270.92 lux

Normal Probability Distribution



*Rotating shift nurses working 1, 2, & 3 nights per week.

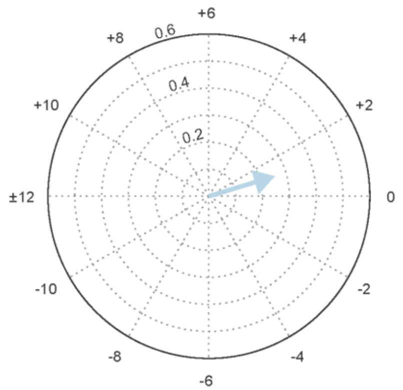
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

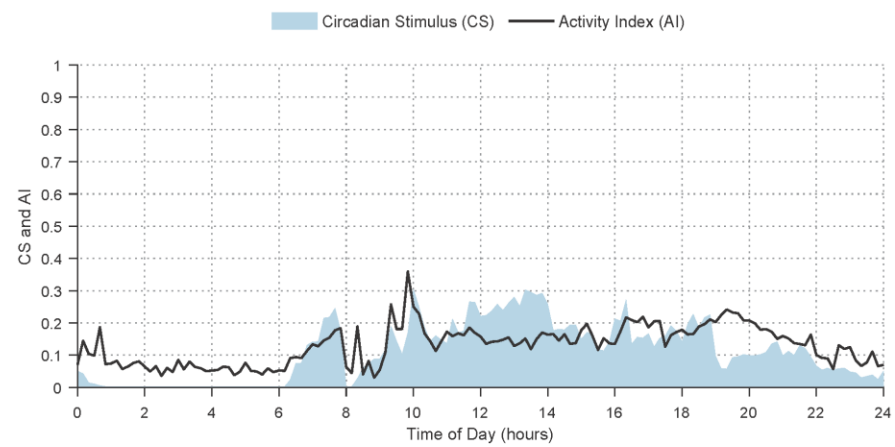
Rensselaer

Wayne Aspinall Federal Building – Winter – Subject 11

Phasor



Average Day



Phasor Magnitude: 0.26
Phasor Angle: 1.12 hours

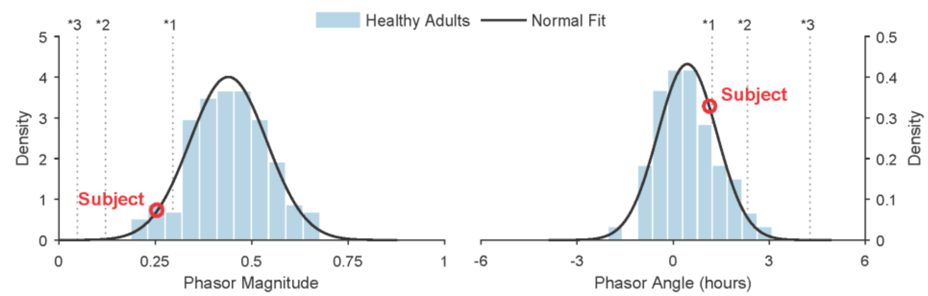
Interdaily Stability (IS): 0.50
Intradaily Variability (IV): 0.97

Mean Waking
Activity Index (AI): 0.16

Mean Waking
Circadian Stimulus (CS): 0.17

Geometric Mean Waking
Photopic Illuminance: 519.81 lux

Normal Probability Distribution

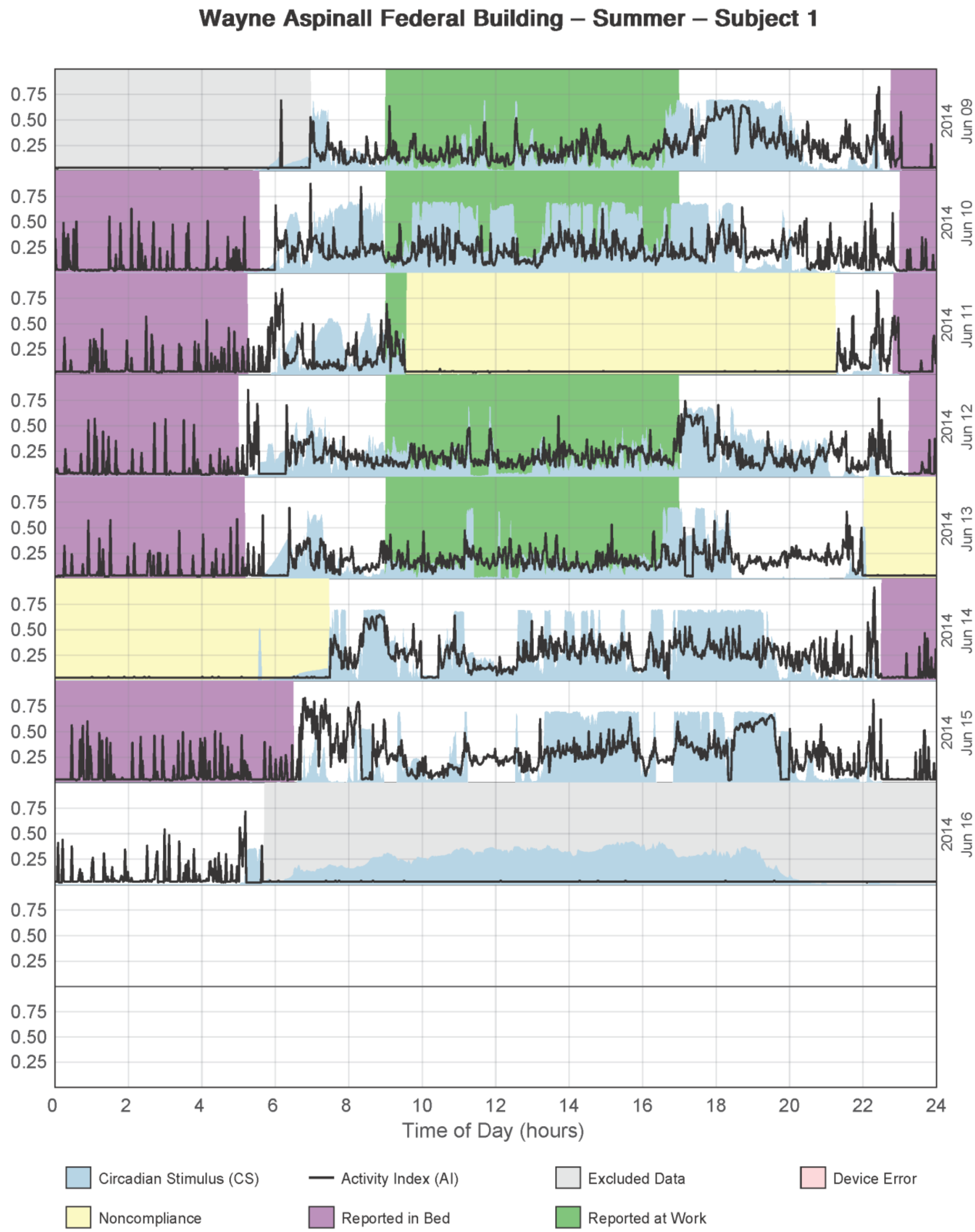


*Rotating shift nurses working 1, 2, & 3 nights per week.

Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

Rensselaer

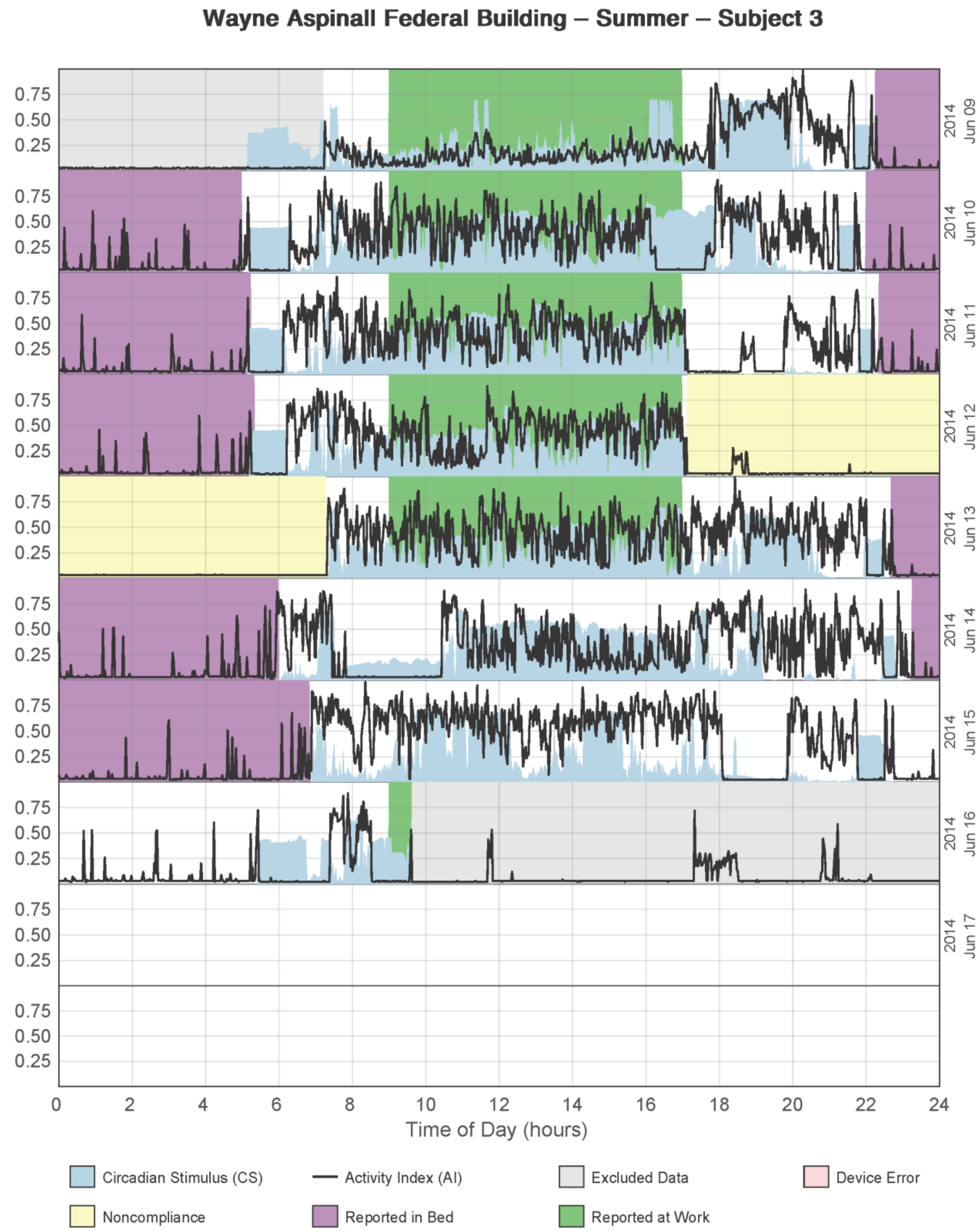


Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:47

1 of 1

Rensselaer



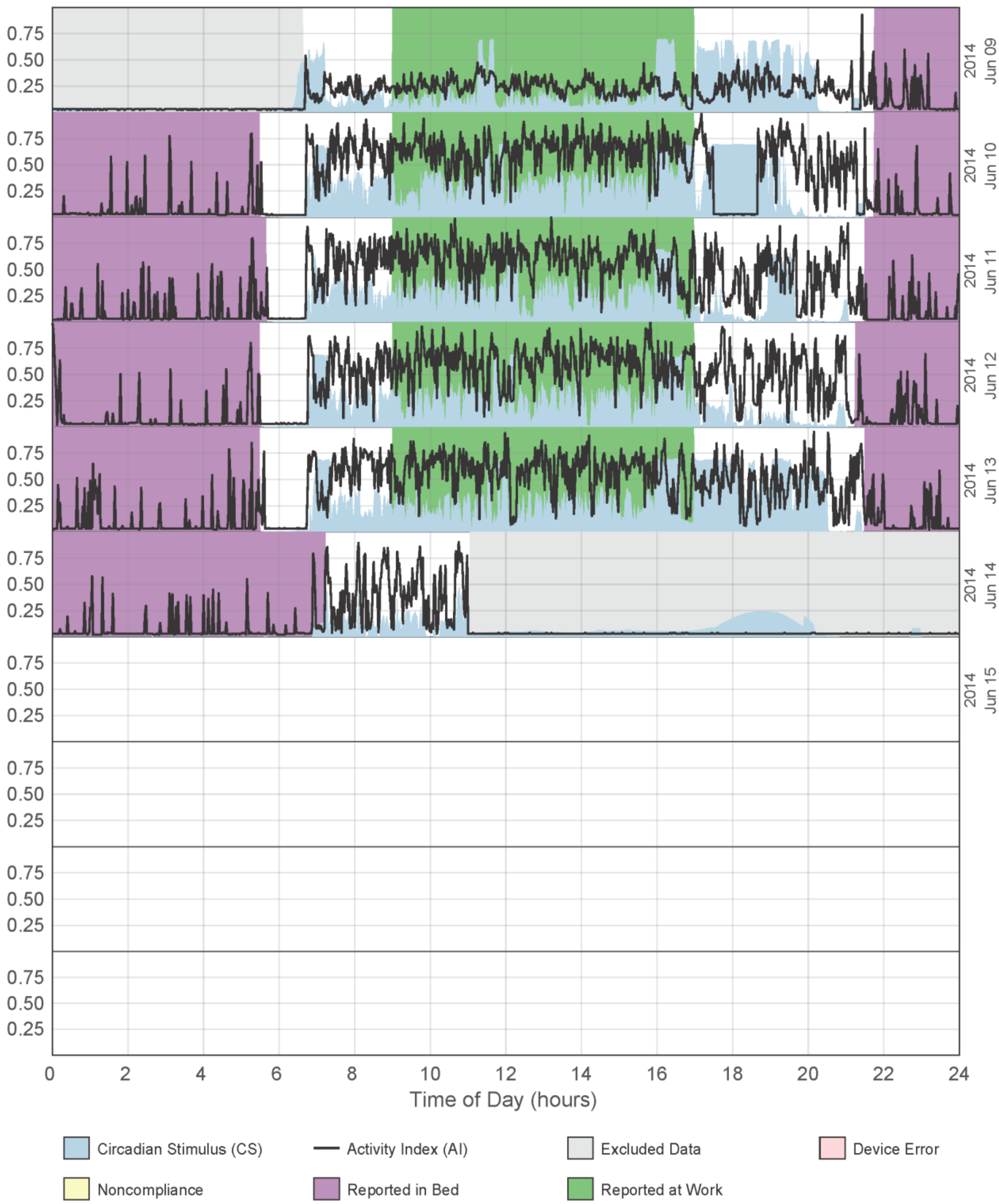
Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:47

