LIGHTING FOR HEALTH AND ENERGY SAVINGS

• OFFICE •

Guidance Document

The recommendations in this guidance document are based on the findings of a study conducted by Light and Health Research Center scientists investigating techniques for designing lighting for health and well-being while minimizing energy use.

Goals

There are two goals when lighting for both health and energy savings:

1. Provide the target circadian stimulus (CS) during the daytime because it has been shown to improve mood, increase daytime alertness and improve nighttime sleep quality in office workers
   a. Achieve an actual CS of 0.3 at the plane of the eye.
   b. Design for an average CS of 0.4 to account for shading and other real-world factors, such as furniture placement and surface finishes.
2. Maximize the ratio of CS to lighting energy use.

Findings

- Providing the recommended amount of CS has the potential to use more energy compared to traditional lighting installations designed just for visual performance in commercial spaces.
- Desktop luminaires delivering narrowband short-wavelength (blue) light (used in conjunction with typical overhead lighting) are the most effective at providing the recommended CS of 0.4 using as little energy as possible.
- If desktop luminaires are not used, then design the overhead lighting to provide the recommended CS of at least 0.3 while minimizing energy use. This requires the use of computer software for modeling, which some manufacturers can help with, and comparing several lighting options. Start by considering:
  - Overhead luminaires with a vertical to horizontal illuminance ratio of at least 0.65:1.
  - Luminaires with wide “batwing” distributions and/or pendants with some direct lighting component.
  - Providing an average illuminance level of 500 lx on the workplane.

Light for Human Health Partnership

Light for Energy Efficiency Partnership

Icahn School of Medicine at Mount Sinai

Light and Health Research Center

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This guide was written by Charles Jarboe based on a study by Mariana Figueiro, Charles Jarboe, and Jeremy Snyder. The author thanks David Pedler for his contributions.

Background

Circadian disruption can have negative health effects.

Recent research has shown that electric lighting can be used to promote alertness and improve people's health and well-being by entraining their circadian rhythms to the natural 24-hour light-dark cycle. Studies have shown that disruption of circadian rhythms, which can occur when one is exposed to high light levels at the wrong time or not exposed to light at the right time, is associated with increased risk for negative health outcomes such as metabolic and cardiovascular disease, some forms of cancer, sleep disruption, and various problems relating to mood and general health.

Providing the recommended CS during the daytime can improve sleep quality, mood and alertness in office workers.

Recent studies by Light and Health Research Center (LHRC) scientists at Mount Sinai and the U.S. General Services Administration investigating circadian-effective light exposures among federal office workers, demonstrated that providing a circadian stimulus (CS) greater than or equal to 0.3 during the daytime improved measures of sleep, alertness and mood.

The CS metric is derived from circadian light (CL_A) which is irradiance at the cornea weighted to reflect the spectral sensitivity of the human circadian system. CS is defined as the percent nocturnal melatonin suppression achieved after a one-hour light exposure from threshold (CS = 0.1) to saturation (CS = 0.7). A CS level of 0.3 or greater for at least two hours a day, especially in the morning, was found to be effective at improving sleep quality, and reducing depression in people with Alzheimer's disease and related dementia living in long term care facilities. As such, lighting for improved alertness and circadian entrainment is fast gaining interest among lighting specifiers and manufacturers.

The daytime light levels required for circadian entrainment and alertness are often higher than what is required for visual performance. This has the potential to use more energy compared to traditional lighting installations.

A drawback to delivering high levels of circadian-effective light (or CS) during the daytime is that more energy can be required to deliver the appropriate amount of light to the eye than is required for visual performance.

Specifications

For circadian entrainment and alertness, the LHRC recommends providing CS≥0.3 during the daytime, followed by CS≤0.2 in the evening, and CS≤0.1 in the nighttime.

To account for the shading of light by natural facial features such as the nose and brow, as well as shading from furniture, the LHRC recommends a daytime design target CS value of 0.4 to accommodate for these factors and ensure that most occupants of the space will receive the needed amount of light.

