LIGHTING FOR HEALTH AND ENERGY SAVINGS

• K-12 CLASSROOM •

Guidance Document

The recommendations in this document are based on the findings of a study conducted by the Light and Health Research Center investigating techniques for designing lighting for health and well-being while minimizing energy use in a K-12 classroom.

Goals

There are two goals when lighting for both health and energy savings in a classroom environment:

1. Provide the target circadian stimulus (CS) during the school-day to improve sleep quality, psychological well-being, and daytime alertness and potentially increase scholastic performance in K-12 students.
   a. Achieve a delivered 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 power demand.

Findings

- Providing the recommended level of CS has the potential to use more energy compared to traditional lighting installations designed for visual performance in classrooms.
- A supplemental layer of overhead lighting delivering narrowband short-wavelength (blue) light (used in conjunction with typical overhead lighting) is the most effective at providing the recommended design target CS of 0.4 using as little energy as possible.
- If supplemental blue light is not used, design the general 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, and comparing several lighting options. Start by considering:
  - Overhead luminaires with a vertical to horizontal illuminance ratio of at least 0.60:1.
  - Luminaires with diffuse distributions and/or pendants with some direct and a 'batwing' indirect 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, Jennifer Brons, Allison Thayer and Charles Jarboe. The author thanks David Pedler for his contributions.

Background

Delayed circadian phase can reduce sleep duration and scholastic performance in K-12 students.

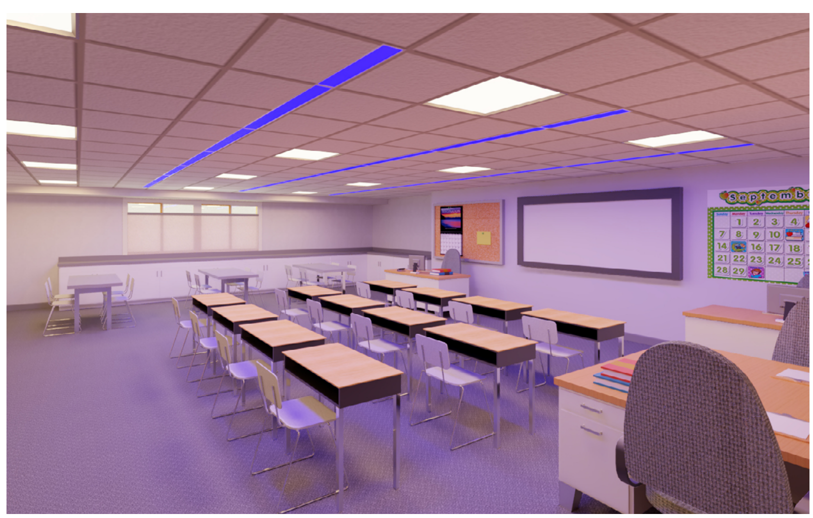
Young school-age children begin to exhibit gradual shifts in their circadian rhythm and sleep-wake cycle, with preferences for later sleep-onset and wake times beginning at approximately 5-7 years of age [1]. This can cause reduced sleep duration because the naturally occurring delays in the sleep-wake cycle conflict with rigid school schedules that require earlier than desired wake times. This circadian desynchrony is often compounded by inadequate levels of early morning circadian stimulation from low electric light levels in the built classroom environment. A lack of adequate morning light exposure to advance and re-entrain the circadian clock to the natural 24-hour light-dark pattern, and exposure to excessively high nighttime light levels from self-luminous displays and other electric light sources, has the potential to cause further reductions in sleep quality that can negatively affect scholastic performance in K-12 students.

Providing adequate daytime CS levels, and limiting evening light exposures, can improve circadian entrainment and sleep quality in adolescents.

Recent studies by researchers at the Light and Health Research Center (LHRC) at Mount Sinai have demonstrated that a lack of morning light combined with exposures to high levels of evening light can significantly delay dim light melatonin onset (DLMO) in adolescents [2] [3]. As a result, the LHRC recommends providing students with a daytime circadian stimulus (CS) of 0.3 or greater and limiting exposures to evening light to avoid circadian disruption and negative sleep outcomes.

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 in classrooms.

The CS metric is derived from circadian light (CLA), 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 psychological wellbeing in various populations such as office workers and people living in long-term care facilities. As such, lighting for improved alertness and circadian entrainment is fast gaining interest among lighting specifiers and manufacturers.



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 alone.

Specifications

Provide a CS ≥ 0.3 in the classroom for the entire school day to ensure students are exposed to at least 2 hours of high CS levels.

For circadian entrainment and alertness, the LHRC recommends providing CS ≥ 0.3 during the entire typical school day (roughly 8 am to 3 pm) to ensure students receive at least 2 hours of exposure throughout the day, followed by CS ≤ 0.2 in the late afternoon, and CS ≤ 0.1 in the evening.

To account for the shading of light by facial features such as the nose and brow, as well as shading and absorption 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.