1 of 1

Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 5



Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:47

1 of 1

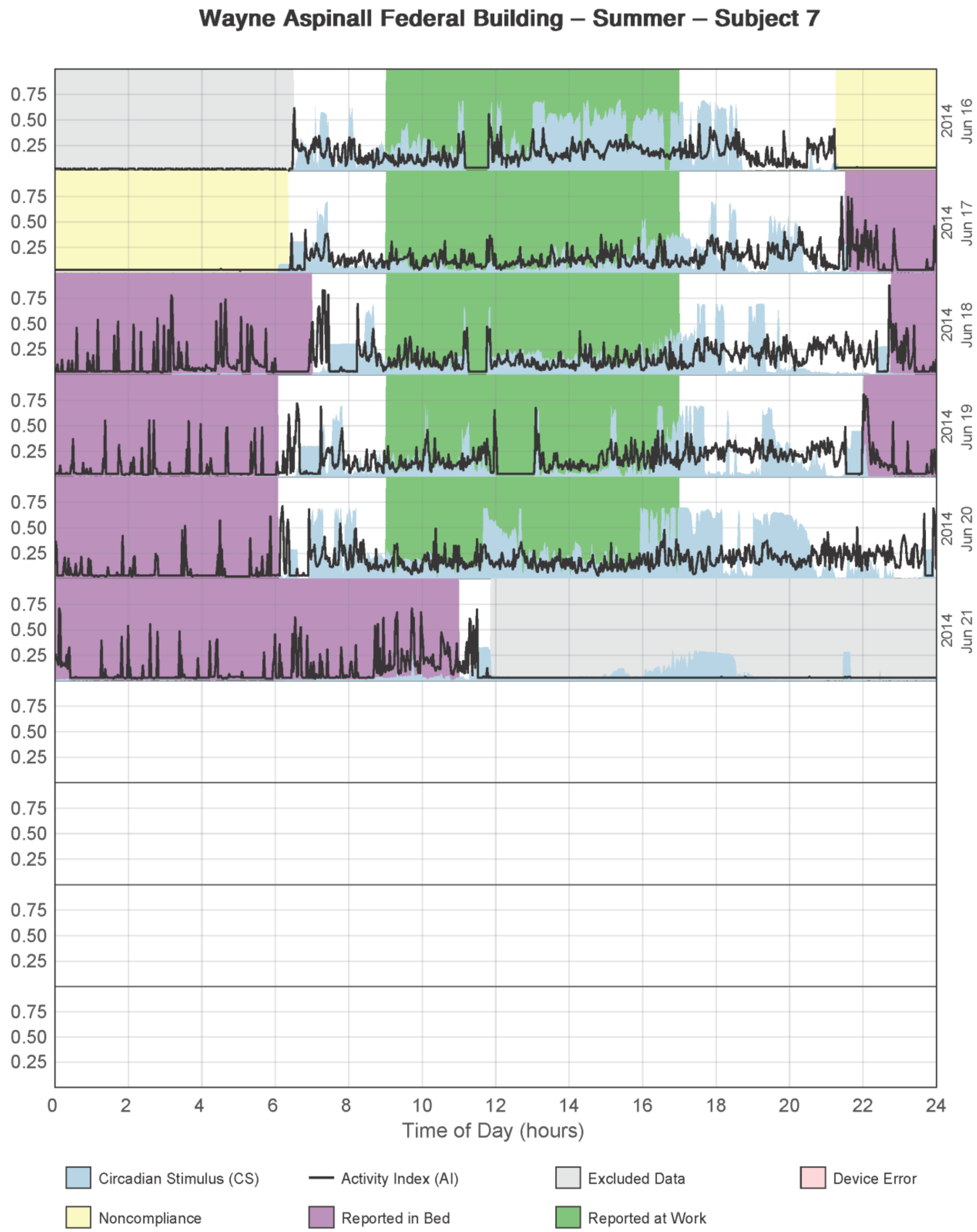
Rensselaer

Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:47

1 of 1

Rensselaer



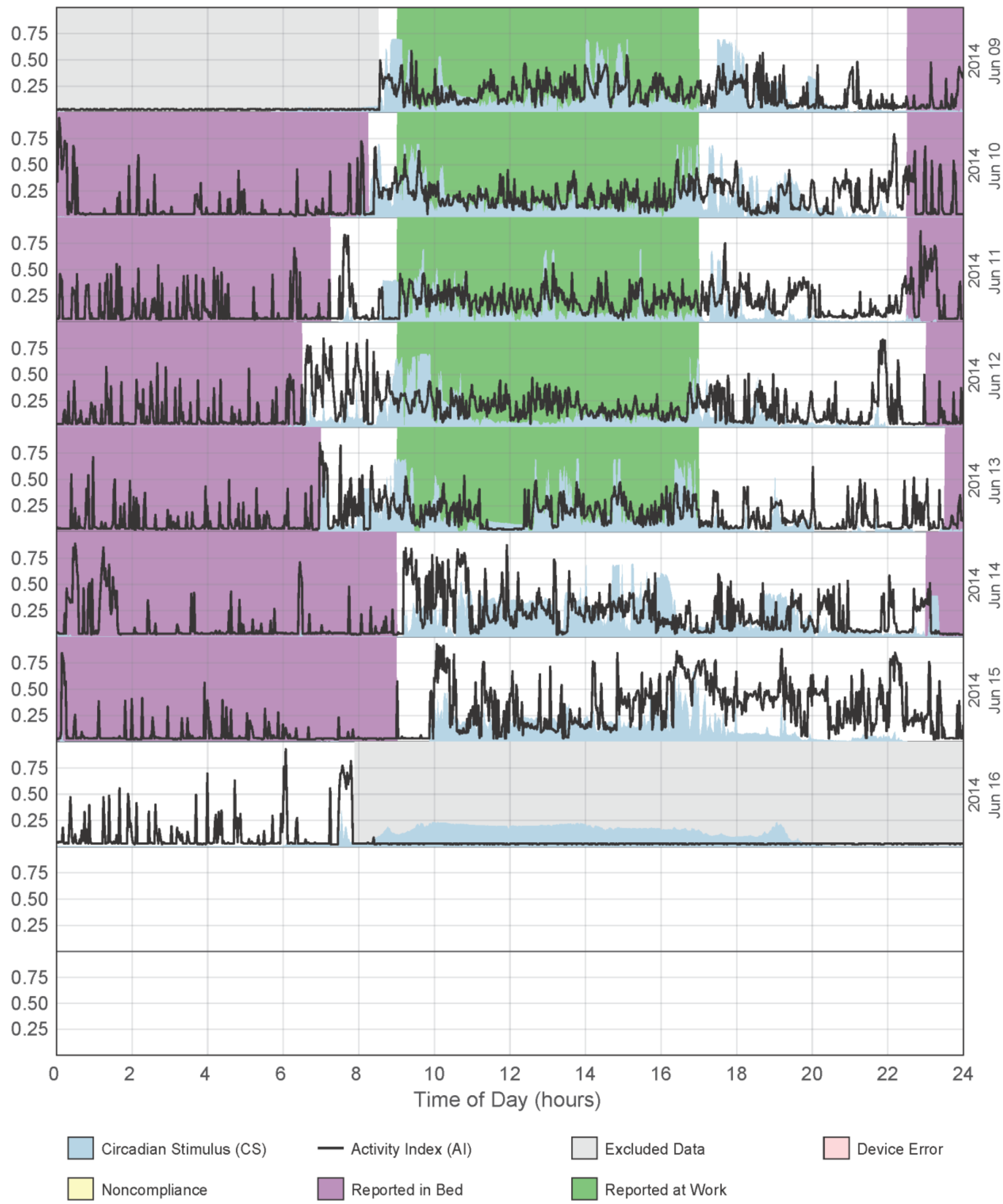
Daysigram Report
Generated: 2016 May 27, 17:47

