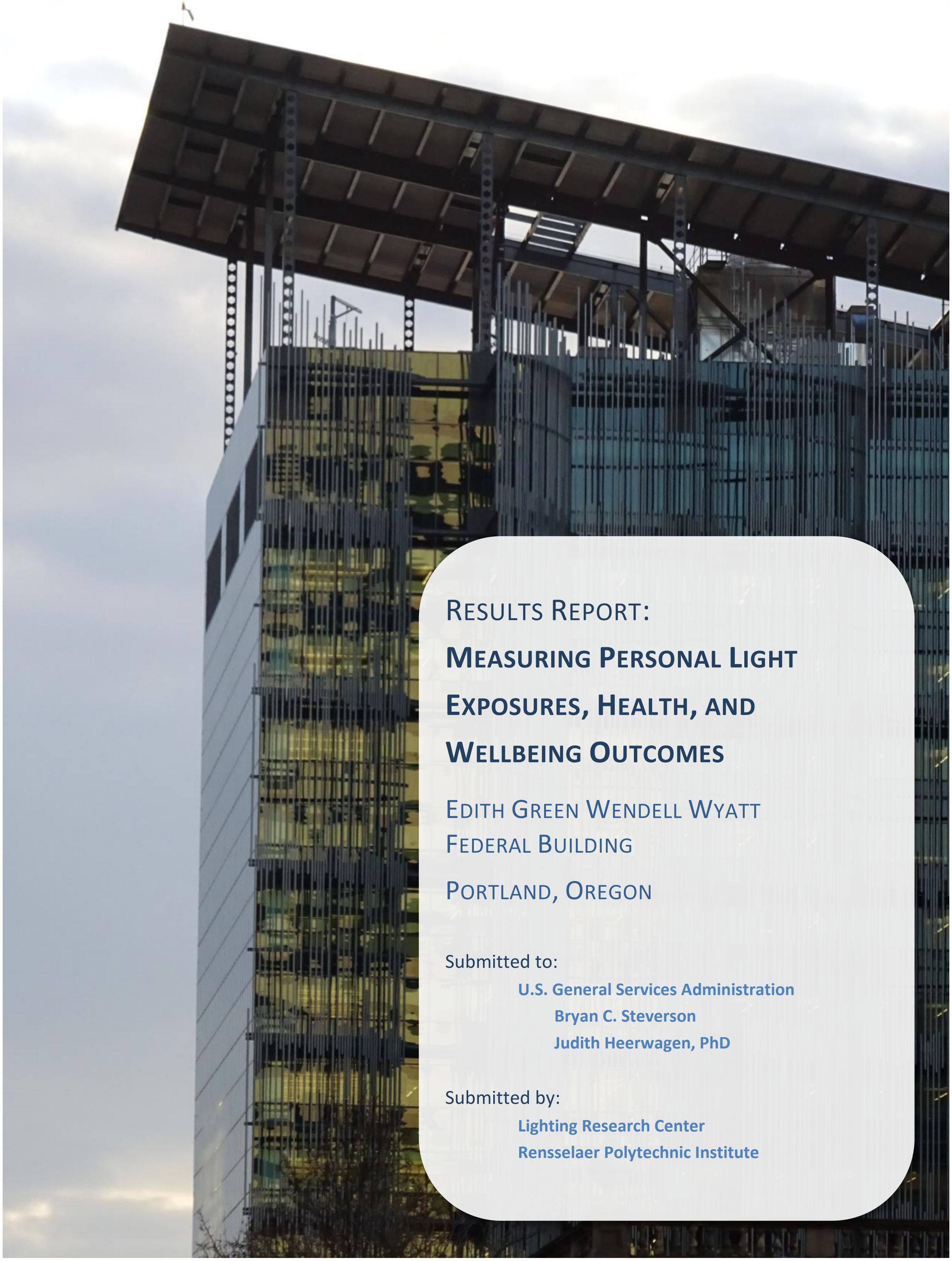

Results Report:

Measuring Personal Light Exposures, Health, and Wellbeing Outcomes

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Portland, Oregon

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

EDITH GREEN WENDELL WYATT FEDERAL BUILDING
PORTLAND, OREGON

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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 15 participants working at the Edith Green-Wendell Wyatt Federal Building in Portland, Oregon, who agreed to wear the Daysimeter, a calibrated light and activity meter, for seven consecutive days during the months of May and June 2014 and repeat the study during the months of November and December 2014. Daysimeters measure continuous light exposures, allowing researchers to perform calculations of how much light that is effective for the circadian system (i.e., circadian stimulus, or CS) the occupants of the building may be receiving. Participants wore the Daysimeter while awake (both in the office and at home) and during sleep, and also filled out a series of self-reports probing their sleep quality, depression, and mood scores. Data for the 24 participants who participated in the summer months only (which includes the 15 participants whose data are being reported here) were already presented in a report delivered to the GSA in August 2014.

Results during the summer months showed that the CS experienced by participants during the work week and while awake was close to the desired CS value of 0.3 [mean ± standard deviation (SD) = 0.24 ± 0.07]. The data suggest that participants were exposed to the highest CS values during their working hours, compared to when at home (early morning and evenings). LRC researchers calculated the CS values between 8:00 a.m. and 5:00 p.m. and found that the mean ± SD CS value was 0.28 ± 0.1, while the mean CS value outside working hours was 0.19± 0.08. (CS value is a surrogate for how much that light stimulus activates the circadian system; a CS value of 0.24 is representative of a circadian stimulus that would result in 24% melatonin suppression if similar light levels were experienced at night for one hour, while values above 0.4 suggest a strong stimulation of the circadian system.) The geometric mean of the light levels experienced by participants during the work week was 178 lux and the arithmetic mean was 1152 lux. The geometric mean during work hours (8:00 a.m. to 5:00 p.m.) was 50 lux and the arithmetic mean was 871 lux.

Phasor magnitudes were used as a measure of circadian entrainment. It quantifies circadian entrainment/disruption in terms of phase and amplitude relationships between measured light-dark and activity-rest patterns. Phasor magnitudes in this population (mean = 0.3) were lower than what the LRC has measured in other dayshift workers (e.g., teachers or nurses), which had mean phasors of 0.4 to 0.5 (Rea et al. 2011; Miller et al. 2010). Participants slept on average 5.9 hours, had a sleep latency of about 22 minutes and a sleep efficiency of 78%. Pittsburgh Sleep Quality Index (PSQI) scores in 12 participants were greater than 5, indicating poor sleep quality, while six participants had scores of 5 or less, indicating no sleep disturbance (one participant did not fill out the PSQI questionnaire). The PROMIS Global Score, another scale probing sleep disturbances, was above 25 for two participants, indicating sleep disturbances. The same two participants who reported having sleep disturbances also reported feeling depressed.

During the winter months, CS experienced by participants during the work week and while awake was lower than the desired amount (mean ± SD = 0.12 ± 0.04) and significantly lower than the values experienced in summer months ($p<0.00$). LRC researchers calculated the CS values between 8:00 a.m. and 5:00 p.m. and found that the mean CS ± SD value was 0.18 ± 0.06, while the mean CS value outside working hours was close to 0.04 ± 0.02. The mean light level was 91 lux during the work week and outside working hours it was much lower (average = 10 lux).

Phasor magnitudes in winter months (mean = 0.28) were very similar to summer months, while phasor angles were significantly different between the two seasons (0.49 hours in summer and 2.11 hours in winter). Participants slept on average 6.1 hours, had a sleep latency of 19 minutes and a sleep efficiency of 79%. None of the sleep parameters were significantly different between summer and winter months. The PROMIS Global Score for two participants was above 25, indicating sleep disturbances. The two same participants who reported feeling depressed in the summer also reported feeling depressed in the winter.

Contrary to the original hypothesis, researchers did not observe any significant differences in sleep parameters and in questionnaire responses between winter and summer months. Unlike the results collected at the Wayne N. Aspinall Federal Building in Grand Junction, CO, which showed that sleep efficiency and duration was increased in summer months compared to winter months, the present results did not show any significant changes in sleep parameters or in subjective responses of mood, depression, and sleep quality between the two seasons. There were no correlations between CS values and self-reports of mood and sleep disorders in either season. While some elevated mood and sleep disturbances were self-reported, they may have been associated with life events that are independent of the amount of daylight exposure that the participants received.

It is not known whether the circadian system will adapt to lower light levels and whether this stimulus, given that it was the strongest that participants received during the day, would be sufficient to maintain entrainment to the 24-hour solar day. It is also not known whether people living in gloomy environments, such as the Northwest, will adapt to lower light levels and the shorter photoperiod in winter months would be less impactful in this population. In other words, those who cannot adapt to less daylight availability are not willing to live in the places like Portland, OR. It is possible that conducting additional studies with larger data sets could determine whether a correlation exists between circadian light exposures at work and self-reports of sleep and mood.

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. GSA staff organized informational sessions at the building during lunchtime hours. There were no exclusion criteria to participate in the study. Two informational sessions were held on April 22 and 23, 2014. All interested parties were invited to attend and ask questions about the research protocol. If interested, participants contacted the Lighting Research Center (LRC) and signed up for the study. A GSA employee was the point person on site and distributed and collected all the devices and questionnaires. The LRC was able to recruit 29 participants for the summer portion of the study; 24 participants completed the study and had usable data (results were reported to GSA in August 2014). The same participants were contacted in late October/early November and 20 participants agreed to repeat the study in winter months. Of those, 15 participants had complete data sets for summer and winter months and their results are reported in this report.

MEASUREMENT PROCEDURES

DEVICES

The Daysimeter, a calibrated light measuring device, was used to collect personal light and activity data. Light sensing by the Daysimeter is performed with an integrated circuit (IC) sensor array (Hamamatsu model S11059-78HT) that includes optical filters for four measurement channels: red (R), green (G), blue (B), and infrared (IR) (Figueiro et al. 2013). 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 magnitude of circadian stimulus (CS), which represents the input-output operating characteristics of the human circadian system from threshold to saturation. Briefly, illuminance is irradiance weighted by the photopic luminous efficiency function (V(λ)), an orthodox measure of the spectral sensitivity of the human fovea, peaking at 555 nm. CL_A is irradiance weighted by the spectral sensitivity of the retinal phototransduction mechanisms stimulating the response of the biological clock, based on nocturnal melatonin suppression. CS is a transformation of CL_A into relative units from 0, the threshold for circadian system activation, to 0.7, response saturation, and is directly proportional to nocturnal melatonin suppression after one hour exposure (0% to 70%).

Recordings of activity-rest patterns were based upon the outputs from three solid-state accelerometers calibrated in g-force units (1 g-force = 9.8 m/s) with an upper frequency limit of 6.25 Hz. An activity index (AI) is determined using the following formula:

$$AI = k\sqrt{(SS_x + SS_y + SS_z)/n}$$

SS_x, SS_y, and SS_z are the sum of the squared deviations from the mean of each channel over the logging interval, n is the number of samples in a given logging interval, and k is a calibration factor equal to 0.0039 g-force per count. Logging intervals for both light and activity were set at 90 seconds.

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 our 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 peaking during the daytime). Furthermore, the lighting characteristics affecting the biological clock are different than those affecting the visual system. In brief, humans need at least 10 times more light to activate their circadian system than to see. Light levels used in offices (e.g., 500 lux [approx. 50 footcandles (fc)] on the work plane; about 100-200 lux [approx. 10-20 fc] at the cornea) are sufficient for a person to read black fonts on white paper, but only slightly affect the biological clock. The biological clock is sensitive to blue light (460 nm), while one aspect of the visual system (i.e., acuity) is maximally sensitive to yellow-green (555 nm). The biological clock cares about when people are exposed to light over the course of the 24-hour day. Morning light will help a person go to bed earlier and wake up earlier while evening light will help a person 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 crucial. 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 one is exposed to may cancel out the effect of morning light; therefore, being able to measure light over the course of the entire waking period is imperative to understand the possible effects of light on health, mood and wellbeing. The goal of this project was to investigate the amount of circadian light one is being exposed to while working in a building where daylight is prominent, and outside of working hours. This study complements the photometric measurements that have already been performed in the same building and can help to understand how occupant behavior and/or design modifications affect personal light exposures in the workplace. Summer measurements were collected and results were reported to GSA in August 2014. The present report summarizes the winter and summer data collected from participants who completed the study in both seasons.

Questionnaires

Participants completed several subjective questionnaires about mood and sleep habits 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): Subjective measure of sleep quality and patterns. It differentiates poor from good sleep by measuring seven areas: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction. Scoring of answers is based on a 0 to 3 scale and yields one global score. A global score of 5 or greater indicates a poor sleeper. (Buysse et al. 1989)

Karolinska Sleepiness Scale (KSS): 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 to 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): 10 positive affects (interested, excited, strong, enthusiastic, proud, alert, inspired, determined, attentive, and active) and 10 negative affects (distressed, upset, guilty, scared, hostile, irritable, ashamed, nervous, jittery, and afraid). Participants are 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): Self-report designed to measure depressive symptoms. This test is a 20-item measure that asks how often over the past week the participants 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. Once enrolled in the study, participants were asked to wear the Daysimeter as a pendant for seven consecutive days in the late spring/early summer months and again in late fall/early winter months. At night while sleeping, participants were asked to wear the device on their wrist 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 data were collected four times per day: wake, noon, dinner, and bedtime.

The devices were mailed to the GSA staff volunteer helping with this study. The volunteer distributed and collected all of the devices but did not have access to any data. All of the devices and questionnaires were placed inside a sealed envelope and the GSA staff was only responsible for giving the envelope to the participant at the start of the study and receiving the envelope at the end of seven days. No issues were reported with this method of delivering/returning the devices to the LRC. Data were collected during the months of May and June 2014 (summer) and November/December 2014 (winter).

DATA ANALYSES

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

PHOTOPIC LIGHT AND CIRCADIAN STIMULUS

In terms of photopic light levels, the LRC calculated these values in two ways: 1) geometric mean of the recorded levels were calculated to help normalize the highly skewed distribution of recorded light levels and 2) arithmetic mean, which are generally higher because of the highly skewed values, such as a trip outdoors during the daytime. In terms of circadian light exposures, we calculated the circadian stimulus during working hours (assumed to be between 8:00 a.m. and 5:00 p.m.) and outside working hours (early morning after waking and evening prior to bedtimes).

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, the LRC used the measured circadian light-dark pattern and activity-rest pattern. Phasor analysis incorporates a fast Fourier transform (FFT) power and phase analysis of the circular correlation function computed from the two sets of time-series data. 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 were 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.

While the Daysimeter devices were worn on the wrist during the nighttime, only the daytime (pendant) data were included in the phasor analyses. This was because the activity patterns differ from when the device is worn as a pendant to when it is worn on the wrist; therefore, to avoid bias in the data, researchers assumed close to zero activity and light during the times at which participants reported being asleep. This allowed a comparison of the phasor analyses from these participants to other data that were already collected.

Activity-rest rhythms consolidation

The two computed measures of activity-rest rhythms consolidation were: 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 nighttime Daysimeter:

- Time in bed is defined as the difference between wake time and bedtime.
- Sleep start time is defined as the first 10-minute interval within the analysis period with one or less epochs scored as wake.
- Sleep end time is defined as the last 10-minute interval within the analysis period with one or less 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, calculated as the difference between sleep start and bedtime.

RESULTS

Table 1 shows the participants' seating locations and window orientations. Tables 2-14 show individual results together with the mean, median and standard error of the mean (SEM) of the sleep, light exposures and phasor analyses from the Daysimeter data and the self-reports sleep and mood questionnaires for winter and summer months. Due to non-compliance, data for 15 participants are included in the Daysimeter 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 generally low in both summer and winter months (average of approximately 5.9 hours per night in summer and 6.1 hours per night in winter). Sleep efficiency was also low, around 78% in the summer and 79% in the winter months.

- Sleep scores from self-reports are mixed. One scale (PSQI) suggests that over half of the participants have sleep disturbances (scores above 5 signify sleep disturbances), while the PROMIS Global Score suggests that only two participants had moderate sleep disturbances (scores above 25 signify sleep disturbances). When considering the adjusted PROMIS score (T-score), these two patients were above the average, again, suggesting that they do have sleep disturbances. When comparing the self-reports for summer and winter, the PSQI scores suggest that 8 out of 18 participants increased their sleep disturbances in winter compared to summer months. The PROMIS Global Score suggests that 10 participants increased their sleep disturbances in winter compared to summer months.

- The mean CS values experienced by participants during their working hours (between 8:00 a.m. and 5:00 p.m.) were about 0.28 in summer and 0.18 during winter months (CS values in winter months were statistically lower than in summer months). The CS of 0.28 is equivalent to 28% melatonin suppression if the light experienced 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 received during summer months were slightly below, but very close to what is considered good stimulation for the circadian system (i.e., 0.3 or greater). Given that participants are exposed to this CS value for periods longer than one hour, it is highly likely that this building provides users with enough circadian stimulation during the summer months. However, CS values during winter months were significantly lower than during the summer months, and lower than the desired CS of 0.3. While entrainment of the circadian system is not the same as acute melatonin suppression, there is not a strong reason to believe that acute melatonin suppression and circadian entrainment have different sensitivity to light. It is important to note, however, that exposure to 0.18 CS values over the course of the working hours may be sufficient to maintain entrainment, so these workers may still be getting sufficient entraining stimulus.

- Workers sitting at desk spaces located in the north façade all had CS values above 0.3 in summer months, but not always in winter months. The lowest CS values were associated with desk spaces located away from windows (B rows) and in the south and east façades, most likely because window shades were drawn to reduce sunlight penetration. Two workers who worked on the sub-floor had the lowest CS values in the summer months; in the winter, the CS values for the one participant who repeated the study were comparable to other workers in the building. Also interesting to point out is the fact that some workers sitting in the west façade had high CS values in summer months, but their CS exposures were much lower in winter months, most likely due to the short photoperiods. The architectural “reeds” installed on the west façade may have contributed to these higher CS levels in the summer, as the experimenters observed that shades were not drawn in this façade.

- Phasor magnitudes were low (mean = 0.30 in summer and 0.28 in winter) compared to other groups of workers, although this was very similar to those obtained from participants at the Grand Junction site. A high phasor magnitude suggests that the person is entrained to the 24-hour day/night cycle. For comparison, our 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 about 0.49 on average in summer, which is a common value for daytime workers who tend to have some activity later in the evening, after sunset. It is interesting that during the winter months, phasor angles were much greater (mean = 2.11). At the Grand Junction site, phasor angles in the summer months were similar (mean = 0.57 in summer and 1.05 in winter). For comparison, the LRC’s data sets show that the mean phasor angles for school teachers and dayshift nurses were 0.94 and 0.68. One interesting observation from these two studies is that phasor angles tend to be more spread and separated in summer months than in winter months. We hypothesize that this is because, in general, people are active after working hours, but during the winter months, this activity occurs in circadian darkness and during the summer the activity occurs while there is circadian light available from daylight.

- Depression scores were high in two participants during both winter and summer months. In one participant, the depression score increased in winter while in the other it remained very similar. The CS values experienced by these two participants were not among the lowest and phasor magnitudes were not the shortest either, suggesting no circadian disruption in this population. It is possible the life events of the two participants who reported feeling depressed are more likely affecting their score than their lighting. Depression scores increased in 8 out of 18 participants from summer to winter months.

- The same two participants who reported feeling depressed also reported high negative scores and low positive scores in the PANAS.

- KSS score (sleepiness) during the noon hour (i.e., while participants were at work) was slightly but not significantly higher in winter than in summer months (3.5 in summer and 3.9 in winter).

Some limitations of the data set include:

- A control study of a building with no daylight availability is not being run, so, while the impact of a daylit building may not be apparent from the data, it could very well be that these scores are worse in those living in the northwest that do not have access to daylight during working hours. Data was collected from four participants who were in the old Federal Central South Building in Seattle. The data showed that their CS during working hours was 0.26 on average, which is not much different than that experienced by participants in Portland. This may have been because participants were outdoors during working hours. Therefore, it was difficult to use them as controls.
- It is not known whether participants' life events are playing a stronger role in their self-report ratings than their personal light exposures. The LRC did not set out to investigate other factors.
- Research questions still unanswered are whether humans adapt to lower levels of light for the circadian system, and whether a CS value of 0.2 may be enough to maintain entrainment. In addition, it is not known whether an 8-hour exposure to this CS value is also sufficient for entrainment.
- Another uncontrolled variable that may have affected the results is caffeine intake, which may have increased in winter months and, therefore, helped with maintaining a certain level of alertness during the working day.

Appendix 1 shows the daily patterns of CS and activity over the course of the week for each of the participants during both winter and summer months. Appendix 2 shows the mean CS and activity over the course of the seven days for each of the participants during both winter and summer months. As shown in these figures, participants were regular and exposed to similar lighting conditions over the course of seven days. Some participants receive a higher amount of light around lunch time, suggesting possibly a trip outdoors during that time. These figures can be seen as a "sketch" of the participants' CS and activity over the course of 24 hours. Figure 1, below, shows the average for all of the 15 participants who were included in the phasor and sleep analyses presented in the tables. 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 are exposed to the highest CS values during their working hours, rather than while at home.

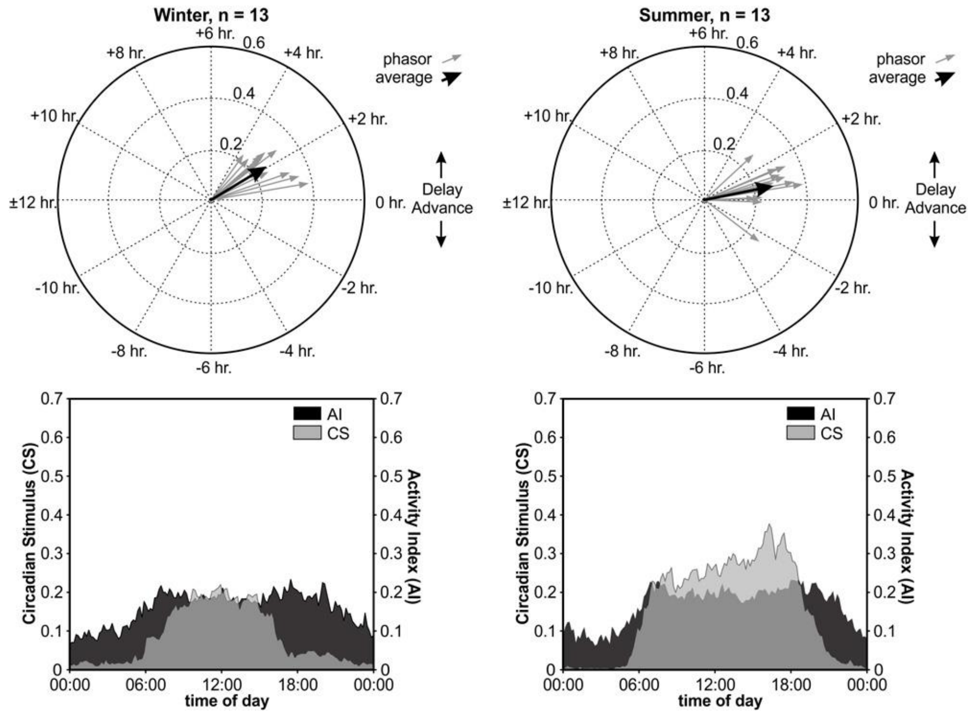

Figure 1: Phasor diagrams for winter (left) and summer (right) for the 13 repeating participants who had usable data. Phasor magnitude (length) quantifies, in terms of the 24-hour period, how closely tied the light-dark and activity-rest patterns are to the 24-hour day and the angle quantifies the relative phase of the light-dark and activity-rest patterns. Bottom graphs: Average circadian stimulus (CS) and activity index (AI) for 5 working days in summer and 5 working days in winter for the 13 repeating participants who had usable data.

