Results Report:

Measuring Personal Light Exposures, Mood, and Sleep Quality

General Services Administration
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1800 F Street NW
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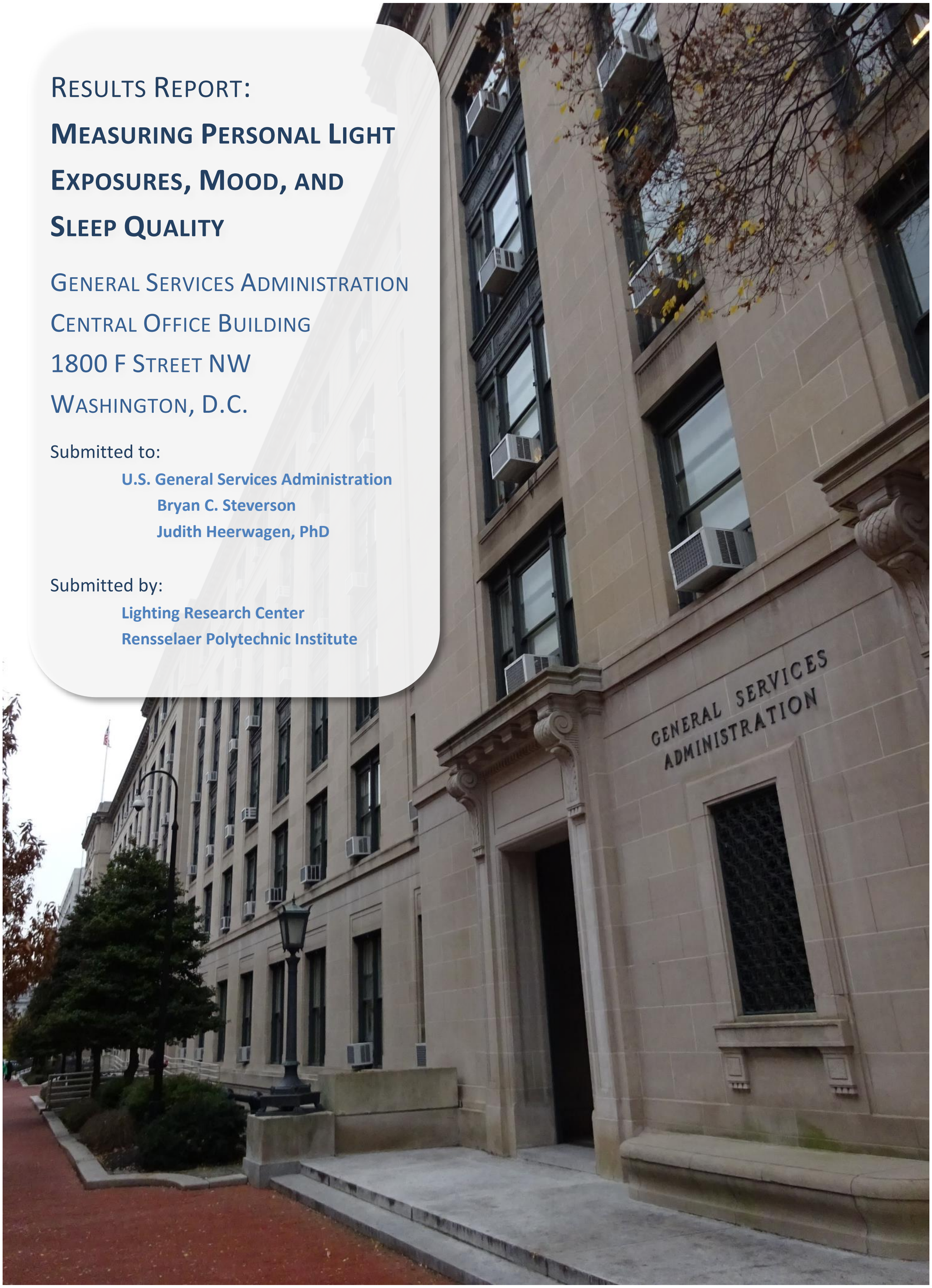

RESULTS REPORT: MEASURING PERSONAL LIGHT EXPOSURES, MOOD, AND SLEEP QUALITY

GENERAL SERVICES ADMINISTRATION CENTRAL OFFICE BUILDING
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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 consumption in buildings. However, the lighting characteristics affecting the biological clock are different from 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, the data provided by this research could have far-reaching implications for sustainable lighting design as a means for achieving energy goals while also enhancing the health and wellbeing of federal workers, improving their overall work effectiveness, and reducing 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 28 participants who took part in the winter portion of the study (between January and February) and also agreed to repeat the study in the summer (between June and August) while working at the GSA's Central Office Building (COB), 1800 F Street NW, Washington DC. Also included in this report are data from 6 participants working at the GSA's Regional Office Building (ROB), 301 7th Street SW, Washington, DC, which was used as a control building. Each participant agreed to wear a Daysimeter, which monitors physical activity and measures continuous light exposures (and thereby permits calculation of circadian stimulus [CS]), for seven consecutive days during the winter and summer data collection periods. Participants wore the Daysimeters 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.

Results showed that the CS experienced by participants in the COB was between 0.09 and 0.39 in summer months, with a mean ± standard deviation (SD) = 0.25 ± 0.09. In winter months, CS experienced by workers during work days was between 0.08 and 0.32, with a mean ± SD of 0.19 ± 0.06. In the ROB, CS exposure during working hours was much lower, ranging from 0.08 to 0.43 in summer months with a mean ± SD = 0.21 ± 0.11, and ranging from 0.09 to 0.18 in winter months with a mean ± SD = 0.13 ± 0.04. This difference in CS exposures between the two buildings was not statistically significant ($p=0.52$) in winter and summer months. (It should be noted that there were more ROB participants in summer than in winter, and fewer COB participants in summer than in winter.) Similar to our previous studies, the present data suggest that, during winter months, the COB participants were exposed to the highest CS values during their working hours, compared to exposures at home (early morning and evenings). This was not the case for the ROB participants, who received similar CS values during and before work hours. During the summer months, participants in the COB received similar levels

of CS (approximately 0.23–0.25) prior to coming to work and during work hours, while those working in the ROB still received the highest CS prior to coming to work.

CS value is a surrogate for how much the light stimulus activates the circadian system; a CS value of 0.06 is representative of a circadian stimulus that would result in 6% melatonin suppression if similar light levels were experienced at night for 1 hour, while values above 0.4 suggest a strong stimulation of the circadian system. In terms of photopic lux, participants received significantly higher amounts of light during summer than during winter months. While working during the winter data collection period, the COB participants experienced geometric mean and arithmetic mean light levels of 95 lux and 390 lux, respectively, and during the summer period they experienced light levels of 193 lux and 2928 lux, respectively. While working during the winter data collection period, the ROB participants experienced geometric mean and arithmetic mean light levels of 47 lux and 1007, respectively, and during the summer period they experienced light levels of 126 lux and 1920 lux, respectively.

Phasor magnitudes using data recorded over a 7-day period were used as a measure of circadian entrainment. (Phasor magnitude quantifies circadian entrainment/disruption in terms of phase and amplitude relationships between measured light–dark and activity–rest patterns.) Phasor magnitudes calculated for participants in the COB (mean = 0.27 [winter] and 0.26 [summer]) and ROB (mean = 0.22 [winter] and 0.24 [summer]) were lower than those measured in other federal buildings in Portland, OR, and in Grand Junction, CO, which ranged between 0.26 and 0.31. Phasor magnitudes decrease when there is little activity in spaces with high circadian light exposures or too much activity in circadian darkness, such as what may occur when subjects go to work too early (before sunrise) or leave work too late (after sunset). In comparison, phasor magnitudes calculated for schoolteachers and dayshift nurses—who are known to be followers of regular schedules and are entrained—range between 0.46 and 0.52.

The COB participants slept an average of 5.7 hours per night in the winter and summer, had a sleep latency of about 20 minutes in winter and 15 minutes in summer, and a sleep efficiency of 75% in winter and 78% in summer. In this respect, they are similar to their colleagues who were studied by the LRC in the Edith Green Building, Portland, OR. Pittsburgh Sleep Quality Index (PSQI) scores for the COB participants (5.5 [winter], 5.1 [summer]) indicate borderline sleep disturbance; however, the COB participants' mean PROMIS Global Score, another scale that measures sleep disturbance, was below 25 (mean=16 [both seasons]), indicating no sleep disturbance in this population. None of the COB participants reported being clinically depressed or stressed. The ROB participants slept about 5.6 hours per night in winter and 5.5 hours per night in summer, had a sleep latency of 52 minutes (significantly higher than those in the COB) in winter and 16 minutes in summer, and a sleep efficiency of 72% in winter and 75% in summer. The ROB participants' PSQI scores in winter months were 7.8, which is higher than those from the COB participants and suggestive of sleep disturbance; in summer months, their PSQI scores of 7.5 were again higher than those of the COB participants. While the ROB participants' mean PROMIS Global Score was also below 25 (mean = 21.3 [winter], mean = 21.5 [summer]), it was nonetheless higher than the means recorded in the COB participants. Self-reports of stress and depression levels were also higher among ROB participants than their COB colleagues, although none of the scores reported by the former suggest that they are clinically depressed or stressed.

Although there were few participants from the control building (ROB), where little daylight was available, participants in that group were exposed to significantly less circadian stimulus, had significantly greater sleep latency (perhaps suggesting a delayed circadian clock), and significantly greater self-reported sleep disturbances. No effects of light on mood and stress were found, but again, since these were self-reports, it may be that the sample size required to achieve statistical significance is greater due to more individual variability in the data set.

While inconclusive, these data are encouraging in that they show that very low circadian stimulation during the working hours (below the threshold of 0.1) may be associated with sleep disturbances. Additional data from participants in the control group are needed to better understand this apparent relationship.

BACKGROUND

Lighting design for office buildings has focused largely on the amount of light available for work, strategies to reduce visual discomfort, and the use of daylight as a means to reduce energy consumption in buildings. Little attention has been given to understanding the experience of light, however, 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) and it has been argued that daylight positively affects work performance (Heschong Mahone Group 1999, 2003a, 2003b). Although a cause-and-effect mechanism relating daylight to improved performance and psychological wellbeing cannot be reliably demonstrated (Boyce 2004; Boyce & Rea 2001), another line of research has emerged in the last 30 years that shows the potential to provide a physiological foundation for this as yet undocumented relationship.

Basic research in circadian photobiology (Arendt 1995; Klein 1993; Moore 1997; Turek & Zee 1999a) 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 1999b; Van Someren et al. 1997). In contrast to the visual system, however, activation of the circadian system requires higher light levels and shorter wavelength (i.e., blue) light (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, which stops production of the hormone melatonin when the retina is exposed to a sufficient level of 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, it is conceivable that daylight acting on the circadian system could positively affect performance. Current 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 light-emitting diode (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.

Currently, however, there are no data available on light–dark exposure patterns experienced by people working in buildings that were designed to utilize daylight. Therefore, the overarching goal of this research is to assess the occupants' experience of light and to identify health outcomes linked to measured light exposure. If health benefits are identified, the data provided by this research could have far-reaching implications for sustainable lighting design as a means for achieving energy goals while also enhancing the health and wellbeing of federal workers, improving their overall work effectiveness, and reducing 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 GSA staff who worked in the Central Office Building (COB). GSA staff distributed emails, displayed posters, posted information on internal webpages and social media, and organized informational sessions at the building during lunchtime hours. There were no exclusion criteria for participation in the study. Two informational sessions were held in December 2014. All interested parties were invited to attend and ask questions about the research protocol. If interested, participants contacted LRC staff and signed up for the study. A GSA employee served as the onsite point person, distributing and collecting the devices and questionnaires employed in the study.

During the winter months at the COB, 41 individuals (21 females, 20 males; average age of 47 years ± SD 13.1 years) participated in the study. The COB participants' average chronotype was 3.2 ± SD 2.0. A chronotype between 1 and 2 suggests that a person is a lark (early person), a chronotype between 5 and 6 suggests that a person is an owl (late person), and a chronotype of 3 suggests that the person is neither a lark nor an owl. At the GSA Regional Office Building (ROB) during the same period, 6 individuals (4 females, 2 males; average age of 51 years ± SD 7 years) participated in the study. The ROB participants' average chronotype of 3 ± SD 1.6 suggests, like their COB colleagues, that they were neither extreme larks nor extreme owls.