1 of 1

Lighting Research Center

Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 8

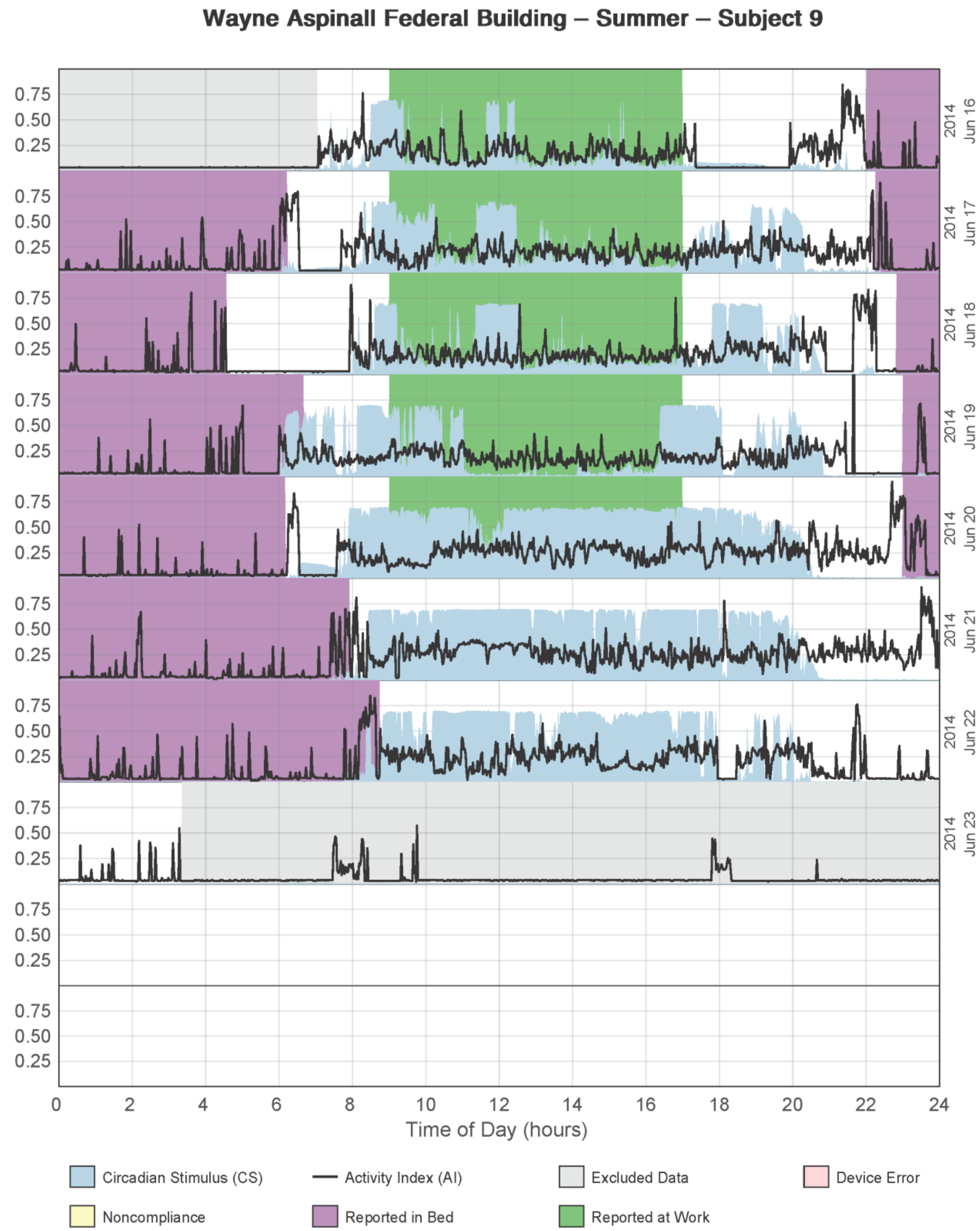


Lighting Research Center

Daysigram Report
Generated: 2016 May 27, 17:47

1 of 1

Rensselaer



Lighting Research Center

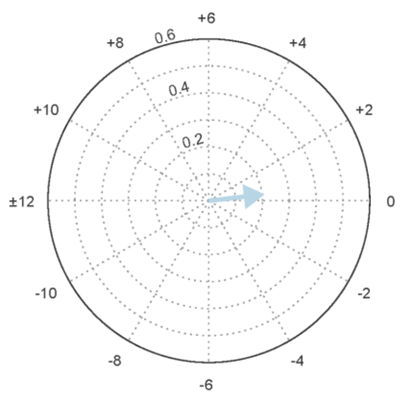
Daysigram Report
Generated: 2016 May 27, 17:48

