Methodology Report:
Lighting Guidelines Field Demonstrations

Department of Veterans Affairs
Medical Center
White River Junction, Vermont

Federal Highway Administration
Turner-Fairbank Highway
Research Center
McLean, Virginia

Submitted to:

U.S. General Services Administration
Bryan C. Steverson
Judith Heerwagen, PhD

Submitted by:

Lighting Research Center
Rensselaer Polytechnic Institute

TECHNICAL REPORT:
LIGHTING GUIDELINES FIELD DEMONSTRATIONS

DEPARTMENT OF VETERANS AFFAIRS MEDICAL CENTER
WHITE RIVER JUNCTION, VERMONT

FEDERAL HIGHWAY ADMINISTRATION
TURNER-FAIRBANK HIGHWAY RESEARCH CENTER
MCLEAN, VIRGINIA

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LIGHTING RESEARCH CENTER
21 UNION STREET
TROY, NY 12180

WWW.LRC.RPI.EDU

EXTENDED EXECUTIVE SUMMARY

BACKGROUND

The human body's circadian system is made up of biological rhythms that repeat themselves roughly every 24 hours. The circadian system helps to keep people in-sync with the 24-hour day by regulating digestion, the release of certain hormones, body temperature, and when a person feels alert or sleepy. Light–dark patterns reaching the back of the eye are the major synchronizers of circadian rhythms to a person's local time on Earth. If left in darkness, the human circadian clock will free-run with a period that is slightly greater than 24 hours. Short-wavelength (blue) light peaking close to 460 nanometers (nm) delivered in the morning will promote entrainment by resetting the internal clock on a daily basis so that it runs with a period of 24 hours. At any time of day or night, light can also elicit an acute, alerting effect on humans, similar to a "cup of coffee." Our research shows that saturated blue (peak close to 460 nm), saturated red (peak close to 640 nm), and white polychromatic light can elicit an alerting effect at any time of day and night.

Using published action spectrum data for acute melatonin suppression, Rea and colleagues proposed a mathematical model of human circadian phototransduction, which is how the retina converts light signals into electrical signals for the biological clock. This model is also based on fundamental knowledge of retinal neurophysiology and neuroanatomy, including the operating characteristics of circadian phototransduction, from response threshold to saturation.

Using this phototransduction model, the spectral irradiance at the cornea is first converted into circadian light (CL_A), reflecting the spectral sensitivity of the circadian system, and then, second, transformed into the circadian stimulus (CS), reflecting the absolute sensitivity of the circadian system. Thus, CS is a measure of the *effectiveness* of the retinal light stimulus for the human circadian system from threshold (CS = 0.1) to saturation (CS = 0.70) (Figure 1). It was hypothesized that a CS ≥ 0.3 would provide sufficient circadian stimulation to promote entrainment and alertness, and as a result, the CS metric has been successfully applied to quantify lighting interventions in many other laboratory and field studies. In the laboratory, the CS metric was used to predict melatonin suppression from self-luminous devices, and in the field, it was used to predict entrainment in nuclear submariners as well as sleep quality and mood in persons with Alzheimer's disease living in senior facilities.

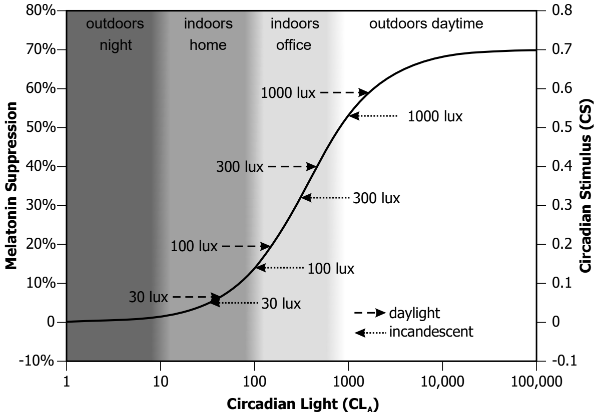


Figure 1. Modeled absolute sensitivity of the circadian system.

In previous studies, the Lighting Research Center (LRC), Rensselaer Polytechnic Institute, and the General Services Administration (GSA) investigated the relationship between morning and daytime circadian-effective light (CS ≥ 0.3) and office workers' sleep and mood. Results showed that compared to office workers who received low levels of circadian-effective light (CS ≤ 0.15) in the morning (before noon), those who received high levels (CS ≥ 0.3) in the morning fell asleep faster at night (especially in winter), experienced better sleep quality, and had overall lower levels of depression. High levels of circadian-effective light during the entire day (08:00 am to 05:00 pm) were also associated with reduced depression and increased sleep quality.

GOALS OF THE PRESENT STUDY

Given that the results of our earlier studies showed that daytime CS is important for improved sleep and mood, the purpose of the Phase 2 study was to demonstrate: (1) whether circadian-effective lighting could be installed in office buildings and (2) whether this lighting intervention would provide similar health benefits for alertness and vitality of office workers. It was hypothesized that a 2-day exposure to CS ≥ 0.3 would increase alertness, vitality, and energy in office workers. Given the short duration of the protocol employed, the present study was designed to measure the acute, alerting effects of light. It is not known whether sleep may have been improved as a result of the 2-day lighting intervention and therefore, contributed to the results observed.

PARTICIPANTS

Volunteers from 2 federal buildings participated in this study: the Federal Highway Administration's Turner-Fairbanks Highway Research Center (FHWA) in McLean, Virginia, and the Department of Veteran's Affairs (VA) Medical Center in White River Junction, Vermont. Data were collected in summer (July-August 2016) and fall (October-November 2016). A total of 11 participants (8 females) from the VA site and 25 (9 females) from the FHWA site agreed to participate in the study in the summer; of those, 8 participants (7 females) and 18 participants (7 females) agreed to repeat the study in the fall.

METHODOLOGY

LRC researchers demonstrated two basic strategies to achieve circadian-effective lighting (i.e., CS ≥ 0.3) by using: (1) an overhead light using a power-over-ethernet (PoE) system (only used at the Federal Highway Administration site) and (2) desktop lighting built by the LRC. For the desktop lighting, two types of light (i.e., cool white and blue) were used to deliver the same circadian-effective light at the participants' eyes. While all types of light delivered a CS ≥ 0.3 at eye level, the different light delivery methods permitted LRC researchers to compare workers' preferences for each approach. The LRC installed and calibrated the new lighting at both facilities during summer and then again during late fall of 2016.

Baseline data were collected prior to turning on the lights on Day 1. Participants were provided with Daysimeters to wear as pendants while in the office and asked to fill out two questionnaires [Karolinska Sleepiness Scale (KSS) and Subjective Vitality Scale (SVS)] probing their subjective sleepiness, vitality, and energy scores. The questionnaires were filled out four times per day (upon arrival, 12:00 p.m., 3:00 p.m., and at departure/end of the work day), although these times may have varied due to workers' flexible schedules. Upon arrival at work on Day 2, participants were instructed to turn on their desktop lights. (For those at the FHWA site who had overhead lights, those lights were automatically turned on when the office space was occupied.) As with Day 1, participants were asked to wear the Daysimeters and fill out the questionnaires on Days 2 and 3, following the same schedule for the completion of questionnaires (Figure 2). For those who received the overhead lighting intervention, baseline data were collected prior to, or in some cases weeks after, the period in which the lights were turned on, depending on participants' availability.

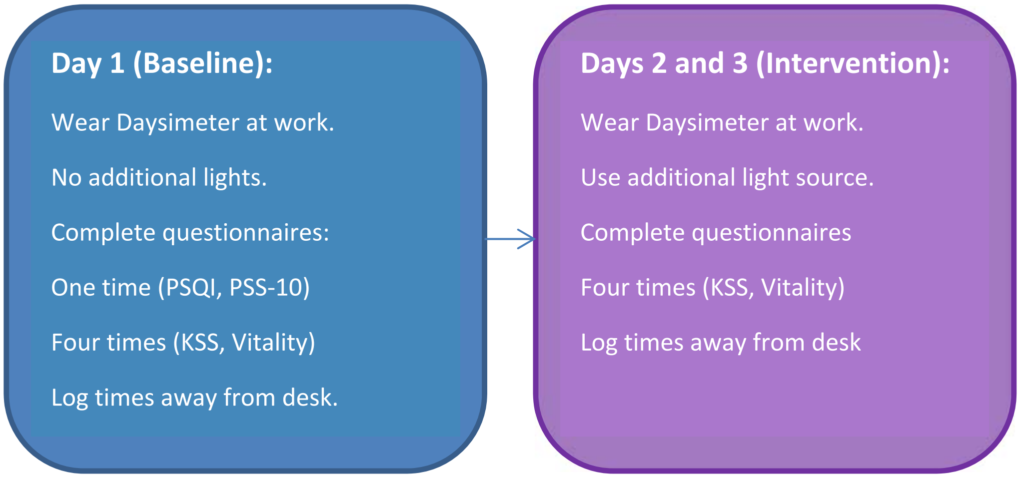


Figure 2. The experimental protocol used in this study.

The two measures used to collect subjective sleepiness (KSS) and subjective vitality and energy (Subjective Vitality Scale [SVS]) data are described below.

KAROLINSKA SLEEPINESS SCALE (KSS)

The KSS questionnaire is a subjective measure of sleepiness that assesses participants' present state on a 9-point scale ranging from 1 ("extremely alert") to 9 ("very sleepy, great effort to keep awake, fighting sleep").

SUBJECTIVE VITALITY SCALE (SVS)

The SVS questionnaire is a subjective measure of energy, vitality, and alertness that assess participants' present responses to 7 statements. Participants are instructed to evaluate the truth of each statement by selecting responses that range from 1 ("not true at all") to 7 ("very true"). The 7 statements are: (1) "at this moment, I feel alive and vital;" (2) "I don't feel very energetic right now;" (3) "currently, I feel so alive I just want to burst;" (4) "at this time, I have energy and spirit," (5) "I am looking forward to each new day;" (6) "at this moment, I feel alert and awake;" and (7) "I feel energized right now."

RESULTS

Data were subjected to a mixed-model regression analyses. Given that the results showed no statistically significant differences between the VA and FHWA sites, all data were pooled and results from the combined data set are presented here.

EFFECT OF INTERVENTION ON KSS SCORES (SUBJECTIVE SLEEPINESS)

Day of intervention came close to having a significant effect on KSS scores ($F_{2,597}$ = 2.81, $p = 0.061$). Across all times of day except for 12:00 p.m., KSS scores fell from Day 1 (mean = 4.07 ± 0.11) through Day 2 (mean = 3.84 ± 0.11) to Day 3 (mean = 3.71 ± 0.11). Interestingly, the KSS scores for each time of day were widely divergent on Day 1.

By Day 3, however, KSS scores for all times of day almost converged to the mean value, suggesting consistently greater alertness throughout the entire day as the protocol progressed. Season had no significant effect on sleepiness scores.

EFFECTS OF INTERVENTION ON SVS SCORES (ALERTNESS, ENERGY AND VITALITY)

As hypothesized, overall, the study's participants reported feeling more vital, more energetic, and more alert on Days 2 and 3 (during the intervention) as compared to baseline Day 1. Self-reported scores of vitality increased over the course of the day, indicating greater feelings of vitality at departure than upon arrival. Reported energy levels were greater in the middle of the day than they were upon arrival or at departure.

CONCLUSIONS

Phase 1 of the research performed by the LRC and GSA demonstrated that exposure to a CS ≥ 0.3 in the morning was associated with shorter sleep onset latency and greater circadian phasor magnitude (both of which suggest greater circadian entrainment), better self-reports of sleep quality, and lower depression scores. All-day exposure to a CS ≥ 0.3 was also associated with better self-reports of sleep quality and lower depression scores. Given that the results of those earlier studies showed that daytime CS is important for improved sleep and mood, the purpose of the Phase 2 research was to demonstrate ***Goal 1:*** whether circadian-effective light, defined here as delivering a CS ≥ 0.3, could be installed in office buildings; and ***Goal 2:*** whether this intervention would affect self-reports of subjective sleepiness and vitality for office workers.