During the summer months at the COB, 28 individuals (14 females, 14 males; average age of 47 years ± SD 13.4 years) participated in the study, and their average chronotype was 3.6 ± SD 1.6. At the ROB during the same period, 10 individuals (6 females, 4 males; average age of 50.2 years ± SD 10.3 years) participated in the study, and their average chronotype was 2.2 ± SD 1.8. Like the winter participants, the average chronotypes of the summer participants from both buildings suggest that they were neither extreme larks nor extreme owls.

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 via 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 ($V(\lambda)$), 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 1-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:

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

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.

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.

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): A self-assessment of subjective sleepiness. The scale ranges from 1 (most alert) to 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, etc.) 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)*:** Consists of 10 positive affects (i.e., interested, excited, strong, enthusiastic, proud, alert, inspired, determined, attentive, and active) and 10 negative effects (i.e., distressed, upset, guilty, scared, hostile, irritable, ashamed, nervous, jittery, and afraid). Participants are asked to rate items on a scale from 1 (very slightly or not at all) to 5 (extremely). (Watson et al. 1988)

Center for Epidemiologic Studies Depression Scale (CES-D): A 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 7 consecutive days during the winter (between January and

February) and summer (between June and August) data collection periods. To permit monitoring of their sleep/wake activity patterns at night, the participants were asked to wear the device on their wrist while sleeping.

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 any naps taken. KSS data were collected 4 times per day: awakening, noon, dinnertime, and bedtime. Participants were also asked to note: (a) the days in which they were in the office and (b) the desk space number they used during those days. All participants were asked to spend at least 3 days in the building during the data collection period.

The devices and questionnaires were mailed in sealed envelopes to the GSA staff volunteer serving as the on-site point person, who then distributed the envelopes to the participants. Upon completion of the 7-day data collection period, the staff volunteer collected the devices and questionnaires (again in sealed envelopes), and did not have access to any data at any time. The staff volunteer had no other role in the study, and no issues were reported in regard to this method of delivering/returning study materials from/to the LRC. Participants in the winter portion of the study were contacted again and asked to participate during the summer period. Of the 43 participants in the COB, 27 agreed to collect data during the summer period; in the ROB, 10 participants agreed to collect data during the summer period.

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: (a) geometric mean of the recorded levels was calculated to help normalize their highly skewed distribution and (b) arithmetic mean of the recorded levels, which is 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 overall circadian light exposures during the study, as well as the circadian stimulus during working hours (assumed to be between 08:00 am and 05:00 pm) and outside working hours (early morning after waking and evening prior to bedtimes) on days that participants were in the building.

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 Daysimeters were worn on the wrist during the nighttime, only the daytime (while worn as a pendant) data were included in the phasor analyses. This procedure was followed because the activity patterns differ between when the device is worn as a pendant and 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: (a) 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, and (b) intra-daily variability (IV), an indication of the fragmentation of the activity–rest rhythm (Van Someren et al. 1997). The IS quantifies the extent to which all recorded 24-hour activity profiles resemble each other, which represents the day-by-day regularity of the sleep–wake pattern. The IV quantifies the fragmentation of the rhythm; that is, the frequency and extent of transitions between periods of rest and activity.

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, it is calculated as the difference between sleep start and bed time.

RESULTS

Table 1 shows the statistical summary by floor, wing, and orientation for winter months (revised from report delivered in April 2015 because of the addition of one participant whose data came in later). Table 2 shows the statistical summary for the winter for the COB and ROB separately, along with two-tailed unpaired t-tests comparing the results from the two buildings. Table 3 shows the statistical summary by floor, wing, and orientation for summer months. Table 4 shows the statistical summary for the summer for the COB and ROB separately, along with two-tailed unpaired t-tests comparing the results from the two buildings. Tables 5 and 6 show the same type of data, but for the participants who completed data collection in both winter and summer months.

Figure 1 shows mean CS and activity over the course of the 7 days for the COB and ROB participants in winter and summer months. Figure 2 shows similar data, but includes only those days in which participants report being in the buildings. These figures can be seen as a "sketch" of the participants' CS and activity over the course of 24 hours. As shown in Figure 2, participants were regular and exposed to similar lighting conditions over the course of 7 days. Participants in the COB received the higher amounts of circadian light during working hours, while this pattern was not as pronounced in those working at the ROB. It is important to note that because fewer participants are included in the ROB graphs in Figure 2, the data do not look as smooth. As with other populations, activity levels over the course of 7 days 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. Figure 3 shows mean CS and activity only for those who participated in both phases of the study (winter and summer).

The following observations have been drawn from the data:

- The mean CS values experienced by participants during their working hours (days in which they were in the office between 8:00 a.m. and 5:00 p.m.) were significantly different between buildings in winter months, but not in summer months. The CS values experienced by ROB participants were close to those experienced by COB participants in summer months, while they were significantly lower in winter months. The mean CS of 0.24 experienced in summer months is equivalent to 24% melatonin suppression if the light experienced was applied for 1 hour in the middle of the night, when melatonin levels are high. This suggests that the amount of light that participants were exposed to in both buildings was below that which is hypothesized to be good stimulation for the circadian system (i.e., 0.3 or greater), although it was above the threshold (0.1) for activation of the circadian system (in winter months, the CS value in the ROB was below the threshold). Given that participants are exposed to this CS value for periods longer than 1 hour, it may be possible that users still had enough circadian stimulation. 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 0.24 CS over the course of the working hours may be sufficient to maintain entrainment, so the workers in the COB may still be getting sufficient entraining stimulus. Those in the ROB received a CS of 0.13 in winter months, but the CS values measured during summer months were 0.18, much higher than in winter months.

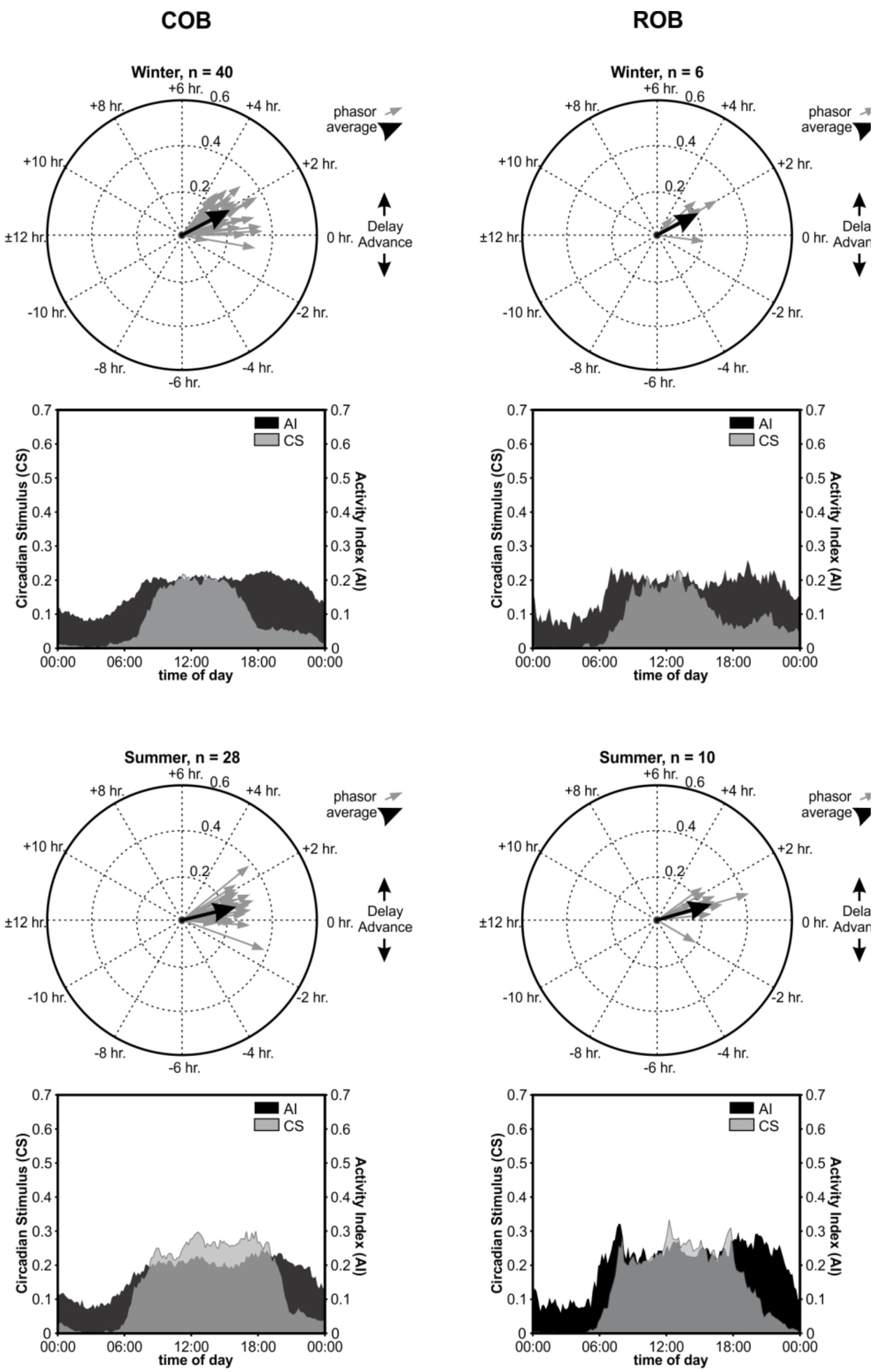

Figure 1. Phasor diagrams (circles, upper) and average CS and AI graphs (rectangles, lower) for the consecutive 7-day collection periods in the winter (top) and summer (bottom) for participants in the COB (left) and the ROB (right) who had usable data. Phasor magnitude (length) quantifies, in terms of 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. Average CS and AI values were calculated for the participants who had usable data.