1 of 1

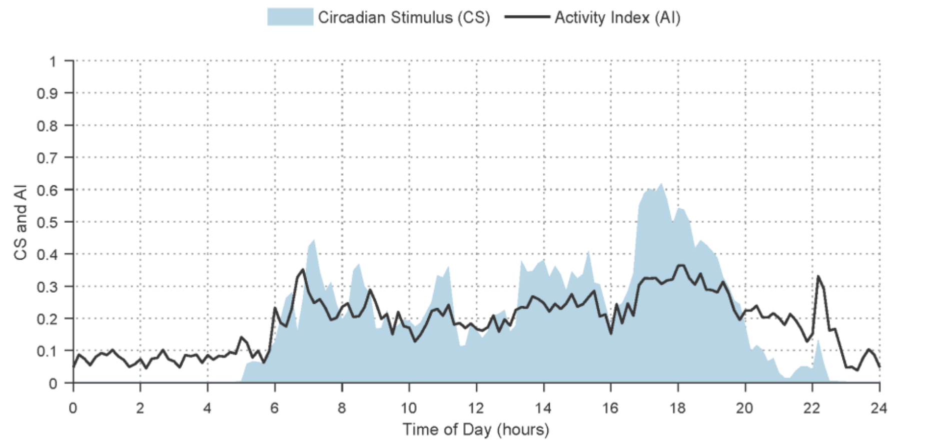
Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 1

Phasor

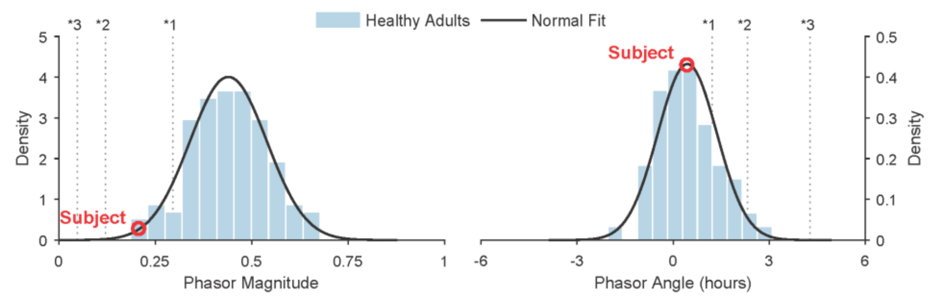


Average Day



Phasor Magnitude:	0.21	
Phasor Angle:	0.43	hours
Interdaily Stability (IS):	0.43	
Intradaily Variability (IV):	0.68	
Mean Waking Activity Index (AI):	0.22	
Mean Waking Circadian Stimulus (CS):	0.24	
Geometric Mean Waking Photopic Illuminance:	2102.65	lux

Normal Probability Distribution



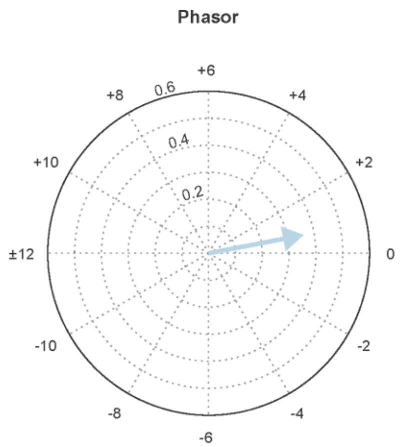
*Rotating shift nurses working 1, 2, & 3 nights per week.

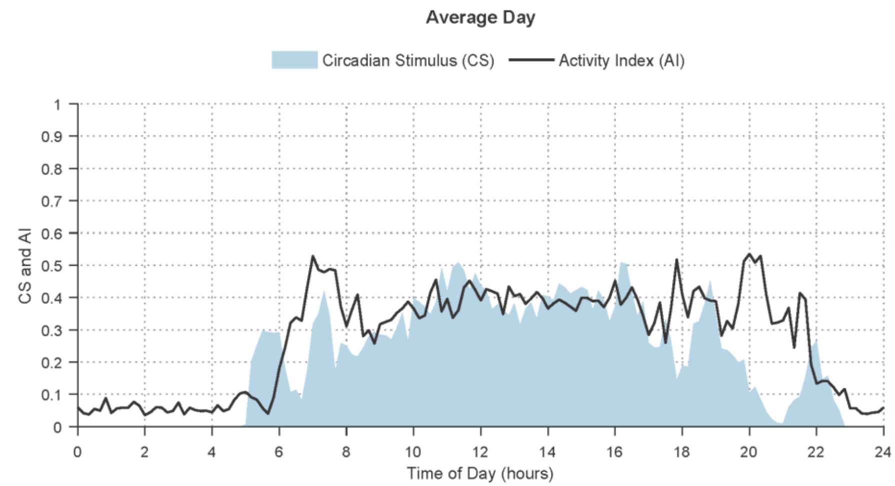
Lighting Research Center

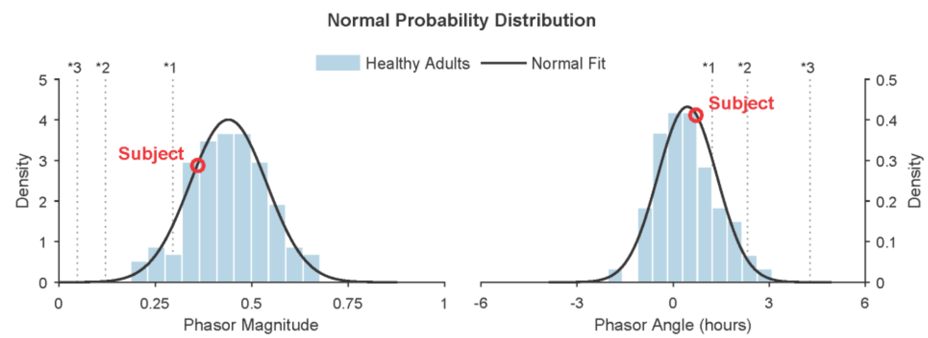
Composite Report
Generated: 2016 June 06, 17:06

Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 3







*Rotating shift nurses working 1, 2, & 3 nights per week.