Table 1. Window orientation and office characteristics

Participant	Dates	Floor	Window Orientation	Window Proximity (Row)
1	May 12-18/ Dec 1-7	16	West	B
2	May 12-18/Nov 17-23	4	West	A
4	May 12-19/Nov 10-16	4	South	A
5	May 13-18*/Nov 17-23	–	–	–
7	May 12-19/Nov 10-16	4	South	A
8	May 19-23*/Nov 10-16	10	North	B
10	May 20-25*/Nov 10-16	4	South	A
11	May 19-25/Dec 1-7	4	West	A
13	May 19-26/Dec 1-7	16	SW Corner	A
15	May 19-25/Nov 17-23	15	North	A
17	May 19-25/Nov 17-23	3	South	A
18	May 19-25/Dec 1-7	10	East	C
19	May 19-25/Nov 10-16	16	West	A
23	June 2-9/Nov 17-23	15	South	A
24	June 2-8/Dec 8-14	16	South	A
26	June 2-9/Nov 10-16	4	West	B
27	June 2-9/Nov 10-16	0/Sub-floor	–	–
28	June 9-12/Nov 17-23	6	North	C
29	June 2-8/Dec 1-7	12	North	A

Note: While participants were asked to wear the Daysimeter for seven consecutive days, some participants did not comply for the full seven days but still had usable data; these dates are marked with an asterisk (*). Row A is located closest to the window, while Row C is farthest from the window. Row B is next to Row A. Many offices are open plan cubicles.

Table 2. Sleep analysis, summer

Participant	Nights Avg.	Sleep Time (min)	Sleep Time (%)	Actual Wake Time (min)	Actual Wake (%)	Sleep Efficiency (%)	Sleep Onset Latency (min)
1	5	421	93%	32	7%	85%	17
2	5	332	84%	62	16%	77%	11
4	5	335	87%	50	13%	79%	11
5	3	316	87%	48	13%	75%	39
7	4	458	92%	40	8%	79%	68
11	5	422	89%	52	11%	85%	7
13	5	334	91%	35	9%	87%	3
15	5	462	93%	37	7%	87%	3
17	5	365	89%	45	11%	80%	13
18	4	296	91%	29	9%	81%	11
19	5	364	83%	77	17%	74%	47
23	5	273	94%	17	6%	75%	16
24	5	333	77%	97	23%	64%	21
27	5	324	85%	59	15%	72%	38
29	5	296	77%	93	23%	71%	21

Note: Results from Participants 8, 10, 26, and 28 were not included.

Table 3. Phasor analysis, summer

Participant	Phasor Magnitude	Phasor Angle (h)	Interdaily Stability (IS)	Intradaily Variability (IV)
1	0.23	-0.14	0.84	0.62
2	0.34	1.51	0.88	0.60
4	0.31	1.23	0.93	0.53
5	0.20	0.11	0.78	0.70
7	0.26	2.85	0.76	0.71
11*	0.43	0.35	0.89	0.57
13	0.31	1.56	0.89	0.50
15	0.33	1.06	0.90	0.43
17	0.36	0.75	0.90	0.57
18*	0.14	-0.33	0.74	0.85
19*	0.48	-0.12	0.74	0.41
23*	0.34	0.12	0.80	0.71
24	0.24	0.74	0.76	0.70
27	0.23	0.15	0.76	0.52
29	0.27	-2.49	0.54	0.56

Table 4. Light levels, summer

	Circadian Stimulus (CS)			Photopic Light Levels (Lux)					
	Arithmetic Mean			Arithmetic Mean			Geometric Mean		
Participant	Non-zero	Workday	Post-workday	Non-zero	Workday	Post-workday	Non-zero	Workday	Post-workday
1	0.21	0.19	0.26	1121	819	1514	107	115	143
2	0.33	0.42	0.18	1472	1249	1118	227	502	53
4	0.21	0.28	0.17	1019	973	1324	95	184	58
5	0.18	0.18	0.20	444	446	472	72	95	62
7	0.19	0.33	0.14	720	892	614	55	262	35
11*	0.34	0.33	0.30	1133	1267	792	94	312	21
13	0.25	0.36	0.12	865	1202	236	130	280	46
15	0.23	0.36	0.12	837	1492	313	0	0	0
17	0.25	0.34	0.13	1053	1425	959	128	299	34
18*	0.16	0.11	0.18	383	124	335	64	56	47
19*	0.34	0.40	0.31	1492	1085	1811	205	371	128
23*	0.27	0.26	0.19	1647	2582	647	54	104	22
24	0.15	0.15	0.04	1049	744	282	0	47	9
27	0.16	0.13	0.17	637	234	1282	71	71	68
29	0.28	0.32	0.31	4121	7103	935	0	361	0

Table 5. Activity, summer

Participant	Activity		
	Arithmetic Mean		
	Non-zero	Workday	Post-workday
1	0.22	0.19	0.28
2	0.18	0.16	0.17
4	0.27	0.25	0.29
5	0.25	0.23	0.26
7	0.22	0.20	0.25
11	0.24	0.25	0.21
13	0.21	0.20	0.21
15	0.17	0.19	0.16
17	0.23	0.21	0.21
18	0.15	0.13	0.15
19	0.26	0.23	0.27
23	0.21	0.21	0.23
24	0.17	0.16	0.15
27	0.18	0.17	0.21
29	0.16	0.15	0.17

Table 6. Sleep analysis, winter

Participant	Nights Avg.	Sleep Time (min)	Sleep Time (%)	Actual Wake Time (min)	Actual Wake (%)	Sleep Efficiency (%)	Sleep Onset Latency (min)
1	5	408	94%	29	6.5%	90%	0
2	4	334	84%	66	16.3%	79%	0
4	5	381	87%	61	13.4%	78%	14
5	5	361	91%	38	9.2%	85%	6
7	5	329	78%	110	21.9%	59%	110
11	5	453	84%	89	16.5%	81%	7
13	4	337	90%	39	10.3%	87%	0
15	5	356	84%	68	16.1%	75%	5
17	5	402	87%	62	13.3%	82%	18
18	3	294	90%	34	10.3%	80%	14
19	5	403	81%	95	18.7%	66%	51
23	5	341	94%	24	6.1%	82%	34
24	5	402	78%	112	21.8%	73%	3
27	5	376	89%	46	11.3%	80%	11
29	4	327	86%	54	14.2%	79%	11

Table 7. Phasor analysis, winter

Participant	Phasor Magnitude	Phasor Angle (h)	Interdaily Stability (IS)	Intradaily Variability (IV)
1	0.39	0.64	0.97	0.57
2	0.28	2.76	0.93	0.77
4	0.26	2.65	0.90	0.39
5	0.32	2.48	0.84	0.53
7	0.22	3.63	0.68	0.62
11	0.36	2.09	0.86	0.47
13	0.22	3.18	0.90	0.53
15	0.27	2.77	0.82	0.35
17	0.33	1.28	0.85	0.58
18	0.16	1.92	0.70	0.92
19	0.34	2.76	0.72	0.46
23	0.26	0.70	0.81	0.56
24	0.25	1.74	0.78	0.58
27	0.36	1.00	0.19	0.62
29	0.22	2.11	0.68	0.97

Note: Results from Participants 8, 10, 26, and 28 were not included.

Table 8. Light levels, winter

	Circadian Stimulus (CS)			Photopic Light Levels (Lux)					
	Arithmetic Mean			Arithmetic Mean			Geometric Mean		
Participant	Non-zero	Workday	Post-workday	Non-zero	Workday	Post-workday	Non-zero	Workday	Post-workday
1	0.15	0.18	0.04	294	169	42	0	103	0
2	0.19	0.30	0.07	346	427	55	73	236	20
4	0.07	0.10	0.01	185	270	13	0	0	0
5	0.12	0.17	0.03	165	144	28	42	83	13
7	0.06	0.11	0.03	78	187	23	13	54	9
11	0.16	0.24	0.04	263	347	38	0	0	0
13	0.11	0.16	0.05	106	123	49	31	59	14
15	0.10	0.17	0.03	116	178	24	27	65	11
17	0.11	0.20	0.02	127	188	16	0	111	0
18	0.09	0.12	0.05	89	133	41	14	21	9
19	0.17	0.17	0.04	470	792	15	32	62	5
23	0.10	0.17	0.05	301	554	37	22	60	11
24	0.10	0.17	0.02	328	237	20	0	64	8
27	0.22	0.32	0.09	692	465	106	99	316	24
29	0.10	0.14	0.03	117	142	27	30	58	10

Table 9. Activity, winter

Participant	Activity		
	Arithmetic Mean		
	Non-zero	Workday	Post-workday
1	0.19	0.18	0.18
2	0.16	0.15	0.16
4	0.29	0.30	0.29
5	0.24	0.22	0.22
7	0.24	0.20	0.23
11	0.21	0.20	0.20
13	0.20	0.19	0.21
15	0.17	0.19	0.14
17	0.19	0.19	0.16
18	0.18	0.20	0.16
19	0.20	0.17	0.23
23	0.21	0.22	0.20
24	0.16	0.15	0.17
27	0.18	0.18	0.15
29	0.17	0.17	0.22

Table 10. Mean/standard deviation/p values, summer/winter

	Mean		Standard Deviation		p Value
	Summer	Winter	Summer	Winter	
Sleep Time (min)	355	367	59	42	0.46
Sleep Time (%)	87%	86%	5%	5%	0.39
Actual Wake Time (min)	51	62	23	29	0.13
Actual Wake (%)	13%	14%	5%	5%	0.39
Sleep Efficiency (%)	78%	79%	7%	8%	0.85
Sleep Onset Latency (min)	22	19	18	29	0.58
Phasor Magnitude	0.30	0.28	0.09	0.07	0.50
Phasor Angle (h)	0.49	2.11	1.18	0.90	**<0.001***
Interdaily Stability (IS)	0.81	0.77	0.10	0.19	0.45
Intradaily Variability (IV)	0.60	0.59	0.12	0.17	0.91
Circadian Stimulus Arithmetic Mean Non-zero (CS)	0.24	0.12	0.07	0.04	**< 0.001***
Circadian Stimulus Arithmetic Mean Workday (CS)	0.28	0.18	0.10	0.06	**0.01***
Circadian Stimulus Arithmetic Mean Post-workday (CS)	0.19	0.04	0.08	0.02	**< 0.001***
Photopic Light Level Arithmetic Mean Non-zero (Lux)	1199	245	887	169	**0.00***
Photopic Light Level Arithmetic Mean Workday (Lux)	1443	290	1673	193	**0.02***
Photopic Light Level Arithmetic Mean Post-workday (Lux)	842	36	490	23	**< 0.001***
Photopic Light Level Geometric Mean Non-zero (Lux)	87	25	67	29	**< 0.001***
Photopic Light Level Geometric Mean Workday (Lux)	204	86	148	84	**0.01***
Photopic Light Level Geometric Mean Post-workday (Lux)	48	9	41	7	**< 0.001***
Activity Arithmetic Mean Non-zero	0.21	0.20	0.04	0.04	0.22
Activity Arithmetic Mean Workday	0.19	0.19	0.04	0.04	0.88
Activity Arithmetic Mean Post-workday	0.21	0.20	0.05	0.04	0.06

Asterisks (*) indicate statistically significant values.

Table 11. Self-reported sleep analysis, summer/winter

	Summer				Winter			
Participant	PSQI Global Score	PROMIS Global Score	PROMIS T-score	PROMIS Standard Error	PSQI Global Score	PROMIS Global Score	PROMIS T-score	PROMIS Standard Error
1	6	18	50.2	2.6	8	18	50.2	2.6
2	6	13	43.9	2.9	4	15	46.7	2.7
4	7	18	50.2	2.6	7	13	43.9	2.9
5	9	19	51.3	2.6	11	16	47.9	2.7
7	14	32	64	2.6	15	33	65.1	2.6
8	–	12	42.2	3	9	12	42.2	3
10	7	12	42.2	3	8	12	42.2	3
11	8	23	55.3	2.5	5	26	58.1	2.5
13	6	14	45.3	2.8	5	25	57.2	2.5
15	6	11	40.4	3.1	7	16	47.9	2.7
17	6	9	35.3	3.7	5	15	46.7	2.7
18	4	17	49.1	2.6	4	18	50.2	2.6
19	4	14	45.3	2.8	5	14	45.3	2.8
23	5	19	51.3	2.6	6	18	50.2	2.6
24	4	12	42.2	3	4	14	45.3	2.8
26	6	15	46.7	2.7	2	19	51.3	2.6
27	4	9	35.3	3.7	8	10	38.1	3.3
28	10	30	62	2.6	4	24	56.2	2.5
29	3	14	45.3	2.8	8	11	40.4	3.1
Mean	6.39	16.37	47.24	2.85	6.50	17.32	48.69	2.75
Median	6.00	14.00	45.30	2.80	5.50	16.00	47.90	2.70
SEM	0.62	1.45	1.75	0.08	0.72	1.36	1.55	0.05

Note: PSQI > 5 and PROMIS >25 indicate sleep disturbances; PROMIS T-score of 50 is considered an average score (lower score is better and higher score is worse).

Table 12. Self-reported mood, summer/winter

	Summer			Winter		
Participant	**PANAS Total Positive**	**PANAS Total Negative**	**CES-D Total Score**	**PANAS Total Positive**	**PANAS Total Negative**	**CES-D Total Score**
1	35	18	5	41	12	2
2	27	12	5	26	12	4
4	21	11	7	32	13	3
5	41	17	6	41	18	4
7	38	14	5	34	15	11
8	42	16	7	44	15	7
10	37	17	4	33	17	9
11	15	24	21	16	13	20
13	34	12	3	40	14	11
15	31	11	3	28	15	6
17	20	18	11	23	14	11
18	30	10	1	31	12	0
19	44	12	0	45	11	1
23	35	17	4	38	11	2
24	37	12	3	21	12	5
26	38	26	8	41	18	5
27	31	11	0	26	11	1
28	22	19	19	24	22	23
29	36	12	2	35	10	0
Mean	32.32	15.21	6.00	32.58	13.95	6.58
Median	35.00	14.00	5.00	33.00	13.00	5.00
SEM	1.85	1.04	1.30	1.93	0.70	1.47

Note: CES-D > 16 – depression symptoms; PANAS positive (higher = better); PANAS negative (lower = better)

Table 13. Self-reported sleepiness (KSS), summer

	Day 1				Day 2				Day 3				Day 4				Day 5				Day 6				Day 7			
Participant	**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	3	7	3	8	2	8	3	8	3	4	4	8	2	7	4	8	2	8	2	9	1	5	3	8	2	5	3	8
2	5	2	2	6	5	2	2	7	6	2	2	6	4	2	2	5	2	2	2	5	6	2	2	5	2	2	2	2
4	5	3	3	6	5	3	3	6	5	3	6	6	6	6	6	7	5	5	4	3	5	4	3	6	5	5	3	6
5	2	3	6	6	2	2	7	8	1	1	7	8	1	1	7	7	1	6	8	8	3	5	5	5	6	9	3	6
7	9	7	7	8	6	6	7	8	6	8	4	7	4	4	6	7	6	8	3	6	3	4	3	7	3	4	6	7
8	1	1	4	5	1	1	2	4	1	1	1	2	2	1	1	6	-	-	-	-	-	-	-	-	-	-	-	-
10	6	3	3	5	3	4	3	7	6	3	3	7	6	3	3	5	6	7	6	6	5	5	4	5	6	5	5	6
11	8	6	5	9	5	4	4	7	5	4	4	6	4	4	4	6	8	8	8	8	5	4	3	2	7	5	8	6
13	2	4	4	6	3	5	6	6	3	4	5	7	5	2	3	7	3	2	2	6	4	4	5	6	3	2	2	6
15	6	3	6	7	6	3	5	7	5	3	5	7	5	3	6	7	6	3	4	6	5	3	3	6	6	3	5	6
17	8	5	9	3	7	3	6	7	5	5	6	9	4	3	8	9	3	3	8	8	2	2	7	8	3	2	6	9
18	6	5	3	3	6	6	2	3	6	4	3	5	6	6	5	6	6	4	4	8	5	4	4	5	4	3	3	6
19	6	2	2	8	7	2	2	8	8	2	2	8	8	2	2	7	6	1	2	8	5	2	2	8	5	2	3	8
23	6	1	4	7	8	2	6	8	6	3	6	8	6	3	8	9	4	5	8	9	1	1	1	7	6	2	2	8
24	4	6	3	8	5	3	3	7	7	4	3	3	8	3	3	6	8	2	3	3	6	2	3	7	5	5	7	7
26	5	3	4	8	5	3	2	4	5	2	4	7	5	3	4	7	4	2	4	7	4	2	4	7	4	5	5	7
27	4	2	5	6	5	2	2	6	5	3	3	6	6	2	3	9	3	3	3	7	4	3	3	6	3	3	2	5
28	8	8	9	9	8	8	8	8	7	7	7	7	6	6	7	8	-	-	-	-	-	-	-	-	-	-	-	-
29	2	2	3	7	2	2	3	7	3	2	3	7	2	2	3	8	2	2	3	7	-	-	-	-	-	-	-	-
Mean	5.1	3.8	4.5	6.6	4.8	3.6	4.0	6.6	4.9	3.4	4.1	6.5	4.7	3.3	4.5	7.1	4.4	4.2	4.4	6.7	4.0	3.3	3.4	6.1	4.4	3.9	4.1	6.4
Median	5	3	4	7	5	3	3	7	5	3	4	7	5	3	4	7	4	3	4	7	4.5	3.5	3	6	4.5	3.5	3	6
SEM	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.3	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.3	0.5	0.6	0.5	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4

Note: Higher scores indicate greater sleepiness.

Table 14. Self-reported sleepiness (KSS), winter

	Day 1				**Day 2**				**Day 3**				**Day 4**				**Day 5**				**Day 6**				**Day 7**			
Participant	**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	8	7	5	5	8	7	4	5	8	6	4	6	4	4	4	5	7	4	4	6	4	6	6	5	3	3	4	5
2	-	-	-	-	6	2	1	5	5	3	2	6	7	4	4	7	8	3	3	6	8	2	3	6	8	4	3	4
4	8	6	5	5	6	5	5	6	5	4	3	6	6	4	3	5	6	4	3	4	5	5	6	7	5	4	5	6
5	2	6	6	8	2	5	6	8	2	4	5	8	3	4	4	8	3	4	5	8	6	2	6	8	6	2	6	8
7	8	4	6	6	6	8	6	7	7	4	5	7	6	6	7	8	8	9	4	4	4	9	6	7	8	5	5	8
8	1	2	3	7	1	2	4	8	1	3	3	9	1	2	5	7	1	2	4	9	1	2	3	8	1	2	4	6
10	4	3	3	6	6	4	4	5	4	3	3	4	4	5	6	6	4	6	4	5	3	5	4	7	5	6	6	7
11	8	5	6	7	8	5	5	6	6	4	5	8	8	4	5	6	6	4	4	7	5	5	6	7	5	5	5	8
13	4	3	3	6	4	4	5	6	5	4	2	6	3	3	3	6	2	2	4	6	2	3	2	5	2	2	2	7
15	6	3	5	6	6	3	6	6	8	6	6	8	4	3	3	6	6	3	4	6	3	3	5	8	3	3	3	5
17	6	7	8	7	3	5	6	8	3	6	7	9	3	5	7	8	8	5	6	9	5	4	7	3	5	6	7	8
18	-	-	-	-	6	3	2	2	6	3	2	4	6	3	2	6	6	3	2	6	5	3	2	6	4	3	2	4
19	2	2	4	4	3	3	3	4	2	3	4	3	2	2	3	3	2	2	3	3	3	2	2	2	2	2	2	3
23	2	1	5	7	6	3	4	6	6	3	4	7	6	3	3	7	6	3	8	9	2	2	6	9	2	1	5	6
24	8	6	3	8	9	6	2	8	8	5	4	8	9	8	3	7	6	6	6	9	5	4	4	9	7	5	5	7
26	3	3	7	6	6	3	7	6	6	3	4	5	5	6	5	7	6	6	4	4	5	3	3	6	6	5	4	5
27	3	2	4	7	3	2	2	2	2	2	2	7	3	2	2	8	3	2	2	2	2	2	2	8	6	2	2	6
28	9	9	9	9	6	4	8	9	9	9	9	9	6	4	8	9	6	4	9	9	9	9	9	9	7	6	8	9
29	2	2	2	-	2	2	2	-	2	6	2	-	2	2	6	-	2	2	2	-	2	6	2	-	2	2	2	-
Mean	4.9	4.2	4.9	6.5	5.1	4.0	4.3	5.9	5.0	4.3	4.0	6.7	4.6	3.9	4.4	6.6	5.1	3.9	4.3	6.2	4.2	4.1	4.4	6.7	4.6	3.6	4.2	6.2
Median	4	3	5	6.5	6	4	4	6	5	4	4	7	4	4	4	7	6	4	4	6	4	3	4	7	5	3	4	6
SEM	0.6	0.5	0.4	0.3	0.5	0.4	0.4	0.4	0.6	0.4	0.4	0.4	0.5	0.4	0.4	0.3	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4

Note: Higher scores indicate greater sleepiness.

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 adds data to our previous studies by obtaining circadian light-dark and activity patterns in office workers in another 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 our measurements, despite the daylight availability at the Edith Green-Wendell Wyatt Federal Building, most of the participants are being exposed to CS values between 0.2 and 0.4 during the working day in the summer months, with the exception of a few who were in the sub-floor or who likely have their shades down. These light levels are still slightly higher than those measured from participants working at the Grand Junction site. During winter months, CS values were significantly lower than in summer months, irrespective of building orientation. CS values ranged from 0.11 to 0.32, with the majority of the values being between 0.15 and 0.20.