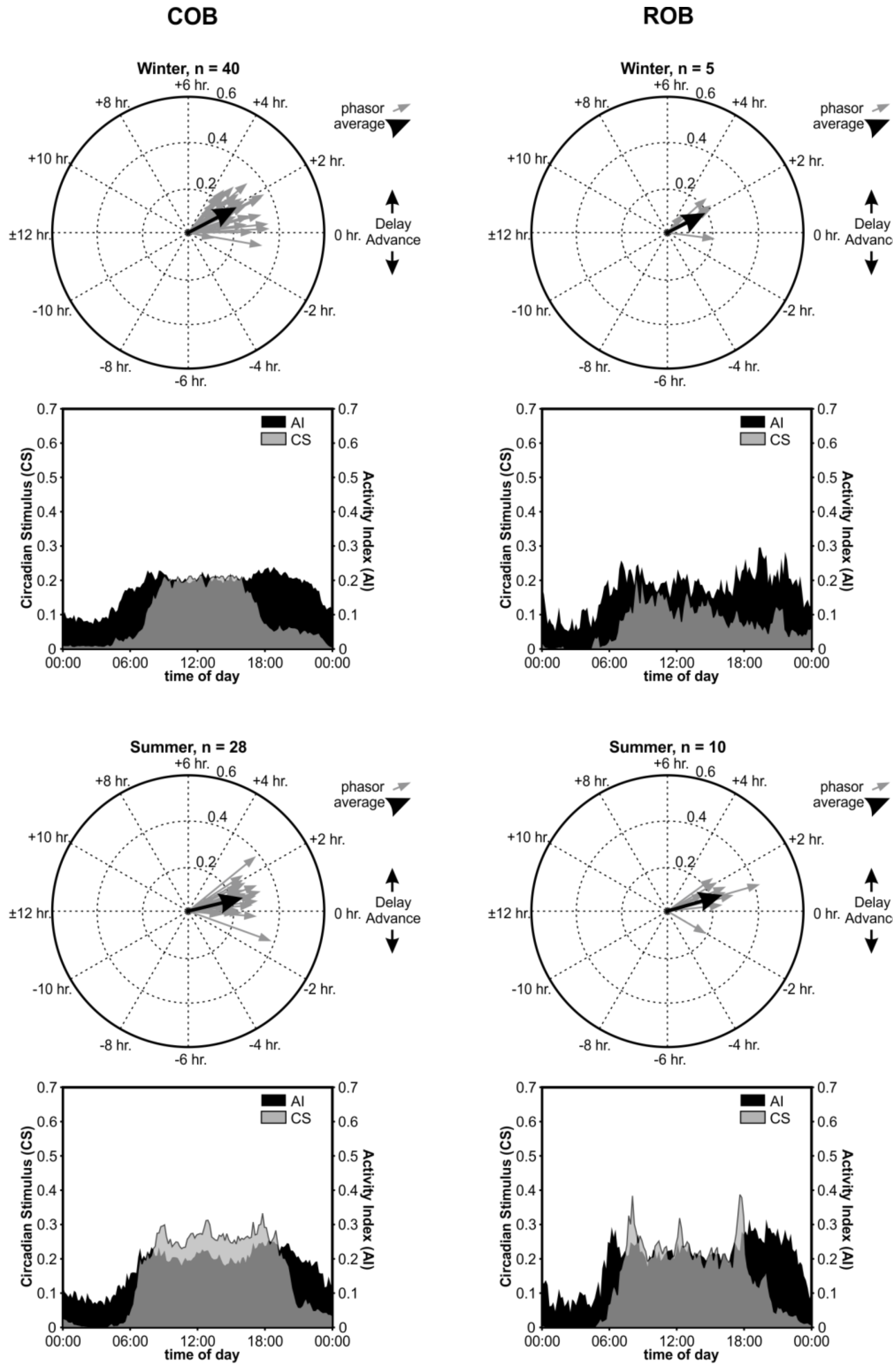

Figure 2. Phasor diagrams (circles, upper) and average CS and AI graphs (rectangles, lower) for the winter (top) and summer (bottom) for participants in the COB (left) and the ROB (right) who had usable data. Only the days in which participants reported being in their respective buildings are included. Circadian stimulus experienced by ROB workers was lower than that experienced by COB workers. 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.

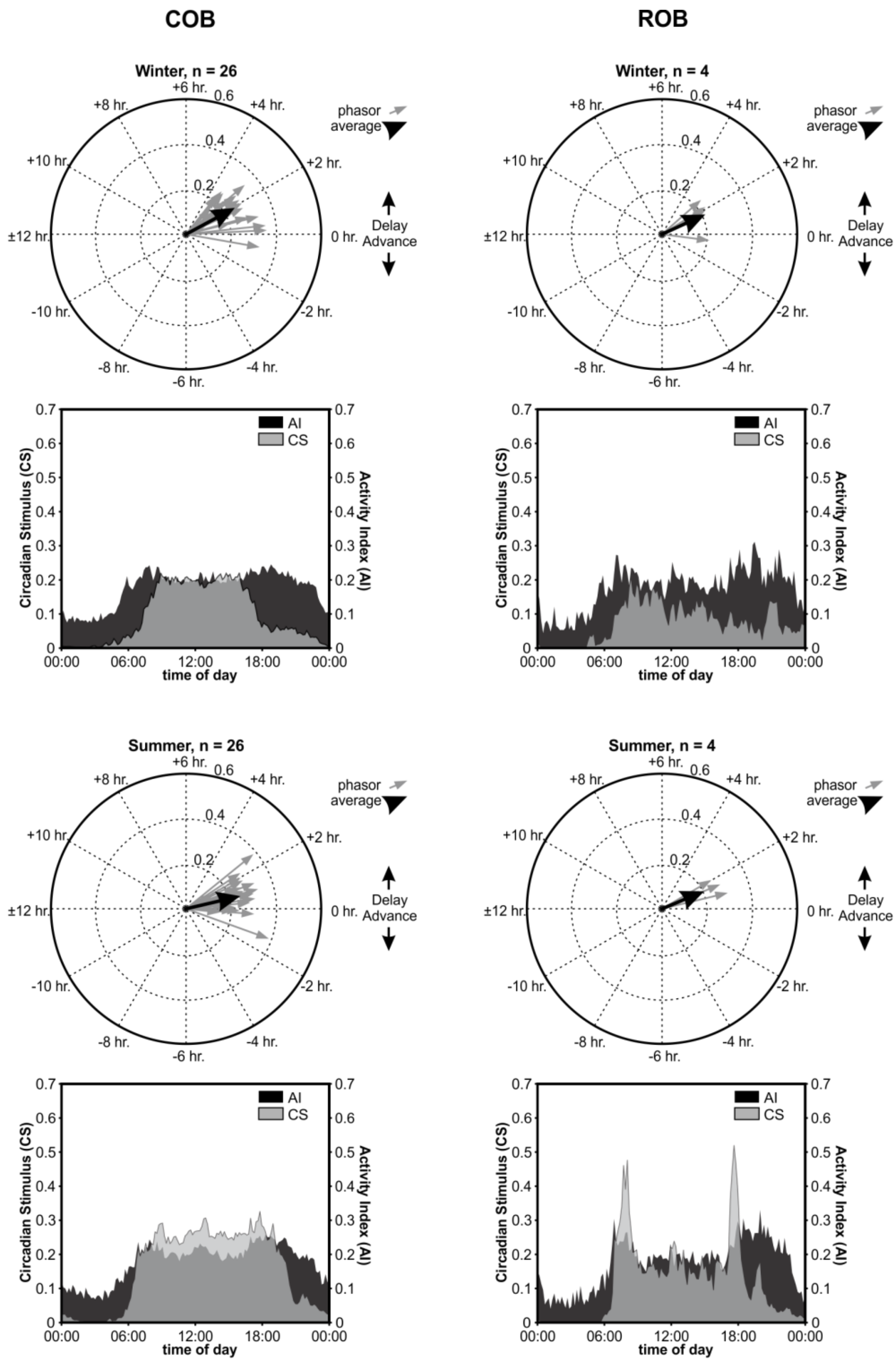

Figure 3. Phasor diagrams (circles, upper) and average CS and AI graphs (rectangles, lower) for the winter (top) and summer (bottom) for participants in the COB (left) and the ROB (right) who participated in both phases of the study (winter and summer) and had usable data. Only the days in which participants reported being in their respective buildings are included. Circadian stimulus experienced during the winter by ROB workers was lower than that experienced by COB workers. 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.

- The mount of light received prior to working hours in participants working in the ROB was greater than the light received during work hours in winter months. For the COB, participants received a greater amount of circadian light in their working hours than prior to coming to work during both winter and summer months.
- Phasor magnitudes were low overall (mean = 0.27 for the COB participants [winter] and 0.26 [summer] and 0.22 [winter] and 0.25 [summer] for the ROB participants) compared to other groups of workers. A high phasor magnitude suggests that the person is entrained to the 24-hour day–night cycle. By way of comparison, other available data sets show mean phasor magnitudes in school teachers and dayshift nurses of 0.52 and 0.46, respectively (Rea et al. 2011; Miller et al. 2010). Therefore, data suggest that federal workers are more disrupted than a population of school teachers or dayshift nurses, who tend to have more regimented, regular schedules.
- Phasor angles were lower in summer than in winter in both buildings. These values are similar to those obtained in the other federal buildings and it may result from the increased light availability in the evening, when activity is still high.
- Based on Daysimeter actigraphy data, the sleep times in this group of workers were generally low and consistent with data for workers in other federal buildings. There was no significant change in sleep parameters between winter and summer months. It is interesting to note that sleep onset latency was significantly shorter ($p = 0.02$) for those in the COB compared to those in the ROB (20 min vs. 52 min) in winter, suggesting that the ROB participants may have been more delayed, perhaps due to lack of morning light exposure during work. This was not the case in summer months, as indicated by both within-subjects and between-subjects comparisons. Additional participants should be included in the ROB control group for any future studies.
- Sleep scores from self-reports were mixed. The average PSQI global score was 5.5 for the COB participants in winter and 5.1 in summer, suggesting that on average this group did not have sleep disturbances. (It should be noted, however, that 17 out of 41 COB winter participants had scores at or above 6, suggesting sleep disturbances, and 10 out of 27 COB summer participants had scores ≥ 6). Participants in the ROB had a score of 7.5 in winter (with 3 out of 5 participants reporting sleep disturbances) and 6.9 in the summer (with 5 out of 10 participants reporting sleep disturbances). The PROMIS Global Score suggests that, in winter, 5 out of 41 COB participants and 3 out of 5 ROB participants had moderate sleep disturbances (scores > 25 signify sleep disturbances). In summer, 2 out of 27 COB participants and 3 out of 10 ROB participants reported sleep disturbances. Participants in the ROB had almost significantly ($p = 0.09$ in winter and $p = 0.02$ in summer) higher scores (21.3 in winter and 20.0 in summer) than those in the COB (16.3 in winter and 16.1 in summer).
- Depression scores were low for all participants. Perceived stress was within the normal values (score of 12–15) as well as PANAs positive and PANAs negative. While the ROB participants seemed to report having a slightly higher perceived stress and slightly more negative mood, these differences were not statistically significant.
- KSS score (sleepiness) at waking was higher in those working in the ROB than in those working in the COB.

Some limitations of the data set include:

- The number of participants from the control building (ROB) was small, but the data clearly show that the amount of circadian light received by those working in the ROB is significantly lower in winter, but not in summer months. The effect of less circadian light exposures on sleep and mood cannot be clearly identified from these data, although the results are in the expected direction (i.e., poorer sleep and mood in those who receive less circadian light).
- 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 these other factors.
- Research questions that remain unanswered include whether (a) humans adapt to lower light levels of light for the circadian system and (b) a CS value of 0.15–0.2 may be sufficient to maintain entrainment. It also remains unknown whether an 8-hour exposure to this CS value is also sufficient for entrainment.

DISCUSSION

Daylight is a remarkably ideal light source for the circadian system. Thus, it is reasonable to pursue the hypothesis that daylight exposure might improve health and wellbeing through the circadian system, or, conversely, that a 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 those buildings, which will then aid our understanding of how occupant behavior or design modifications can affect personal light exposures at work. The present study is the first to obtain circadian light/dark and activity patterns in office workers in federal buildings.

Given that 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 provides measurements of circadian stimulation for building occupants. The fact that a person simply 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, participants in the COB are being exposed to CS values between 0.08 and 0.32 during the working day. During the summer, the CS values were higher, ranging from 0.15 to 0.39, except for two participants on Floor 2 who were exposed to a CS value below 0.1. In general, CS stimulus values for those working in this building are equal, if not higher than those measured from participants working at the other studied GSA sites. The pattern of light availability is not consistent with other buildings, where higher floors tend to receive higher CS values. During the winter months, Floor 7 had the lowest mean CS, but during the summer, it had the highest mean CS. The LRC's previous photometric measurements taken from other GSA facilities showed that daylight penetration in office spaces on a building's south facade was limited because workers drew the shades to avoid experiencing sunlight, resulting in lower overall CS exposures for those with deskspaces in the south facade compared to their colleagues in the north and west facades. This was particularly true in the Edith Green-Wendell Wyatt building in Portland, OR, where during summer months, for example, spectroradiometric measurements showed that the south facade had CS values of 0.29 compared to a value of 0.49 for the north facade. In the COB, this remained consistent, with participants on the south façade having the lowest CS values and the west façade having the highest for both winter and summer. (CS values ranged from 0.17 in the south façade to 0.24 in the west façade [winter] and 0.24 in the south façade to 0.34 in the west façade [summer].) The fact that the floor plan in this building is narrow and windows are available on both sides of each wing might also have contributed to this more uniform daylight availability in the space. Another possibility may be that the shading devices in the COB are automated (expect for Wings 0 and 3). Therefore, shades would only be drawn at times when there is sunlight penetration and not at all times, as occurs in buildings where the occupants control the shades.

Figure 4 shows the absolute sensitivity of the human circadian system plotted as a function of light level where the spectral power distribution of different light sources is weighted according to the Curve C (x-axis). The right ordinate (y-axis), labeled circadian stimulus (CS), is scaled to be proportional to the left ordinate representing the relative amount of melatonin suppressed after exposing the retina for one hour, ranging from 0.0 (no suppression) to a maximum of 0.7 (70% suppression).