GOAL 1

The lessons learned from the present study showed that circadian-effective lighting can be delivered to workspaces via either ceiling or desktop lighting using cool white or blue light. New LED technologies that are now commercially available made it possible to deliver our target circadian-effective light in both private offices and cubicles, with and without access to daylight. The use of different lighting modes (i.e., desktop lighting vs overhead lighting) to deliver the intervention did not produce significantly different results. Therefore, it can be assumed that the circadian system is agnostic to a specific light delivery method; as long as the circadian stimulus at the eye level is equivalent, any delivery method should be effective.

While the LRC has not developed a formal feedback questionnaire about users' experiences with the intervention light sources, and given the fact that most participants were not present when the lights were removed, we nonetheless recorded a few user comments about the desktop lights:

> *"It's too much right in my eyes; maybe it would be more comfortable if it were (mounted) up a little more."*
>
> *"I kinda liked it once I got used to it."*
>
> *"You're taking it away? Where I can I buy one?"*

Considered together, these user comments suggest that tuning the lighting intervention's spectrum to decrease the amount of light needed to deliver the desired CS level at the eye may be the most practical way to create more-comfortable working environments.

GOAL 2

The lighting intervention improved subjective reports of sleepiness and feelings of vitality, alertness, and energy. Although not statistically significant, self-reported sleepiness (KSS) scores were reduced on Days 2 and 3 compared to Day 1, suggesting that subjective sleepiness remained lower throughout the entire workday with the intervention. As hypothesized, participants reported feeling more vital, more energetic, and more alert on Days 2 and 3 and their self-reports of vitality increased over the course of the day, indicating greater feelings of vitality at departure than upon arrival. These results were reflected on the various changes in SVS scores from Day 1 to Days 2 and 3.

The present study demonstrates that high circadian stimulus levels during daytime hours can also elicit an acute alerting effect on office workers. Although replication of these results in a larger group is warranted, these initial data are very promising.

EXTENDED REPORT

INTRODUCTION

This study was conducted at 2 GSA-managed facilities, one in eastern Vermont, within 1.5 mi of the New Hampshire border and the other in northern Virginia within 0.5 mi of the Potomac River.

The White River Junction Department of Veterans Affairs (VA) Medical Center is located at 163 Veterans Dr., White River Junction, Vermont. Among the many services provided at this facility are psychiatric and medical outpatient services. The LRC worked with personnel who, due to the nature of their sensitive work, attend to veteran patients in their private offices. Most of the participants at this site have little or no access to daylight. The volunteers who responded to the LRC's call for participants worked in buildings 88 and 39 (Figure 1).

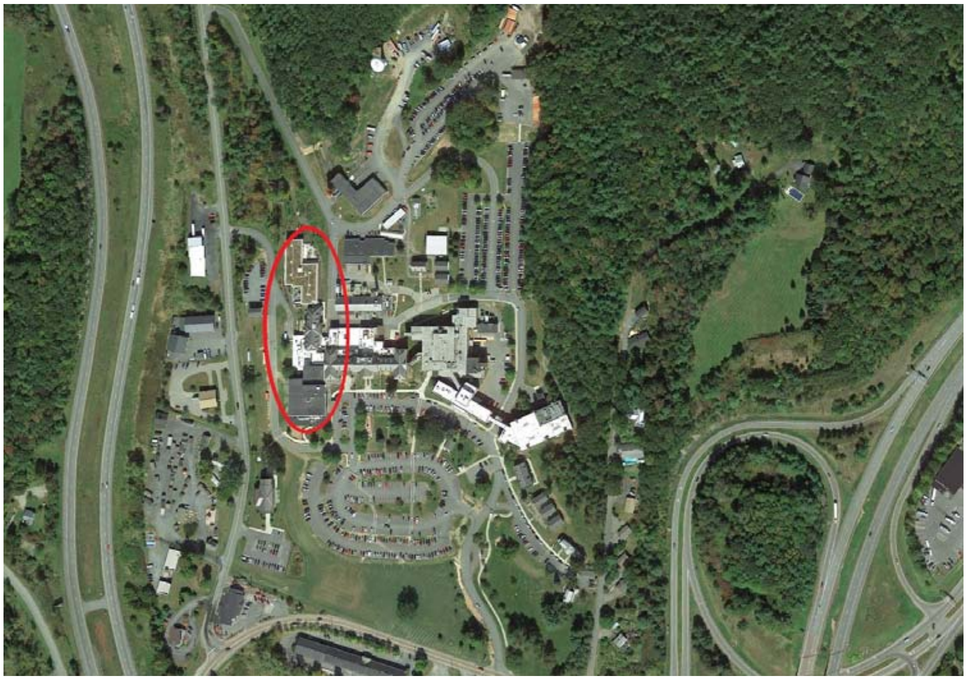


Figure 1. Satellite view of the VA site. The desk locations are in Buildings 88 and 39, circled in red.

The Turner-Fairbank Highway Research Center is a Federal Highway Administration (FHWA) site located at 6300 Georgetown Pike, McLean, Virginia, near Washington, D.C. The site consists of several buildings containing laboratories, workshops, and offices (Figure 2). The workspaces include both open-plan and private offices. Some desks have access to daylight, while others are entirely windowless.

Figure 2. Satellite view of the FHWA site. The desk locations are in the Turner, Fairbank, and Annex Buildings, circled in red.

RESEARCH OBJECTIVES

The original purpose of this research was to demonstrate circadian-effective office lighting (i.e., lighting which delivers CS ≥ 0.3)[1] in the field. When selecting the sites, GSA had a very positive response and testing was performed in 36 deskspaces (11 participants in the VA site and 25 participants in the FHWA site). The LRC demonstrated two basic strategies to increase the amount of light and CS levels at the eye using: (1) overhead lighting and (2) desktop lighting. As the research was designed to demonstrate that CS criteria can be achieved in several ways, multiple light source colors (i.e., cool white, blue, and color-tuning white) were employed using desktop and ceiling luminaires. All of the solutions were designed and calibrated on site to deliver a CS of at least 0.3 at eye level. We hypothesized that, because all three light types were delivering the same CS value at eye level, personal preference for a type of light would not affect subjective ratings of sleepiness and vitality.

With help from the GSA, the LRC collaborated with volunteers at the two sites. Participants completed a 3-day protocol involving the use of supplemental/intervention lighting, the wearing of a Daysimeter light meter device, [2] and the completion of several questionnaires.

METHODS

PARTICIPANT RECRUITMENT

The LRC and GSA conducted an informational session at each site to recruit study participants. There were no exclusion criteria for participation. Interested volunteers contacted the LRC staff to discuss the research protocol and, if they were willing to participate, enrolled in the study. One employee from each location served as the on-site point of contact, and they were responsible for distributing the Daysimeter and questionnaires to the participants at the beginning of the study and collecting everything at the end. (These individuals did not participate in any other aspect of the study.) In all, 36 participants completed the summer protocol and 26 participants completed the fall repeat protocol (Table 1).

Table 1. Summary of Intervention Status and Demographic Data for Participants in this Study, by Site.

	Season	
Participant Intervention Status and Demographic Data	Summer	Fall
White River Junction Department of Veterans Affairs (VA)		
Lighting intervention employed	11	8
Gender	3 M, 8 F	1 M, 7 F
Mean age (yr)	48.3	47
Turner–Fairbank Highway Research Center (FHWA)		
Lighting intervention employed	19	12
Gender	12 M, 7 F	7 M, 5 F
Mean age (yr)	47.2	46.8
Lighting intervention not necessary	6	6
Gender	4 M, 2 F	4 M, 2 F
Mean age (yr)	53.2	53.2
Subtotal, FHWA	25	18
Total, both sites	36	26

MEASUREMENT PROCEDURES

DEVICE

The Daysimeter, a calibrated light-measuring device, was used to collect personal light and activity data from the participants. 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). [2] 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 0.1 (the threshold for circadian system activation) to 0.7 (response saturation), and is directly proportional to nocturnal melatonin suppression after 1-hour exposure (10-70%). Participants wore the

Daysimeter during work hours so that the amount of CS they were exposed to during work could be determined.

QUESTIONNAIRES

Participants completed several questionnaires asking questions on sleep habits (Pittsburgh Sleep Quality Index [PSQI] and Karolinska Sleepiness Scale [KSS]), stress (Perceived Stress Scale [PSS-10]), and subjective feelings about vitality and alertness (Subjective Vitality Scale [SVS]). These questionnaires were selected because they have been used to probe subjects subjective sleepiness, vitality and energy levels in previous studies.

The PSQI questionnaire [3] is a subjective measure of sleep quality and patterns experienced by participants for the majority of days and nights over the past month. It measures sleep quality from responses in 7 areas: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction. Answers are scored on a scale ranging from 0 to 3, and the questionnaire yields a single global score. A global score of ≥ 5 indicates a poor sleeper. This questionnaire was completed once at the start of the study.

The KSS questionnaire [4] is a subjective measure of sleepiness that assesses participants' present state on a 9-point scale ranging from 1 ("extremely alert") to 9 ("very sleepy, great effort to keep awake, fighting sleep"). This questionnaire was completed 4 times per day (arrival, 12:00 p.m., 3:00 p.m., and departure) during the 3 days of the study (see protocol below).

The PSS-10 questionnaire [5] assesses participants' thoughts and feelings over the past month by posing 10 questions concerning how often they have thought or felt a specific way. Answers are scored on a 5-point scale ranging from 0 (never) to 4 (almost always). Total scores ≥ 20 are considered to indicate high stress. This questionnaire was assessed once at the start of the study.

The SVS questionnaire [6] assesses participants' perceptions of feeling alive, vital, energetic or energized, alert, awake, and optimistic "at the present time." The participants' responses to 7 individual statements were scored on a 7-point scale ranging from 1 (not at all true) to 7 (very true). This questionnaire was completed 4 times per day (arrival, 12:00 p.m., 3:00 p.m., and departure) during the 3 days of the study.

PROTOCOL

Participants at both sites completed the experimental protocol in the summer of 2016, and most (72%) of them agreed to repeat the protocol in fall of 2016. The study was conducted over 3 days; baseline data collection was performed in Day 1 and intervention data collection was performed in Days 2 and 3. The protocol is presented in Table 2. The same Daysimeter, questionnaire, and log-out routines were maintained between all experimental lighting conditions for each day of the study. At the end of Day 3, the participants placed their Daysimeters and completed questionnaires into a sealed envelope, which they submitted to the on-site point of contact for return to the LRC.

Table 2. Procedures employed in the experiment protocol for each day of the study.

Procedure		Day 1	Day 2	Day 3
Wear Daysimeter at work (arrival to departure)		✓	✓	✓
Questionnaires	PSQI, PSS-10 (arrival)	✓	–	–
	KSS, Vitality (arrival, 12:00 p.m., 3:00 p.m., departure)	✓	✓	✓
Log time away from desk		✓	✓	✓
Experimental lighting condition[a]	Desktop Luminaires	–	✓	✓
	Additional Overhead Luminaires[b]	–	✓	✓
	Daylight with Existing Luminaires (no additional luminaires)[c]	✓	✓	✓
Submit envelope containing questionnaires and Daysimeter to site contact		–	–	✓

Notes: (a) Lighting specifications are described in Lighting Interventions, below; (b) Procedure occurred at FHWA only; (c) Procedure occurred at FHWA only, and only among participants already receiving morning CS ≥ 0.3 as determined by baseline lighting assessment.