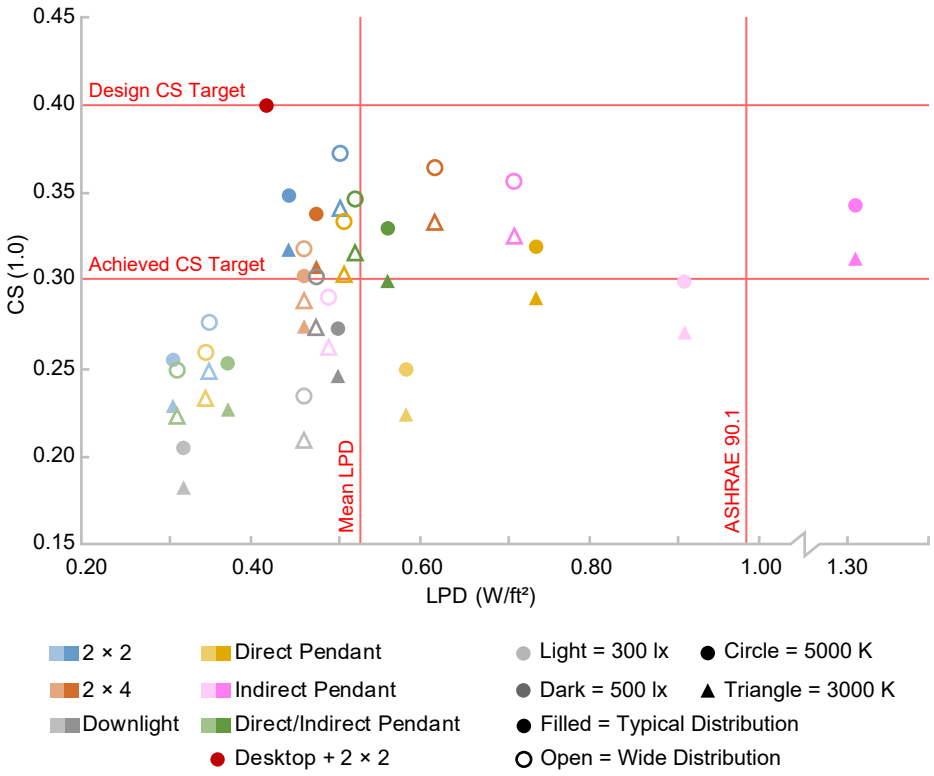
	Circadian Stimulus	
Time of Day	**Achieved**	**Design**
Daytime	0.3	0.4
Evening	0.2	0.2
Nighttime	0.1	0.1

To ensure CS is being delivered while minimizing energy use, the LHRC recommends maximizing the CS:Lighting Power Density (LPD) ratio to the greatest extent possible. And though numerous lighting products and configurations can be used to meet these performance specifications, the "Design Process" section below will point specifiers towards products that are most likely to maximize the CS:LPD ratio.

The LHRC has additionally published a more detailed specification and recommended practice for designing circadian-effecting lighting as part of an initiative with Underwriters Laboratories (UL).

The chart below shows the CS to LPD performance of the six luminaire types evaluated for this study, as well as the desktop luminaire, at two target horizontal illuminance levels (300 lx and 500 lx), two CCTs (3000 K and 5000 K) and two intensity distributions (typical and wide). These conditions were chosen for demonstration purposes and can be achieved with any light levels and any CCT.

Design for a CS of 0.4 to ensure that most occupants receive a CS of 0.3



Design Process

Step 1 Decide if desktop luminaires can be used

The circadian effectiveness of the overhead lighting is far less important if desktop luminaires can be used to provide high CS to occupants in the space

Decide early in the design process if you are going to use desktop luminaires, or overhead lighting only

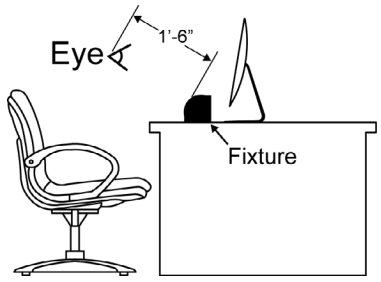
Consider an additional layer of light in the vertical plane close to the eyes of the occupants. This was the most effective technique for providing CS of at least 0.3 at the eye for the lowest LPD (results from this study showed 0.06 W/ft² less than the overhead lighting system with the lowest LPD that provided a CS of at least 0.3).

Desktop luminaires can be especially useful when horizontal illuminance and/or CCT constraints make CS delivery difficult from overhead luminaires alone, and were the only luminaire type capable of achieving the design target CS value of 0.4 without exceeding 500 lx horizontal or 5000 K CCT.