Based on Figure 4, the threshold for circadian activation is close to 0.1 and the saturation is close to 0.7. A CS value of 0.3 is somewhat close to the half maximum saturation and should be a good value to stimulate the circadian system. 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 1 hour during the morning, circadian entrainment would be achieved; that is, a person would be in synchrony with the external light–dark cycle. In winter months, only 7 out of 41 participants in the COB were exposed to CS values above 0.25. In summer months, 13 out of 28 participants in the COB received a CS of 0.25 or greater. However, it is important to note that, with the exception of a few participants, the highest amount of light that participants received during winter was during working hours, which was not the case during the summer months. This was not the case with the participants in the ROB, where participants had slightly higher CS values before work hours during the winter, and 6 participants had slightly higher CS values before work hours (not above 0.25 CS), while only 3 had CS values above 0.25 while during work hours in the summer.

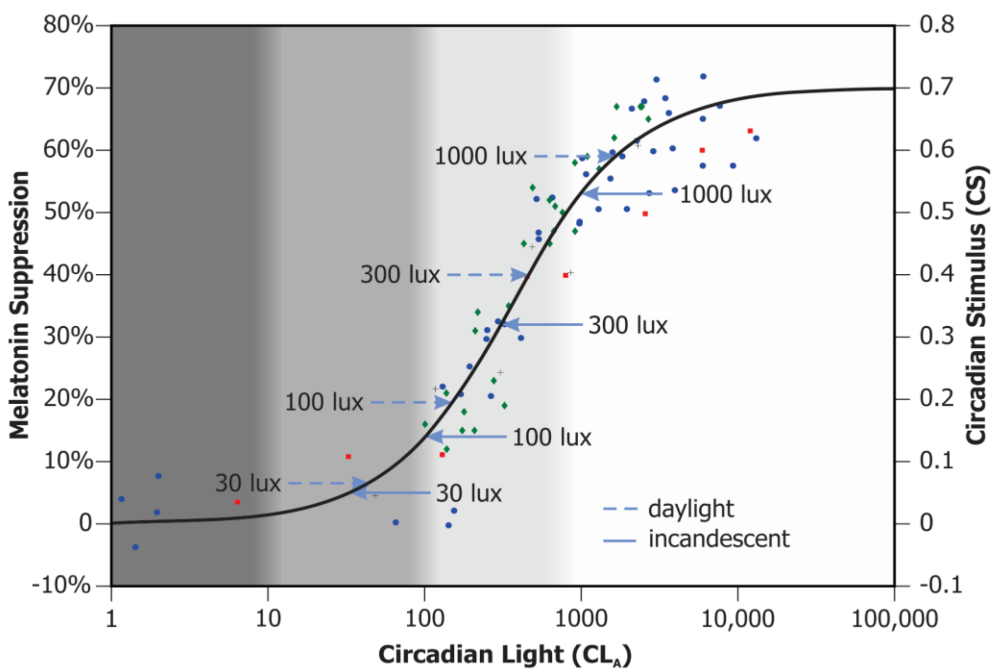

Figure 4. Absolute sensitivity of the human circadian system plotted as a function of light level where the spectral power distribution of different light sources is weighted according to the Curve C (x-axis). The right ordinate (y-axis), labeled circadian stimulus (CS), is scaled to be proportional to the left ordinate representing the relative amount of melatonin suppressed after exposing the retina for one hour, ranging from 0.0 (no suppression) to a maximum of 0.7 (70% suppression).

Objectively, not inconsistent with measurements in other federal buildings, most of the participants who participated in the study slept fewer than 8 hours per night and had lower sleep efficiency than one would expect from healthy individuals. Although there were few participants from the control building (ROB), where little daylight was available, participants in that group were exposed to significantly less circadian stimulus, had significantly greater sleep latency (perhaps suggesting a delayed circadian clock), and significantly greater self-reported sleep disturbances. Preliminary results from regression analyses (to be added) show that very low circadian stimulation during the working hours (below the threshold of 0.1) may be associated with sleep disturbances and mood disorders. Additional data from participants in the control group are needed to better understand this apparent relationship.

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Table 1. Washington, DC, Daysimeter results: statistical summary by floor, wing, orientation - Winter Months

		Location		Phasor			IS & IV		Post-work Sleep						
				days used	magnitude	angle (hours)	interdaily stability	intradaily variability	days used	actual sleep time (mins.)	actual sleep (%)	actual wake time (mins.)	actual wake (%)	sleep efficiency (%)	sleep onset latency (mins.)
Sort by Floor	COB	Floor G*	(n=1)	7	0.20	2.55	0.74	0.54	1	353	82%	76	18%	74%	9
		Floor 1*	(n=1)	7	0.27	3.38	0.55	0.71	2	328	93%	25	7%	81%	1
		Floor 2*	(n=16)	7	0.24	2.32	0.54	0.54	3	338	86%	57	14%	77%	16
		Floor 3*	(n=3)	7	0.23	0.97	0.55	0.54	2	314	85%	55	15%	77%	19
		Floor 4	(n=5)	6	0.30	1.26	0.69	0.44	2	431	83%	80	17%	77%	13
		Floor 5*	(n=10)	6	0.28	1.78	0.64	0.55	2	338	86%	56	14%	74%	30
		Floor 6	(n=2)	6	0.30	1.78	0.59	0.45	3	309	78%	83	22%	61%	25
		Floor 7	(n=3)	6	0.24	2.19	0.68	0.51	2	304	83%	57	17%	70%	25
	ROB all		(n=6)	7	0.22	1.94	0.62	0.57	2	334	89%	40	11%	72%	52
Sort by Wing	COB	Wing 0	(n=4)	7	0.17	1.82	0.57	0.62	3	313	82%	69	18%	72%	20
		Wing 1*	(n=6)	7	0.26	1.66	0.63	0.55	1	369	89%	49	11%	81%	26
		Wing 2*	(n=9)	6	0.26	1.86	0.57	0.52	3	344	85%	60	15%	72%	33
		Wing 3*	(n=4)	6	0.28	2.03	0.67	0.53	2	432	92%	30	8%	86%	5
		Wing 4*	(n=18)	7	0.28	2.10	0.59	0.50	3	325	83%	69	17%	73%	15
	ROB all		(n=6)	7	0.22	1.94	0.62	0.57	2	334	89%	40	11%	72%	52
Sort by Window Orientation	COB	North*	(n=10)	6	0.26	2.29	0.63	0.56	3	326	85%	59	15%	75%	19
		South*	(n=12)	7	0.25	1.65	0.53	0.50	2	324	82%	73	18%	72%	13
		East*	(n=13)	6	0.26	1.83	0.65	0.53	2	356	87%	52	13%	78%	28
		West*	(n=3)	5	0.28	2.01	0.67	0.60	2	417	89%	35	11%	78%	20
		Unknown*	(n=3)	5	0.29	2.45	0.49	0.46	4	358	84%	75	16%	75%	14
	ROB all		(n=6)	7	0.22	1.94	0.62	0.57	2	334	89%	40	11%	72%	52

*Contains data from a small number of devices that still require calibration.

		location		waking average					pre-work average**				
				days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean	days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean
Sort by Floor	COB	Floor G*	(n=1)	7	0.10	274	39	0.20	1	0.07	127	6	0.20
		Floor 1*	(n=1)	6	0.11	150	22	0.22	1	0.06	56	12	0.25
		Floor 2*	(n=16)	5	0.11	256	23	0.21	1	0.10	184	28	0.23
		Floor 3*	(n=3)	5	0.13	322	32	0.20	1	0.08	142	5	0.28
		Floor 4	(n=5)	4	0.16	436	68	0.23	1	0.13	172	37	0.26
		Floor 5*	(n=10)	5	0.15	777	29	0.21	1	0.13	405	31	0.22
		Floor 6	(n=2)	5	0.16	457	14	0.24	1	0.10	196	6	0.23
		Floor 7	(n=3)	4	0.12	342	18	0.18	1	0.07	93	10	0.18
	ROB all		(n=6)	5	0.13	392	20	0.21	1	0.13	626	36	0.23
Sort by Wing	COB	Wing 0	(n=4)	4	0.10	253	14	0.17	1	0.08	132	6	0.23
		Wing 1*	(n=6)	5	0.15	848	56	0.20	1	0.13	367	18	0.25
		Wing 2*	(n=9)	5	0.14	354	13	0.22	1	0.10	160	21	0.23
		Wing 3*	(n=4)	5	0.11	144	30	0.25	1	0.07	72	19	0.29
		Wing 4*	(n=18)	5	0.13	417	31	0.21	1	0.12	262	33	0.22
	ROB all		(n=6)	5	0.13	392	20	0.21	1	0.13	626	36	0.23
Sort by Window Orientation	COB	North*	(n=10)	5	0.14	494	32	0.19	1	0.12	355	34	0.22
		South*	(n=12)	5	0.12	325	27	0.23	1	0.08	118	17	0.25
		East*	(n=13)	5	0.14	524	34	0.20	1	0.13	273	28	0.22
		West*	(n=3)	5	0.13	171	23	0.27	1	0.05	55	7	0.30
		Unknown*	(n=3)	4	0.13	405	11	0.23	1	0.15	304	40	0.18
	ROB all		(n=6)	5	0.13	392	20	0.21	1	0.13	626	36	0.23

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

	location			work average**					post-work average**				
				days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean	days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean
Sort by Floor	COB	Floor G*	(n=1)	4	0.08	113	36	0.18	1	0.06	66	13	0.22
		Floor 1*	(n=1)	4	0.26	269	189	0.21	1	0.04	40	19	0.25
		Floor 2*	(n=16)	4	0.18	258	74	0.20	3	0.05	71	10	0.20
		Floor 3*	(n=3)	3	0.16	286	83	0.22	2	0.10	125	19	0.22
		Floor 4	(n=5)	2	0.23	425	172	0.24	2	0.08	118	21	0.25
		Floor 5*	(n=10)	4	0.20	461	128	0.19	2	0.07	212	18	0.20
		Floor 6	(n=2)	4	0.19	396	46	0.22	4	0.03	31	3	0.24
		Floor 7	(n=3)	2	0.16	516	63	0.19	2	0.08	93	9	0.20
	ROB all		(n=6)	2	0.13	191	48	0.19	2	0.06	85	13	0.23
Sort by Wing	COB	Wing 0	(n=4)	3	0.17	417	82	0.18	3	0.06	66	8	0.19
		Wing 1*	(n=6)	3	0.19	310	121	0.20	2	0.08	115	26	0.20
		Wing 2*	(n=9)	3	0.20	395	77	0.23	2	0.08	90	13	0.22
		Wing 3*	(n=4)	4	0.18	183	121	0.24	2	0.04	43	11	0.28
		Wing 4*	(n=18)	4	0.19	383	104	0.19	2	0.06	153	12	0.20
	ROB all		(n=6)	2	0.13	191	48	0.19	2	0.06	85	13	0.23
Sort by Window Orientation	COB	North*	(n=10)	3	0.20	502	122	0.18	2	0.07	241	15	0.19
		South*	(n=12)	4	0.17	281	85	0.21	3	0.05	56	8	0.22
		East*	(n=13)	3	0.18	319	93	0.20	2	0.08	101	21	0.21
		West*	(n=3)	3	0.25	251	177	0.25	3	0.08	75	11	0.30
		Unknown*	(n=3)	4	0.22	486	59	0.23	2	0.03	29	4	0.22
	ROB all		(n=6)	2	0.13	191	48	0.19	2	0.06	85	13	0.23