As stated in an earlier report, based on predictions obtained using a mathematical model of human circadian entrainment, if a person is exposed to a CS level of 0.25 for one hour during the morning, circadian entrainment would be achieved; that is, a person would be in synchrony with the external light-dark cycle. In summer months, only 5 out of 15 participants were exposed to CS values below 0.25. In the winter months, 13 out of 15 participants were exposed to CS values below 0.25. However, it is important to note that, with the exception of a few participants, the highest amounts of light that participants received during both, winter and summer months, was during the working hours. This is not always the case, especially if office workers do not have access to a daylit space. Light levels at times when they were likely to be at home (early morning and evening) were much lower. In fact, one possible explanation for the lower light levels observed during working hours is the fact that some of these workers telecommute; that is, they may have spent some work days at home rather than in the building.

Although there were not any strong correlations observed between CS and self-reports of mood and sleep disorders, it is possible that larger data sets and the use of a control group receiving even lower CS values would allow researchers to determine whether there is a correlation between circadian light exposures at work and self-reports of sleep and mood.

Objectively, most of the participants who participated in the study sleep less than 8 hours per night and have lower sleep efficiency than one would expect from healthy individuals.

One very interesting finding from this building that can be directly applied to architectural designs was the use of the reeds on the west façade. The reeds that were used in this building allowed daylight to come into the space but reduced the amount of sunlight penetration in the space. As a result, shades were up and daylight penetrated the space more than if shades were pulled down during the summer months. The same effect was not observed during the winter months, most likely because of the shorter photoperiods. The higher CS values measured in summer months are particularly noticeable in deskspaces located near the windows. The LRC’s previous research in this building showed that daylight in the office spaces in the east and south façades was limited, because workers drew the shades to avoid experiencing sunlight. Participants who had deskspaces in the east and south façades had overall lower CS exposures than those in the north and west façades; it is hypothesized that this is due to sunlight penetration that led the users to draw the shades.

It would be very interesting to compare self-reports provided by users of this building with self-reports of those working in a “control” building, where no daylight is available. In fact, the two participants who worked on the sub-floor, which had much less daylight availability, were exposed to much lower CS values during working hours. While one of these two participants seemed to have more sleep disturbances and mood disorders, the other participant did not show signs of suffering from sleep or mood disorders. Therefore, the small sample size makes it difficult to link lower CS exposures to worse sleep and mood, especially without a control group. Nevertheless, the data obtained from this building and the Grand Junction site are valuable and reveal interesting insights about personal light exposures in buildings.

One main difference observed in the data collection in Portland, OR, was that, despite the significant lower CS exposures in winter months compared to summer months, sleep parameters and mood were not significantly changed from summer to winter. These results are not consistent with the findings in Grand Junction, CO. In that study, a significant increase in sleep efficiency in summer months was observed even though no significant changes in self-reports of mood were observed. One hypothesis to be further tested is that those who live in gloomier places, such as Portland, may be more adapted to the darker winter months than those who live in Grand Junction, CO, who are exposed to very sunny days in the summer and may be, therefore, more sensitive to the short photoperiods in winter months.

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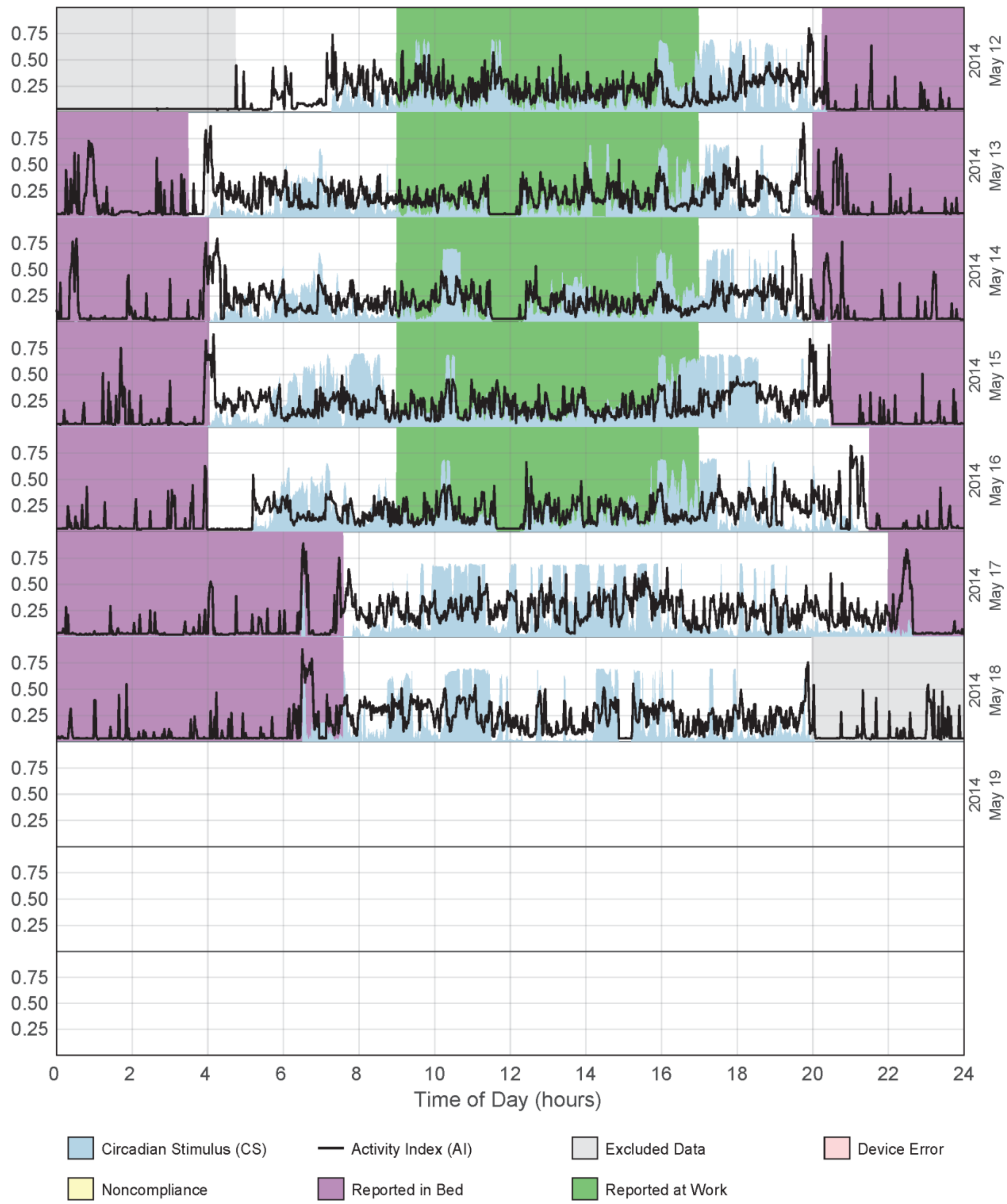

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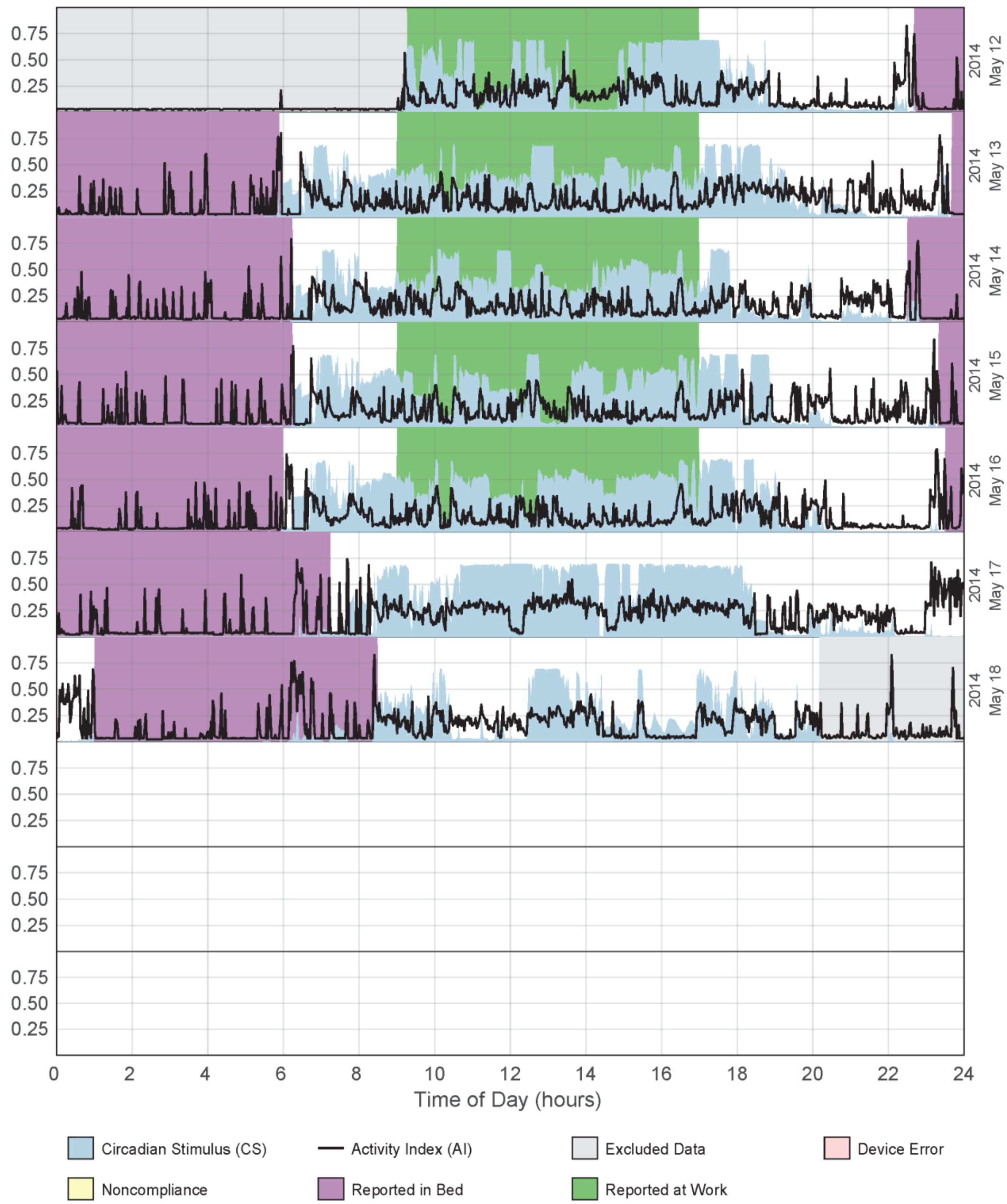

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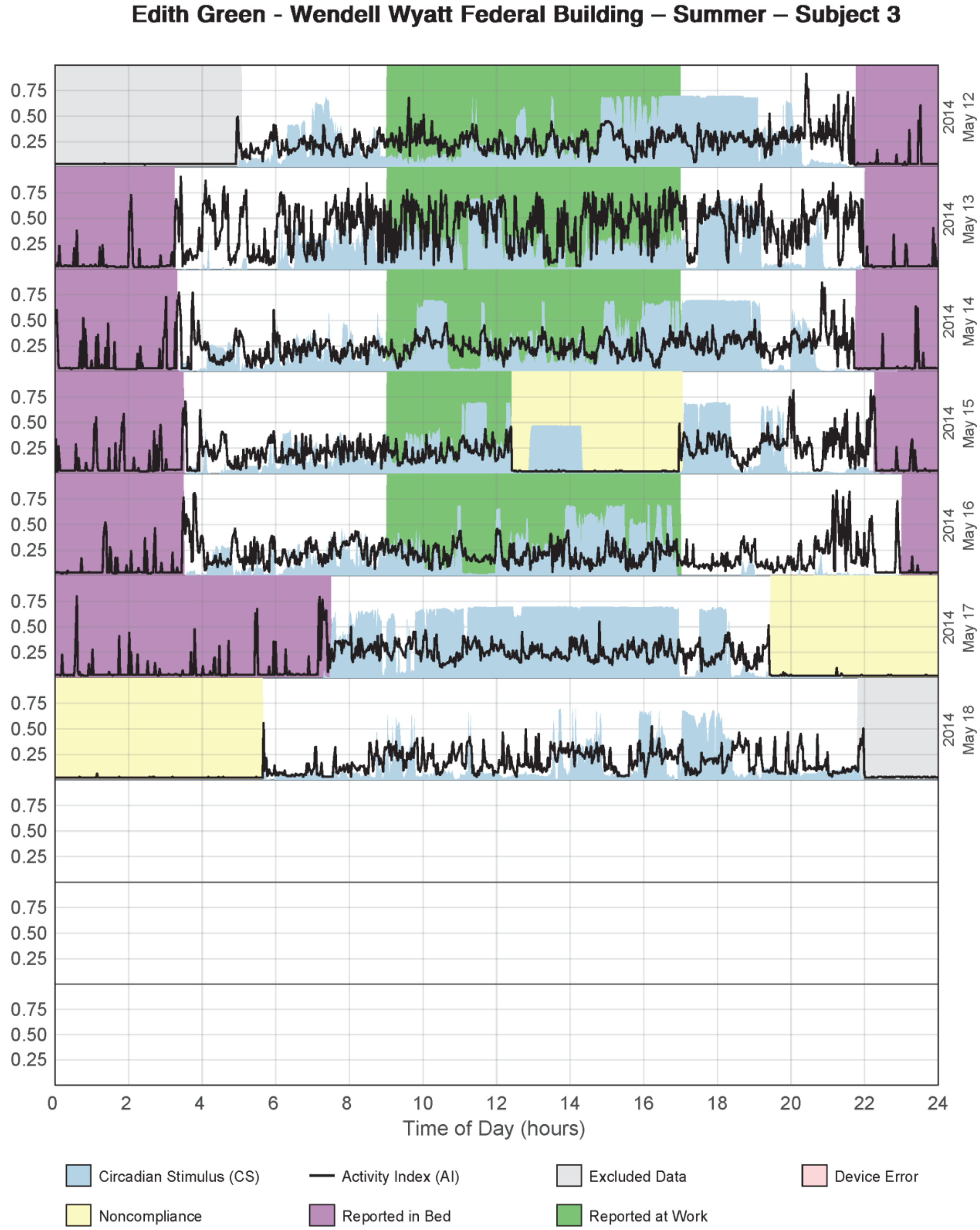

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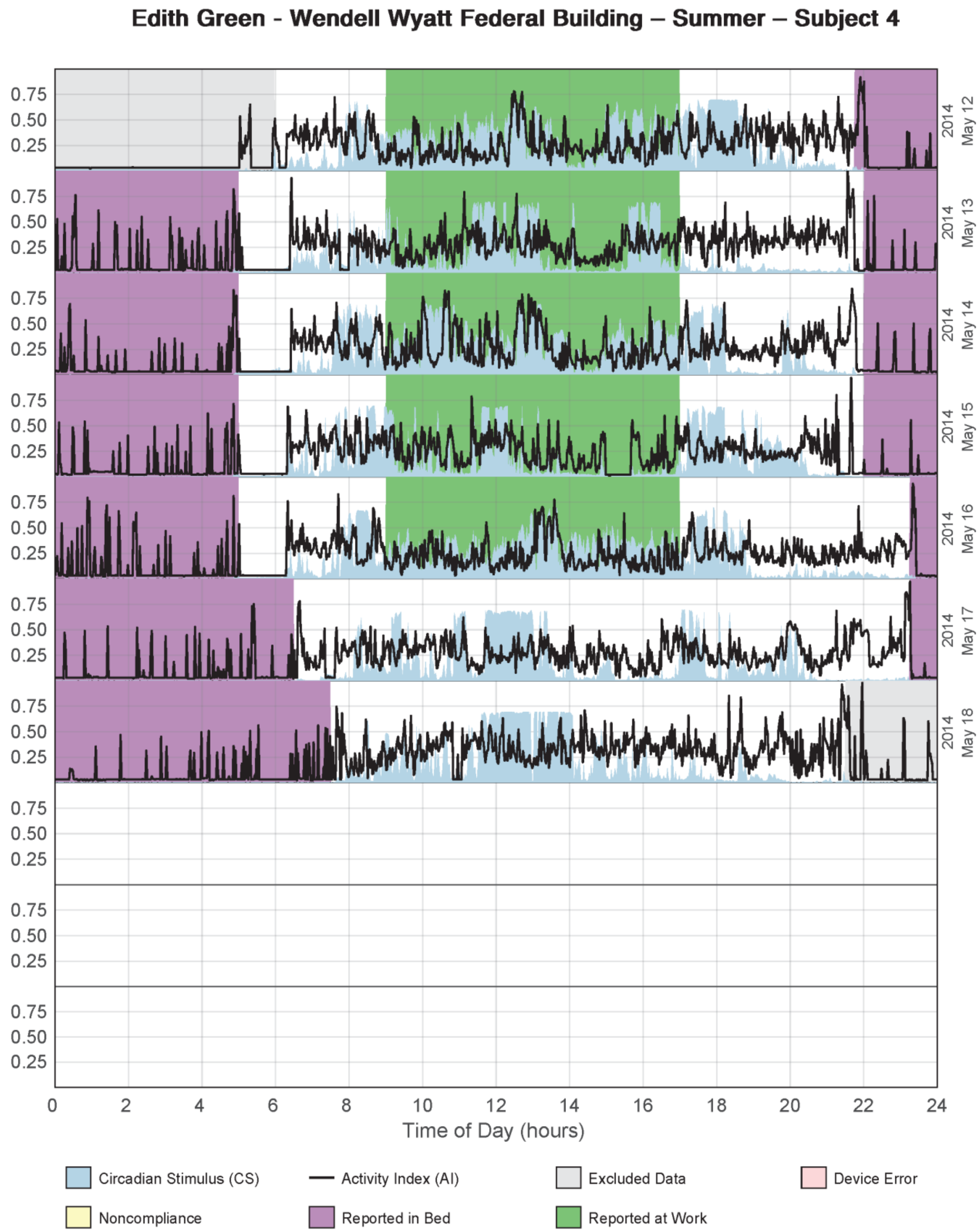

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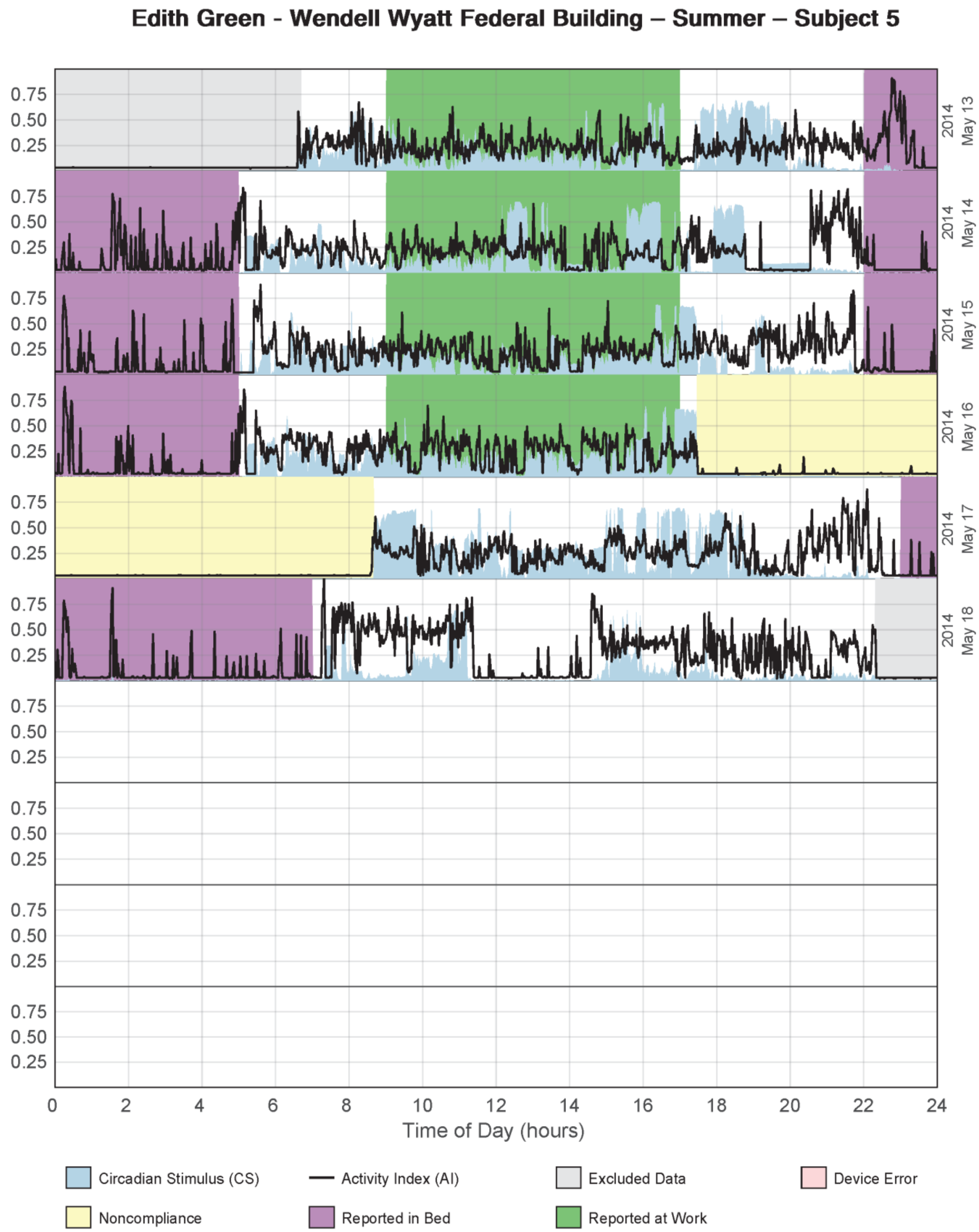