Most participants had desktop LED luminaires installed at their workstations, though several participants at the FHWA site had an overhead luminaire installed overtop of their workstation. On Day 1, participants left the desktop light turned off in order to capture baseline lighting conditions. On Days 2 and 3, participants turned on their desktop LED luminaire upon arrival and left them on for the entire workday. Participants at the FHWA site, who had the overhead luminaires installed, were exposed to the lighting for the entire workday on Days 2 and 3 only. Because the additional overhead luminaires were centrally controlled without access to individual wall switches, participants exposed to this second condition conducted their Day 1 baseline assessment over an established period when the additional overhead lighting was turned off. Because Days 2 and 3 were not necessarily successive, the additional overhead lighting remained on over a period a several weeks. During the summer data collection, 2 participants experienced the overhead lights prior to data collection for 12 days, 1 participant experienced it for 13 days, 2 participants experienced it for 2 days, and 1 participant experienced it for 8 days. We did not observe any difference in responses between the participants who experienced the condition for 2 days and those who experienced it for 13 days. In the fall data collection, 3 participants experienced the lighting 2 days prior to data collection and 2 participants experienced it 12 days prior to data collection. The individual differences (between-participants responses and within-participants responses between seasons) were greater than the effect of the number of days that elapsed prior to participants experiencing the lighting condition.

There were several participants at the FHWA site who had access to daylight and were receiving a morning CS ≥ 0.3. They did not require supplemental electric lighting. On Day 1, these participants were asked to close their window blinds to remove daylight in the space while the existing overhead lighting remained on. Upon arrival at work on Day 2, the participants were asked to open the blinds and leave them open until the end of the protocol. The existing luminaires remained on during Days 2 and 3.

BASELINE (PRE-INTERVENTION) PHOTOMETRIC ANALYSIS

VA SITE

On June 9 and 10, 2016, the LRC researchers performed a preliminary evaluation of the VA site to prepare for the study. The researchers also held an informational seminar for potentially interested participants.

Researchers collected photometric data using a spectroradiometer system consisting of a spectrometer (model USB650, Ocean Optics, Dunedin, FL) equipped with a remote sensor and connected to a laptop computer. The raw spectral power distribution (SPD) data collected via the spectroradiometer system were post-processed using Matlab version R2014a software (MathWorks, Natlick, MA).

The LRC researchers measured CS and other photometric conditions at eye-level at the desks of 16 people who expressed interest. Ultimately, 11 participants completed the summer protocol and 8 completed the fall protocol. Offices with access to daylight were measured repeatedly throughout the day, and offices with electric lighting only (no daylight) were measured once. The purpose of the baseline data collection and analysis was to ensure that the LRC's manufactured desktop lighting would be of sufficient output to achieve the criterion CS value. As Figure 3 indicates, even with daylight exposure in June, these desks did not achieve the target CS of 0.3 (indicated by red dashed line) When the LRC returned to install the desktop lights, CS was re-measured following the same procedures (see Results).

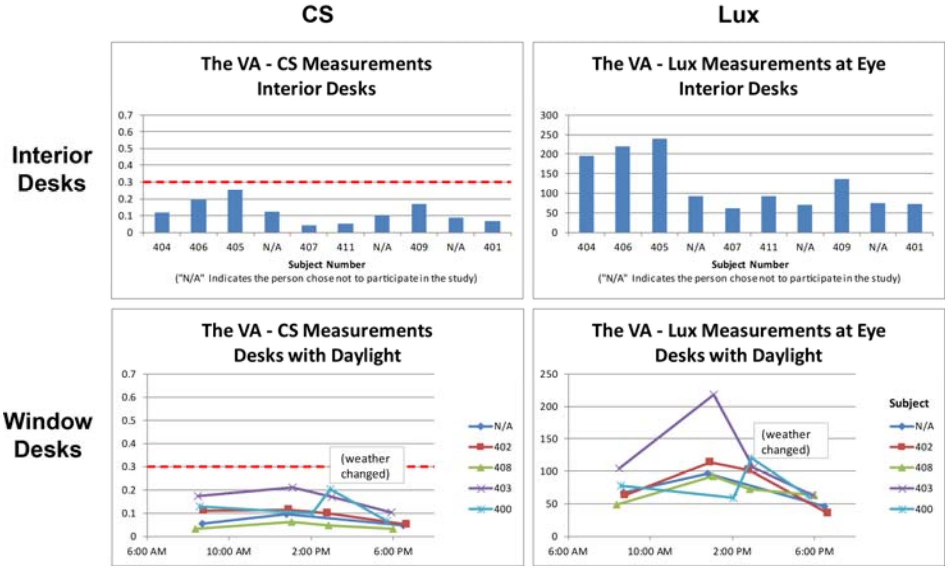


Figure 3. Preliminary photometric measurements at the VA site. The red dashed lines indicate the CS target criterion.

As Figure 4 indicates, the windows in these private offices are relatively small and overlook the base of a hillside. Due to the private nature of their psychological counseling work with veterans, VA workers keep their perforated window shades down. Office occupants also did not have their desks facing the window.

Figure 4. LRC researchers collected dimensional information about computer monitor heights and user distance from monitors when seated. This information was used to develop the desktop luminaires.

FHWA SITE

On June 20, 2016, the LRC performed a preliminary evaluation of the FHWA site (Figure 5). The evaluation team and analytical procedures were the same as those used at the VA site. The LRC evaluated photometric conditions at the desks of 25 people who expressed interest in the study, with 25 of them participating in the summer protocol and 18 participating in the fall protocol.

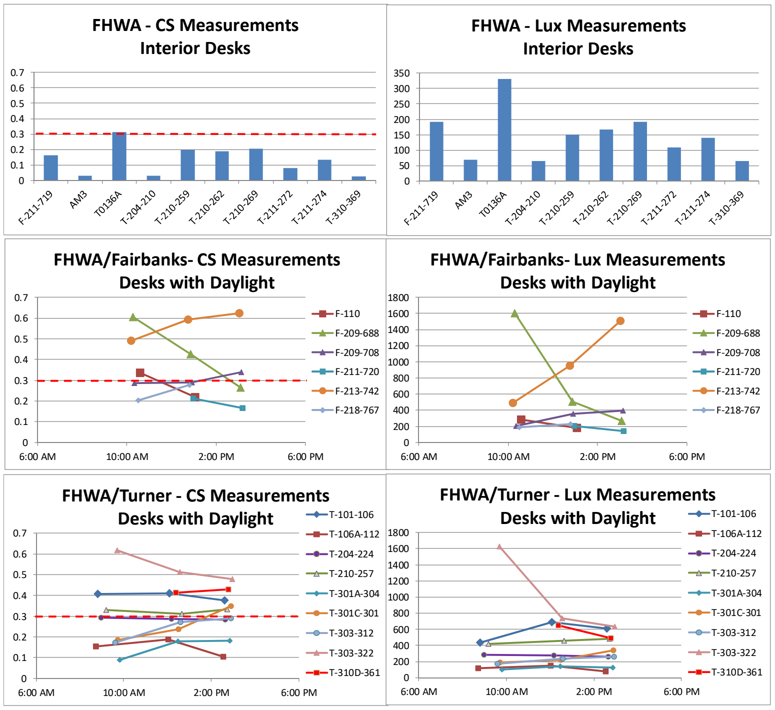


Figure 5. Preliminary photometric measurements at the FHWA site; red dashed line indicates CS target criterion.

LIGHTING INTERVENTIONS

The original purpose of the study was to demonstrate techniques to deliver a CS of 0.3 in a deskspace and an "oasis" space. Given the large interest by workers in the two buildings, however, GSA and LRC agreed to recruit as many participants as possible for the study. Since the study was intended to demonstrate that CS criteria can be achieved in several ways, multiple light source colors (i.e., cool white, blue, and color-tuning white) were used.

DESKTOP LUMINAIRES

The LRC developed the lighting interventions based on the baseline pre-intervention analysis. As the positioning and configuration of most of the desks in the space (along with other practical considerations) would not permit the installation of additional overhead lighting, the LRC developed plug-in luminaires for mounting on desktops near computer monitors (Figure 6).

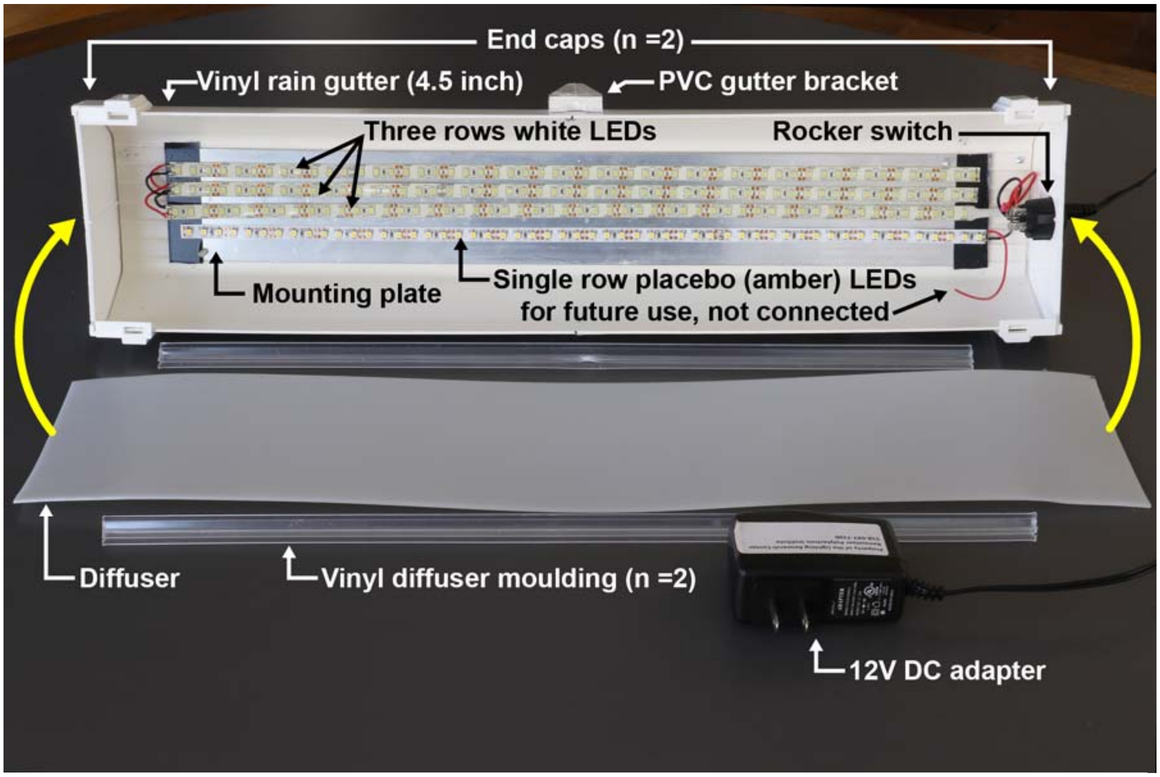


Figure 6. Interior view of a white-light desktop luminaire, with the relevant internal components annotated. This luminaire was designed to emit broad-band (i.e., white) light; for the blue (470 nm) light luminaire, two rows of blue LEDs replace the three rows of white LEDs shown here.

The LRC built 7 blue-light (470-nm) and 8 white-light desktop units. Figure 7 shows the SPDs for the desktop light sources; photometric measurements from when these lights were installed in the field will be shown later in this report. All of the units were calibrated to develop a CS of at least 0.3 at eye level of participants. The number of LED strips in each light was determined based on the CS value reached at eye level. As shown below, calibration checks were performed on-site using a spectroradiometer that calculates CS. The availability of both cool white and blue lights provided the participants with some degree of choice in the desk unit selected. Given that the cool white light had to be much brighter to achieve the same CS as the blue light, some participants expressed a preference for the blue light. The desktop lights were designed to provide flexibility for mounting, either on an elevated stand or resting on office furniture in the vicinity of the participants' computer displays (Figure 8). Given that both luminaires (blue and white lights) were designed and calibrated to deliver the same CS at the eye, no differences in outcomes were expected. Indeed, *post hoc* analyses showed no significant differences in participants' responses that were based on the type of luminaire used during the study.