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

		location		total CES-D (winter)	PSQI (winter)	PSS-10 (winter)	sleep disturbance global score (winter)	sleep disturbance t-score (Winter)	sleep disturbance standard error (winter)	PANAS total positive (winter)	PANAS total negative (winter)
Sort by Floor	**COB**	Floor G	(n=1)	0.0	7.0	14.0	14.0	45.3	2.8	37.0	15.0
		Floor 1	(n=1)	13.0	11.0	19.0	21.0	53.4	2.6	31.0	16.0
		Floor 2	(n=16)	7.8	5.6	14.4	16.9	47.6	2.9	33.0	17.3
		Floor 3	(n=3)	9.0	5.7	14.7	14.0	45.1	2.8	25.7	13.0
		Floor 4	(n=5)	5.3	7.5	15.8	19.5	48.9	3.2	30.0	16.0
		Floor 5	(n=10)	5.4	5.1	12.3	14.3	44.5	5.3	35.6	13.8
		Floor 6	(n=2)	5.5	4.5	10.0	18.0	50.2	2.6	33.0	14.5
		Floor 7	(n=3)	2.5	6.0	7.7	18.3	48.1	3.1	30.3	12.0
	ROB all		(n=6)	7.2	7.8	14.2	21.3	53.1	2.7	30.8	17.0
Sort by Wing	**COB**	Wing 0	(n=4)	10.0	7.6	17.0	16.6	47.0	2.9	20.6	14.4
		Wing 1	(n=6)	6.0	4.5	10.3	12.3	40.1	3.6	33.0	13.0
		Wing 2	(n=9)	11.0	6.3	15.9	20.1	51.8	5.2	31.1	19.4
		Wing 3	(n=4)	5.8	6.0	17.0	14.5	45.4	2.9	34.0	14.5
		Wing 4	(n=18)	4.6	5.3	11.1	16.0	46.6	3.0	36.4	14.2
	ROB all		(n=6)	7.2	7.8	14.2	21.3	53.1	2.7	30.8	17.0
Sort by Window Orientation	**COB**	North	(n=10)	6.6	5.3	12.0	14.7	44.9	3.0	34.5	14.9
		South	(n=12)	5.7	5.9	14.2	17.7	49.2	2.7	32.0	15.2
		East	(n=13)	7.3	5.9	14.2	17.0	47.2	5.1	31.9	15.3
		West	(n=3)	6.7	6.3	15.3	16.0	47.5	2.8	33.7	14.0
		Unknown	(n=3)	8.5	6.3	11.5	16.8	46.1	3.2	30.5	18.0
	ROB all		(n=6)	7.2	7.8	14.2	21.3	53.1	2.7	30.8	17.0

Table 2. Washington, DC, Daysimeter results: statistical summary by building - Winter Months

	location	Phasor		IS & IV		Post-work Sleep					
		magnitude	angle (hours)	interdaily stability	intradaily variability	actual sleep time (mins.)	actual sleep (%)	actual wake time (mins.)	actual wake (%)	sleep efficiency (%)	sleep onset latency (mins.)
All	mean	0.26	2.05	0.60	0.53	343	86%	58	14%	75%	23
	std dev	0.07	1.09	0.14	0.10	73	8%	36	8%	12%	29
	median	0.27	2.07	0.62	0.52	338	88%	52	12%	76%	17
COB	mean	0.27	2.07	0.60	0.53	344	85%	61	15%	75%	20
	std dev	0.06	1.06	0.14	0.09	76	9%	37	9%	12%	24
	median	0.27	2.09	0.62	0.51	340	87%	58	13%	78%	15
ROB	mean	0.22	1.94	0.62	0.57	334	89%	40	11%	72%	52
	std dev	0.06	1.31	0.16	0.13	40	4%	10	4%	8%	52
	median	0.22	2.07	0.61	0.56	322	90%	39	10%	75%	38
	p value	0.11	0.80	0.78	0.33	0.79	0.28	0.23	0.28	0.63	0.02

	location	waking average				pre-work average**			
		CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean
All*	mean	0.13	427	30	0.21	0.12	308	26	0.24
	std dev	0.05	545	40	0.05	0.07	396	29	0.08
	median	0.12	226	27	0.20	0.10	142	13	0.21
COB*	mean	0.13	435	32	0.21	0.11	249	25	0.24
	std dev	0.05	593	43	0.06	0.07	361	30	0.09
	median	0.12	226	29	0.20	0.09	125	12	0.21
ROB	mean	0.13	392	20	0.21	0.13	626	36	0.23
	std dev	0.07	249	25	0.03	0.05	465	21	0.04
	median	0.11	287	17	0.20	0.13	399	34	0.22
	p value	1.00	0.87	0.53	0.77	0.52	**0.05**	0.44	0.77

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

	location	work average**				post-work average**			
		CS ari-mean	**illuminance ari-mean**	**illuminance geo-mean**	**activity ari-mean**	**CS ari-mean**	**illuminance ari-mean**	**illuminance geo-mean**	**activity ari-mean**
All*	mean	0.18	322	99	0.20	0.06	91	13	0.22
	std dev	0.07	331	69	0.07	0.05	120	14	0.06
	median	0.18	265	92	0.19	0.04	35	8	0.21
COB*	mean	0.19	347	109	0.20	0.06	92	12	0.22
	std dev	0.07	352	70	0.07	0.04	120	14	0.07
	median	0.20	266	103	0.19	0.04	35	9	0.20
ROB	mean	0.13	191	48	0.19	0.06	85	13	0.23
	std dev	0.04	146	21	0.03	0.08	130	15	0.04
	median	0.11	92	41	0.17	0.03	34	8	0.22
	p value	**0.05**	0.34	0.07	0.58	0.82	0.91	0.94	0.70

	location	total CES-D (winter)	PSQI (winter)	PSS-10 (winter)	sleep disturbance global score (winter)	sleep disturbance t-score (winter)	sleep disturbance standard error (winter)	PANAS total positive (winter)	PANAS total negative (winter)
All	mean	6.8	6.0	13.5	17.1	47.8	2.9	32.4	15.5
	std dev	5.5	2.6	6.3	6.5	8.4	0.6	8.2	5.4
	median	5.0	5.0	13.0	15.5	47.3	2.7	33.0	15.0
COB	mean	6.9	5.9	13.9	16.3	47.1	3.3	33.3	15.7
	std dev	5.3	2.3	6.2	5.9	7.6	3.1	7.4	5.3
	median	5.5	5.0	14.0	14.0	45.3	2.8	34.0	15.0
ROB	mean	7.2	7.8	14.2	21.3	53.1	2.7	30.8	17.0
	std dev	5.2	3.6	5.5	7.4	7.9	0.2	8.0	4.6
	median	9.0	9.0	15.0	21.5	53.7	2.6	30.0	16.0
	p value	0.86	0.10	0.78	**0.09**	0.10	0.26	0.64	0.52

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

Table 3. Washington, DC, Daysimeter results: statistical summary by floor, wing, orientation - Summer Months

		Location		Phasor			IS & IV		Post-work Sleep						
				days used	magnitude	angle (hours)	interdaily stability	intradaily variability	days used	actual sleep time (mins.)	actual sleep (%)	actual wake time (mins.)	actual wake (%)	sleep efficiency (%)	sleep onset latency (mins.)
Sort by Floor	COB	Floor 1*	(n=1)	6	0.27	1.19	0.54	0.84	1	361	90%	40	10%	83%	10
		Floor 2*	(n=13)	6	0.24	1.01	0.52	0.57	3	347	87%	53	13%	78%	18
		Floor 3*	(n=2)	6	0.20	0.84	0.58	0.53	1	330	85%	66	15%	79%	7
		Floor 4	(n=4)	6	0.26	-0.23	0.69	0.49	2	338	87%	49	13%	79%	22
		Floor 5	(n=6)	7	0.29	1.44	0.72	0.52	3	322	85%	59	15%	76%	15
		Floor 6	(n=1)	6	0.31	0.56	0.70	0.44	3	398	85%	65	15%	79%	0
		Floor 7	(n=1)	6	0.30	0.89	0.64	0.43	1	339	84%	65	16%	74%	1
	ROB all		(n=10)	6	0.26	1.10	0.57	0.54	2	334	87%	49	13%	76%	15
Sort by Wing	COB	Wing 0	(n=2)	5	0.18	0.30	0.67	0.74	5	291	81%	68	19%	70%	21
		Wing 1*	(n=4)	7	0.24	0.58	0.64	0.47	2	282	83%	57	17%	73%	29
		Wing 2*	(n=5)	6	0.29	1.12	0.50	0.51	2	342	83%	68	17%	73%	19
		Wing 3*	(n=4)	5	0.26	0.39	0.61	0.60	3	410	95%	19	5%	91%	7
		Wing 4*	(n=12)	7	0.27	1.15	0.62	0.52	3	343	87%	55	13%	79%	13
		Unknown*	(n=1)	6	0.22	1.29	0.58	0.63	1	377	78%	105	22%	74%	0
	ROB all		(n=10)	6	0.26	1.10	0.57	0.54	2	334	87%	49	13%	76%	15
Sort by Window Orientation	COB	North*	(n=7)	6	0.27	1.38	0.64	0.62	3	326	84%	63	16%	74%	18
		South*	(n=10)	7	0.25	0.66	0.55	0.55	3	352	87%	51	13%	81%	10
		East*	(n=5)	6	0.25	0.97	0.56	0.48	2	337	88%	47	12%	79%	13
		West*	(n=5)	6	0.28	0.54	0.69	0.46	2	337	86%	50	14%	77%	30
		Unknown*	(n=1)	6	0.22	1.29	0.58	0.63	1	377	78%	105	22%	74%	0
	ROB all		(n=10)	6	0.26	1.10	0.57	0.54	2	334	87%	49	13%	76%	15

		location		waking average					pre-work average				
				days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean**	activity ari-mean	days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean**	activity ari-mean
Sort by Floor	COB	Floor 1*	(n=1)	4	0.16	292	45	0.21	1	0.04	54	2	0.11
		Floor 2*	(n=13)	4	0.22	1094	89	0.21	3	0.25	1612	119	0.23
		Floor 3*	(n=2)	6	0.15	773	23	0.21	1	0.14	532	27	0.20
		Floor 4	(n=4)	4	0.24	1002	103	0.26	2	0.27	2699	181	0.30
		Floor 5	(n=1)	5	0.22	1153	74	0.22	4	0.22	1148	95	0.26
		Floor 6	(n=1)	4	0.23	1392	92	0.22	3	0.27	4009	155	0.25
		Floor 7	(n=1)	4	0.22	948	75	0.22	2	0.17	302	35	0.19
		ROB all	(n=10)	4	0.21	1046	97	0.26	1	0.25	1001	115	0.28
Sort by Wing	COB	Wing 0	(n=2)	4	0.20	874	20	0.16	2	0.22	602	42	0.17
		Wing 1*	(n=4)	5	0.22	888	90	0.20	2	0.22	1719	190	0.22
		Wing 2*	(n=5)	4	0.23	1334	108	0.21	2	0.27	1729	188	0.22
		Wing 3*	(n=4)	3	0.21	991	116	0.28	3	0.20	2070	66	0.33
		Wing 4*	(n=12)	4	0.22	1071	70	0.22	4	0.23	1503	83	0.23
		Unknown*	(n=1)	6	0.14	537	26	0.22	1	0.24	1020	46	0.17
		ROB all	(n=10)	4	0.21	1046	97	0.26	1	0.25	1001	115	0.28
Sort by Window Orientation	COB	North*	(n=7)	4	0.23	1177	90	0.21	3	0.23	1265	101	0.23
		South*	(n=12)	4	0.21	941	61	0.21	3	0.21	1228	54	0.22
		East*	(n=6)	4	0.20	882	82	0.20	3	0.21	1389	128	0.22
		West*	(n=6)	4	0.23	1347	118	0.27	2	0.29	2994	230	0.31
		Unknown*	(n=1)	4	0.14	537	26	0.22	1	0.24	1020	46	0.17
		ROB all	(n=10)	4	0.21	1046	97	0.26	1	0.25	1001	115	0.28