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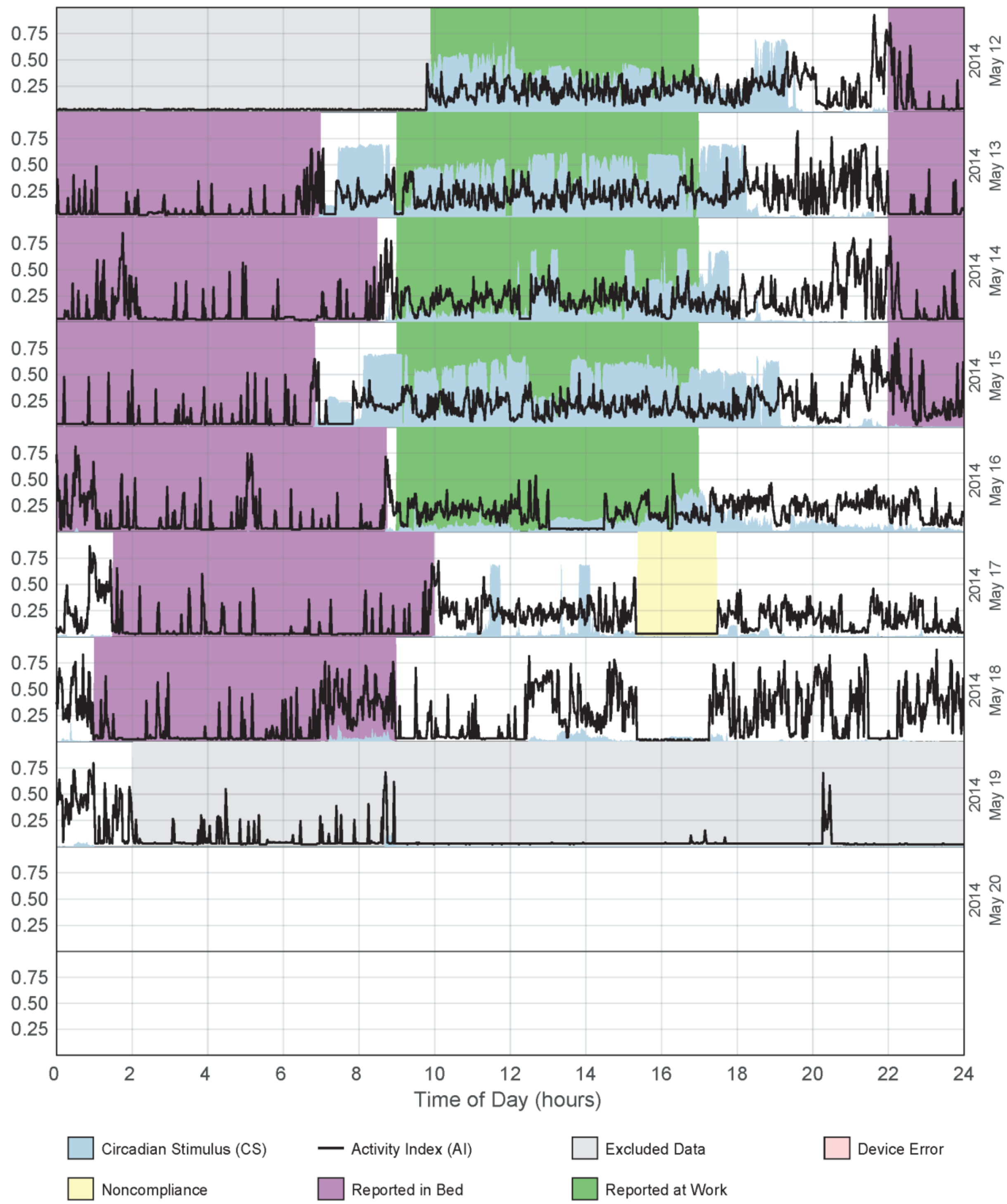

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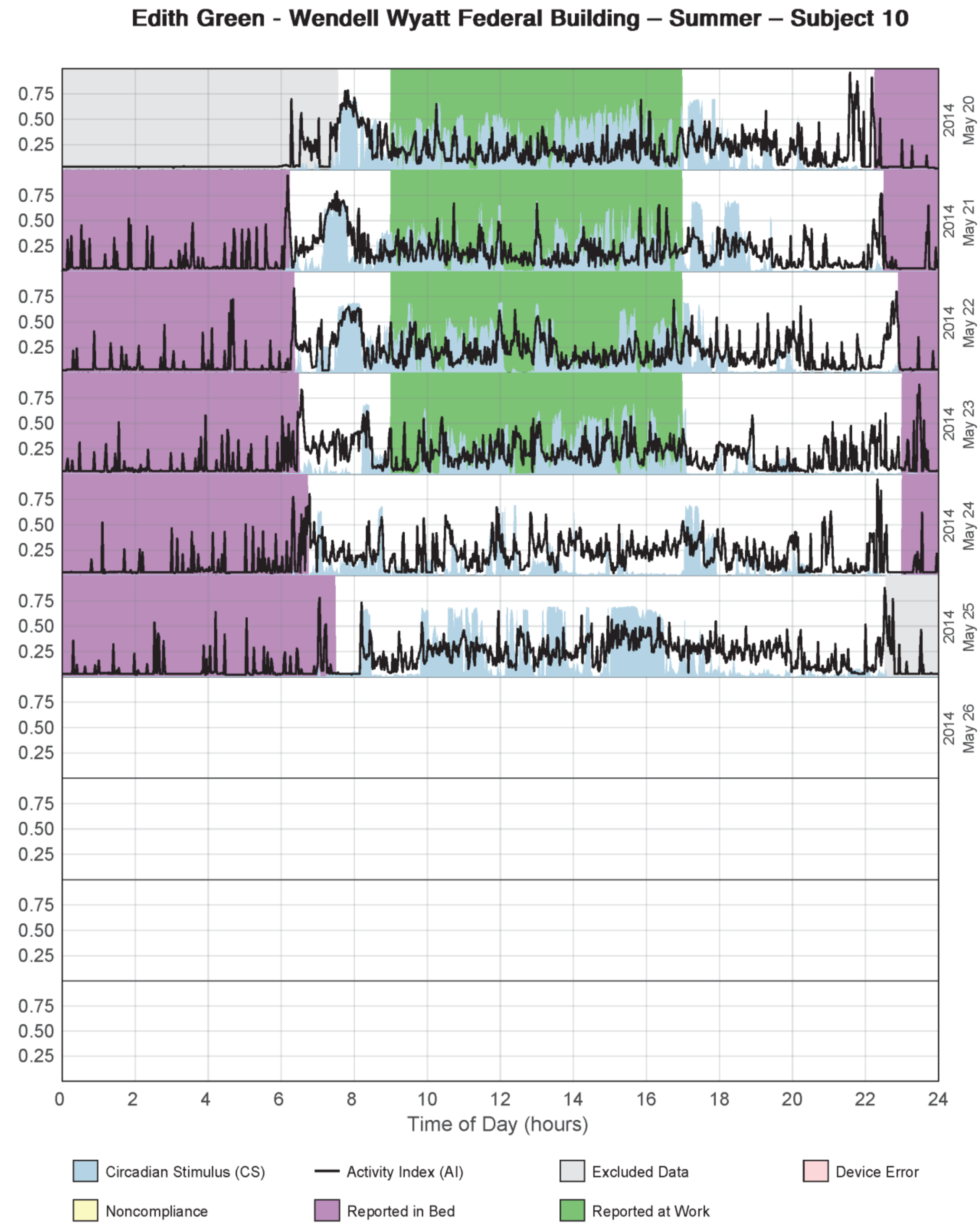

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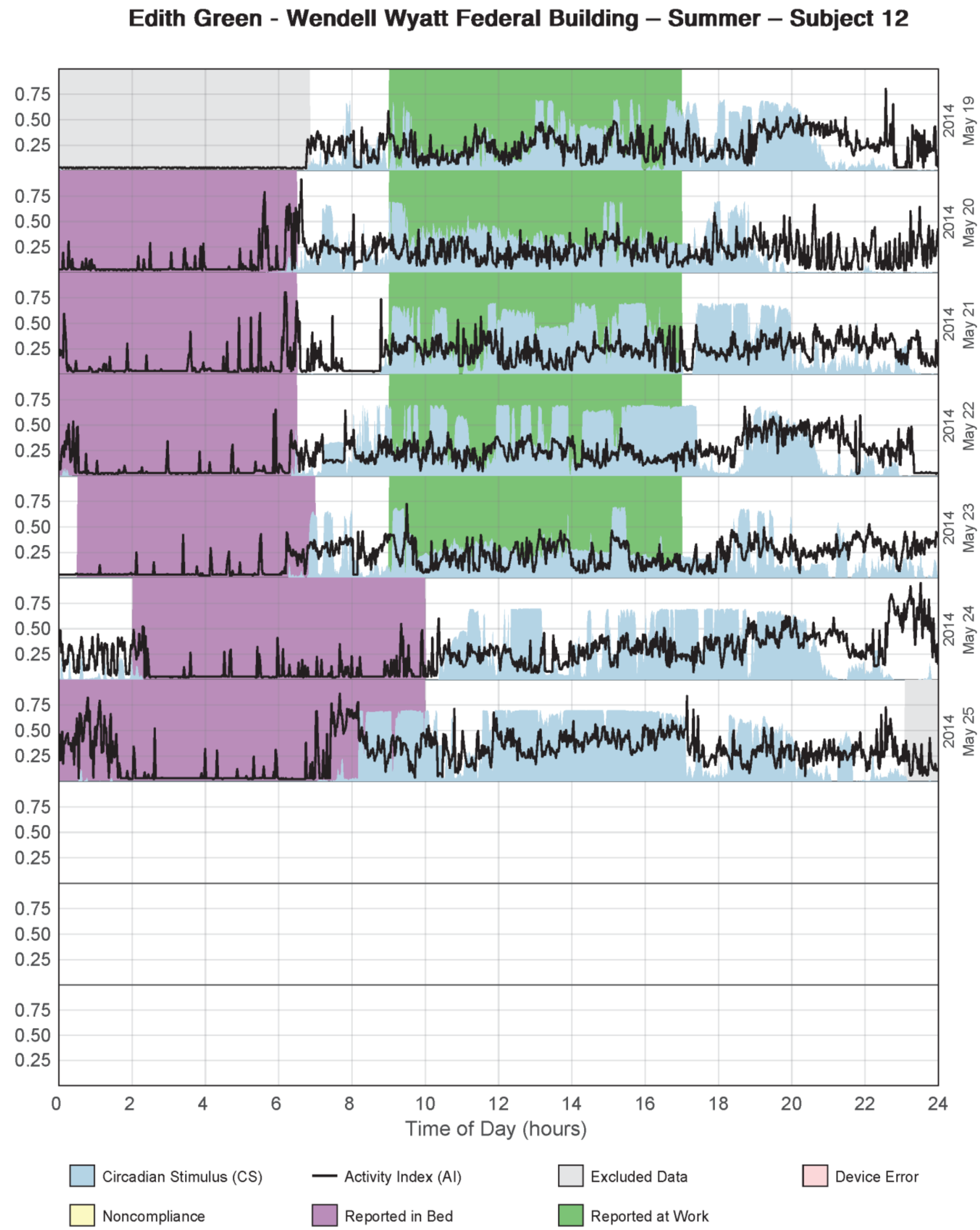

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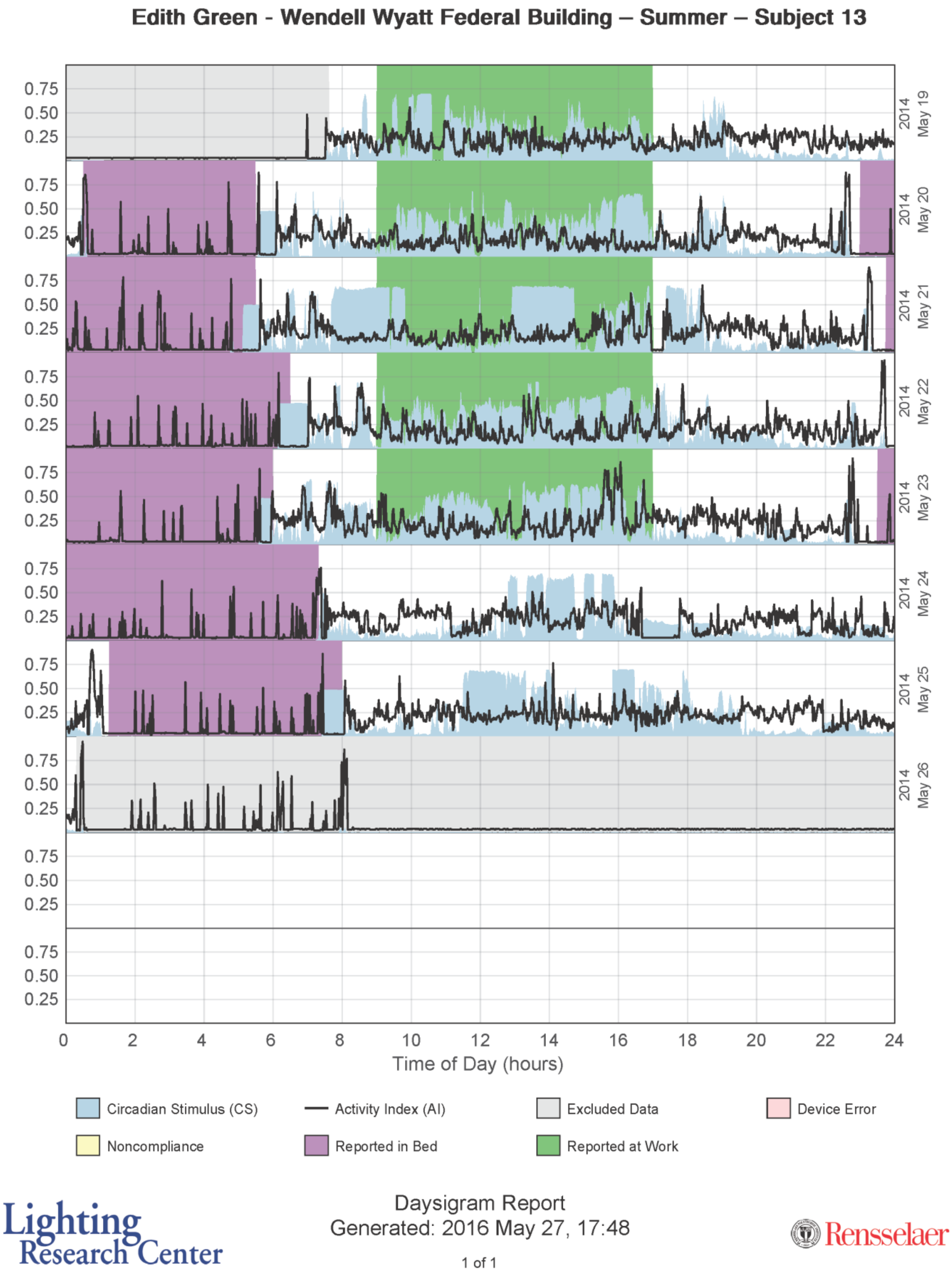
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0.75
0.50
0.25
2014 May 19
2014 May 20
2014 May 21
2014 May 22
2014 May 23
2014 May 24
2014 May 25
2014 May 26
0 2 4 6 8 10 12 14 16 18 20 22 24
Time of Day (hours)
Circadian Stimulus (CS)
Activity Index (AI)
Excluded Data
Device Error
Noncompliance
Reported in Bed
Reported at Work
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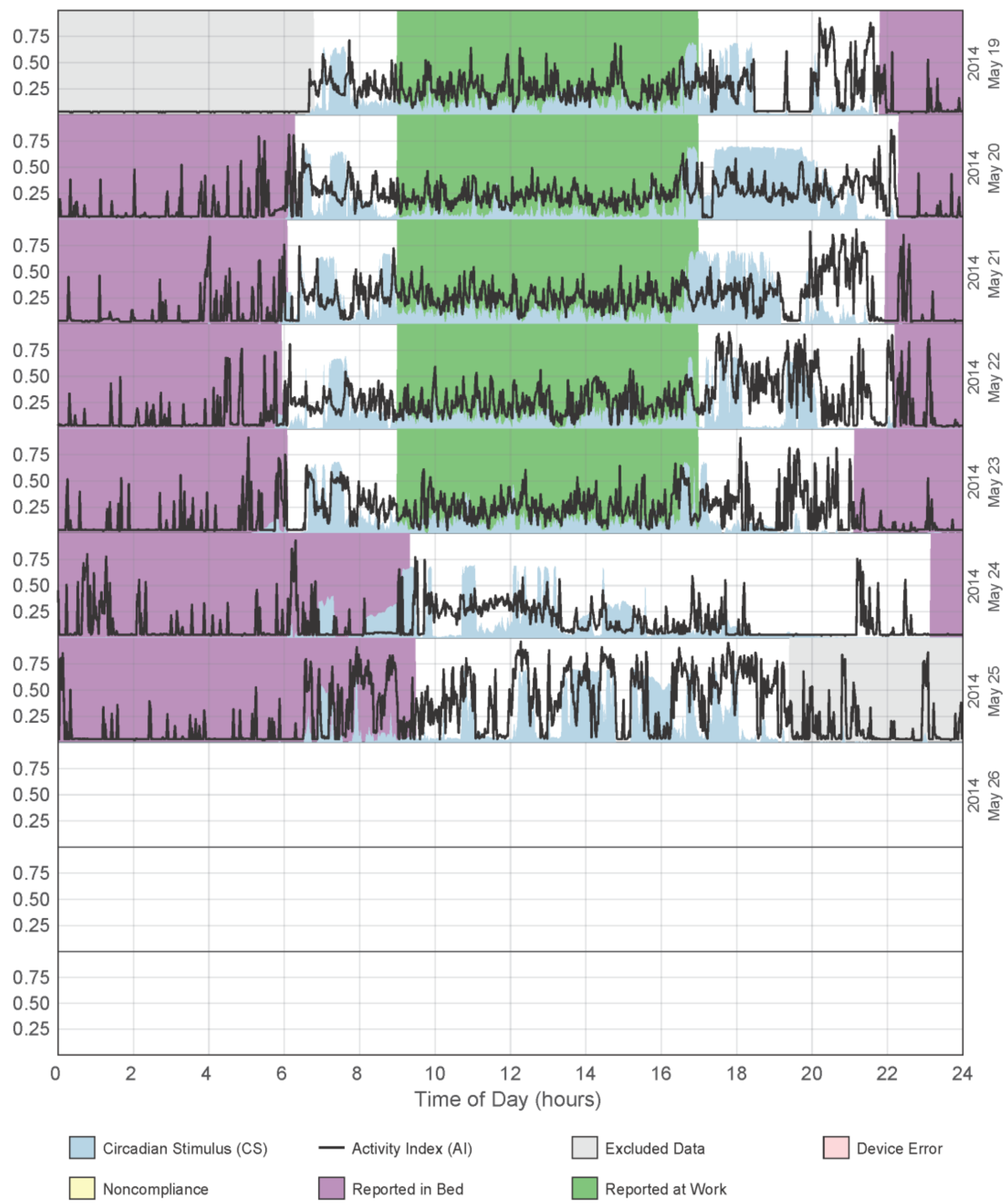

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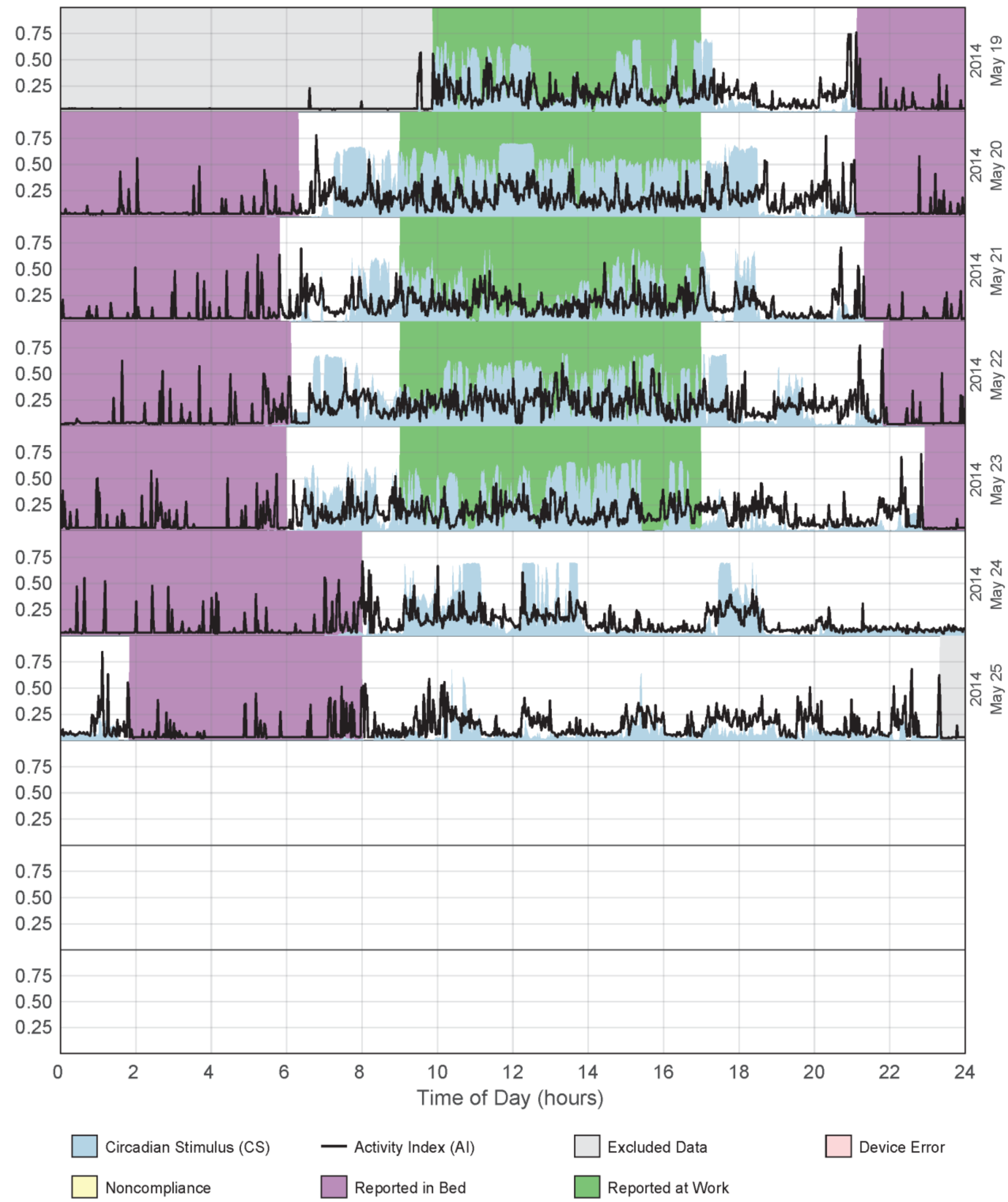