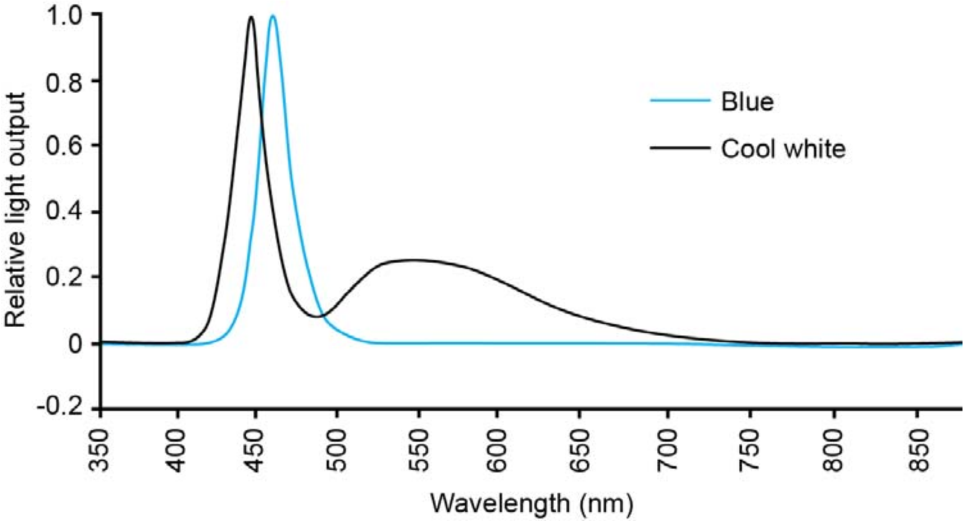


Figure 7. Spectral power distribution of blue and cool white desktop lights.

Figure 8. Desktop light mounting options. (The photograph on the left clearly shows the external configuration of the device illustrated in Figure 6.)

ADDITIONAL OVERHEAD LIGHTING INTERVENTION

The FHWA site provided the study with an opportunity to install additional overhead lighting at selected desks. With help from the LRC's collaborators in the lighting industry, a loan of lighting equipment was obtained from CREE, Inc. (Durham, NC), which provided luminaires to install above 10 desks. Desks equipped with additional overhead lighting did not demonstrate desktop lights.

The equipment employed in this intervention is a new type of lighting infrastructure that uses low-voltage data cabling to provide both power and control commands to LED luminaires via ethernet. (Power over Ethernet [PoE] is being developed by several lighting manufacturers.) The CREE PoE system uses a dedicated Cisco data server to direct commands to the lights (Figure 9). The commands are issued from a laptop and software, also loaned by CREE (Appendix A).

The FHWA provided the data wiring to connect each light to the dedicated server. Due to some limitations with the overhead luminaire's proximity to the server, only 8 of the FHWA participants occupied desks that were in appropriate locations for the installation and control of additional overhead lighting.

Figure 9. Electrician connected each light to the dedicated Cisco server (left); as shown on the right, the luminaires could easily be moved from one location to another. Also shown at right, the two luminaires have not yet been programmed to match color temperature.

The overhead luminaires were 2x2 troffers that are part of CREE's "SmartCast" product line (Figure 10). Each luminaire can be set for one of a range of color temperatures (3000K, 3500K, 4000K, 4500K, and 5000K). Light output can be dimmed indirectly by adjusting the specific occupancy sensor settings (Appendix A). Because participants did not have a manual switch to turn off their overhead CREE lights when they left for the day, the integral occupancy sensors were programmed to turn off the lights ("0% output") after a time delay of 20 minutes ("1200 seconds"). Although these luminaires do have the capability to be dimmed in response to daylight, the LRC disabled that feature for this study.

Figure 10. Examples of CREE 2x2 troffers (indicated by red arrows) used as lighting intervention at the FHWA site.

RESULTS

BASELINE PHOTOMETRIC ANALYSIS OF LIGHTING INTERVENTIONS

VA SITE

In early July 2016, the LRC installed desktop lights at the desks of 12 volunteers at the VA site who agreed to start the protocol (Figure 11). (Eleven participants actually completed the protocol.) Measurements from the baseline photometric analysis indicated that all of the participants required an electric lighting intervention to achieve the criterion value of CS ≥ 0.3.

When participants were present for the installation of intervention, LRC researchers gave them the choice between a blue or cool white light source; otherwise the devices were assigned randomly. Figure 12 shows in situ CS measurements (obtained via the spectroradiometer system) with and without the desktop intervention lights turned on. It is not surprising that the existing overhead lights contributed little in terms of CS. As all of the VA site desks are located in small private offices, most of the overhead light is reflected by architectural surfaces before it reaches the eye. When the desktop lights were re-installed in November 2016, the LRC again used the spectroradiometer system to confirm that CS was ≥ 0.3 at all participants' desks.

Figure 11. Examples of desktop lights at the VA site.

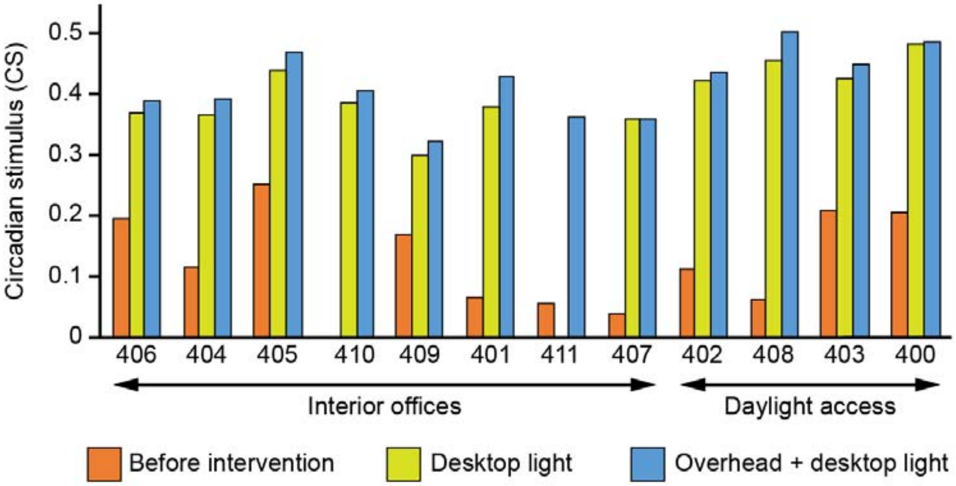


Figure 12. CS measurements at the VA site before (orange bars) and after the intervention for interior offices and offices with access to daylight.

FHWA SITE

Upon the completion of data gathering at VA, the desktop lights were removed and shipped to the FHWA site. The desktop lights were installed in late July and August 2016, and remained in place (but not turned on) at FHWA until the fall intervention began in October (Figure 13).

The additional overhead lights were installed at the FHWA site in mid-July 2016, and the LRC programed the lights at that time. Participants who were present during the programming were given a choice of color temperature, which ranged 3000–5000K in 500K increments (see above). The subsequent SPDs that were demonstrated at this site are shown in Figure 14.

Figure 13. Installing and measuring desktop lights at FHWA site.

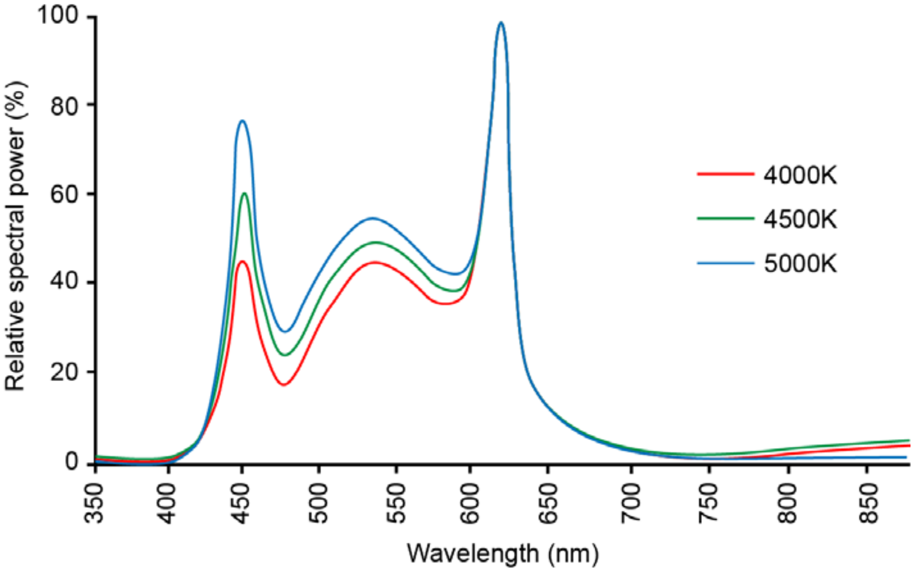


Figure 14. The SPDs of the CREE tunable white overhead lights installed at the FHWA site, showing three color temperatures.

The results of field measurements recorded for the summer participants' desks at the FHWA are shown in Figure 15. For those desks that had access to windows where multiple measurements were taken throughout the day, the "Before Intervention" value shown here is the morning measurement, unless otherwise noted. The "During Intervention" values include daylight and conventional overhead lighting, unless otherwise noted.

The desktop lights remained in place at FHWA until the follow-up study in October and early November. As the overhead lights were needed by the manufacturer, they were temporarily removed and then reinstalled for the fall intervention. The LRC returned to FHWA in early November to remove the desktop lights and to program the re-installed overhead lights. The spectroradiometer system was used by the LRC to confirm that the overhead lights were still achieving the CS criterion at each of the desks.

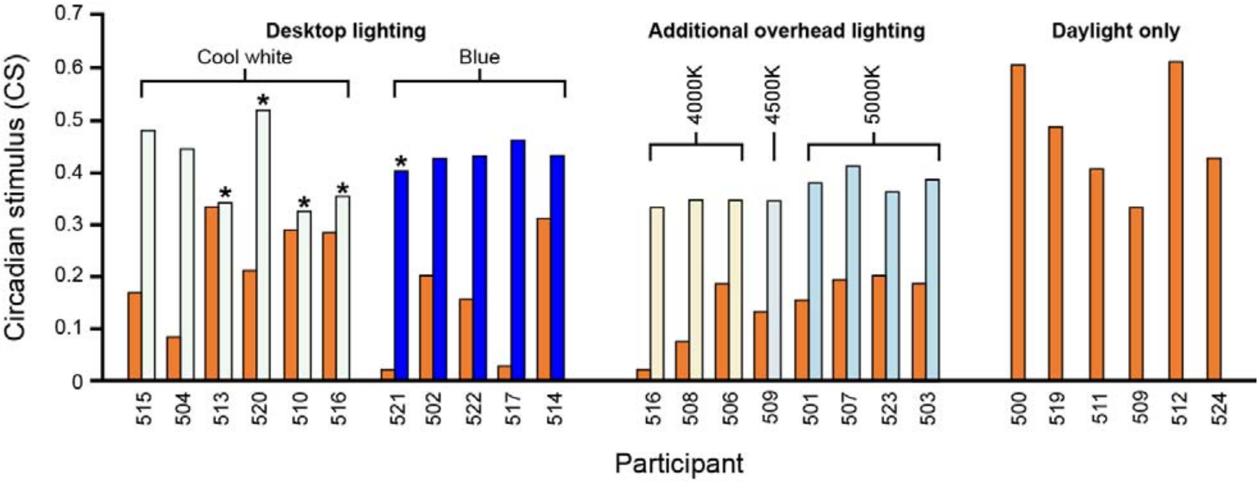


Figure 15. CS Measurements taken at the FHWA site, showing the values recorded before the intervention in orange. The CS values recorded during the intervention are represented by the variously colored bars on the right side of the paired values for each participant. Measurements that were taken at night are indicated by an asterisk (*). CS measurements are always taken at the eye. In an office environment such as this, CS is measured at the eye when facing the computer.