		location		work average					post-work average				
				days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean**	activity ari-mean	days used	CS ari-mean	illuminance ari-mean	illuminance geo-mean**	activity ari-mean
Sort by Floor	COB	Floor 1*	(n=1)	3	0.22	463	131	0.22	1	0.03	39	3	0.19
		Floor 2*	(n=13)	4	0.24	776	192	0.18	3	0.18	1195	65	0.22
		Floor 3*	(n=2)	3	0.17	497	101	0.20	1	0.16	1246	2	0.18
		Floor 4	(n=4)	4	0.27	994	214	0.25	2	0.22	817	96	0.28
		Floor 5	(n=1)	4	0.28	910	233	0.21	3	0.14	681	21	0.22
		Floor 6	(n=1)	5	0.25	962	160	0.20	2	0.14	647	24	0.21
		Floor 7	(n=1)	3	0.31	650	272	0.24	1	0.10	569	21	0.17
		ROB all	(n=10)	3	0.21	569	167	0.22	3	0.13	533	40	0.28
Sort by Wing	COB	Wing 0	(n=2)	6	0.16	742	21	0.15	2	0.19	680	55	0.17
		Wing 1*	(n=4)	3	0.27	696	267	0.19	2	0.19	1343	32	0.21
		Wing 2*	(n=5)	4	0.29	992	281	0.20	2	0.18	926	63	0.20
		Wing 3*	(n=4)	4	0.21	742	147	0.27	3	0.15	1060	74	0.29
		Wing 4*	(n=12)	4	0.26	840	194	0.20	3	0.17	906	46	0.23
		Unknown*	(n=1)	2	0.16	307	81	0.19	1	0.07	161	4	0.17
		ROB all	(n=10)	3	0.21	569	167	0.22	3	0.13	533	40	0.28
Sort by Window Orientation	COB	North*	(n=7)	4	0.26	919	261	0.18	3	0.16	615	31	0.22
		South*	(n=12)	4	0.24	711	115	0.20	2	0.17	1200	60	0.22
		East*	(n=6)	4	0.25	700	208	0.20	2	0.17	1030	42	0.20
		West*	(n=6)	3	0.27	1047	281	0.25	2	0.20	1002	76	0.28
		Unknown*	(n=1)	2	0.16	307	81	0.19	1	0.07	161	4	0.17
		ROB all	(n=10)	3	0.21	569	167	0.22	3	0.13	533	40	0.28

	location			total CES-D (summer)	PSQI (summer)	PSS-10 (summer)	sleep disturbance global score (summer)	sleep disturbance t-score (summer)	sleep disturbance standard error (summer)	PANAS total positive (summer)	PANAS total negative (summer)
Sort by Floor	COB	Floor 1*	(n=1)	12.0	9.0	16.0	21.0	53.4	2.6	30.0	18.0
		Floor 2*	(n=13)	6.1	4.6	14.1	16.9	45.2	3.0	34.2	16.5
		Floor 3*	(n=2)	3.5	5.5	7.5	16.0	47.8	2.7	34.5	11.0
		Floor 4	(n=4)	8.3	5.0	16.3	15.0	44.1	3.2	33.0	17.0
		Floor 5	(n=1)	2.2	4.7	8.3	14.7	44.4	3.2	38.2	13.0
		Floor 6	(n=1)	4.0	5.0	14.0	13.0	43.9	2.9	34.0	11.0
		Floor 7	(n=1)	3.0	6.0	9.0	8.0	30.5	4.9	42.0	14.0
	ROB all		(n=10)	6.9	6.9	12.3	20.0	51.8	2.7	33.4	14.5
Sort by Wing	COB	Wing 0	(n=2)	12.0	9.0	22.0	28.5	60.6	2.6	19.0	20.5
		Wing 1*	(n=4)	4.8	4.3	9.8	10.8	39.1	3.3	35.0	13.8
		Wing 2*	(n=5)	8.4	5.8	17.4	13.0	42.5	3.2	37.0	19.2
		Wing 3*	(n=4)	6.5	5.0	14.8	14.8	45.5	2.9	34.0	16.5
		Wing 4*	(n=12)	2.8	4.2	9.6	16.7	44.3	3.1	37.7	13.2
		Unknown*	(n=1)	6.0	5.0	8.0	18.0	50.2	2.6	30.0	10.0
	ROB all		(n=10)	6.9	6.9	12.3	20.0	51.8	2.7	33.4	14.5
Sort by Window Orientation	COB	North*	(n=7)	4.0	4.3	10.4	20.6	46.3	3.2	35.1	14.9
		South*	(n=12)	6.1	6.0	14.0	16.4	47.5	2.8	35.2	15.5
		East*	(n=6)	5.4	5.0	12.0	11.4	39.9	3.4	33.4	15.6
		West*	(n=6)	5.8	3.8	14.2	11.8	41.0	3.2	37.2	15.8
		Unknown*	(n=1)	6.0	5.0	8.0	18.0	50.2	2.6	30.0	10.0
	ROB all		(n=10)	6.9	6.9	12.3	20.0	51.8	2.7	33.4	14.5

Table 4. Washington, DC, Daysimeter results: statistical summary by building - Summer Months

		Phasor		IS & IV		Post-work Sleep					
	location	magnitude	angle (hours)	interdaily stability	intradaily variability	actual sleep time (mins.)	actual sleep (%)	actual wake time (mins.)	actual wake (%)	sleep efficiency (%)	sleep onset latency (mins.)
All	mean	0.25	0.99	0.58	0.56	339	86%	55	14%	77%	16
	std dev	0.07	0.84	0.16	0.17	54	7%	30	7%	10%	16
	median	0.26	1.10	0.61	0.52	335	85%	56	15%	78%	13
COB	mean	0.26	0.90	0.60	0.55	342	86%	57	14%	78%	15
	std dev	0.07	0.88	0.14	0.14	53.4	8%	33	8%	10%	18
	median	0.26	0.95	0.62	0.53	337	85%	57	15%	79%	12
ROB	mean	0.24	1.44	0.53	0.58	332	87%	50	13%	75%	16
	std dev	0.05	0.40	0.18	0.22	61	6%	25	6%	9%	11
	median	0.26	1.40	0.57	0.48	306	89%	45	11%	75%	14
	p value	0.68	0.15	0.22	0.59	0.63	0.58	0.54	0.58	0.60	0.97

		waking average				pre-work average**			
	location	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean
All*	mean	0.21	990	81	0.22	0.23	1481	113	0.24
	std dev	0.05	463	74	0.06	0.09	1202	117	0.09
	median	0.21	862	70	0.22	0.24	1113	86	0.23
COB*	mean	0.21	1047	81	0.22	0.23	1574	110	0.24
	std dev	0.06	484	79	0.06	0.09	1281	126	0.10
	median	0.22	976	60	0.22	0.23	1286	84	0.23
ROB	mean	0.18	724	80	0.23	0.26	1045	125	0.24
	std dev	0.04	210	46	0.04	0.06	632	59	0.03
	median	0.19	735	76	0.22	0.27	896	105	0.25
	p value	0.21	0.12	0.97	0.53	0.52	0.34	0.79	0.93

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

location		work average**				post-work average**			
		CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean	CS ari-mean	illuminance ari-mean	illuminance geo-mean	activity ari-mean
All*	mean	0.24	717	183	0.20	0.16	896	49	0.23
	std dev	0.09	504	145	0.06	0.07	775	61	0.06
	median	0.22	569	138	0.19	0.17	735	33	0.22
COB*	mean	0.25	807	197	0.20	0.17	951	51	0.22
	std dev	0.08	511	151	0.06	0.08	826	66	0.07
	median	0.24	634	154	0.19	0.17	735	33	0.22
ROB	mean	0.18	298	121	0.20	0.13	639	40	0.25
	std dev	0.10	112	97	0.03	0.05	430	37	0.04
	median	0.17	339	100	0.20	0.14	687	28	0.25
	p value	0.09	**0.02**	0.25	0.85	0.21	0.38	0.70	0.30

location		total CES-D (summer)	PSQI (summer)	PSS-10 (summer)	sleep disturbance global score (summer)	sleep disturbance t-score (summer)	sleep disturbance standard error (summer)	PANAS total positive (summer)	PANAS total negative (summer)
All	mean	5.9	5.6	12.6	16.2	46.8	2.9	34.4	15.2
	std dev	5.0	2.8	6.4	6.2	8.0	0.6	7.9	4.6
	median	4.0	5.0	11.0	14.0	45.3	2.8	37.0	14.0
COB	mean	5.4	5.1	12.3	16.1	45.5	3.0	34.9	14.8
	std dev	4.9	2.2	6.0	7.3	7.2	0.6	7.2	4.6
	median	4.0	5.0	10.0	14.0	45.3	2.8	37.0	14.0
ROB	mean	6.9	6.9	12.3	20.0	51.8	2.7	33.4	14.5
	std dev	5.2	3.6	6.5	6.7	7.2	0.2	8.9	4.7
	median	7.0	6.5	11.0	19.0	51.3	2.6	35.5	13.0
	p value	0.51	0.07	0.84	**0.02**	0.02	0.09	0.64	0.60

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

Table 5. Washington, DC, Daysimeter results: statistical summary by floor, wing, orientation - Combined

Location				Phasor: days used		Phasor: magnitude		Phasor: angle (hours)		IS & IV: interdaily stability		IS & IV: intradaily variability	
				Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Sort by Floor	COB	Floor 1*	(n=1)	6	7	0.27	0.27	1.19	3.38	0.54	0.55	0.84	0.71
		Floor 2*	(n=13)	6	7	0.24	0.26	1.01	2.17	0.52	0.58	0.57	0.54
		Floor 3*	(n=1)	6	7	0.18	0.21	0.40	1.84	0.58	0.67	0.44	0.51
		Floor 4*	(n=3)	5	5	0.30	0.32	-0.59	0.91	0.72	0.77	0.51	0.46
		Floor 5*	(n=6)	7	7	0.29	0.29	1.44	1.96	0.72	0.64	0.52	0.56
		Floor 6*	(n=1)	6	6	0.31	0.25	0.56	1.66	0.70	0.47	0.44	0.44
		Floor 7	(n=1)	6	7	0.30	0.28	0.89	1.94	0.64	0.65	0.43	0.44
		Multiple*	(n=2)	6	7	0.18	0.19	1.06	3.24	0.60	0.54	0.53	0.65
	ROB all*		(n=6)	6	7	0.24	0.22	1.44	1.94	0.54	0.62	0.49	0.57
Sort by Wing	COB	Wing 0	(n=2)	5	7	0.18	0.17	0.30	2.34	0.67	0.58	0.74	0.61
		Wing 1*	(n=4)	7	7	0.24	0.27	0.58	1.50	0.67	0.63	0.49	0.57
		Wing 2*	(n=5)	6	6	0.29	0.28	1.12	2.06	0.50	0.58	0.51	0.56
		Wing 3*	(n=4)	5	6	0.26	0.28	0.39	2.03	0.60	0.67	0.57	0.53
		Wing 4*	(n=12)	7	7	0.27	0.27	1.15	2.12	0.62	0.59	0.52	0.51
		Multiple*	(n=1)	6	8	0.22	0.22	1.29	3.44	0.58	0.71	0.63	0.63
	ROB all*		(n=6)	6	7	0.24	0.22	1.44	1.94	0.54	0.62	0.49	0.57
Sort by Window Orientation	COB	North*	(n=7)	6	7	0.27	0.25	1.38	2.32	0.64	0.60	0.62	0.55
		South*	(n=9)	7	6	0.25	0.27	0.61	1.80	0.55	0.56	0.52	0.50
		East*	(n=5)	6	7	0.25	0.27	0.97	2.16	0.56	0.65	0.48	0.55
		West*	(n=2)	5	5	0.34	0.29	0.45	1.32	0.78	0.73	0.38	0.54
		Multiple*	(n=5)	6	7	0.24	0.25	0.85	2.40	0.60	0.61	0.60	0.60
	ROB all*		(n=6)	6	7	0.24	0.22	1.44	1.94	0.54	0.62	0.49	0.57

*Contains data from a small number of devices that still require calibration.