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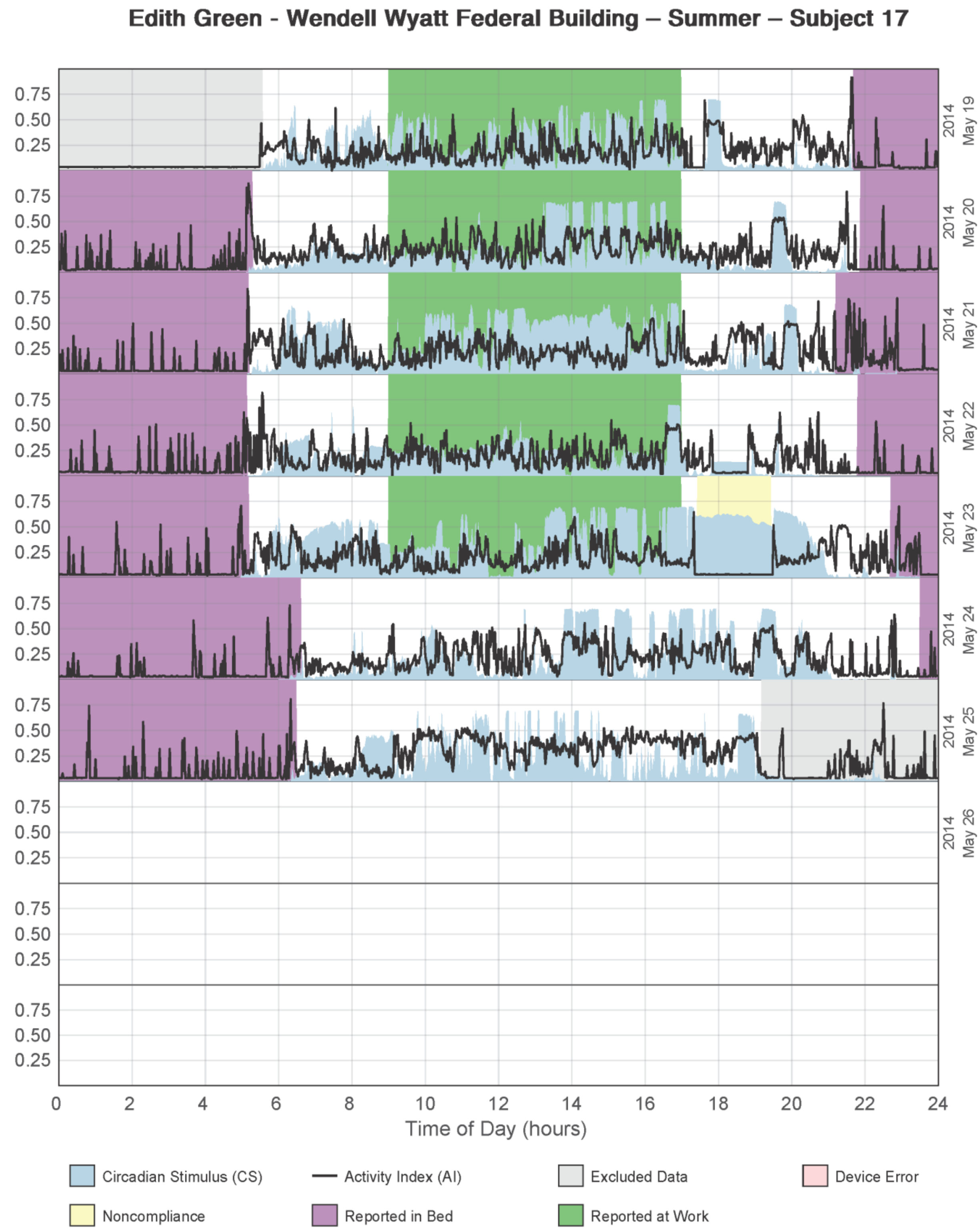

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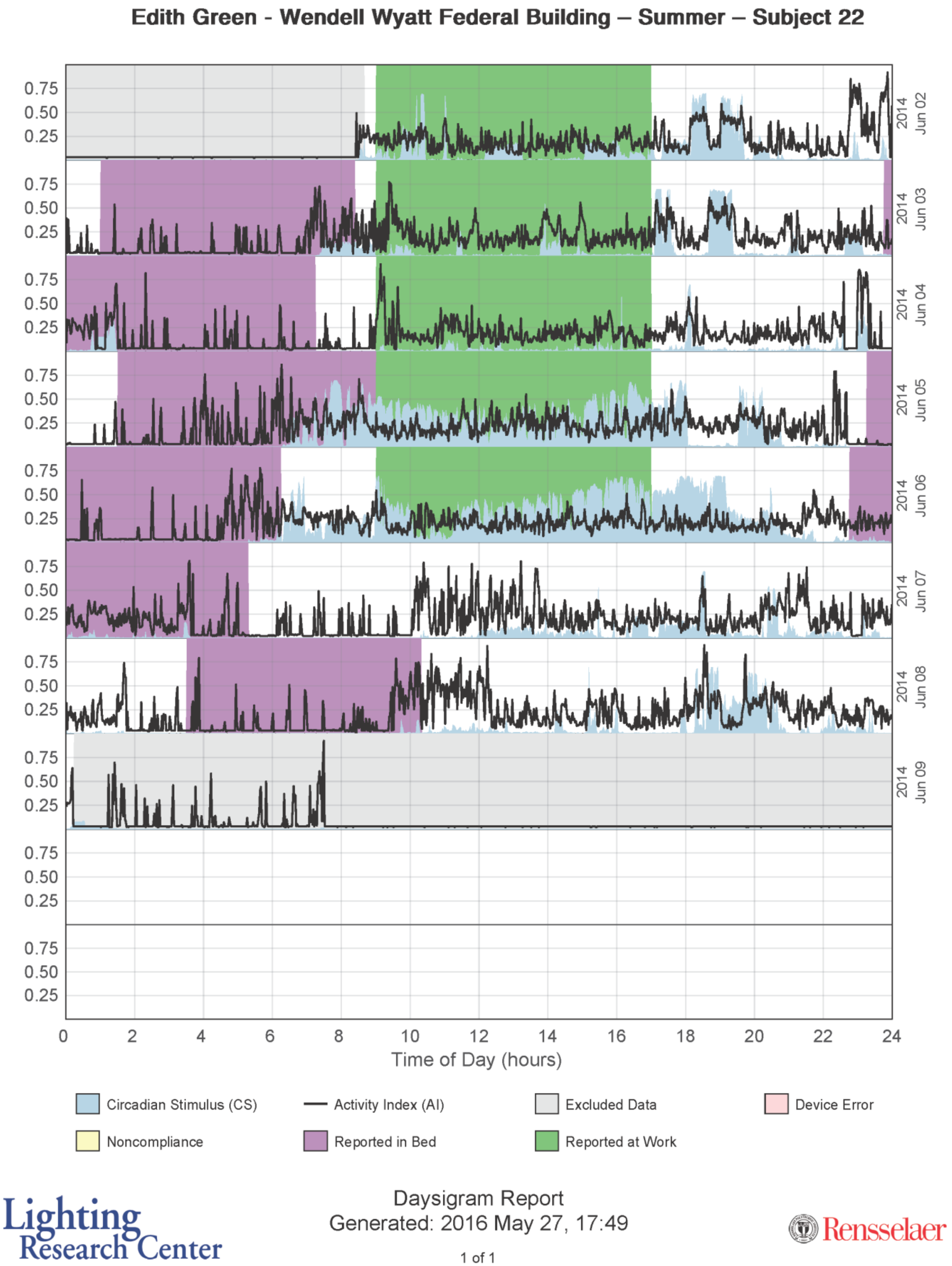
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0.75
0.50
0.25
2014 Jun 02
2014 Jun 03
2014 Jun 04
2014 Jun 05
2014 Jun 06
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2014 Jun 08
2014 Jun 09
0 2 4 6 8 10 12 14 16 18 20 22 24
Time of Day (hours)
Circadian Stimulus (CS)
Activity Index (AI)
Excluded Data
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Noncompliance
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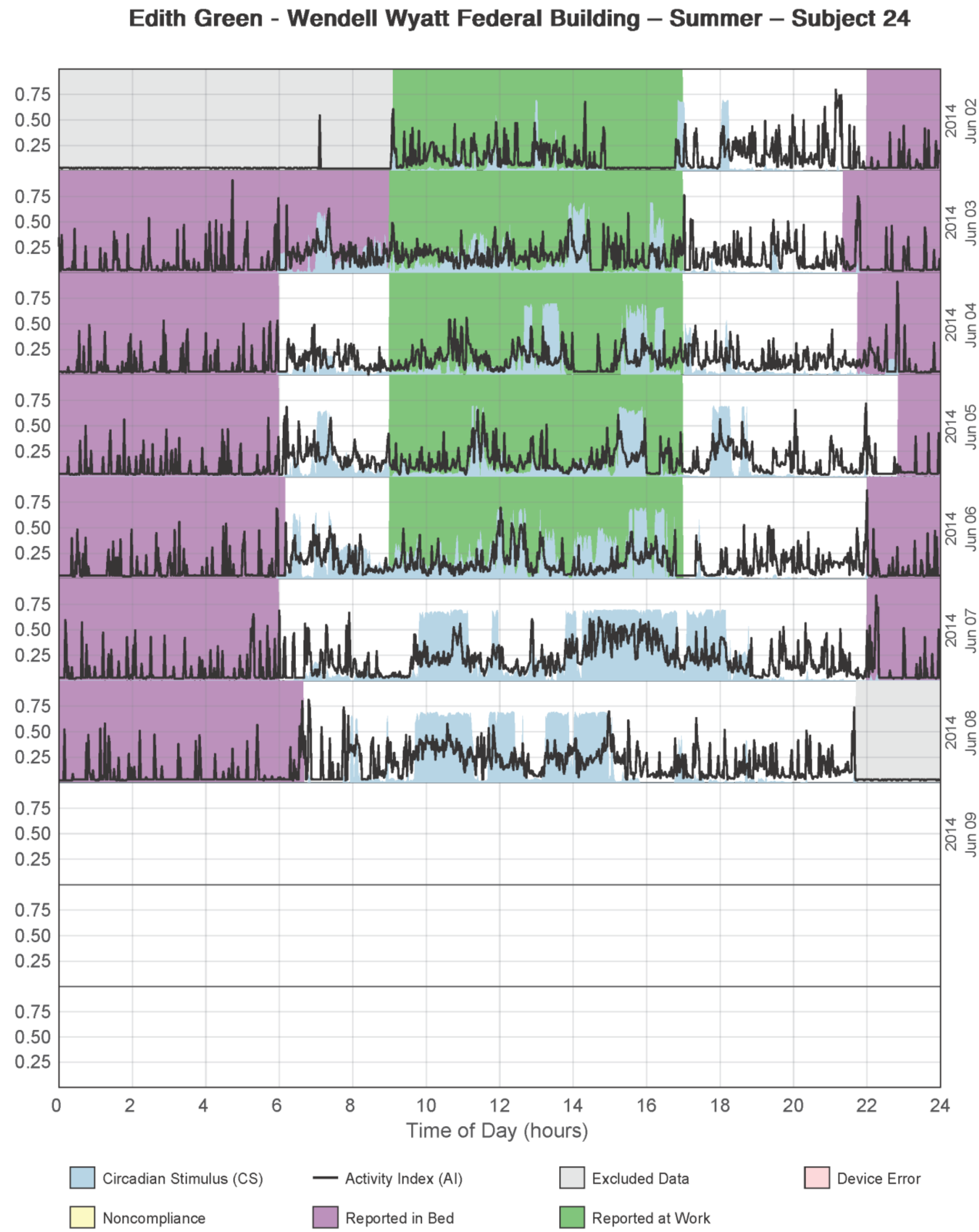

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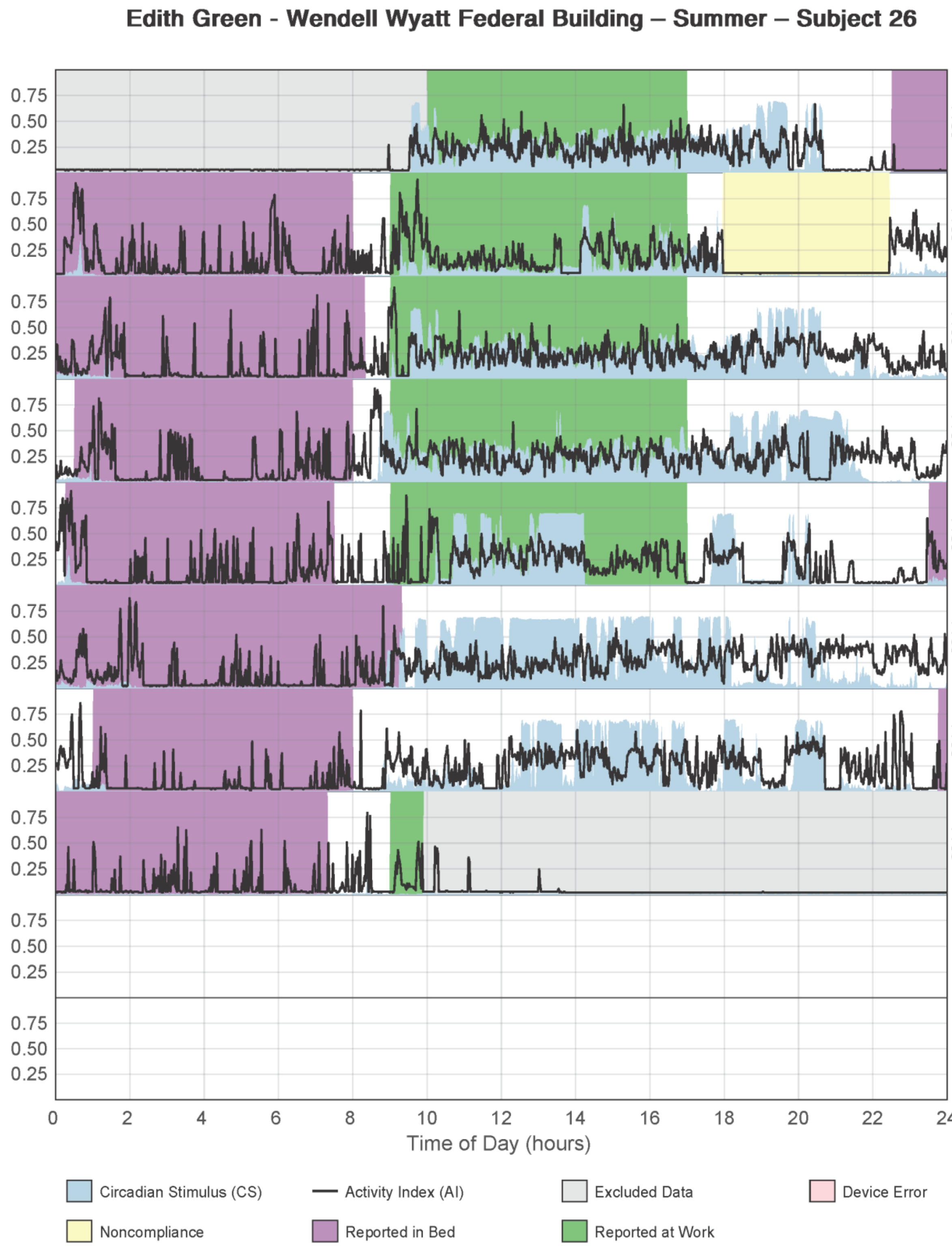

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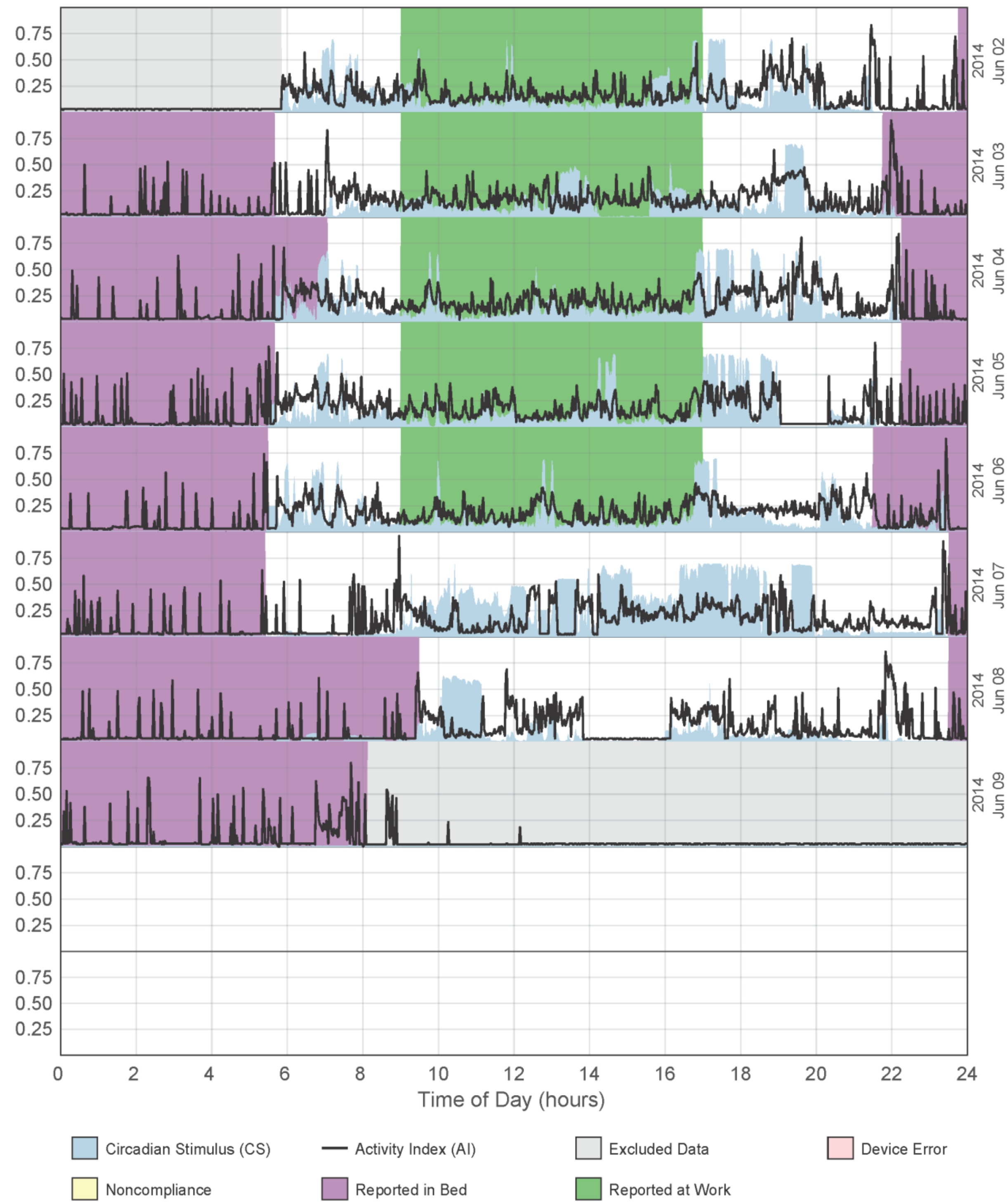

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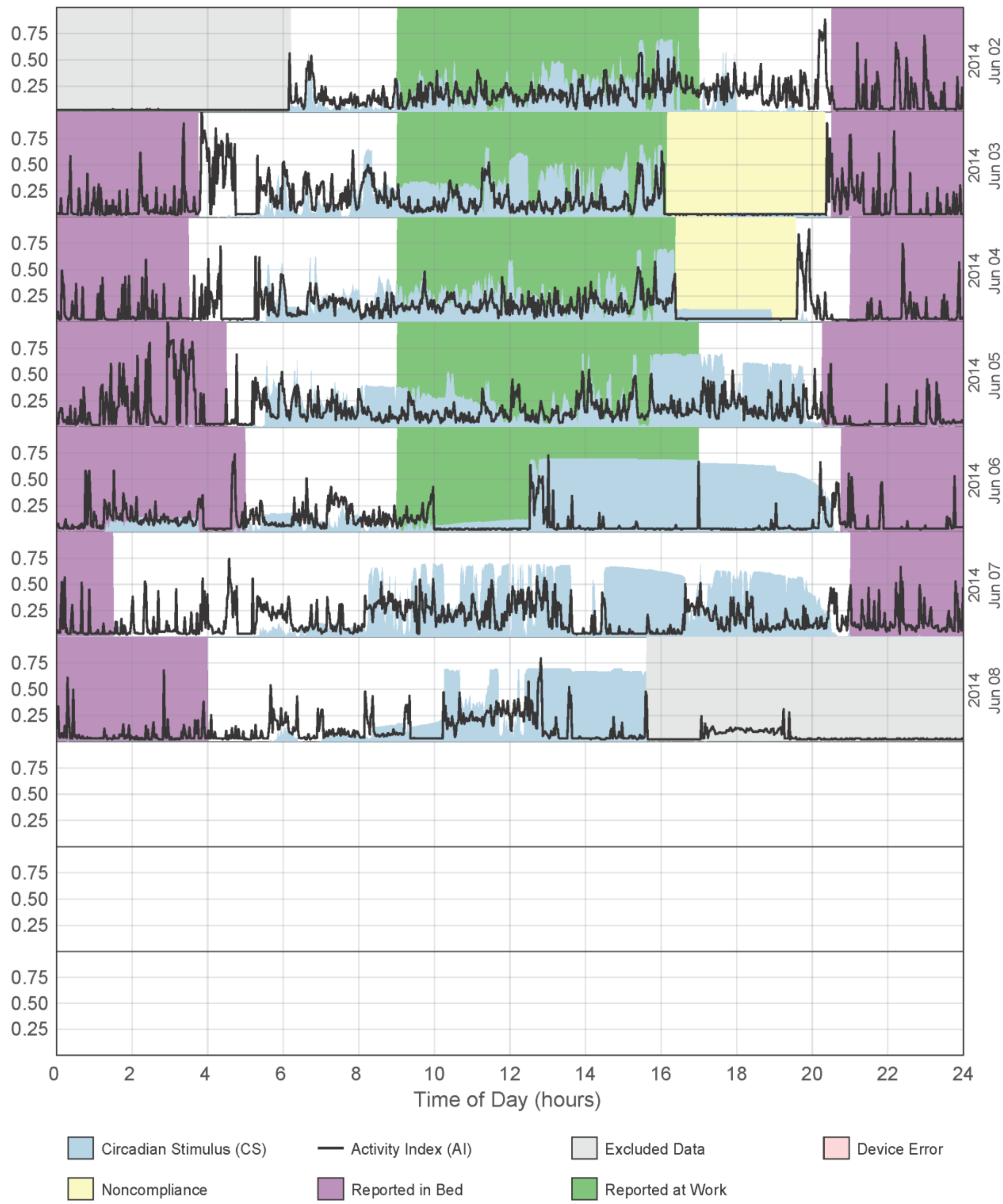