EFFECTS OF DAY, TIME OF DAY, AND BUILDING ON KAROLINSKA SLEEPINESS SCALE (KSS) SCORES

The KSS scores throughout all times of day, for each day, exhibited a U-shaped pattern (Figure 16) which starts relatively high upon arrival at work (mean ± SEM = 3.90 ± 0.16), falls at 12:00 p.m. (mean = 3.59 ± 0.11), rises at 3:00 p.m. (mean = 3.95 ± 0.11), and continues to rise at the end of the workday (mean = 4.08 ± 0.11). This effect was also statistically significant ($F_{3, 593} = 4.03$, $p = 0.007$). Lower KSS scores are associated with less sleepiness.

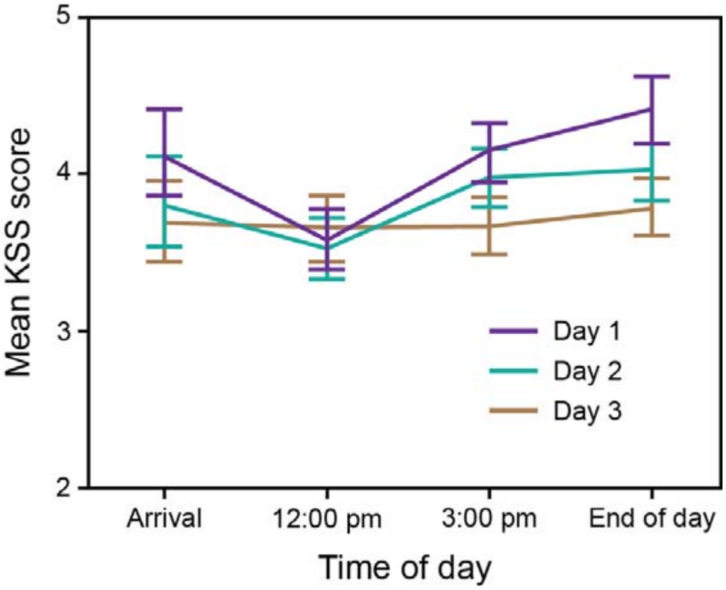


Figure 16. Mean KSS scores by time of day for all intervention days.

Day of intervention came close to having a significant effect on KSS scores ($F_{2,597}$ = 2.81, $p = 0.061$). Across all times of day except for 12:00 p.m., KSS scores fell from Day 1 (mean = 4.07 ± 0.11) through Day 2 (mean = 3.84 ± 0.11) to Day 3 (mean = 3.71 ± 0.11). Interestingly, the KSS scores for each time of day were widely divergent on Day 1. By Day 3, however, KSS scores for all times of day almost converged to the mean value, suggesting consistently greater alertness throughout the entire day as the protocol progressed. The mean KSS scores for all intervention days and all times of day are provided in Table 3. The results of the Type III tests of fixed effects for the KSS analysis are provided in Appendix B.

Table 3. Mean KSS Scores for Recorded for the VA and FHWA sites.

	KSS Scores, Day 1				KSS Scores, Day 2				KSS Scores, Day 3			
Measure	Time 1	Time 2	Time 3	Time 4	Time 1	Time 2	Time 3	Time 4	Time 1	Time 2	Time 3	Time 4
	Summer											
Mean	4.471	3.656	4.333	4.576	4.031	3.290	4.032	4.000	3.935	3.387	3.500	3.906
SEM	0.373	0.237	0.241	0.303	0.368	0.235	0.260	0.234	0.321	0.249	0.225	0.251
	Fall											
Mean	3.704	3.593	3.852	4.120	3.556	3.889	3.926	4.120	3.360	4.042	3.833	3.542
SEM	0.380	0.268	0.243	0.260	0.411	0.275	0.232	0.240	0.395	0.316	0.274	0.217
	Both Seasons											
Mean	4.131	3.600	4.117	4.379	3.767	3.542	3.949	4.018	3.632	3.661	3.643	3.750
SEM	0.270	0.177	0.173	0.203	0.275	0.183	0.177	0.167	0.243	0.190	0.166	0.164

Table 4. Mean SVS Scores Recorded for the VA and FHWA Sites.

	Subjective Vitality Scale (SVS) Statement						
Value	1	2	3	4	5	6	7
	Summer						
Mean	4.575	3.489	2.558	4.192	4.847	4.690	4.283
SEM	0.073	0.084	0.081	0.077	0.083	0.076	0.075
	Fall						
Mean	4.685	3.149	2.780	4.466	5.209	4.825	4.568
SEM	0.080	0.089	0.097	0.076	0.092	0.075	0.081
	Both Seasons						
Mean	4.622	3.346	2.651	4.308	5.000	4.747	4.403
SEM	0.054	0.062	0.063	0.055	0.062	0.054	0.056

EFFECTS OF DAY, TIME OF DAY, AND BUILDING ON THE SUBJECTIVE VITALITY SCALE (SVS)

Table 4 shows the mean score and the standard error of mean (SEM) for the summer, winter, and both seasons for each of the 7 questions within the SVS. The results of the Type III tests of fixed effects for the SVS analysis are provided in Appendix B.

STATEMENT 1 (“AT THIS MOMENT, I FEEL ALIVE AND VITAL”)

Day of intervention was the only factor that had a statistically significant effect ($F_{2,\,601}$ = 6.18, $p = 0.002$) on participants’ responses to SVS Statement 1 (Figure 17). A higher score is associated with greater vitality.

The SVS Statement 1 scores increased throughout all times of day, for each day, from Day 1 (mean ± SEM = 4.40 ± 0.098) through Day 2 (mean = 4.53 ± 0.090) to Day 3 (mean = 4.73 ± 0.090).

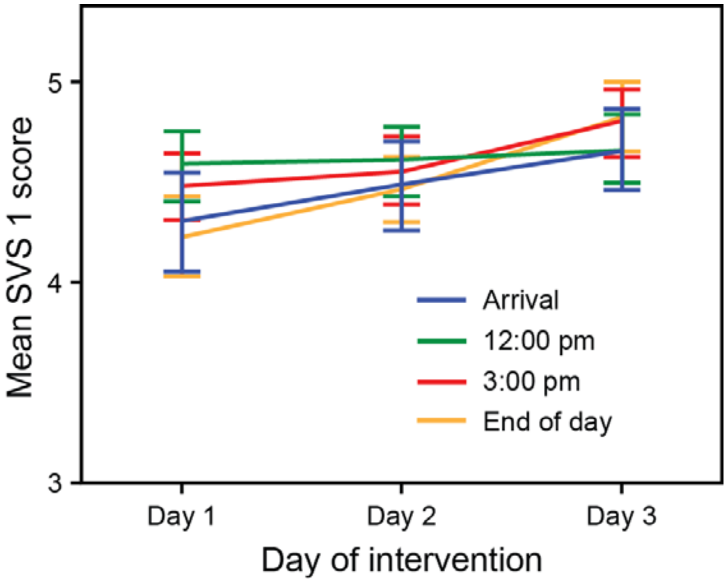


Figure 17. Mean SVS Statement 1 response scores by time of day for all intervention days.

STATEMENT 2 (“I DON’T FEEL VERY ENERGETIC RIGHT NOW”)

Day of intervention significantly affected ($F_{2,\,609}$ = 8.76, $p < 0.0001$) participants’ responses to SVS Statement 2 (Figure 18). These responses were highest on Day 1 (mean ± SEM = 3.66 ± 0.11), falling through Day 2 (mean = 3.40 ± 0.10) and Day 3 (mean = 3.14 ± 0.11). A lower score is associated with greater energy or vitality.

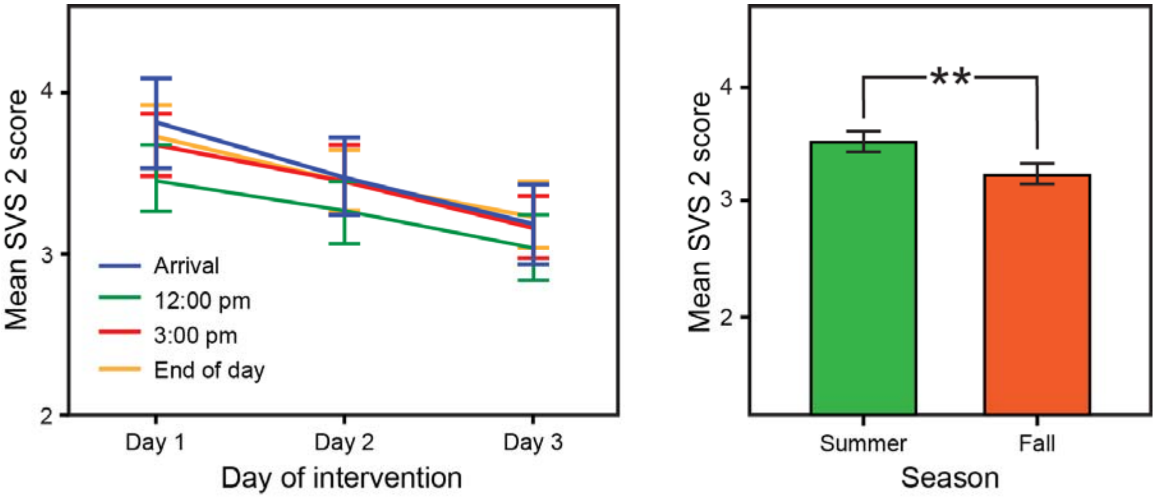


Figure 18. Mean SVS Statement 2 response scores by time of day for all intervention days (left) and by season (right).

Season also had a significant effect ($F_{1,627} = 8.79$, $p = 0.003$) on the responses to SVS Statement 2 (see Figure 18), with lower scores in fall (mean = 3.24 ± 0.09) compared to summer (mean = 3.52 ± 0.09).

STATEMENT 3 ("CURRENTLY, I FEEL SO ALIVE I JUST WANT TO BURST")

Day of intervention significantly affected ($F_{2,606} = 8.56$, $p < 0.0001$) participants' responses to SVS Statement 3 (Figure 19). Across all times of day, their scores exhibited a slight downward trend from Day 1 (mean ± SEM = 2.46 ± 0.11) to Day 2 (mean ± SEM = 2.43 ± 0.10), and then increased to a greater degree on Day 3 (mean ± SEM = 2.73 ± 0.11). A higher score is associated with greater vitality.

Season also had a significant effect ($F_{1,611} = 8.07$, $p = 0.005$) on responses to Statement 3, with mean scores being slightly lower in summer (mean ± SEM = 2.48 ± 0.08) compared to fall (mean ± SEM = 2.61 ± 0.09).