Desktop luminaires delivering blue light were the most effective at providing high CS for as little energy as possible

To achieve a CS of 0.3, 14 lx of blue light at the eye (in addition to the 2×2 troffer delivering 300 lx horizontal at 3000 K) were needed from the desktop luminaire, for an additional 0.04 W/ft².

Unfortunately, there are currently very few, if any, commercially available products similar to the luminaire used in this study.



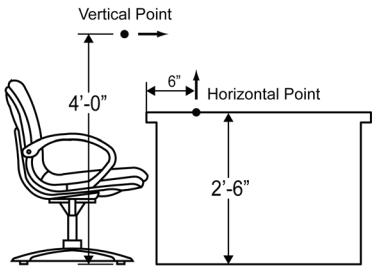
If desktop luminaires cannot be used...

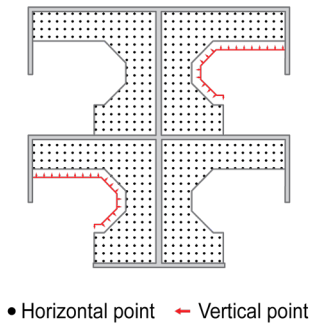
Step 2A Model your space

Build a 3D computer model of the environment in a photometric simulation program such as AGi32 and arrange vertical and horizontal illuminance calculation points

Some manufacturers may offer photometric simulation services, or provide assistance with the process upon request.

Use a photometric simulation model of the space you are designing to calculate horizontal illuminance on the work plane, as well as vertical illuminance at the eye of occupants in the space. Arrange horizontal calculation points on the work plane in a 6" × 6" grid, as well as vertical points along a line 4'-0" above finished floor pointed in the direction of the eye of an occupant seated at that location. Using the spectral power distribution (SPD) of the light source you are using, calculate CS using the web CS calculator developed by the LHRC: https://cscalc.light-health.org/





Step 2B Design overhead lighting to provide adequate CS and maximize CS:LPD

Specify overhead luminaires with an intensity distribution and correlated color temperature (CCT) that will most likely provide a high CS for limited energy use

Look for overhead luminaires with a vertical to horizontal illuminance ratio of at least 0.65:1

Troffers with wide "batwing" distributions and pendants with some direct lighting component will be most likely to provide the CS target with the lowest energy use

A CCT of 5000 K is more likely to achieve the target CS value than a CCT of 3000 K, though illuminance plays a larger role

Percent of Overhead Luminaires that Provided CS ≥ 0.3

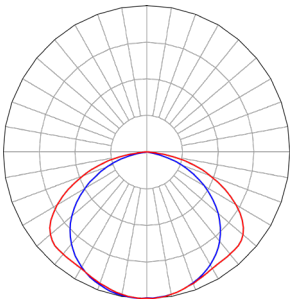
E_H Target	3000 K	5000 K
300 lx	8%	33%
500 lx	83%	92%

Providing the achieved criterion CS value of 0.3 for the entire work day is the most energy efficient schedule option that provides adequate morning light for entrainment, and afternoon light for alertness

Intensity Distribution

Because light has to reach the back of the observer's eye, and current lighting standards are based on horizontal illuminance, a luminaire intensity distribution that provides a higher vertical to horizontal illuminance ratio can increase CS:LPD ratios.

2×4 Troffer



Typical - E_V:E_H Ratio = 0.74:1
Wide - E_V:E_H Ratio = 0.78:1

Evaluate the intensity distributions of lighting products using photometric simulation software and favor products that deliver a high vertical to horizontal illuminance ratio of at least 0.65:1.

Troffers with wide "batwing" distributions, as well as pendant luminaires with some direct lighting component as well as an indirect component will be the most likely to have a high vertical to horizontal illuminance ratio, and provide relatively more CS to the eye for an equal amount of energy.

CCT & Illuminance

The SPD (not just the CCT) of the light source is important to know. At 3000 K, CS ranged from 0.22 to 0.26 for eight different SPDs.

When feasible, provide higher light levels (500 lx horizontal) during the daytime hours. Increasing illuminance levels from 300 lx horizontal on the work plane to 500 lx played a larger role in increasing CS than increasing CCT from 3000 K to 5000 K.