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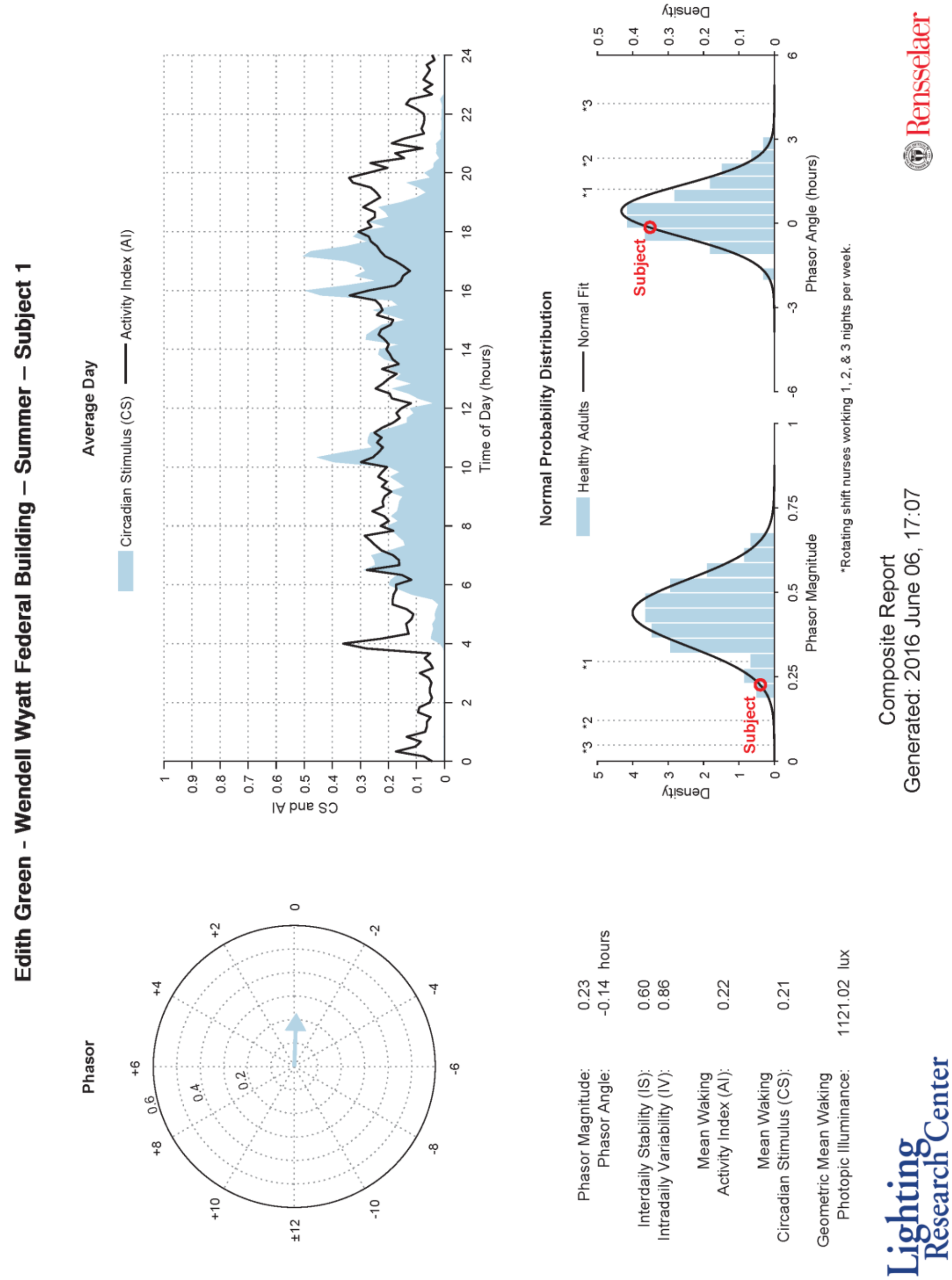
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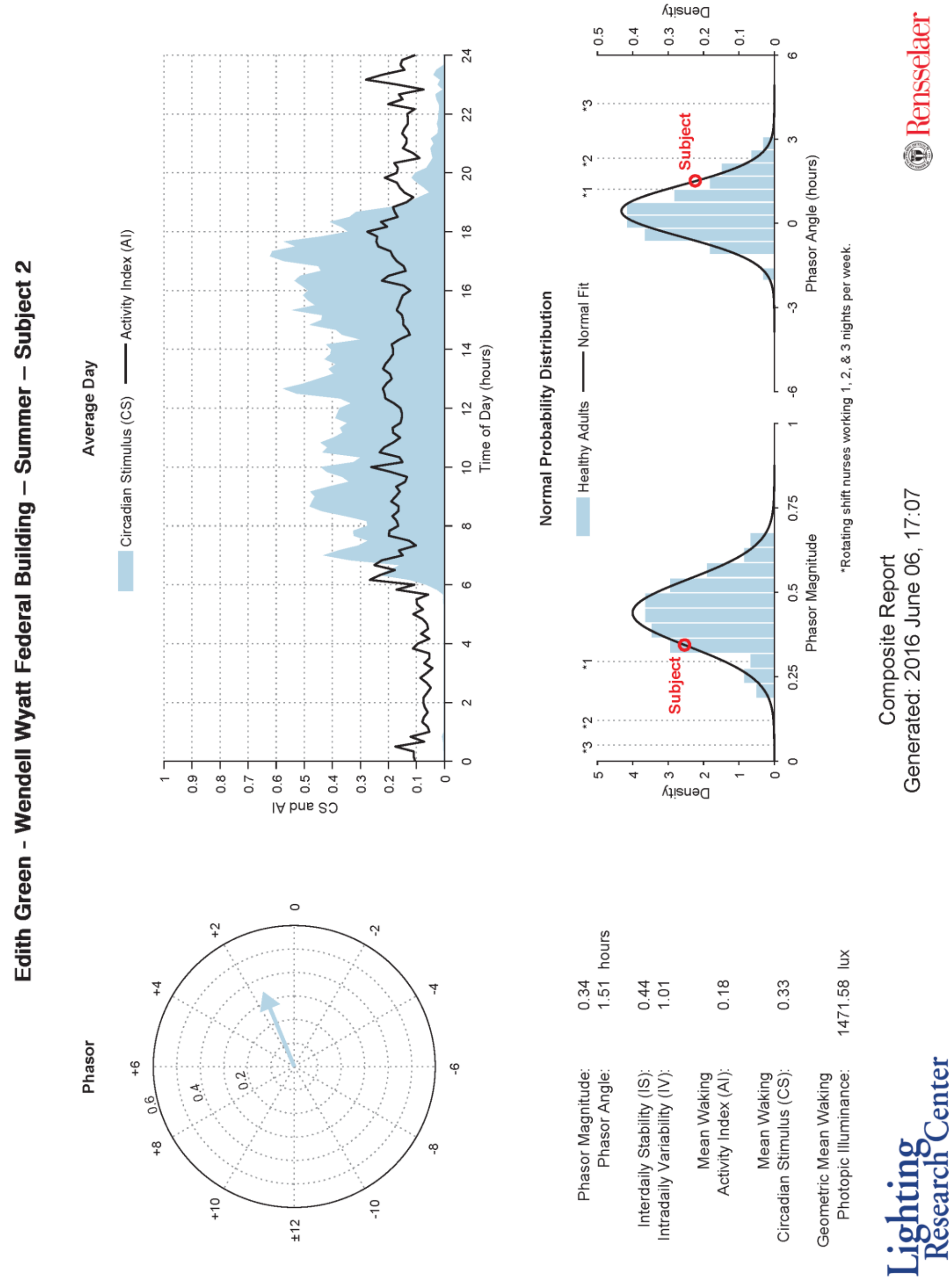
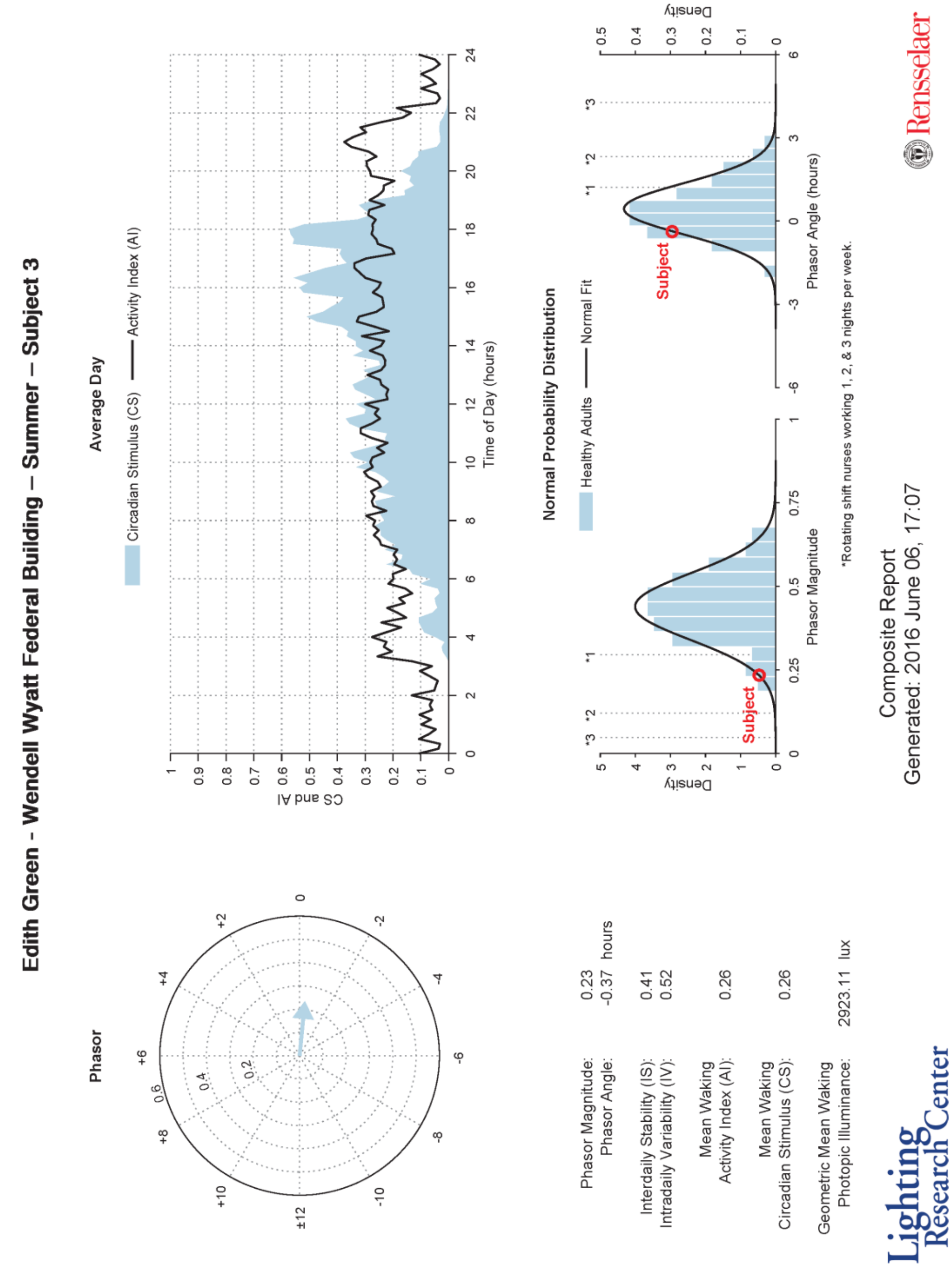
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.23
Phasor Angle: -0.14 hours
Interdaily Stability (IS): 0.60
Intradaily Variability (IV): 0.86
Mean Waking Activity Index (AI): 0.22
Mean Waking Circadian Stimulus (CS): 0.21
Geometric Mean Waking Photopic Illuminance: 1121.02 lux
Composite Report
Generated: 2016 June 06, 17:07
Lighting Research Center
Rensselaer


Edith Green - Wendell Wyatt Federal Building – Summer – Subject 2
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.34
Phasor Angle: 1.51 hours
Interdaily Stability (IS): 0.44
Intradaily Variability (IV): 1.01
Mean Waking Activity Index (AI): 0.18
Mean Waking Circadian Stimulus (CS): 0.33
Geometric Mean Waking Photopic Illuminance: 1471.58 lux
Composite Report
Generated: 2016 June 06, 17:07
Lighting Research Center
Rensselaer


Edith Green - Wendell Wyatt Federal Building – Summer – Subject 3
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Phasor Magnitude: 0.23
Phasor Angle: -0.37 hours
Interdaily Stability (IS): 0.41
Intradaily Variability (IV): 0.52
Mean Waking Activity Index (AI): 0.26
Mean Waking Circadian Stimulus (CS): 0.26
Geometric Mean Waking Photopic Illuminance: 2923.11 lux
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
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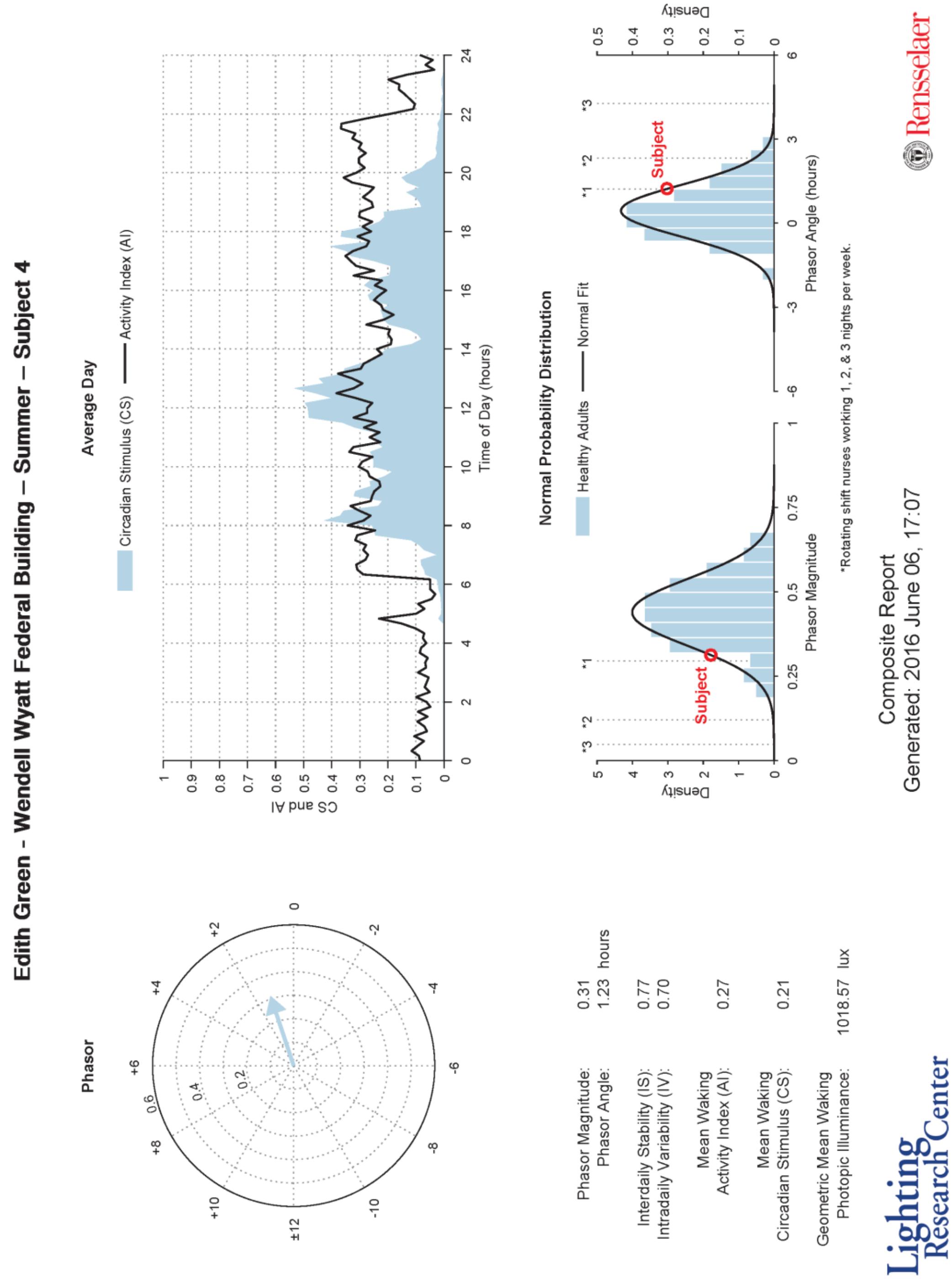
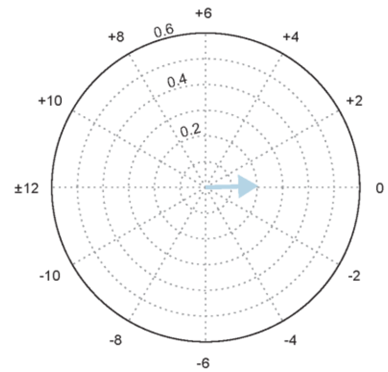
Lighting Research Center
Rensselaer

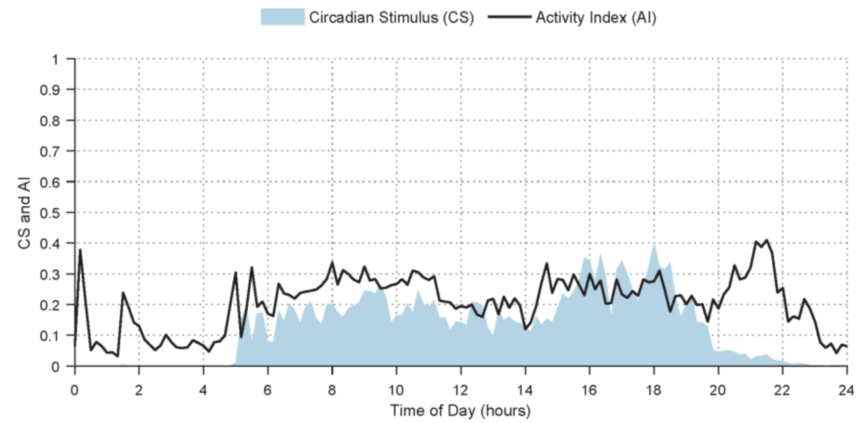

Edith Green - Wendell Wyatt Federal Building – Summer – Subject 4
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Density
Phasor Magnitude
Phasor Angle (hours)
Subject
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.31
Phasor Angle: 1.23 hours
Interdaily Stability (IS): 0.77
Intradaily Variability (IV): 0.70
Mean Waking Activity Index (AI): 0.27
Mean Waking Circadian Stimulus (CS): 0.21
Geometric Mean Waking Photopic Illuminance: 1018.57 lux
Composite Report
Generated: 2016 June 06, 17:07
Lighting Research Center
Rensselaer

Edith Green - Wendell Wyatt Federal Building – Summer – Subject 5

Phasor

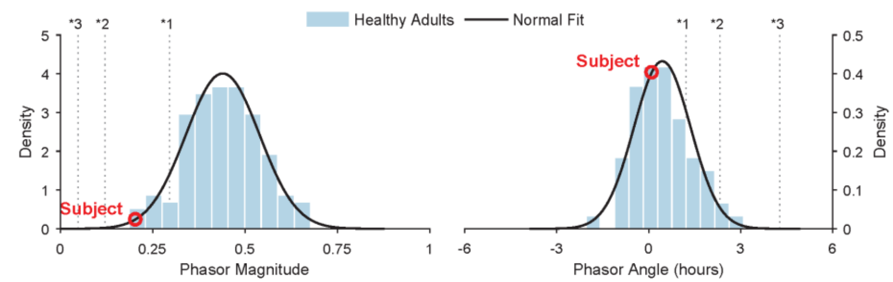


Average Day



Phasor Magnitude:	0.20	
Phasor Angle:	0.11	hours
Interdaily Stability (IS):	0.41	
Intradaily Variability (IV):	1.01	
Mean Waking Activity Index (AI):	0.25	
Mean Waking Circadian Stimulus (CS):	0.18	
Geometric Mean Waking Photopic Illuminance:	443.72	lux