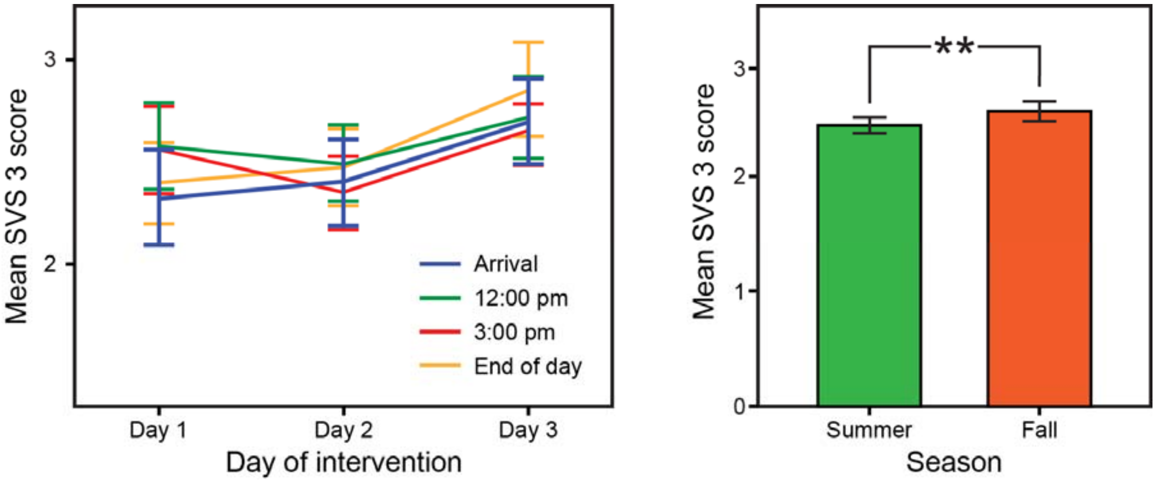


Figure 19. Mean SVS Statement 3 response scores by time of day for all intervention days (left) and by season (right).

STATEMENT 4 ("AT THIS TIME, I HAVE ENERGY AND SPIRIT")

Day of intervention significantly affected ($F_{2,606} = 14.04$, $p < 0.0001$) participants' responses to SVS Statement 4 (Figure 20). Across all times of day, scores were level or increased slightly from Day 1 (mean ± SEM = 4.03 ± 0.10) to Day 2 (mean = 4.14 ± 0.09), and then increased to a greater degree on Day 3 (mean = to 4.54 ± 0.09). A higher score is associated with greater vitality.

Responses to Statement 4 generally peaked at midday, with mean scores increasing from arrival at work (mean = 4.02 ± 0.13) to 12:00 p.m. (mean = 4.40 ± 0.10), and then deceasing from 3:00 p.m. (mean = 4.29 ± 0.10) to the end of the day (mean = 4.22 ± 0.10). This time of day effect was significant ($F_{3,601} = 3.89$, $p = 0.009$).

Season also had a significant effect ($F_{1,620} = 4.56$, $p = 0.033$) on responses to Statement 4 (Figure 21), with mean scores being lower in summer (mean ± SEM = 4.14 ± 0.08) compared to fall (mean = 4.36 ± 0.07).

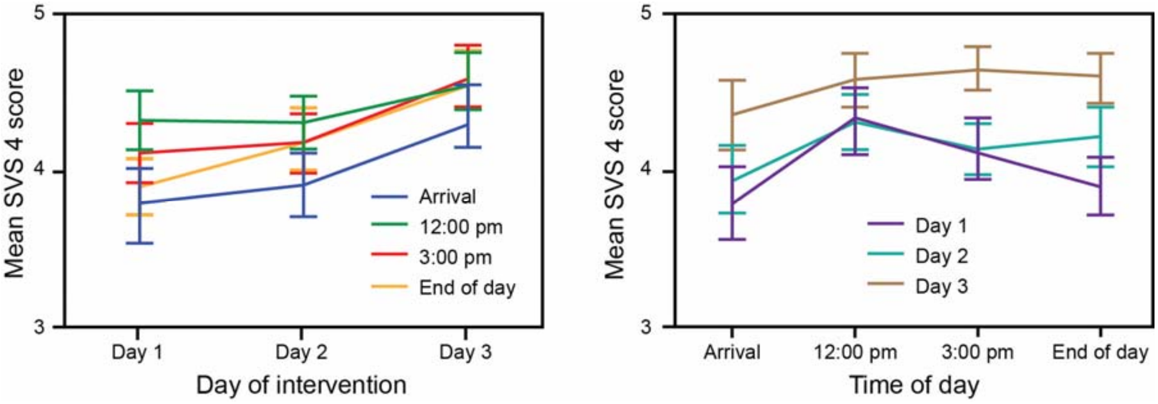


Figure 20. Mean SVS Statement 4 response scores by treatment day for time of day (left) and by time of day (right) for all intervention days.

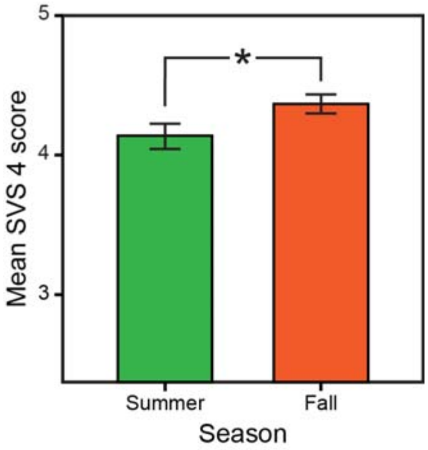


Figure 21. Mean SVS Statement 4 response scores by season.

STATEMENT 5 (“I AM LOOKING FORWARD TO EACH NEW DAY”)

Day of intervention significantly affected ($F_{2,605} = 3.69$, $p = 0.026$) participants’ responses to SVS Statement 5 (Figure 22). Across all times of day, scores decreased slightly from Day 1 (mean ± SEM = 4.92 ± 0.11) to Day 2 (mean = 4.89 ± 0.11), and then increased slightly on Day 3 (mean = 4.99 ± 0.11). A higher score is associated with greater vitality.

Responses to Statement 5 peaked at midday, with mean scores increasing from arrival at work (mean = 4.80 ± 0.13) to 12:00 p.m. (mean = 5.01 ± 0.12), and then deceasing from 3:00 p.m. (mean = 4.92 ± 0.13) with a slight increase at the end of the day (mean = 5.00 ± 0.13). This time of day effect was significant ($F_{3,604} = 3.43$, $p = 0.017$).

Season also had a significant effect ($F_{1,607} = 38.52$, $p < 0.0001$) on responses to Statement 5 (Figure 23), with lower mean scores in summer (mean = 4.85 ± 0.08) compared to fall (mean = 5.21 ± 0.08).

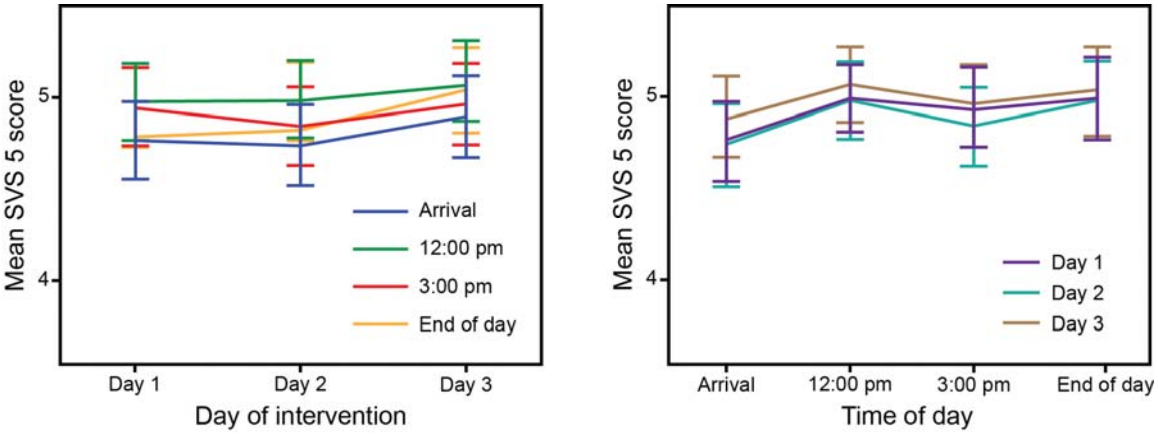
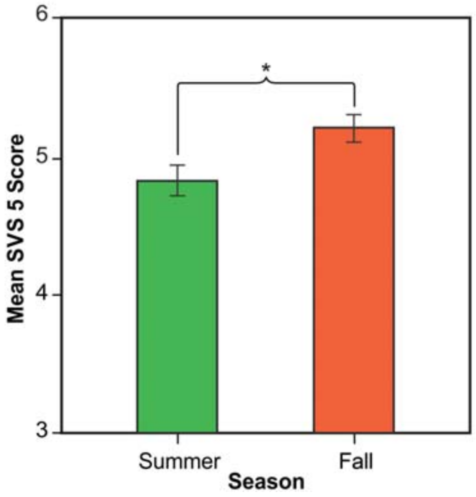


Figure 22. Mean SVS Statement 5 response scores by treatment day for time of day (left) and time of day (right) for all intervention days.

Figure 23. Mean SVS Statement 5 response scores by season.



STATEMENT 6 ("AT THIS MOMENT, I FEEL ALERT AND AWAKE")

Day of intervention significantly affected ($F_{2, 608} = 3.67$, $p = 0.026$) participants' responses to SVS Statement 6 (Figure 24). Mean scores increased steadily from Day 1 (mean ± SEM = 4.58 ± 0.10) through Day 2 (mean = 4.64 ± 0.10) to Day 3 (mean = 4.85 ± 0.09). A higher score is associated with greater vitality.

Responses to Statement 6 peaked at midday, with mean scores increasing from arrival at work (mean = 4.47 ± 0.13) to 12:00 p.m. (mean = 4.92 ± 0.10), and then deceasing from 3:00 p.m. (mean = 4.70 ± 0.09) to the end of the day (mean = 4.68 ± 0.10). This time of day effect was significant ($F_{3, 603} = 4.58$, $p = 0.004$).

Statement 6 was the only SVS measure for which building had a significant effect ($F_{1, 31} = 5.17$, $p = 0.030$) on scores (Figure 25). Mean scores recorded at the VA site (mean = 4.90 ± 0.06) were higher than those at the FHWA site (mean = 4.26 ± 0.10).

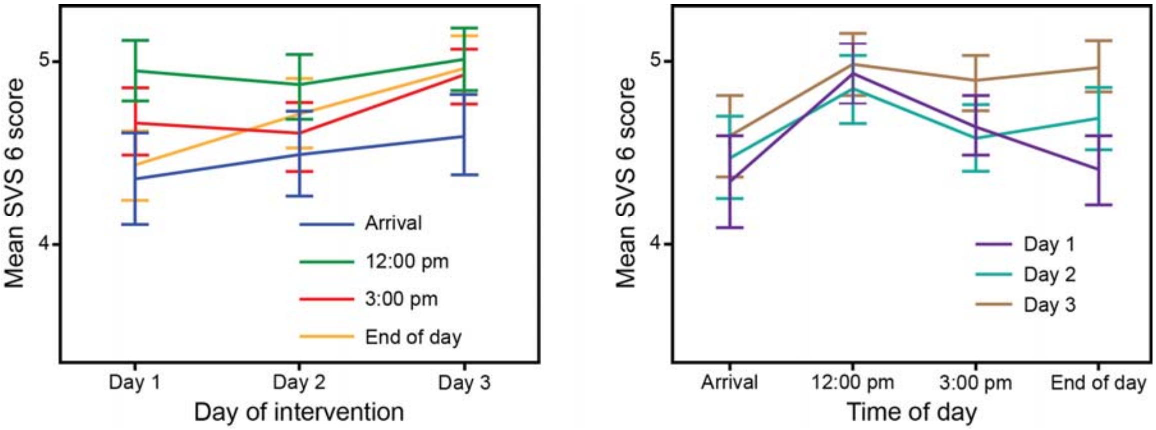
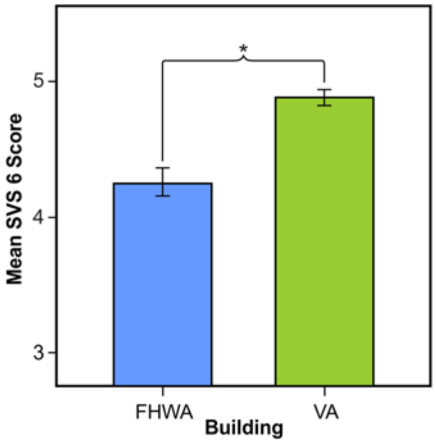


Figure 24. Mean SVS Statement 6 response scores by treatment day for time of day (left) and by time of day (right) for all intervention days.