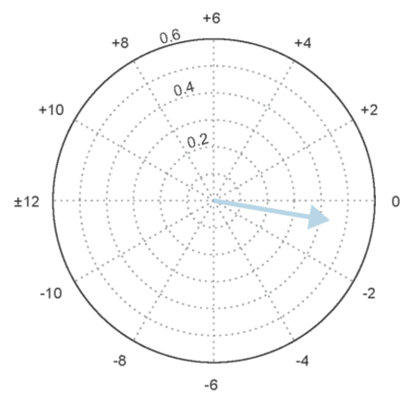
Phasor Magnitude:	0.36
Phasor Angle:	0.72 hours
Interdaily Stability (IS):	0.51
Intradaily Variability (IV):	0.56
Mean Waking Activity Index (AI):	0.35
Mean Waking Circadian Stimulus (CS):	0.29
Geometric Mean Waking Photopic Illuminance:	1389.76 lux

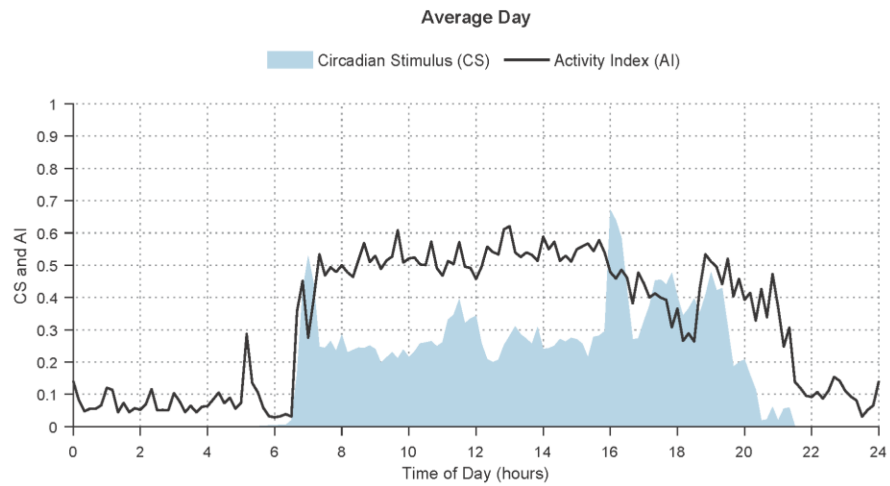
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

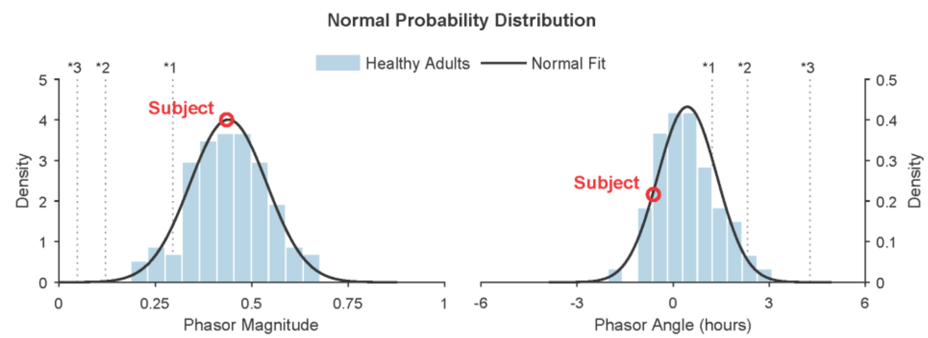
Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 5





Phasor Magnitude:	0.44	
Phasor Angle:	-0.64	hours
Interdaily Stability (IS):	0.77	
Intradaily Variability (IV):	0.37	
Mean Waking Activity Index (AI):	0.45	
Mean Waking Circadian Stimulus (CS):	0.27	
Geometric Mean Waking Photopic Illuminance:	1314.26	lux



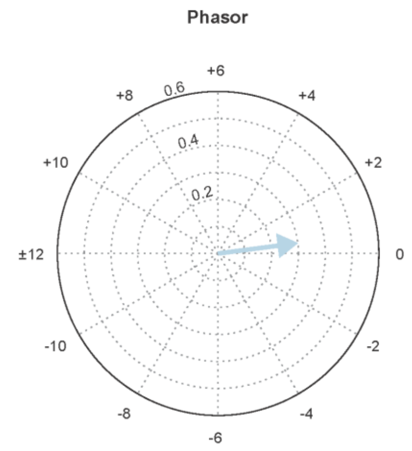
*Rotating shift nurses working 1, 2, & 3 nights per week.

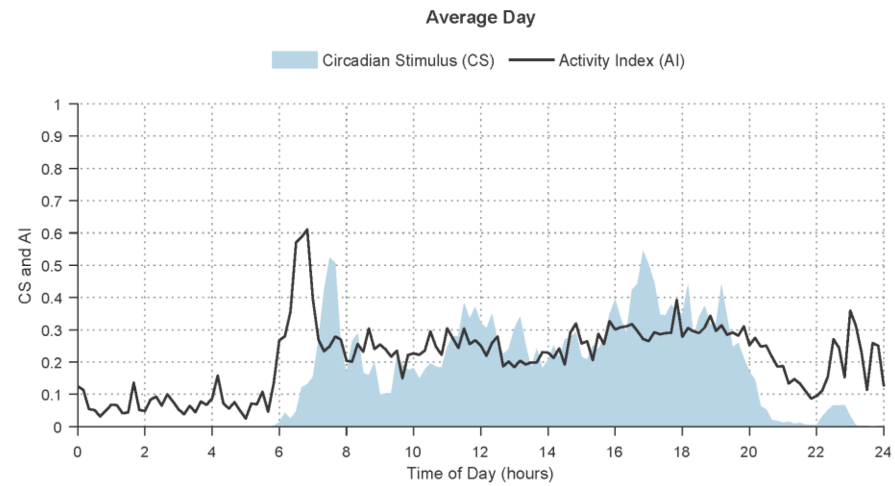
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

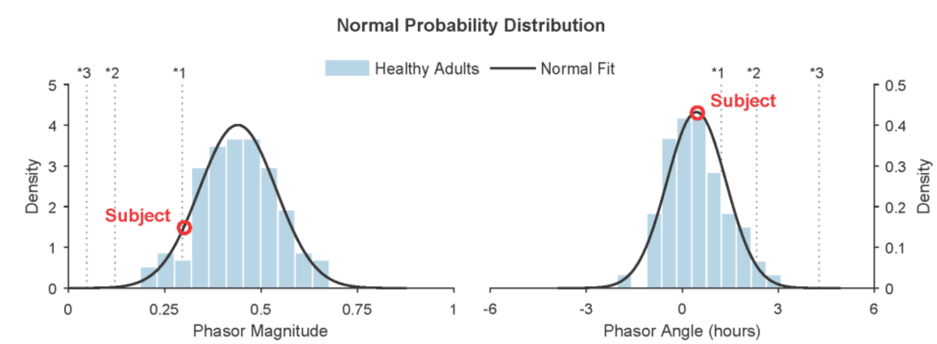
Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 6





Phasor Magnitude:	0.30	
Phasor Angle:	0.49	hours
Interdaily Stability (IS):	0.56	
Intradaily Variability (IV):	0.70	
Mean Waking Activity Index (AI):	0.26	
Mean Waking Circadian Stimulus (CS):	0.25	
Geometric Mean Waking Photopic Illuminance:	1338.21	lux



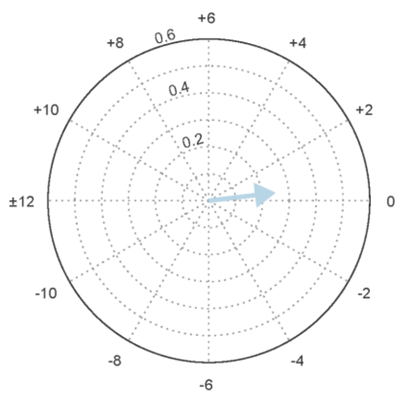
*Rotating shift nurses working 1, 2, & 3 nights per week.