Normal Probability Distribution



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

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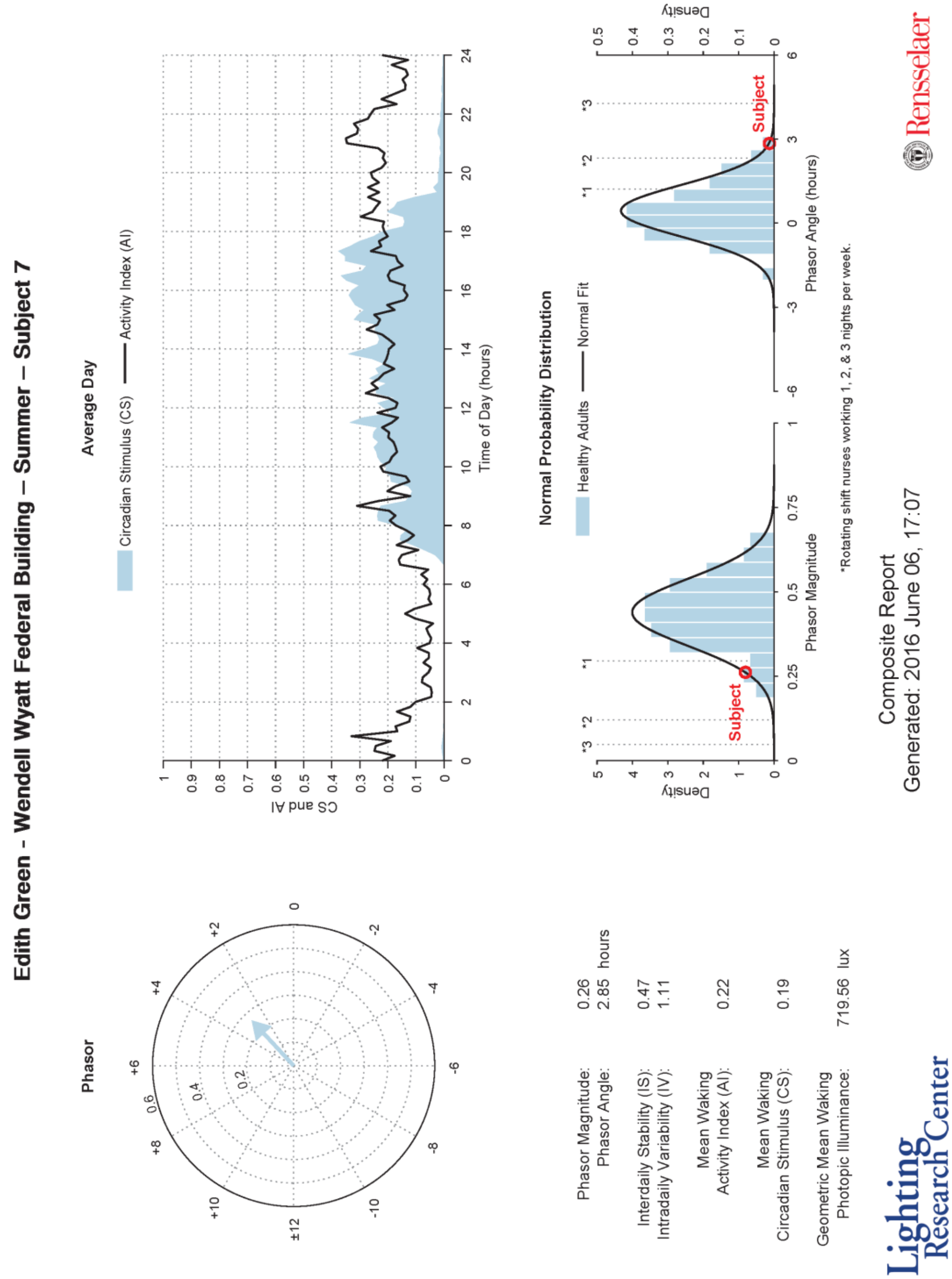
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 7
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Density
Phasor Magnitude
Phasor Angle (hours)
Subject
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.26
Phasor Angle: 2.85 hours
Interdaily Stability (IS): 0.47
Intradaily Variability (IV): 1.11
Mean Waking Activity Index (AI): 0.22
Mean Waking Circadian Stimulus (CS): 0.19
Geometric Mean Waking Photopic Illuminance: 719.56 lux
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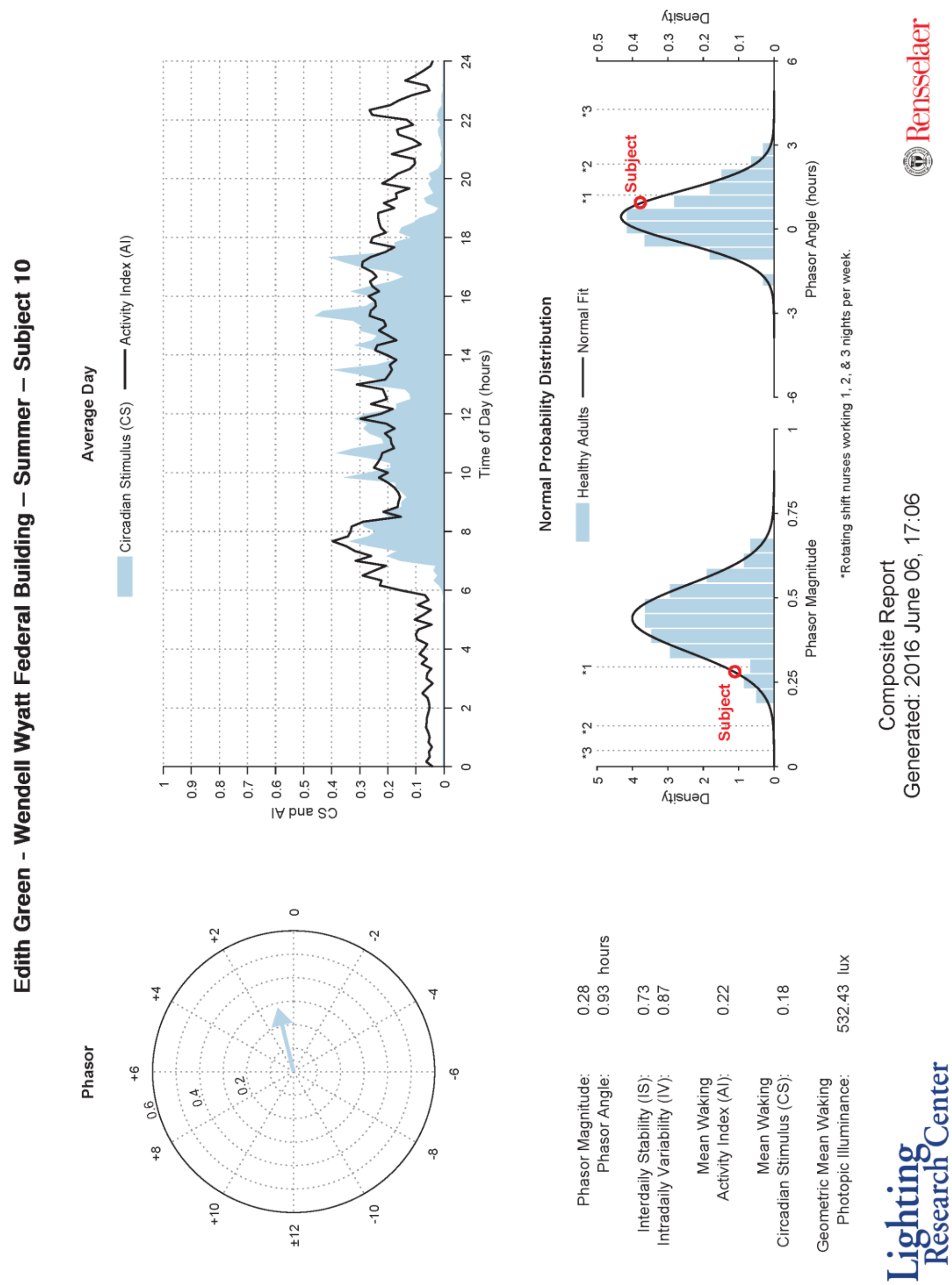
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 10
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Phasor Magnitude: 0.28
Phasor Angle: 0.93 hours
Interdaily Stability (IS): 0.73
Intradaily Variability (IV): 0.87
Mean Waking Activity Index (AI): 0.22
Mean Waking Circadian Stimulus (CS): 0.18
Geometric Mean Waking Photopic Illuminance: 532.43 lux
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
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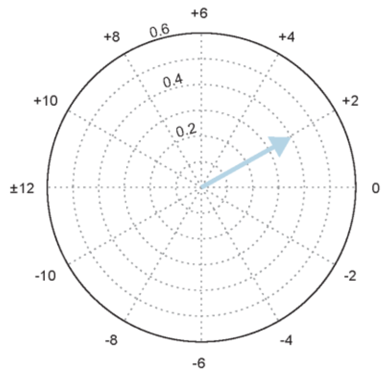
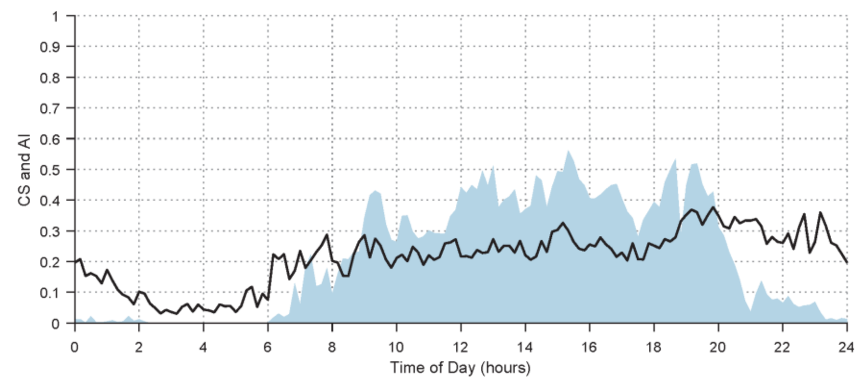
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 12

Phasor

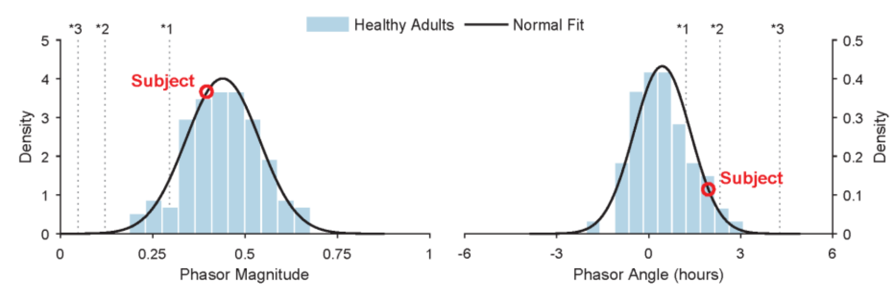


Average Day



Phasor Magnitude:	0.40	
Phasor Angle:	1.95	hours
Interdaily Stability (IS):	0.58	
Intradaily Variability (IV):	0.53	
Mean Waking Activity Index (AI):	0.26	
Mean Waking Circadian Stimulus (CS):	0.30	
Geometric Mean Waking Photopic Illuminance:	2258.68	lux

Normal Probability Distribution



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

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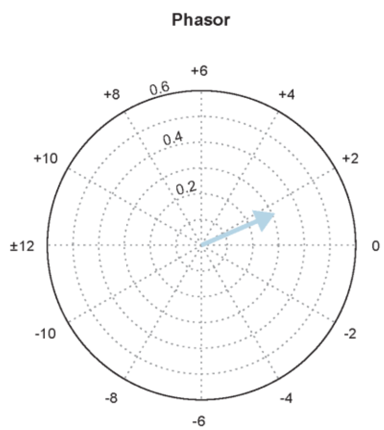
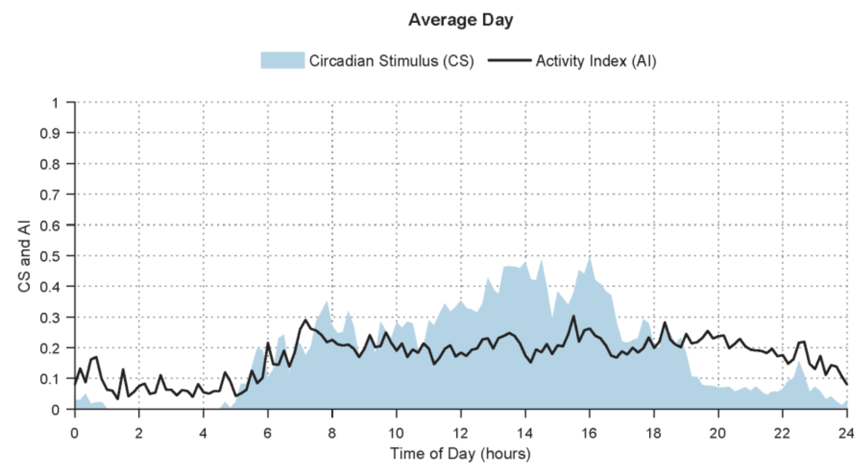
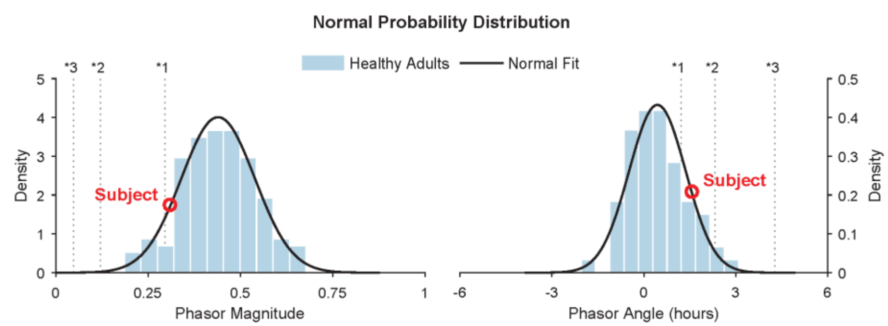
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 13





Phasor Magnitude:	0.31
Phasor Angle:	1.56 hours
Interdaily Stability (IS):	0.62
Intradaily Variability (IV):	0.74
Mean Waking Activity Index (AI):	0.21
Mean Waking Circadian Stimulus (CS):	0.25
Geometric Mean Waking Photopic Illuminance:	865.31 lux



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

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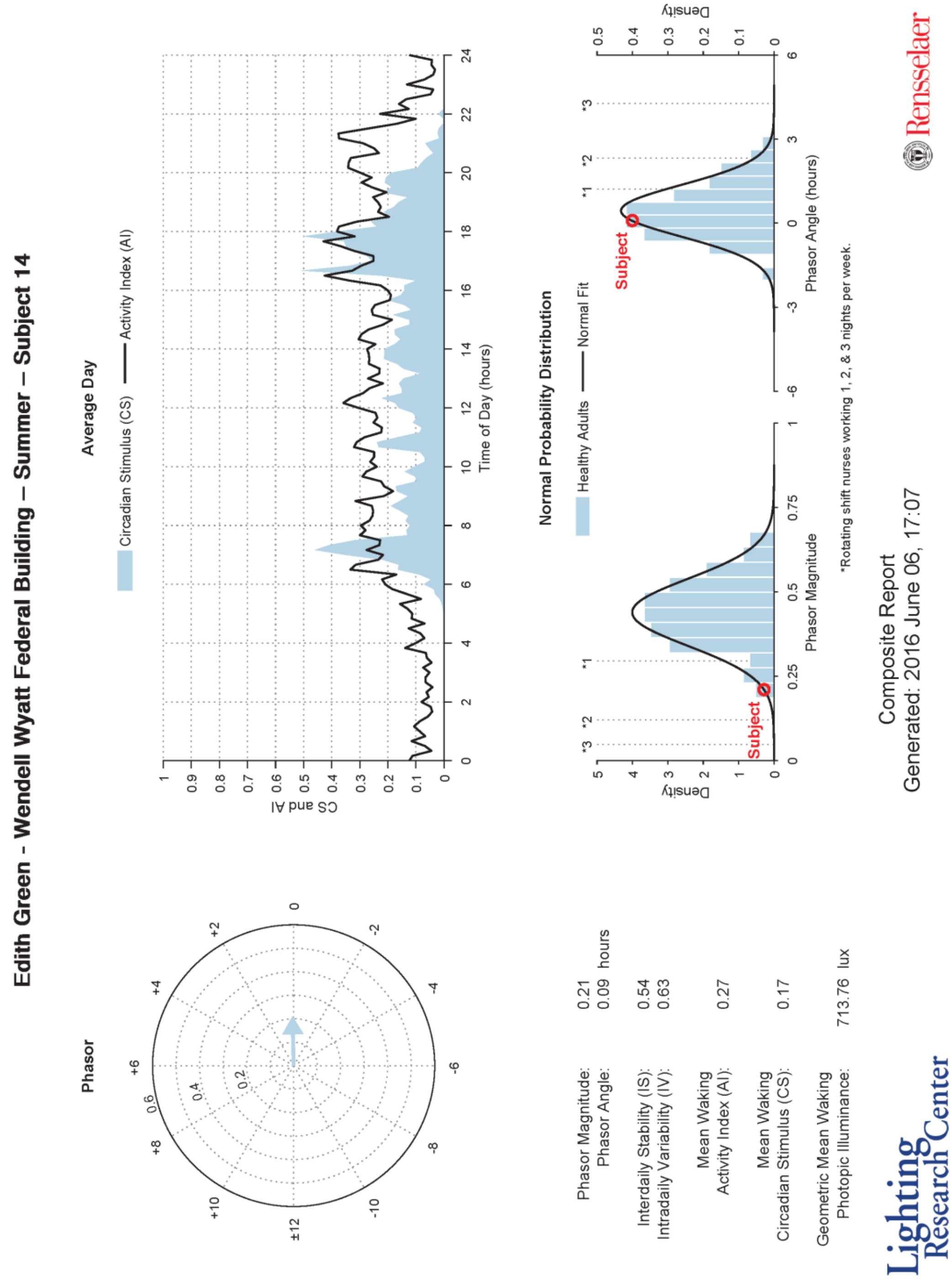
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 14
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.21
Phasor Angle: 0.09 hours
Interdaily Stability (IS): 0.54
Intradaily Variability (IV): 0.63
Mean Waking Activity Index (AI): 0.27
Mean Waking Circadian Stimulus (CS): 0.17
Geometric Mean Waking Photopic Illuminance: 713.76 lux
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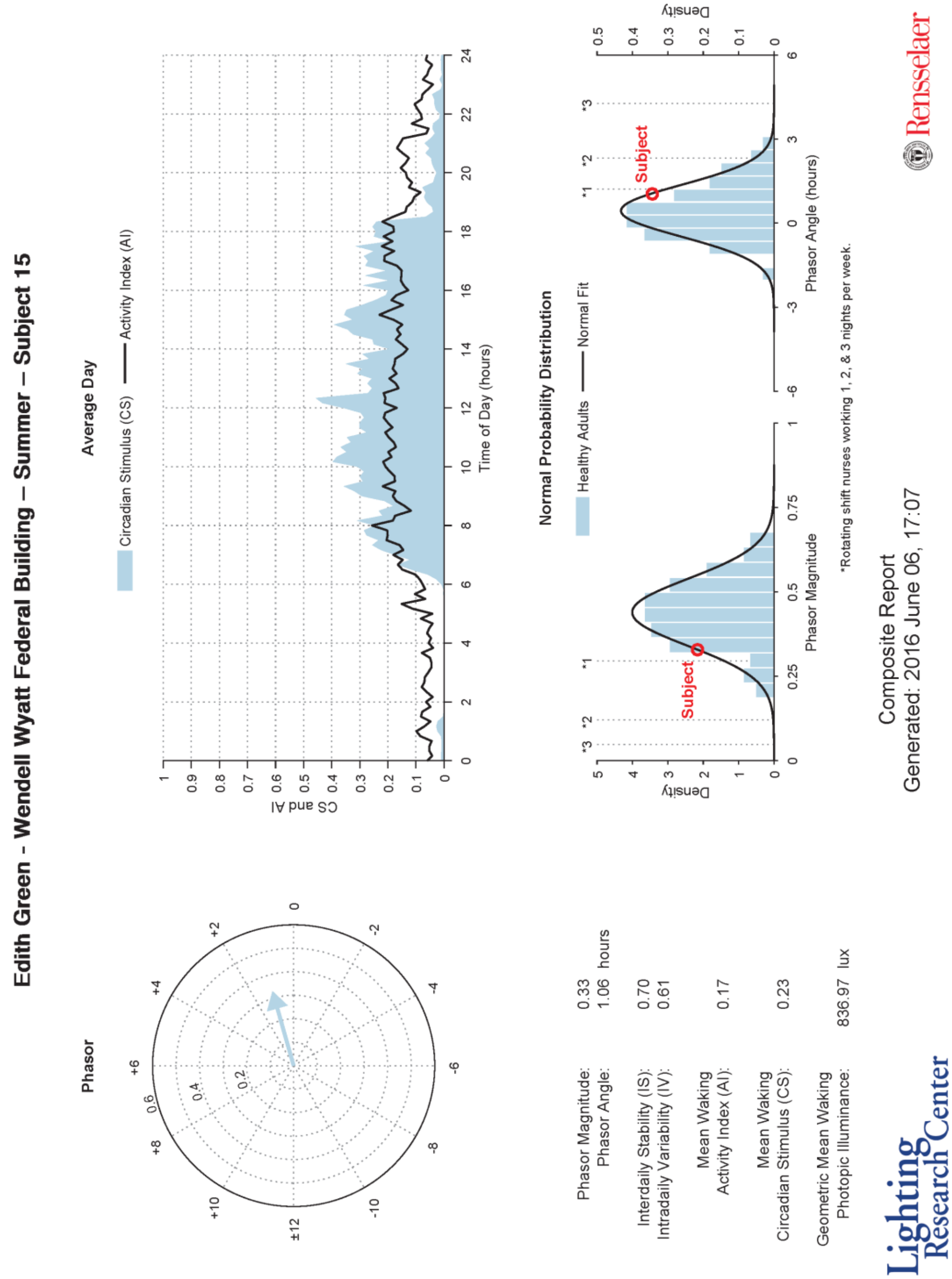
Rensselaer