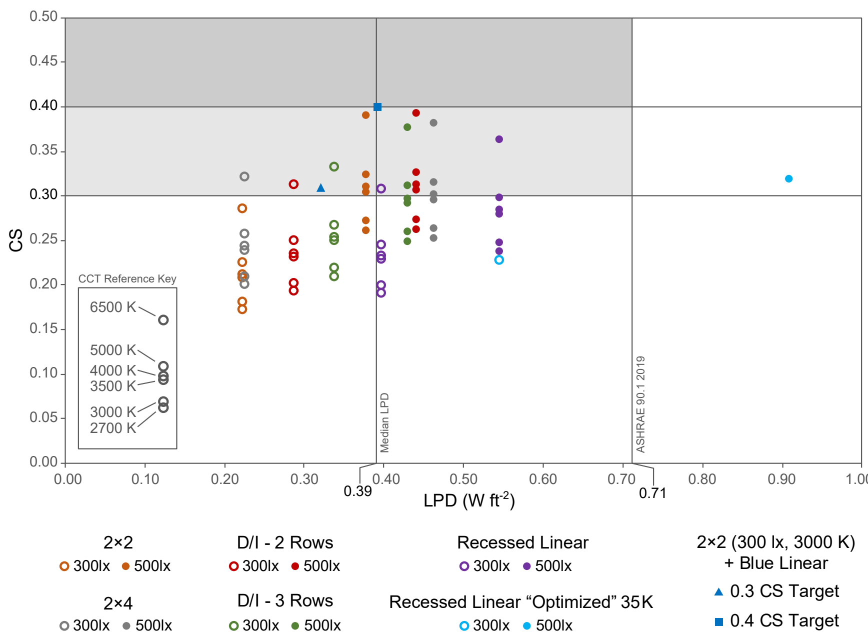
To ensure CS is being delivered while minimizing energy use, maximize the CS-to-Lighting Power Density (LPD in W ft^{-2}) ratio to the greatest extent possible. And though numerous lighting products and configurations can be used to meet these performance specifications, the "Design Process" section below will point specifiers towards products that are most likely to maximize the CS:LPD ratio for a classroom application.

Time of Day	**CS**
School day	≥ 0.3
Late Afternoon	0.2
Evening	≤ 0.1

Further detailed specifications and methodologies for designing circadian-effective lighting for day-active people can be found in the recently published UL Design Guideline 24480.

The chart below compares the CS:LPD performance of the five luminaire types and layouts evaluated for this study at two target horizontal illuminance levels (300 lx and 500 lx), and six CCTs (2700, 3000, 3500, 4000, 5000, and 6500 K), as well as a 'spectrally optimized' source, and a supplemental blue light layer used in combination with the 2×2 troffer at 300 lx and 3000 K targeting both a CS of 0.3 and 0.4.

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



Comparison of CS and LPD performance for the different luminaire types and configurations examined in this study. Designs should aim to be at least within the light gray zone providing a daytime CS of 0.3 or greater while staying below ASHRAE guidelines for a maximum LPD of 0.71 W ft^{-2}. The median LPD was derived from the entire set of LPD values for each lighting condition evaluated for the study.

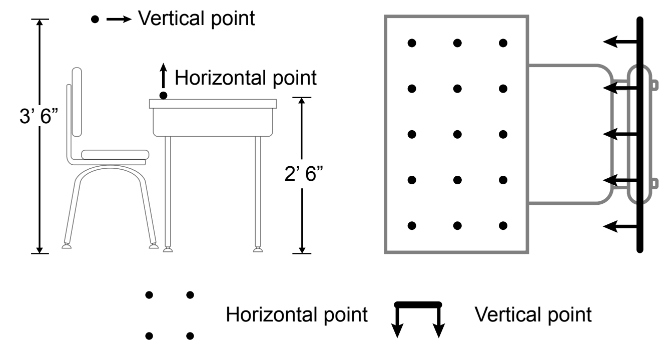
Design Process

Step 1 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 3’-6” 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 2A Decide if a supplemental layer of blue light can be used

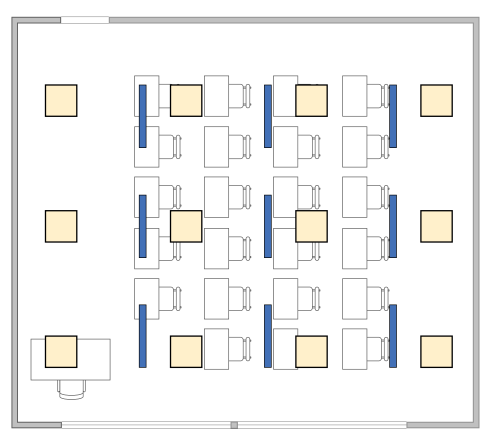
The circadian effectiveness of the general overhead lighting is far less critical if supplemental blue light can be used to provide high CS to occupants in the classroom space

Decide early in the design process if you are going to use an additional layer of blue light to supplement the typical overhead lighting.

Using supplemental blue light was the most effective means of providing a CS of 0.3 for as little energy as possible without exceeding 5000 K CCT.