Location				Post-work Sleep													
				days used		actual sleep time (mins.)		actual sleep (%)		actual wake time (mins.)		actual wake (%)		sleep efficiency (%)		Sleep onset latency (mins.)	
				Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Sort by Floor	COB	Floor 1*	(n=1)	2	3	361	328	90%	93%	40	25	10%	7%	83%	81%	10	1
		Floor 2*	(n=13)	3	3	347	332	87%	85%	53	59	13%	15%	78%	77%	18	15
		Floor 3*	(n=1)	3	3	284	316	91%	96%	27	14	9%	4%	84%	90%	14	1
		Floor 4*	(n=3)	3	1	342	455	88%	84%	44	72	12%	16%	79%	77%	26	16
		Floor 5*	(n=6)	3	3	322	308	85%	84%	59	62	15%	16%	76%	71%	15	25
		Floor 6*	(n=1)	3	3	398	262	85%	73%	65	96	15%	27%	79%	55%	0	27
		Floor 7	(n=1)	1	3	339	387	84%	93%	65	28	16%	7%	74%	85%	1	26
		Multiple*	(n=2)	1	1	351	370	81%	89%	85	54	19%	11%	77%	84%	5	11
	ROB all		(n=6)	3	2	324	334	87%	89%	52	40	13%	11%	76%	72%	14	52
Sort by Wing	COB	Wing 0	(n=2)	5	4	291	326	81%	77%	68	99	19%	23%	70%	69%	21	10
		Wing 1*	(n=4)	2	2	281	309	81%	90%	68	38	19%	10%	69%	78%	34	43
		Wing 2*	(n=5)	3	3	342	334	83%	86%	68	51	17%	14%	73%	74%	19	27
		Wing 3*	(n=4)	3	3	385	409	95%	93%	21	27	5%	7%	89%	86%	8	4
		Wing 4*	(n=12)	3	3	343	318	87%	83%	55	69	13%	17%	79%	73%	13	14
		Multiple*	(n=1)	1	1	377	455	78%	83%	105	95	22%	17%	74%	82%	0	0
	ROB all		(n=6)	3	2	324	334	87%	89%	52	40	13%	11%	76%	72%	14	52
Sort by Window Orientation	COB	North*	(n=7)	3	3	326	342	84%	85%	63	62	16%	15%	74%	77%	18	16
		South*	(n=9)	3	3	351	314	87%	81%	53	77	13%	19%	81%	70%	10	12
		East*	(n=5)	3	4	337	340	88%	92%	47	29	12%	8%	79%	83%	13	21
		West*	(n=2)	2	2	359	461	88%	87%	41	40	12%	13%	79%	76%	32	29
		Multiple*	(n=5)	2	1	341	348	85%	88%	63	55	15%	12%	77%	79%	19	18
	ROB all		(n=6)	3	2	324	334	87%	89%	52	40	13%	11%	76%	72%	14	52

Location				Waking Average									
				days used		CS ari-mean		illuminance ari-mean		illuminance geo-mean**		activity ari-mean	
				Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Sort by Floor	COB	Floor 1*	(n=1)	4	6	0.16	0.11	292	150	45	39	0.21	0.22
		Floor 2*	(n=13)	4	5	0.22	0.12	1094	286	89	25	0.21	0.21
		Floor 3*	(n=1)	6	5	0.17	0.10	1009	257	19	0	0.20	0.20
		Floor 4*	(n=3)	4	4	0.27	0.18	1055	387	137	88	0.28	0.26
		Floor 5*	(n=6)	5	6	0.22	0.14	1153	594	74	33	0.22	0.20
		Floor 6*	(n=1)	4	5	0.23	0.14	1392	241	92	29	0.22	0.22
		Floor 7	(n=1)	4	5	0.22	0.09	948	137	75	23	0.22	0.19
		Multiple*	(n=2)	5	5	0.16	0.10	690	1476	13	13	0.21	0.21
	ROB all*		(n=6)	5	5	0.18	0.13	724	392	80	20	0.23	0.21
Sort by Wing	COB	Wing 0	(n=2)	4	4	0.20	0.07	874	165	20	5	0.16	0.17
		Wing 1*	(n=4)	5	5	0.22	0.16	888	383	90	74	0.20	0.21
		Wing 2*	(n=5)	4	5	0.23	0.13	1334	358	108	19	0.21	0.23
		Wing 3*	(n=4)	3	5	0.21	0.11	991	144	116	30	0.28	0.25
		Wing 4*	(n=12)	4	5	0.22	0.14	1071	425	70	31	0.22	0.20
		Multiple*	(n=1)	6	5	0.14	0.11	537	2850	26	0	0.22	0.19
	ROB all*		(n=6)	5	5	0.18	0.13	724	392	80	20	0.23	0.21
Sort by Window Orientation	COB	North*	(n=7)	4	5	0.23	0.14	1177	525	90	25	0.21	0.19
		South*	(n=9)	4	5	0.22	0.12	1013	339	63	30	0.21	0.22
		East*	(n=5)	4	5	0.20	0.11	882	209	82	15	0.20	0.19
		West*	(n=2)	3	4	0.26	0.14	1884	182	181	15	0.35	0.29
		Multiple*	(n=5)	5	5	0.18	0.15	759	807	60	68	0.21	0.21
	ROB all*		(n=6)	5	5	0.18	0.13	724	392	80	20	0.23	0.21

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

Location				Pre-work Average**									
				days used		CS ari-mean		illuminance ari-mean		illuminance geo-mean**		activity ari-mean	
				Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Sort by Floor	COB	Floor 1*	(n=1)	3	4	0.04	0.06	54	56	2	12	0.11	0.25
		Floor 2*	(n=13)	5	1	0.25	0.11	1612	163	119	29	0.23	0.22
		Floor 3*	(n=1)	1	1	0.04	0.09	44	96	9	0	0.23	0.23
		Floor 4*	(n=3)	1	1	0.30	0.12	2687	150	242	20	0.33	0.32
		Floor 5*	(n=6)	4	3	0.22	0.11	1148	325	95	28	0.26	0.24
		Floor 6*	(n=1)	5	4	0.27	0.08	4009	242	155	12	0.25	0.24
		Floor 7	(n=1)	2	3	0.17	0.11	302	148	35	13	0.19	0.21
		Multiple*	(n=2)	3	3	0.22	0.20	1878	910	23	19	0.18	0.28
	ROB all*		(n=6)	4	3	0.26	0.13	1045	626	125	36	0.24	0.23
Sort by Wing	COB	Wing 0	(n=2)	4	3	0.22	0.06	602	122	42	6	0.17	0.17
		Wing 1*	(n=4)	3	4	0.22	0.13	1719	192	190	27	0.22	0.26
		Wing 2*	(n=5)	2	3	0.27	0.07	1730	81	188	4	0.22	0.26
		Wing 3*	(n=4)	5	5	0.20	0.07	2071	72	66	19	0.33	0.29
		Wing 4*	(n=12)	4	3	0.23	0.13	1503	306	83	39	0.23	0.23
		Multiple*	(n=1)	3	3	0.24	0.24	1020	1421	46	0	0.17	0.21
	ROB all*		(n=6)	4	3	0.26	0.13	1045	626	125	36	0.24	0.23
Sort by Window Orientation	COB	North*	(n=7)	4	3	0.23	0.15	1265	426	101	44	0.23	0.23
		South*	(n=9)	4	3	0.22	0.08	1359	112	60	20	0.24	0.24
		East*	(n=5)	4	4	0.21	0.10	1389	108	128	16	0.22	0.21
		West*	(n=2)	2	2	0.29	0.05	2841	54	189	4	0.43	0.33
		Multiple*	(n=5)	3	3	0.23	0.17	2072	519	164	21	0.19	0.27
	ROB all*		(n=6)	4	3	0.26	0.13	1045	626	125	36	0.24	0.23

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

		Location		Work Average: days used Summer	days used Winter	CS ari-mean Summer	CS ari-mean Winter	illuminance ari-mean Summer	illuminance ari-mean Winter	illuminance geo-mean** Summer	illuminance geo-mean** Winter	activity ari-mean Summer	activity ari-mean Winter
Sort by Floor	COB	Floor 1*	(n=1)	3	4	0.22	0.26	463	269	131	189	0.22	0.21
		Floor 2*	(n=13)	4	4	0.24	0.18	776	265	192	82	0.18	0.20
		Floor 3*	(n=1)	4	4	0.17	0.14	687	153	123	92	0.20	0.20
		Floor 4*	(n=3)	5	2	0.29	0.25	1124	440	237	203	0.27	0.27
		Floor 5*	(n=6)	4	4	0.28	0.21	910	594	233	131	0.21	0.19
		Floor 6*	(n=1)	5	3	0.25	0.17	962	198	91	154	0.20	0.18
		Floor 7	(n=1)	3	4	0.31	0.12	650	98	272	45	0.24	0.21
		Multiple*	(n=2)	3	4	0.19	0.14	455	253	113	61	.019	0.20
	ROB all*		(n=6)	4	3	0.22	0.26	463	269	189	110	0.20	0.19
Sort by Wing	COB	Wing 0	(n=2)	6	4	0.16	0.14	742	419	21	72	0.15	0.16
		Wing 1*	(n=4)	3	3	0.27	0.23	696	305	267	163	0.19	0.20
		Wing 2*	(n=5)	4	3	0.29	0.22	992	327	281	78	0.20	0.25
		Wing 3*	(n=4)	4	4	0.21	0.18	742	183	147	121	0.27	0.24
		Wing 4*	(n=12)	4	4	0.26	0.19	840	420	194	113	0.20	0.18
		Multiple*	(n=1)	2	4	0.16	0.09	307	296	81	0	0.19	0.19
	ROB all*		(n=6)	4	3	0.22	0.26	463	269	189	110	0.20	0.19
Sort by Window Orientation	COB	North*	(n=7)	4	4	0.26	0.20	919	575	261	123	0.18	0.19
		South*	(n=9)	5	4	0.24	0.17	739	309	114	93	0.20	0.20
		East*	(n=5)	4	4	0.25	0.18	700	230	208	57	0.20	0.19
		West*	(n=2)	3	2	0.34	0.24	1836	242	385	171	0.33	0.28
		Multiple*	(n=5)	3	3	0.21	0.22	467	289	170	159	0.20	0.21
	ROB all*		(n=6)	4	3	0.22	0.26	463	269	189	110	0.20	0.19

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

Location				Post-work Average									
				days used		CS ari-mean		illuminance ari-mean		illuminance geo-mean**		activity ari-mean	
				Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Sort by Floor	COB	Floor 1*	(n=1)	2	2	0.03	0.04	39	40	3	19	0.19	0.25
		Floor 2*	(n=13)	3	4	0.18	0.06	1195	85	65	10	0.22	0.20
		Floor 3*	(n=1)	3	3	0.25	0.10	2331	152	0	17	0.19	0.22
		Floor 4*	(n=3)	4	2	0.25	0.10	1046	157	128	26	0.29	0.30
		Floor 5*	(n=6)	3	3	0.14	0.05	681	119	21	13	0.22	0.20
		Floor 6*	(n=1)	4	3	0.14	0.03	647	25	24	6	0.21	0.21
		Floor 7	(n=1)	1	3	0.10	0.03	569	29	21	12	0.17	0.19
		Multiple*	(n=2)	2	2	0.10	0.02	147	16	2	6	0.20	0.19
	ROB all*		(n=6)	4	2	0.13	0.06	639	85	40	13	0.25	0.23
Sort by Wing	COB	Wing 0	(n=2)	4	4	0.19	0.04	680	57	4	57	0.17	0.19
		Wing 1*	(n=4)	2	3	0.19	0.11	1343	151	35	39	0.21	0.22
		Wing 2*	(n=5)	2	3	0.18	0.06	926	65	7	64	0.20	0.24
		Wing 3*	(n=4)	4	5	0.15	0.04	1060	43	11	76	0.29	0.28
		Wing 4*	(n=12)	3	3	0.17	0.05	906	110	10	58	0.23	0.19
		Multiple*	(n=1)	2	2	0.07	0.01	161	8	0	6	0.17	0.17
	ROB all*		(n=6)	4	2	0.13	0.06	639	85	40	13	0.25	0.23
Sort by Window Orientation	COB	North*	(n=7)	3	3	0.16	0.06	616	162	31	11	0.22	0.19
		South*	(n=9)	4	3	0.19	0.04	1329	49	66	8	0.22	0.21
		East*	(n=5)	3	4	0.17	0.05	1031	60	42	19	0.20	0.20
		West*	(n=2)	2	2	0.24	0.09	877	92	136	6	0.38	0.32
		Multiple*	(n=5)	2	2	0.13	0.07	692	105	23	19	0.20	0.22
	ROB all*		(n=6)	4	2	0.13	0.06	639	85	40	13	0.25	0.23