Figure 25. Mean SVS Statement 6 response scores by building.



STATEMENT 7 (“I FEEL ENERGIZED RIGHT NOW”)

Day of intervention significantly affected ($F_{2,\,609} = 9.02$, $p < 0.0001$) participants' responses to SVS Statement 7 (Figure 26). Across all times of day, their scores increased from Day 1 (mean ± SEM = 4.26 ± 0.11) through Day 2 (mean = 4.35 ± 0.10) to Day 3 (mean = 4.70 ± 0.10). A higher score is associated with greater vitality.

Responses to Statement 7 again peaked at midday, with mean scores increasing from arrival at work (mean ± = 4.19 ± 0.14) to 12:00 p.m. (mean ± = 4.65 ± 0.11), decreasing at 3:00 p.m. (mean = 4.44 ± 0.11), and increasing at the end of the day (mean = 4.45 ± 0.12). This time of day effect was significant ($F_{3,\,605} = 4.37$, $p = 0.005$).

Season also had a significant effect ($F_{1,\,621} = 22.18$, $p < 0.0001$) on responses to Statement 7 (Figure 27), with lower mean scores in summer (mean = 4.24 ± 0.08) compared to fall (mean = 4.70 ± 0.10).

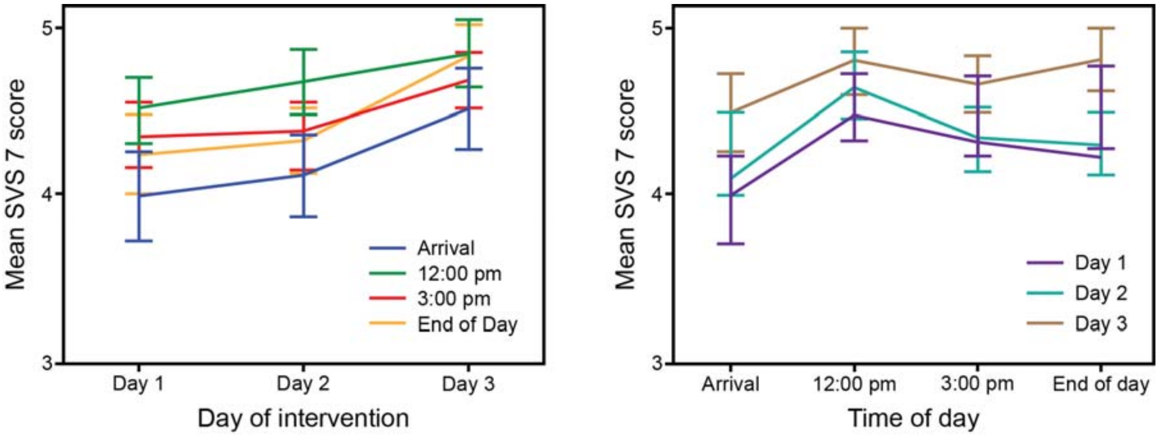
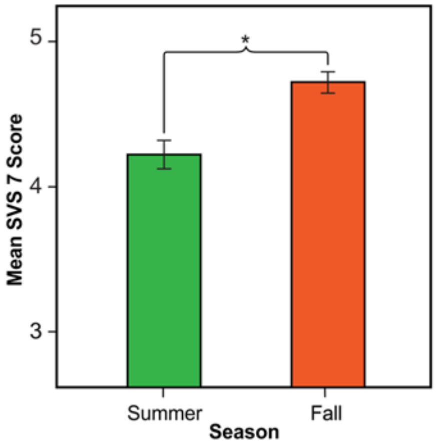


Figure 26. Mean SVS Statement 7 response scores by treatment day for time of day (left) and by time of day (right) for all intervention days.

Figure 27. Mean SVS Statement 7 response scores by season.



DISCUSSION

Phase 1 of the research performed by the LRC and GSA demonstrated that exposure to a CS ≥ 0.3 in the morning was associated with shorter sleep onset latency and greater circadian phasor magnitude (both of which suggest greater circadian entrainment), better self-reports of sleep quality, and lower depression scores. All-day exposure to a CS ≥ 0.3 was also associated with better self-reports of sleep quality and lower depression scores. Given that the results of those earlier studies showed that daytime CS is important for improved sleep and mood, the purpose of the Phase 2 research was to demonstrate: (1) whether circadian-effective light, defined here as delivering a CS ≥ 0.3, could be installed in office buildings and (2) whether this intervention would affect self-reports of subjective sleepiness and vitality for office workers.

On-site photometric measurements demonstrated that both ceiling and desktop luminaires using either cool white or blue light can be used to deliver the desired CS to workspaces. New LED technologies that are now commercially available made it possible for us to deliver our target circadian-effective light in both private offices and cubicles, with and without access to daylight. A secondary goal of the demonstration was to assess user preference for the types of lights employed.

While the LRC has not developed a formal feedback questionnaire about users' experiences with the intervention light sources, and given the fact that most participants were not present when the lights were removed, we nonetheless recorded a few user comments about the desktop lights:

> *"It's too much right in my eyes; maybe it would be more comfortable if it were (mounted) up a little more."*
>
> *"I kinda liked it once I got used to it."*
>
> *"You're taking it away? Where I can I buy one?"*

Because a few of the participants orient their desks and/or computers so that they face the door, a few people commented that the desktop light source blocks their view of visitors (Figure 28).

Regarding the CREE overhead lighting, one of the participants was observed wearing a brimmed hat while the lighting intervention was taking place; when approached, the participant explained that he found the overhead light sources glary. (He confirmed to LRC researchers that he was willing to continue participating in the research without wearing a hat.) An adjacent office neighbor also complained about glare.

Figure 28. For people who sit facing their door, the desktop device may block their view of visitors.

Considered together, these user comments suggest that tuning the lighting intervention's spectrum to decrease the amount of light needed to deliver the desired CS level at the eye may be the most practical way to create more-comfortable working environments.

Users' responses to the desktop lights were slightly mixed. Some participants found that the white light was too bright, while others offered no complaints. Generally speaking, however, the participants did like having the desktop lights in their offices.

In terms of the study's second goal—which was to determine whether the intervention would decrease subjective sleepiness and increase energy/vitality—as we hypothesized, self-reported sleepiness (KSS) scores were reduced, although the reduction was not statistically significant ($p = 0.06$) on Days 2 and 3 (i.e., during the intervention) compared to baseline Day 1. The KSS scores throughout the workday displayed a U-shaped pattern, with higher subjective sleepiness scores upon arrival and at the end of the day and lower scores (indicating less sleepiness) during midday. This pattern changed during the intervention. The KSS scores at each time of the day were divergent on Day 1, but by Day 3 the scores converged around their lower limit at all 4 time points, suggesting that subjective sleepiness remained lower throughout the entire workday. Season had no significant effect on sleepiness scores.

Also as hypothesized, the participants reported feeling significantly more vital, more energetic, and more alert on Days 2 and 3 (i.e., during the intervention) compared to baseline Day 1. Self-reports of vitality increased over the course of the day, indicating greater feelings of vitality at departure than upon arrival. Reported energy levels were greater in the middle of the day than they were upon arrival or at departure.

The use of different lighting modes to deliver the intervention did not produce significantly different results. As expected, if the design criterion is to deliver a CS ≥ 0.3 to participants at eye level, any type of luminaire can be used. It is crucial, however, that the delivered light be comfortable to users in order to avoid non-compliance issues. Over the course of our two-day intervention, no issues relating to user compliance were observed by LRC researchers.

The measured CS values obtained with the Daysimeter worn at chest level were about one third of the values measured at eye level. This difference particularly held true when measuring CS from the desktop luminaire employed in this study, as it was specifically designed to deliver light at the eye and thus had a narrow distribution. We have therefore determined that the Daysimeter was not an appropriate instrument for measuring light that is delivered at the eye from the desktop luminaire. The photometric measurements obtained using the spectroradiometer, however, showed that participants were receiving the desired light dose while working on their computers.

An important consideration to keep in mind is that the lighting intervention was delivered for only 2 consecutive days and, moreover, that the study did not measure or control light exposures outside the work environment. Evening light exposures are just as important as morning light exposures when it comes to entrainment of the circadian system. We cannot determine, however, whether the intervention’s positive results on self-reported sleepiness and energy/vitality scores were mediated by entrainment of the circadian system, because we did not collect any measure of entrainment (e.g., phasor analyse). It is more likely that the observed effects were due to the acute alerting effects that light exerts on people, but we cannot rule out some effect of better entrainment, even though the duration of the intervention was short. It should also be noted that the alerting effects of light have been observed not only with blue and white light exposures, but also with red light exposures. Future studies may test red light’s effect on these outcomes to confirm that these results were indeed not mediated by entrainment of the circadian system.

Unexpectedly, we did not observe any seasonal effect on self-reports of sleepiness, and the seasonal effects that were observed on the vitality/energy scores were contrary to our expectation, as participants reported feeling more energetic and vital during fall rather than during summer. These results are not inconsistent with our Phase 1 results, which did not show a significant seasonal effect on objective measures of sleep and mood.

Participants were asked to fill out the Perceived Stress Scale (PSS) and the Pittsburgh Sleep Quality Index (PSQI) once at start of the study. When adding PSS and PSQI scores to the analyses, PSS had a significant relationship with KSS and with all the vitality statements—the higher the stress, the greater the self-reports of sleepiness and the lower the self-reports of energy, vitality, and alertness.

The present study demonstrated that CS ≥ 0.3 during daytime hours can elicit an acute alerting effect on office workers. Although replication of these results in a larger group is warranted, these initial data are very promising.