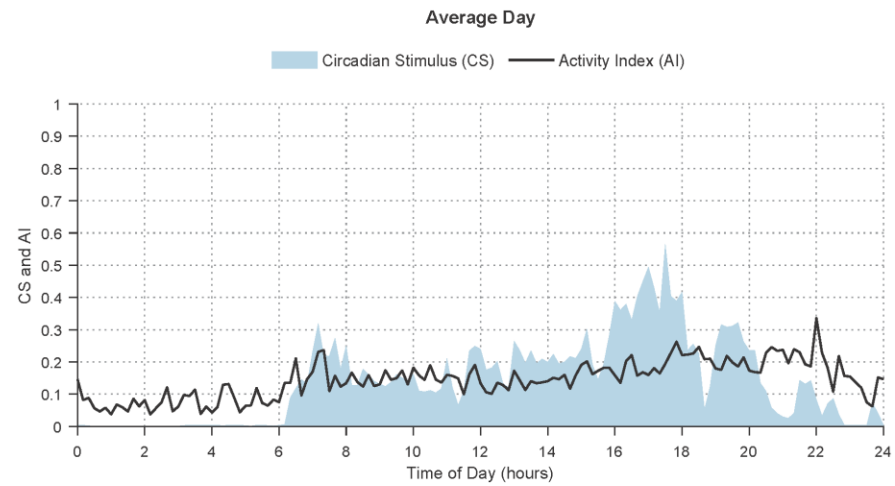
Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:05

Rensselaer

Wayne Aspinall Federal Building – Summer – Subject 7





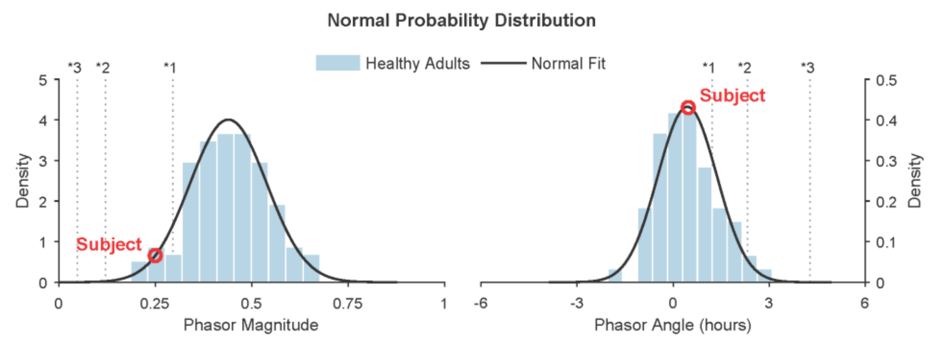
Phasor Magnitude: 0.25
Phasor Angle: 0.45 hours

Interdaily Stability (IS): 0.68
Intradaily Variability (IV): 0.53

Mean Waking
Activity Index (AI): 0.17

Mean Waking
Circadian Stimulus (CS): 0.22

Geometric Mean Waking
Photopic Illuminance: 755.90 lux

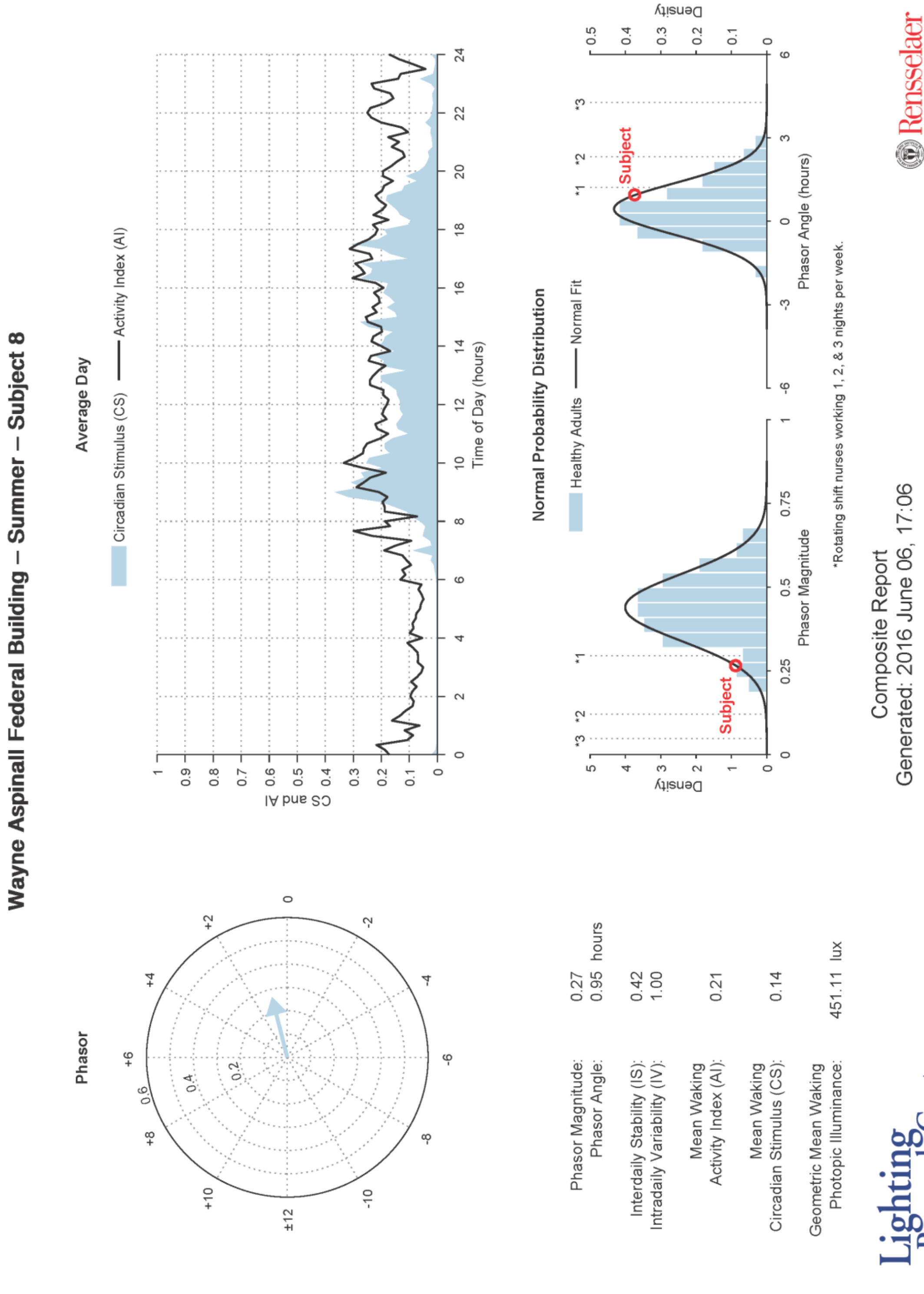


*Rotating shift nurses working 1, 2, & 3 nights per week.