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

		Location		total CES-D (combined)		PSQI (combined)		PSS-10 (combined)		sleep disturbance global score (combined)		sleep disturbance t-score (combined)		Sleep disturbance standard error (combined)		PANAS total positive (combined)		PANAS total negative (combined)	
				Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Sort by Floor	COB	Floor 1*	(n=1)	12.0	13.0	9.0	11.0	16.0	19.0	21.0	21.0	53.4	53.4	2.6	2.6	30.0	31.0	18.0	16.0
		Floor 2*	(n=13)	6.1	7.1	4.6	5.5	14.1	14.0	14.5	17.5	45.2	48.5	2.9	2.9	34.2	34.1	16.7	16.5
		Floor 3*	(n=1)	1.0	6.0	6.0	8.0	7.0	7.0	14.0	12.0	45.3	42.2	2.8	3.0	39.0	41.0	12.0	13.0
		Floor 4*	(n=3)	6.0	4.7	5.3	6.7	14.3	16.7	17.0	16.3	47.0	44.8	3.0	3.4	36.3	30.3	16.0	16.3
		Floor 5*	(n=6)	2.2	3.2	4.7	4.2	8.3	9.7	14.7	12.7	44.4	42.2	3.2	3.2	38.2	38.8	13.0	12.8
		Floor 6*	(n=1)	4.0	6.0	5.0	5.0	14.0	15.0	13.0	19.0	43.9	51.3	2.9	2.6	34.0	31.0	11.0	16.0
		Floor 7	(n=1)	3.0	0.0	6.0	5.0	9.0	5.0	8.0	13.0	30.5	43.9	4.9	2.9	42.0	39.0	14.0	10.0
		Multiple*	(n=2)	10.5	9.0	4.5	5.0	15.0	14.5	13.5	14.5	42.8	43.9	3.2	3.2	26.5	30.5	15.0	15.0
	ROB all*		(n=6)	7.6	7.2	7.5	7.8	12.5	14.2	21.5	21.3	53.3	53.1	2.7	2.7	30.8	30.8	14.2	17.0
Sort by Wing	COB	Wing 0	(n=2)	12.0	13.5	9.0	10.5	22.0	25.5	28.5	24.0	60.6	56.2	2.6	2.6	19.0	17.5	20.5	22.0
		Wing 1	(n=1)	6.0	5.0	3.7	4.7	10.7	9.3	9.7	9.7	37.0	36.0	3.5	3.9	33.7	33.3	14.3	12.7
		Wing 2	(n=3)	8.4	8.4	5.8	5.8	17.4	14.6	13.0	19.6	42.5	51.2	3.2	2.7	37.0	34.6	19.6	19.0
		Wing 3	(n=2)	5.4	5.8	5.2	6.4	13.2	15.0	14.6	14.0	45.5	44.8	2.9	2.9	35.0	35.4	15.6	14.2
		Wing 4	(n=9)	2.8	3.8	4.2	4.7	9.6	10.4	14.1	15.2	44.3	45.3	3.0	3.1	37.7	37.8	13.2	13.6
		Multiple	(n=10)	6.0	9.0	5.0	4.0	8.0	13.0	18.0	20.0	50.2	52.4	2.6	2.6	30.0	32.0	10.0	14.0
	ROB all*		(n=6)	7.6	7.2	7.5	7.8	12.5	14.2	21.5	21.3	53.3	53.1	2.7	2.7	30.8	30.8	14.2	17.0
Sort by Window Orientation	COB	North	(n=6)	4.0	5.9	4.3	4.6	10.4	11.4	16.1	16.0	46.3	46.3	3.1	3.0	35.1	36.1	14.9	14.4
		South	(n=6)	5.4	5.3	5.7	6.2	13.8	13.8	15.9	17.6	46.9	48.2	2.8	2.9	35.8	34.7	15.2	16.6
		East	(n=4)	5.4	7.0	5.0	6.2	12.0	12.4	11.4	15.2	39.9	45.9	3.4	2.9	33.4	34.4	15.6	15.4
		West	(n=1)	6.0	3.5	4.5	4.0	18.5	13.5	13.5	13.5	44.5	44.6	2.9	2.9	40.0	35.0	18.5	13.0
		Multiple	(n=10)	7.0	7.4	4.8	5.8	11.6	14.4	14.2	14.8	43.9	43.9	3.1	3.3	33.2	32.6	14.4	14.4
	ROB all*		(n=6)	7.6	7.2	7.5	7.8	12.5	14.2	21.5	21.3	53.3	53.1	2.7	2.7	30.8	30.8	14.2	17.0

Table 6. Washington, DC, Daysimeter results: statistical summary by building - Combined Months

location		Phasor				IS & IV			
		magnitude		angle (hours)		interdaily stability		intradaily variability	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
All	mean	0.25	0.26	0.99	2.05	0.59	0.61	0.54	0.55
	std dev	0.07	0.07	0.84	1.09	0.15	0.13	0.14	0.10
	median	0.26	0.27	1.10	2.07	0.62	0.65	0.51	0.56
COB	mean	0.26	0.27	0.90	2.07	0.60	0.61	0.55	0.54
	std dev	0.07	0.06	0.88	1.06	0.14	0.12	0.14	0.09
	median	0.26	0.27	0.95	2.06	0.62	0.65	0.53	0.54
ROB	mean	0.24	0.22	1.44	1.94	0.54	0.62	0.49	0.57
	std dev	0.05	0.06	0.40	1.31	0.20	0.16	0.11	0.13
	median	0.26	0.22	1.40	2.07	0.63	0.61	0.43	0.56
	p value	0.68	0.11	0.15	0.80	0.43	0.95	0.37	0.52

location		Post-work Sleep											
		actual sleep time (mins.)		actual sleep (%)		actual wake time (mins.)		actual wake (%)		sleep efficiency (%)		sleep onset latency (mins.)	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
All	mean	338	341	86%	86%	56	57	14%	14%	77%	75%	16	23
	std dev	55	79	7%	8%	32	36	7%	8%	10%	11%	16	28
	median	335	331	85%	88%	57	47	15%	12%	79%	77%	13	17
COB	mean	342	342	86%	85%	57	60	14%	15%	78%	75%	15	17
	std dev	53	85	8%	9%	33	38	8%	9%	10%	12%	18	17
	median	337	332	85%	88%	57	48	15%	12%	79%	79%	12	13
ROB	mean	324	334	87%	89%	52	40	13%	11%	76%	72%	14	52
	std dev	67	40	7%	4%	32	10	7%	4%	8%	8%	8	52
	median	303	322	86%	90%	45	39	14%	10%	75%	75%	12	38
	p value	0.49	0.84	0.77	0.29	0.73	0.26	0.77	0.29	0.70	0.60	0.75	0.01

location		waking average							
		CS ari-mean		illuminance ari-mean		illuminance geo-mean		activity ari-mean	
		summer	winter	summer	winter	summer	winter	summer	winter
All	mean	0.21	0.13	990	427	81	30	0.22	0.21
	std dev	0.05	0.05	463	545	74	40	0.06	0.05
	median	0.21	0.12	862	226	70	27	0.22	0.20
COB	mean	0.21	0.13	1047	435	81	32	0.22	0.21
	std dev	0.06	0.05	484	593	79	43	0.06	0.06
	median	0.22	0.12	976	226	60	29	0.22	0.20
ROB	mean	0.18	0.13	724	392	80	20	0.23	0.21
	std dev	0.04	0.07	210	249	46	25	0.04	0.03
	median	0.19	0.11	735	287	76	17	0.22	0.20
	p value	0.21	1.00	0.12	0.87	0.97	0.53	0.53	0.77

location		pre-work average**							
		CS ari-mean		illuminance ari-mean		illuminance geo-mean		activity ari-mean	
		summer	winter	summer	winter	summer	winter	summer	winter
All*	mean	0.23	0.12	1481	308	113	26	0.24	0.24
	std dev	0.09	0.07	1202	396	117	29	0.09	0.08
	median	0.24	0.10	1113	142	86	13	0.23	0.21
COB*	mean	0.23	0.11	1574	249	110	25	0.24	0.24
	std dev	0.09	0.07	1281	361	126	30	0.10	0.09
	median	0.23	0.09	1286	125	84	12	0.23	0.21
ROB	mean	0.26	0.13	1045	626	125	36	125	36
	std dev	0.06	0.05	632	465	59	21	59	21
	median	0.27	0.13	869	399	105	34	105	34
	p value	0.52	0.52	0.34	0.05	0.79	0.44	0.79	0.44

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

location		work average**							
		CS ari-mean		illuminance ari-mean		illuminance geo-mean		activity ari-mean	
		summer	winter	summer	winter	summer	winter	summer	winter
All*	mean	0.24	0.18	717	322	183	99	0.20	0.20
	std dev	0.09	0.07	504	331	145	69	0.06	0.07
	median	0.22	0.18	569	265	138	92	0.19	0.19
COB*	mean	0.25	0.19	807	347	197	109	0.20	0.20
	std dev	0.08	0.07	511	352	151	70	0.06	0.07
	median	0.24	0.20	634	266	154	103	0.19	0.19
ROB	mean	0.18	0.13	298	119	121	48	0.20	0.19
	std dev	0.10	0.04	112	146	97	21	0.03	0.03
	median	0.17	0.11	339	92	100	41	0.20	0.17
	p value	0.09	0.05	0.02	0.34	0.25	0.07	0.85	0.58

location		post-work average**							
		CS ari-mean		illuminance ari-mean		illuminance geo-mean		activity ari-mean	
		summer	winter	summer	winter	summer	winter	summer	winter
All*	mean	0.16	0.06	896	91	49	13	0.23	0.22
	std dev	0.07	0.05	775	120	61	14	0.06	0.06
	median	0.17	0.04	735	35	33	8	0.22	0.21
COB*	mean	0.17	0.06	951	92	51	12	0.22	0.22
	std dev	0.08	0.04	826	120	66	14	0.07	0.07
	median	0.17	0.04	735	35	33	9	0.22	0.20
ROB	mean	0.13	0.06	693	85	40	13	0.25	0.23
	std dev	0.05	0.08	420	130	37	15	0.04	0.04
	median	0.14	0.03	687	34	28	8	0.25	0.22
	p value	0.21	0.82	0.38	0.91	0.7	0.94	0.30	0.70

*Contains data from a small number of devices that still require calibration.

**Data does not include values from subjects that were non-compliant.

	Location	total CES-D (combined)		PSQI (combined)		PSS-10 (combined)		sleep disturbance global score (combined)		sleep disturbance t-score (combined)		Sleep disturbance standard error (combined)		PANAS total positive (combined)		PANAS total negative (combined)	
		summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
All	Mean	5.9	6.4	5.5	5.9	12.7	13.5	16.0	17.2	46.5	48.0	3.0	2.9	34.1	33.9	15.2	15.6
	std dev	5.0	5.1	2.6	2.8	6.5	6.2	6.3	6.2	8.3	8.0	0.6	0.6	8.3	7.2	4.6	5.0
	median	4.0	5.0	5.0	5.0	11.0	13.0	14.0	16.0	45.3	47.9	2.8	2.7	35.0	34.0	14.0	15.0
COB	Mean	5.6	6.2	5.1	5.5	12.8	13.3	14.8	16.3	44.9	46.9	3.0	2.9	34.8	34.5	15.4	15.3
	std dev	5.0	5.2	2.3	2.5	6.4	6.5	5.4	5.7	7.6	7.8	0.6	0.6	7.6	7.0	4.6	5.1
	median	4.0	5.0	5.0	5.0	11.0	12.0	14.0	15.0	45.3	46.7	2.8	2.7	37.0	34.0	14.0	15.0
ROB	Mean	7.6	7.2	7.5	7.8	12.5	14.2	21.5	21.3	53.3	53.1	2.7	2.7	30.8	30.8	14.2	17.0
	std dev	5.5	5.2	3.4	3.6	7.6	5.5	7.5	7.4	7.9	7.9	0.2	0.2	10.9	8.0	4.8	4.6
	median	7.0	9.0	7.5	9.0	11.0	15.0	21.0	21.5	53.4	53.7	2.6	2.6	30.5	30.0	12.5	16.0
	p value	0.42	0.70	0.04	0.09	0.93	0.76	0.02	0.07	0.02	0.09	0.18	0.28	0.30	0.30	0.56	0.49