CREDITS

LRC Site Researchers: Dr. Mariana Figueiro, Jennifer Brons, Kassandra Gonzales

LRC Research Assistance: Andrew Bierman, Kassandra Gonzales, Geoffrey Jones, Barbara Plitnick, Charles Roohan

Site Evaluation Assistance: Bryan Steverson

Site Coordinators: Sarah Bagby (The VA), Brian Kerr (FHWA)

Graphic Designer: Dennis Guyon

Editor: David Pedler

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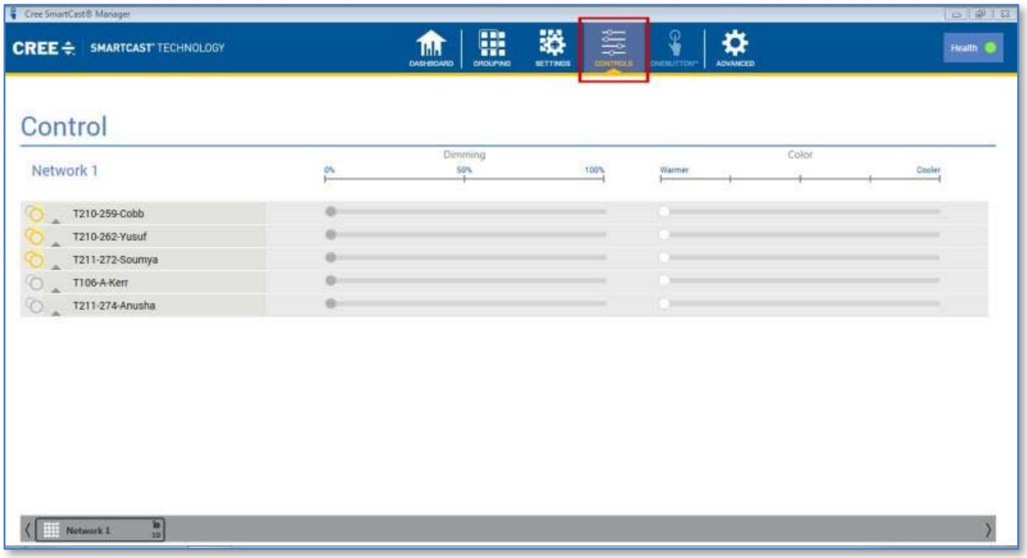
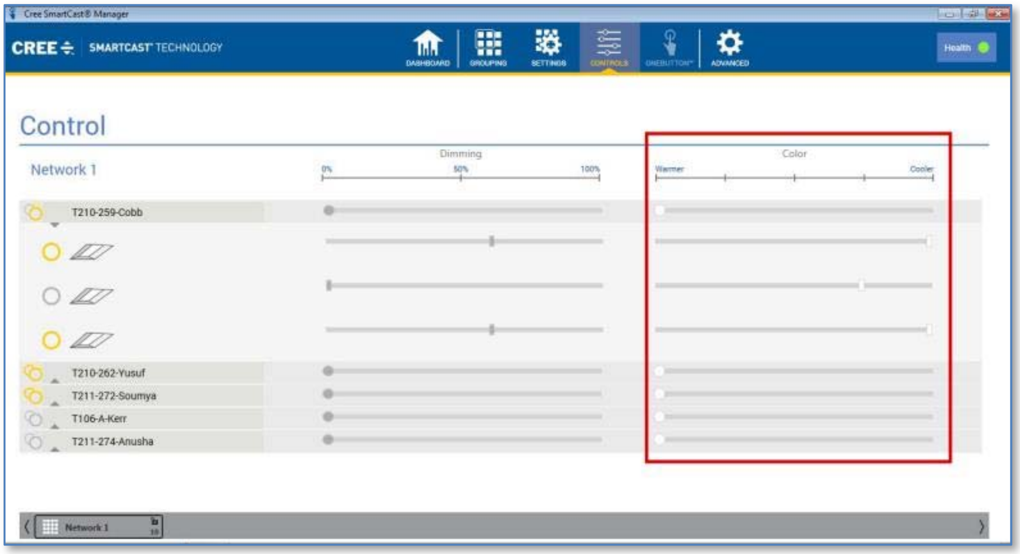
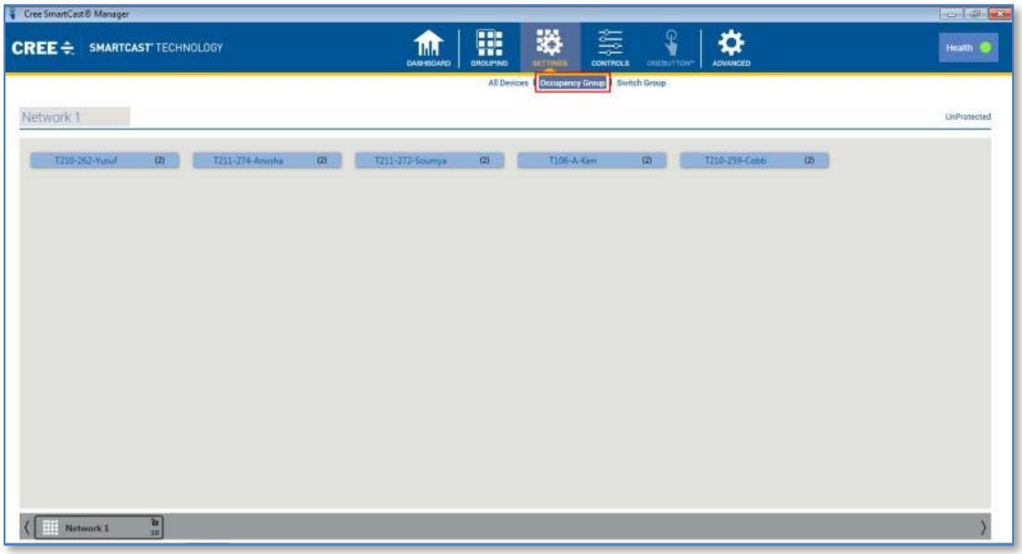
APPENDIX A: CREE PROGRAMMING INTERFACE

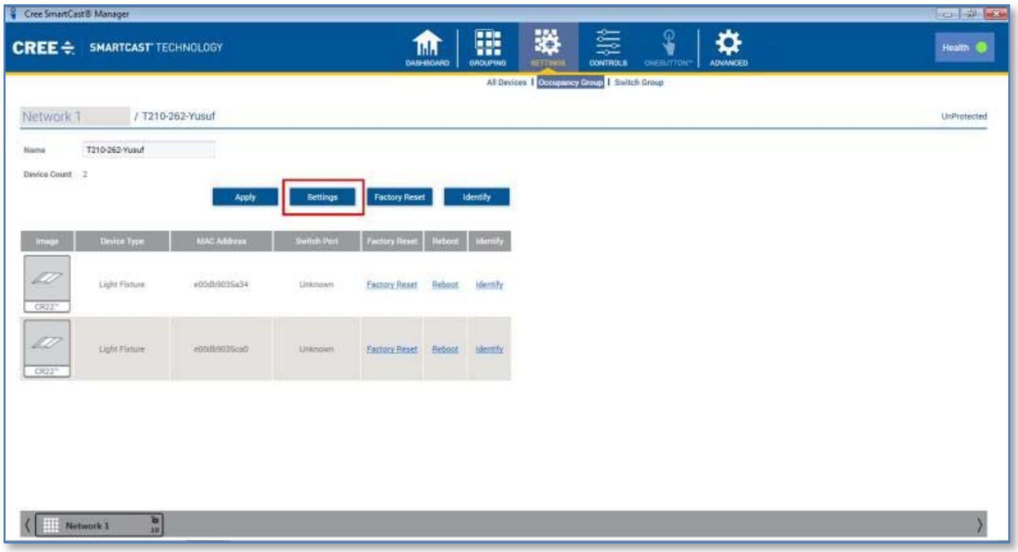
PROCEDURE TO CHANGE CCT





PROCEDURE TO CHANGE LIGHT OUTPUT



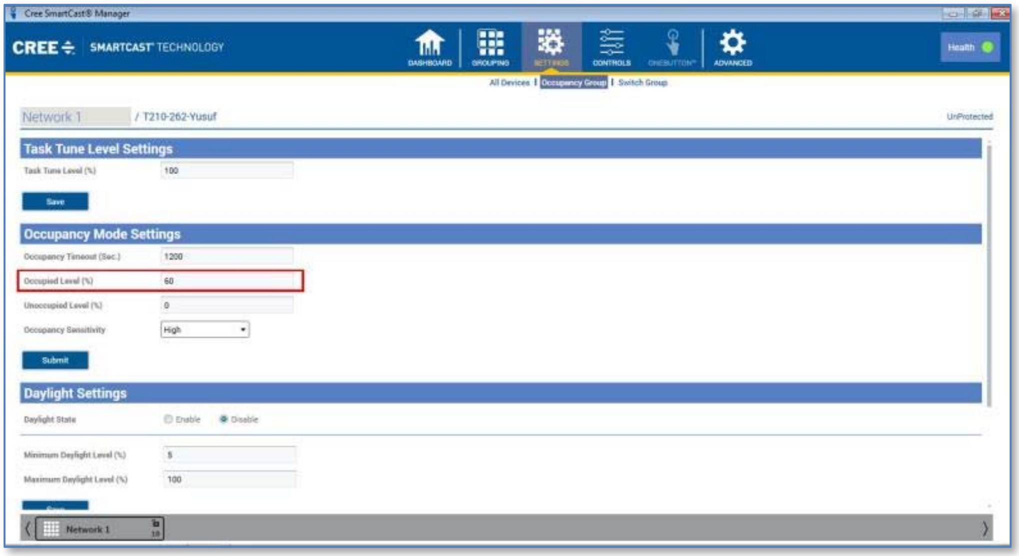


Network 1 / T210-262-Yusuf

Name: T210-262-Yusuf

Device Count: 2

Image	Device Type	MAC Address	Switch Port	Factory Reset	Reboot	Identify
CR22™	Light Fixture	e00db9035a34	Unknown	Factory Reset	Reboot	Identify
CR22™	Light Fixture	e00db9035ca0	Unknown	Factory Reset	Reboot	Identify



Network 1 / T210-262-Yusuf

Task Tune Level Settings

Task Tune Level (%): 100

Occupancy Mode Settings

Occupancy Timeout (Sec.): 1200
Occupied Level (%): 60
Unoccupied Level (%): 0
Occupancy Sensitivity: High

Daylight Settings

Daylight State: ○ Enable ● Disable

Minimum Daylight Level (%): 5
Maximum Daylight Level (%): 100

APPENDIX B: TYPE III TESTS OF FIXED EFFECTS, VA AND FHWA, SUMMER AND FALL COMBINED

Measure/dependent variable	Source	Degrees of freedom		F	Significance
		Numerator	Denominator		
KSS	Intercept	1	74.969	349.500	.000
	day	2	597.120	2.814	.061
	time	**3**	**593.485**	**4.029**	**.007**
	building	1	33.107	2.263	.142
	season	1	618.234	.084	.772
	CS	1	623.131	.029	.864
SVS Statement 1	Intercept	1	63.413	557.809	.000
	day	**2**	**600.693**	**6.175**	**.002**
	time	3	596.077	.934	.424
	building	1	31.958	2.225	.146
	season	1	614.234	1.273	.260
	CS	1	627.549	.420	.517
SVS Statement 2	Intercept	1	73.246	247.447	.000
	day	**2**	**608.988**	**8.761**	**<.0001**
	time	3	603.347	1.544	.202
	building	1	31.094	.824	.371
	season	**1**	**627.109**	**8.791**	**.003**
	CS	1	633.586	.166	.684
SVS Statement 3	Intercept	1	42.220	102.292	.000
	day	**2**	**605.706**	**8.563**	**<.0001**
	time	3	603.934	.379	.768
	building	1	31.951	.529	.472
	season	**1**	**611.178**	**8.069**	**.005**
	CS	1	619.747	.155	.694
SVS Statement 4	Intercept	1	58.859	458.601	.000
	day	**2**	**605.839**	**14.036**	**<.0001**
	time	**3**	**601.422**	**3.893**	**.009**
	building	1	30.392	1.733	.198
	season	**1**	**620.020**	**4.556**	**.033**
	CS	1	634.247	.494	.483
SVS Statement 5	Intercept	1	36.198	314.819	.000
	day	**2**	**604.980**	**3.691**	**.026**
	time	**3**	**604.241**	**3.427**	**.017**
	building	1	32.263	.060	.809
	season	**1**	**607.151**	**38.519**	**<.0001**
	CS	1	610.819	1.440	.231
SVS Statement 6	Intercept	1	71.237	623.963	.000
	day	**2**	**608.606**	**3.667**	**.026**
	time	**3**	**603.066**	**4.581**	**.004**
	building	**1**	**30.851**	**5.166**	**.030**
	season	1	626.438	.908	.341
	CS	1	634.375	.132	.717
SVS Statement 7	Intercept	1	60.194	410.409	.000
	day	**2**	**608.651**	**9.201**	**<.0001**
	time	**3**	**604.891**	**4.374**	**.005**
	building	1	32.844	3.700	.063
	season	**1**	**620.723**	**22.182**	**<.0001**
	CS	1	634.191	.001	.979