Edith Green - Wendell Wyatt Federal Building – Summer – Subject 15
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Density
Phasor Magnitude
Phasor Angle (hours)
Subject
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.33
Phasor Angle: 1.06 hours
Interdaily Stability (IS): 0.70
Intradaily Variability (IV): 0.61
Mean Waking Activity Index (AI): 0.17
Mean Waking Circadian Stimulus (CS): 0.23
Geometric Mean Waking Photopic Illuminance: 836.97 lux
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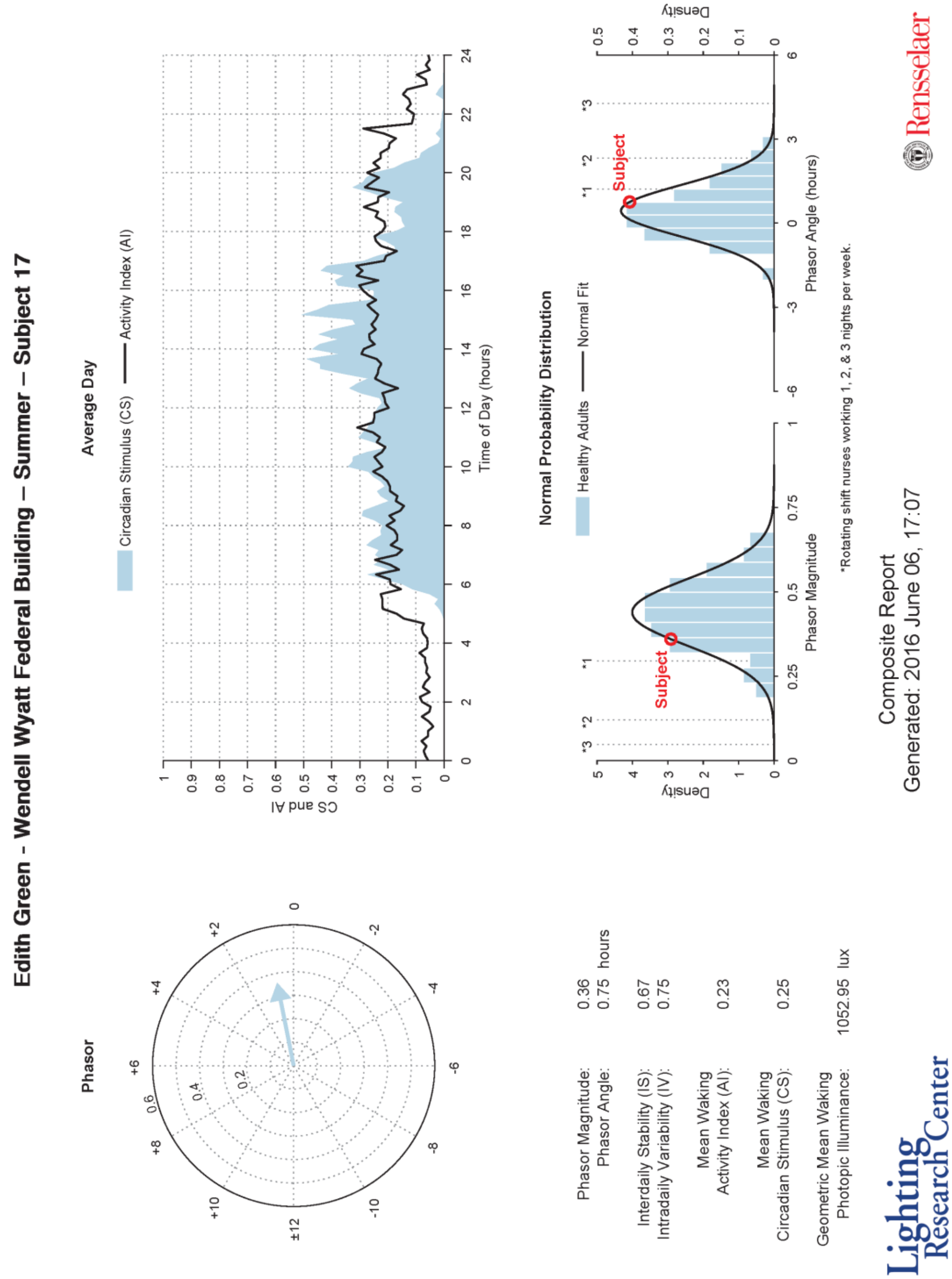
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 17
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.36
Phasor Angle: 0.75 hours
Interdaily Stability (IS): 0.67
Intradaily Variability (IV): 0.75
Mean Waking Activity Index (AI): 0.23
Mean Waking Circadian Stimulus (CS): 0.25
Geometric Mean Waking Photopic Illuminance: 1052.95 lux
Composite Report
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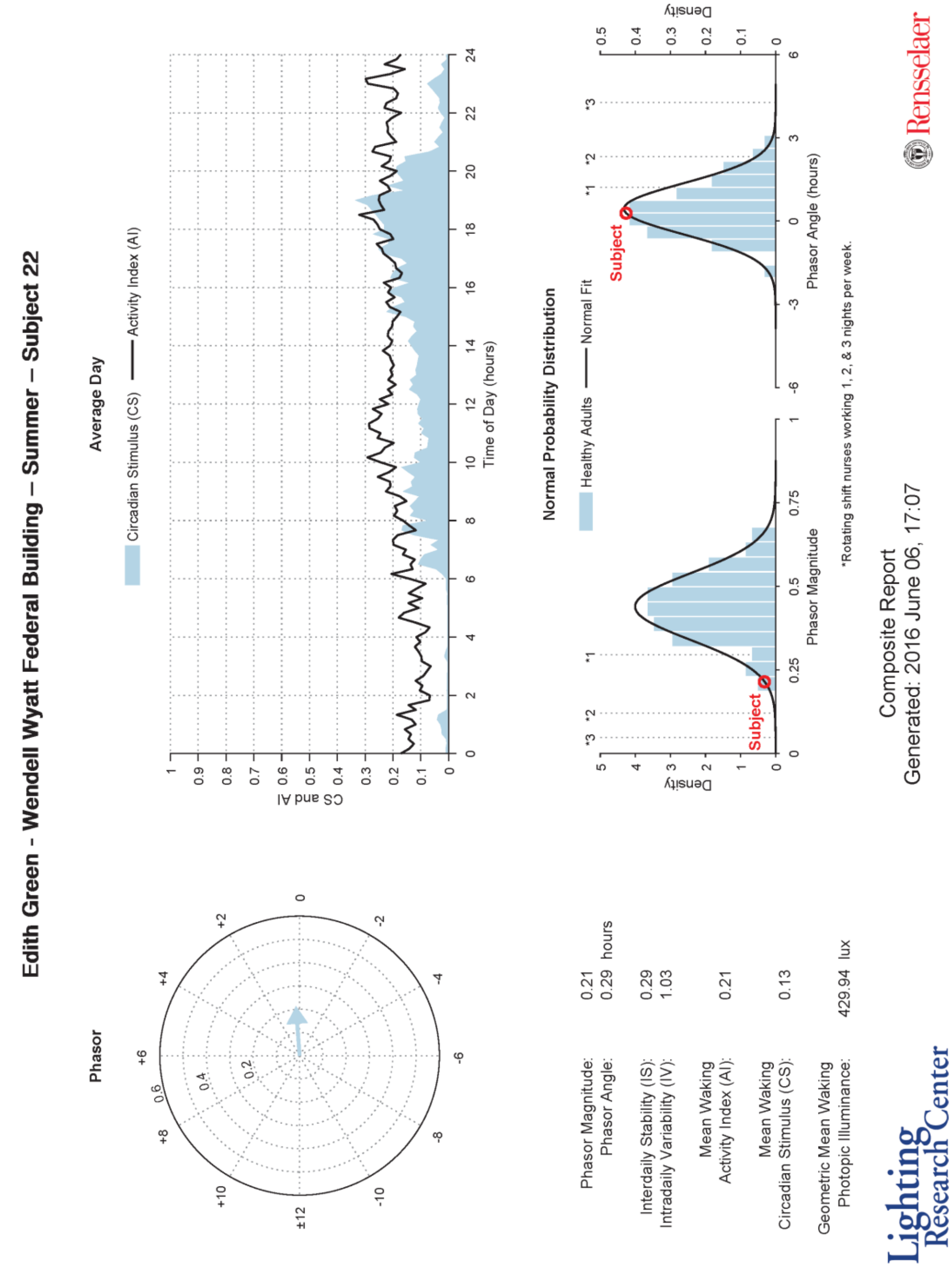
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 22
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Phasor Magnitude: 0.21
Phasor Angle: 0.29 hours
Interdaily Stability (IS): 0.29
Intradaily Variability (IV): 1.03
Mean Waking Activity Index (AI): 0.21
Mean Waking Circadian Stimulus (CS): 0.13
Geometric Mean Waking Photopic Illuminance: 429.94 lux
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
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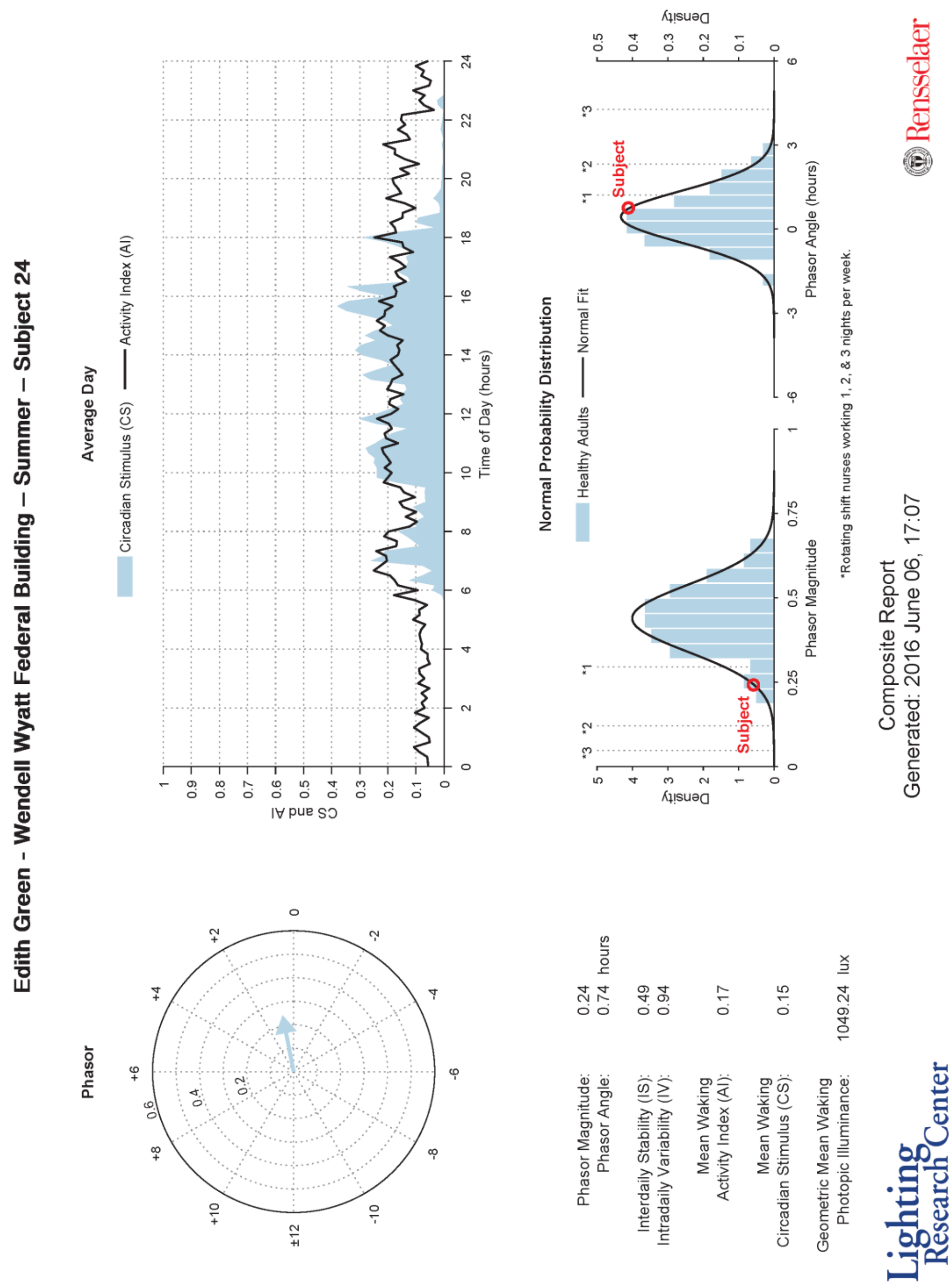
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 24
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Density
Subject
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.24
Phasor Angle: 0.74 hours
Interdaily Stability (IS): 0.49
Intradaily Variability (IV): 0.94
Mean Waking Activity Index (AI): 0.17
Mean Waking Circadian Stimulus (CS): 0.15
Geometric Mean Waking Photopic Illuminance: 1049.24 lux
Composite Report
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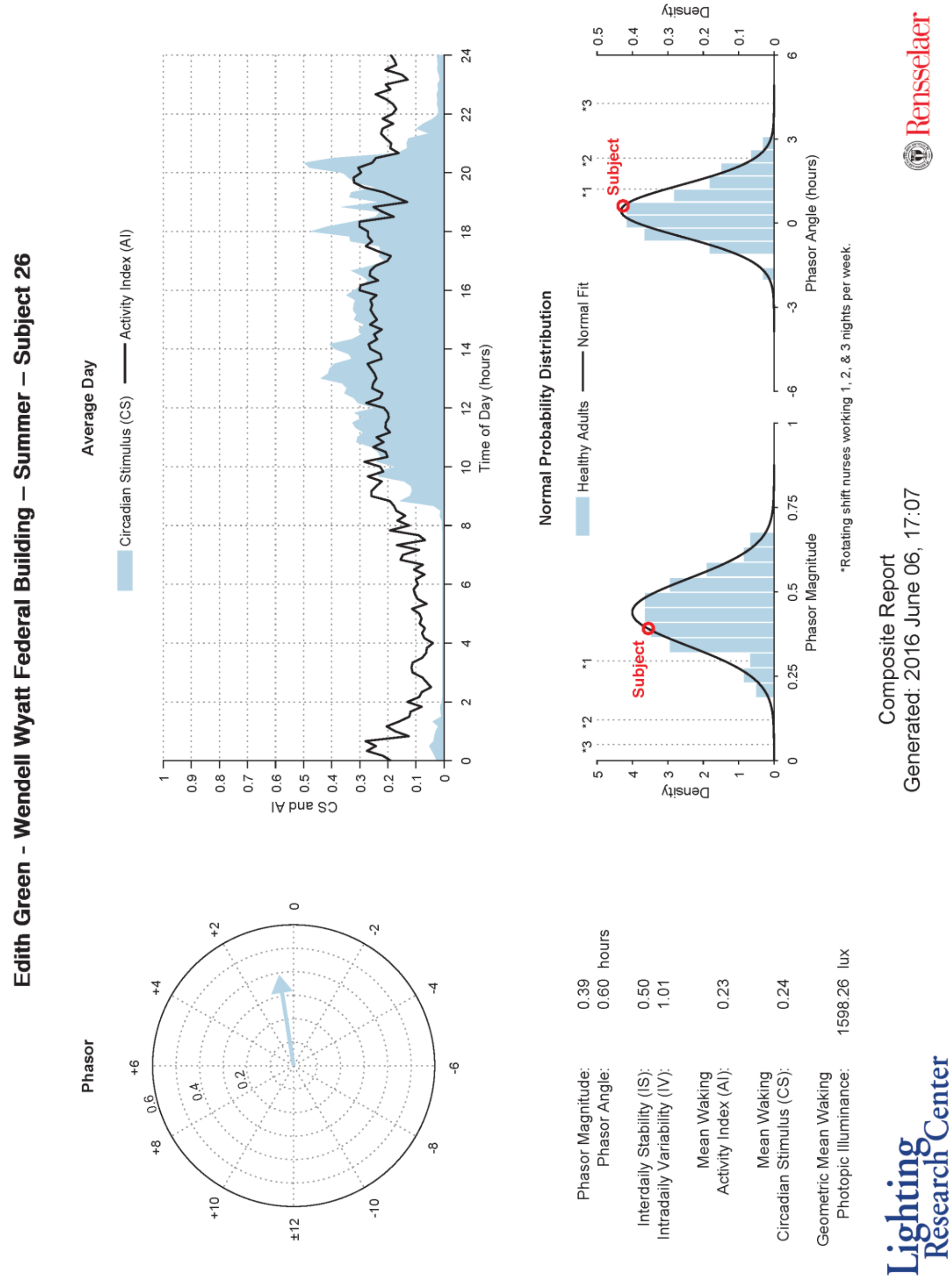
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 26
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Phasor Magnitude: 0.39
Phasor Angle: 0.60 hours
Interdaily Stability (IS): 0.50
Intradaily Variability (IV): 1.01
Mean Waking Activity Index (AI): 0.23
Mean Waking Circadian Stimulus (CS): 0.24
Geometric Mean Waking Photopic Illuminance: 1598.26 lux
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
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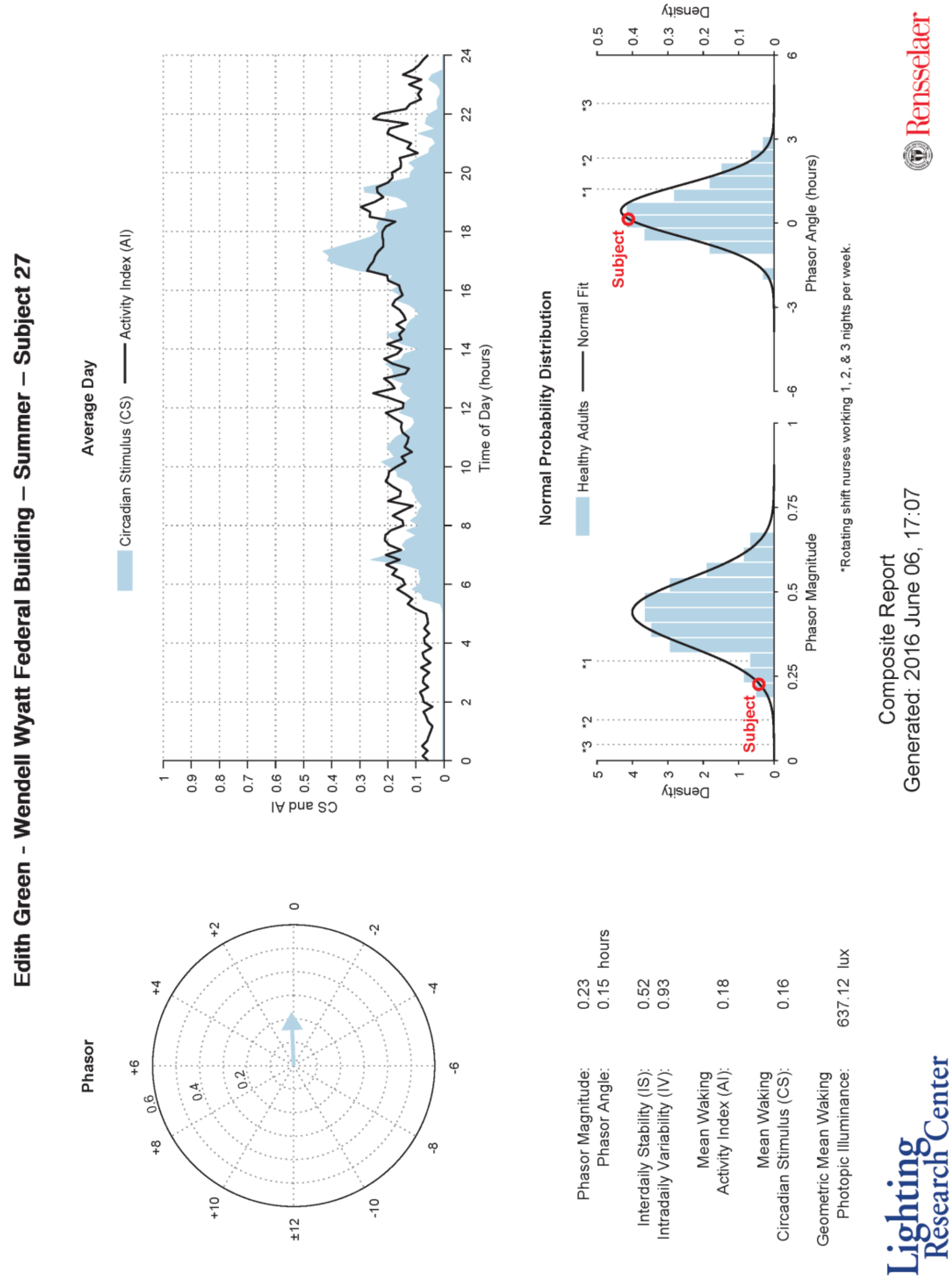
Edith Green - Wendell Wyatt Federal Building – Summer – Subject 27
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Normal Probability Distribution
Healthy Adults
Normal Fit
Subject
Density
Phasor Magnitude
Phasor Angle (hours)
*Rotating shift nurses working 1, 2, & 3 nights per week.
Phasor Magnitude: 0.23
Phasor Angle: 0.15 hours
Interdaily Stability (IS): 0.52
Intradaily Variability (IV): 0.93
Mean Waking Activity Index (AI): 0.18
Mean Waking Circadian Stimulus (CS): 0.16
Geometric Mean Waking Photopic Illuminance: 637.12 lux
Composite Report
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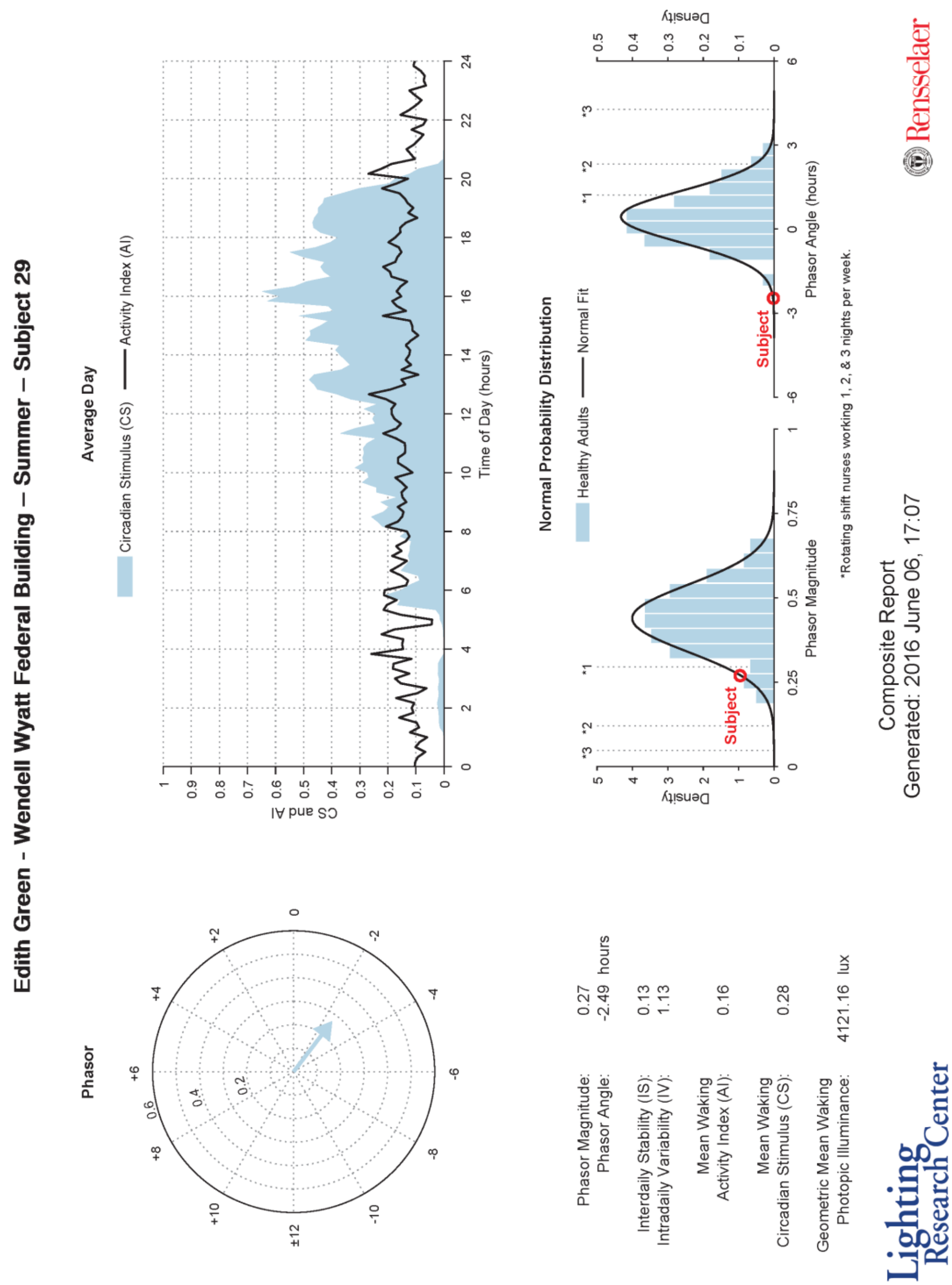
Lighting Research Center
Rensselaer


Edith Green - Wendell Wyatt Federal Building – Summer – Subject 29
Phasor
Average Day
Circadian Stimulus (CS)
Activity Index (AI)
CS and AI
Time of Day (hours)
Phasor Magnitude: 0.27
Phasor Angle: -2.49 hours
Interdaily Stability (IS): 0.13
Intradaily Variability (IV): 1.13
Mean Waking Activity Index (AI): 0.16
Mean Waking Circadian Stimulus (CS): 0.28
Geometric Mean Waking Photopic Illuminance: 4121.16 lux
Normal Probability Distribution
Healthy Adults
Normal Fit
Density
Phasor Magnitude
Phasor Angle (hours)
Subject
*Rotating shift nurses working 1, 2, & 3 nights per week.
Composite Report
Generated: 2016 June 06, 17:07
Lighting Research Center
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