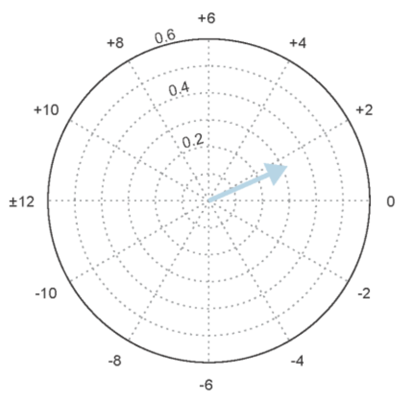
Lighting Research Center

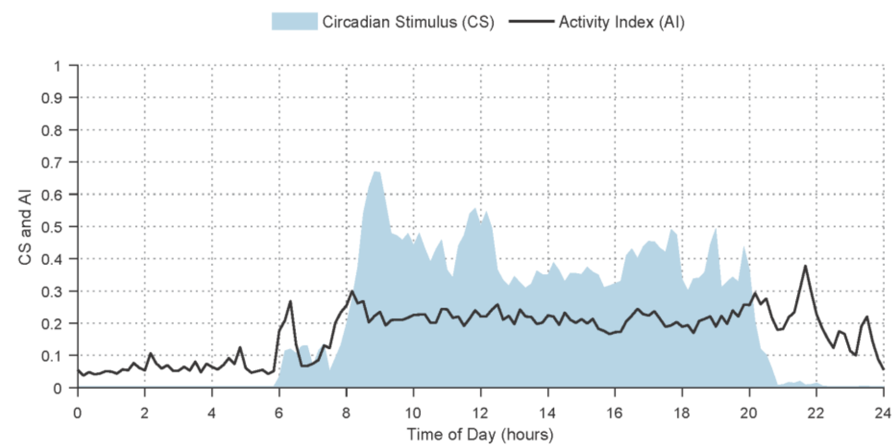
Composite Report
Generated: 2016 June 06, 17:06

Rensselaer


Wayne Aspinall Federal Building – Summer – Subject 8
Phasor
Phasor Magnitude: 0.27
Phasor Angle: 0.95 hours
Interdaily Stability (IS): 0.42
Intradaily Variability (IV): 1.00
Mean Waking Activity Index (AI): 0.21
Mean Waking Circadian Stimulus (CS): 0.14
Geometric Mean Waking Photopic Illuminance: 451.11 lux
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Density
Subject
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Composite Report
Generated: 2016 June 06, 17:06

Wayne Aspinall Federal Building – Summer – Subject 9





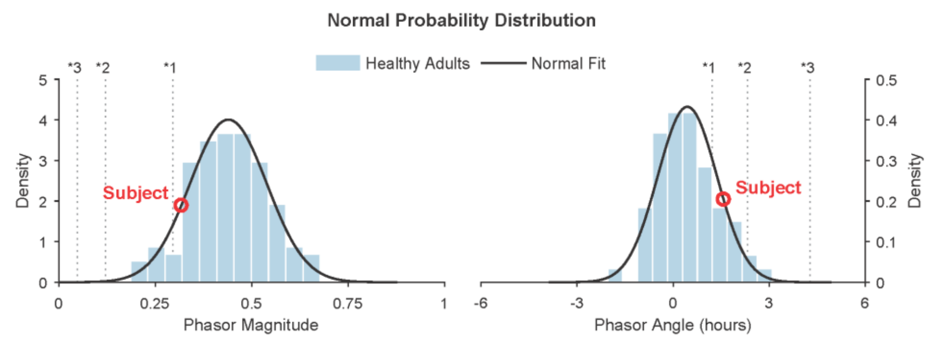
Phasor Magnitude: 0.32
Phasor Angle: 1.57 hours

Interdaily Stability (IS): 0.54
Intradaily Variability (IV): 0.80

Mean Waking Activity Index (AI): 0.21

Mean Waking Circadian Stimulus (CS): 0.31

Geometric Mean Waking Photopic Illuminance: 3200.94 lux



*Rotating shift nurses working 1, 2, & 3 nights per week.

Lighting Research Center

Composite Report
Generated: 2016 June 06, 17:06

Rensselaer

Appendix 5 – Winter and Summer Analyses

The following sleep and phasor analyses, along with two-tailed Student's *t*-tests, only take into account data from the 8 subjects who successfully completed the study in both winter and summer months. Data from Subjects 1, 3, 5, 6, 7, 8, and 9 were included in these analyses; Daysimeter data from Subject 4 were not usable because of low compliance.

Table A. Sleep analyses (winter and summer) and two-tailed Student's *t*-tests.

	Actual sleep (min.)	Actual sleep (%)	Actual wake (min.)	Actual wake (%)	Sleep efficiency (%)	Latency (min.)
Winter Mean	333.34	90%	40.97	10%	69%	96.77
Winter Median	337.20	91%	35.60	9%	69%	90.17
Winter SEM	14.02	2%	7.08	2%	2%	6.43
Summer Mean	366.36	88%	48.09	12%	79%	19.29
Summer Median	386.00	87%	61.67	13%	77%	18.22
Summer SEM	15.75	2%	10.28	2%	2%	4.64
***t*-tests**	0.022	0.653	0.596	0.653	0.002	0.000

Table B. Phasor analyses (winter and summer) and two-tailed Student's *t*-tests.

	Phasor magnitude	Phasor angle	IS	IV	Mean nonzero (CS)	Log mean nonzero (lux)	Mean nonzero (activity)	Mean work day (CS)	Log mean work day (lux)	Mean work day (activity)	Mean post work day (CS)	Log mean post work day (lux)	Mean post work day (activity)
Winter Mean	0.26	1.13	0.77	0.62	0.15	39.23	0.21	0.21	133.25	0.23	0.10	29.04	0.22
Winter Median	0.26	1.06	0.77	0.59	0.15	37.67	0.20	0.20	117.00	0.20	0.11	24.04	0.22
Winter SEM	0.02	0.33	0.04	0.06	0.02	8.52	0.02	0.02	20.51	0.03	0.01	4.91	0.01
Summer Mean	0.31	0.57	0.74	0.54	0.25	105.76	0.27	0.26	207.29	0.27	0.21	64.93	0.26
Summer Median	0.30	0.49	0.76	0.55	0.25	115.72	0.22	0.23	149.14	0.20	0.23	78.07	0.24
Summer SEM	0.03	0.25	0.04	0.05	0.02	24.21	0.04	0.03	44.60	0.05	0.02	14.77	0.03
***t*-tests**	0.106	0.185	0.690	0.204	0.001	0.049	0.176	0.057	0.078	0.406	0.000	0.059	0.118