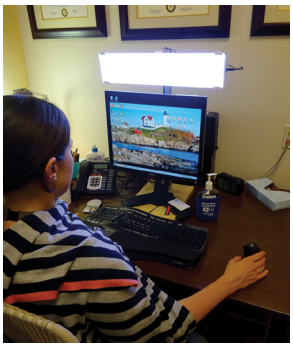
Consider higher CCT light sources (5000 K) to promote circadian entrainment and alertness during the daytime. If warmer CCTs are desired, however, keep in mind that the average LPD of fixtures providing a CS of at least 0.3 at 5000 K was 5% lower than the LPD of fixtures providing the same CS at 3000 K.

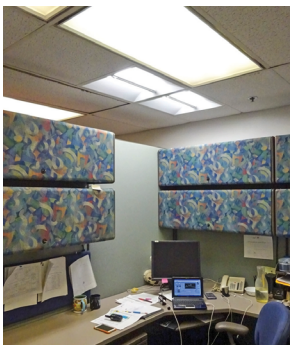
CS Dosage Schedule

Static or tunable-white LED lighting systems can modulate CS delivery at different times of day, potentially saving energy by reducing light levels in the afternoon hours. However, while morning light is most important for circadian entrainment (coupled with reduced evening and nighttime light exposures), afternoon light levels are important for promoting alertness and should not be reduced too dramatically without the addition of supplemental red light from desktop luminaires.

The present study found that providing CS of 0.3 (achieved) for the entire workday (7:00 a.m. - 6:00 p.m.) required less energy than providing a CS of 0.4 in the morning (7:00 a.m. - 12:00 p.m.) followed by a CS of 0.2 in the afternoon (12:00 p.m. - 6:00 p.m.), with red light from desktop luminaires for alertness.

Case Studies





Lighting intervention. (top) An office worker uses a desktop luminaire; (bottom) CREE PoE SmartCast 2×2 troffers installed in an office workspace.

Circadian Light and Its Impact on Alertness in Office Workers

LHRC researchers completed a field study (sponsored by the U.S. General Services Administration) to demonstrate whether circadian-effective lighting with a CS of at least 0.3 or greater installed in office buildings can increase alertness, vitality and energy in office workers.

Methods

- Thirty-six participants from the Veterans Affairs (VA) Medical Center in White River Junction, VT, and the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center participated in the study.
- Overhead lighting using a Power Over Ethernet (PoE SmartCast; CREE Lighting) system was installed at the FHWA site.
- Desktop luminaires were installed at both sites.
- The study took place over a three day period. One day of baseline data collection and two days of post-intervention data.
- Participants wore Daysimeters to measure light exposure, and completed questionnaires to record subjective sleepiness, vitality and energy scores.

Results

- Self-reported sleepiness scores were reduced and remained lower throughout the entire workday on days two and three of the study.
- Participants reported feeling more vital, energetic and alert during the intervention period compared to baseline.

24-Hour Lighting Scheme for Older Adults

LHRC scientists proposed a 24-hour lighting scheme for older adults in an assisted living facility that can positively impact the aging visual, circadian and perceptual systems.

Methods

- The 24-hour lighting system delivered high CS (min. 400 lx at the eye from a circadian-effective light source with more short-wavelength energy) during the day, and low CS (less than 100 lx at the eye from a light source with less short-wavelength energy) at night.
- New lighting was installed in eight rooms in an assisted living facility and participants were surveyed on their preference for the new lighting.
- Sleep quality and activity patterns were measured before and after the lighting installation.

Results

- The four participants who completed the study showed an improvement in sleep quality and activity/rest patterns under the new 24-hour lighting scheme.
- All eight participants reported a strong preference for the 24-hour lighting compared to the previously installed “baseline” lighting system.

Proposed lighting scheme with high CS by day and low CS at night.

Resources

Circadian Stimulus Web-based Calculator

Since December 2016, the LHRC has offered a free, open-access Circadian Stimulus (CS) Calculator to help lighting professionals select light spectra and levels to determine the potential circadian-effective light exposure in the architectural spaces.

The LRHC's new web-based CS Calculator 2.0 was made available in 2021. The calculator is viewable on all major browsers and devices for convenient, practical on-the-fly calculations in the field. The latest calculator permits users to estimate CS levels in spaces with multiple light sources by uploading user-specified sources and variables.

https://cscalc.light-health.org/