Consider a layer of short-wavelength “blue” light in the ceiling to supplement the typical overhead lighting. In the previous chart, this was the only configuration capable of delivering a CS of 0.4 without exceeding 500 lx on the workplane or 6500 K CCT, and was the most energy-efficient means of delivering a CS of 0.3 without exceeding 5000 K, regardless of horizontal illuminance level.

Supplemental blue light can be especially useful when horizontal illuminance, CCT, and/or aesthetic constraints make adequate CS delivery difficult from traditional overhead luminaires alone.



To achieve a CS of 0.3, 8 lx of blue light at the eye (in addition to the 2×2 troffer delivering 300 lx horizontal at 3000 K) was needed from the supplemental layer, for an additional 0.09 W ft^{-2}. For a CS of 0.4, 16 lx of blue light was needed for an additional 0.17 W ft^{-2}.

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 providing an E_V:E_H ratio of at least 0.60:1.

Troffers with wide, diffuse distributions and pendants with some direct and a "batwing" indirect lighting component are most likely to provide the CS target with the lowest energy use.

Though illuminance plays a larger role, a high CCT (5000 K or 6500 K is more likely to achieve the target CS value than a CCT of 3000 K.

Percent of Overhead Luminaires that Provided CS ≥ 0.3

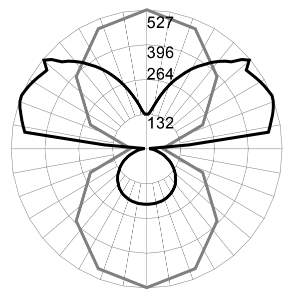
E_H Target	3000 K	5000 K	6500 K
300 lx	0%	0%	80%
500 lx	0%	100%	100%

The "spectrally optimized" source provided slightly more CS than the standard 3500 K source, but required 70% more energy to achieve a CS of 0.3.

Intensity Distribution

Light has to reach the back of the observer's eye to be circadian-effective. However, because current lighting standards are based on horizontal illuminance, a luminaire intensity distribution that provides a high vertical-to-horizontal illuminance (E_V:E_H) ratio can increase CS:LPD ratios.

Direct/Indirect Pendant



E_V:E_H Ratio = 0.60:1

Evaluate the intensity distributions of lighting products using photometric simulation software; favor products that deliver a high E_V:E_H ratio of at least 0.60:1.

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

CCT & Illuminance

When feasible, provide higher light levels (500 lx horizontal) during the school-day 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 or higher) to promote circadian entrainment and alertness during the daytime. If warmer CCTs are desired, keep in mind that the average LPD of fixtures providing a CS of at least 0.3 at 6500 K was 9% lower than the LPD of fixtures providing the same CS at 3500 K.

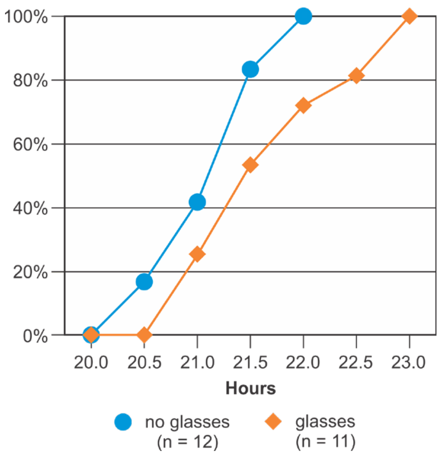
Some manufacturers are beginning to offer light sources "spectrally optimized" to deliver high circadian stimulation during the day or low stimulation at night. The "spectrally optimized" 3500 K source used for the analysis provided marginally higher CS than the standard 3500 K source, but required much more energy (0.37 additional W ft^{-2}) than the standard recessed linear fixture at 500 lx due to much lower luminous efficacy (lm/W). Therefore, use caution when specifying such sources as they may be much less energy efficient.

CS Schedule

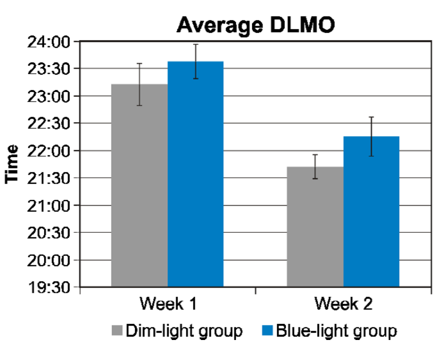
Providing high CS in the morning for at least 2 hours is most important in a K-12 classroom. However, students often change learning environments throughout the school-day, reducing the likelihood they will be exposed to 2 hours of continuous CS levels of at least 0.3. Therefore, provide a CS of at least 0.3 in the classroom for the entire school-day. However, if students will remain in the same classroom for most of the school-day, it is possible to reduce the CS level to 0.2 in the early afternoon (1 - 2 pm) to reduce energy consumption while still promoting entrainment.

Case Studies

Smith Middle School students wearing orange-tinted glasses and Daysimeters.



Cumulative frequencies of DLMO for both groups. Y-axis shows percentage of students who reached DLMO for the hours of 20:00 to 23:00. Those not wearing the orange-tinted glasses reached DLMO earlier than those wearing the glasses.



Mean DLMO +/- SEM by Week and Group. Saliva samples were taken to determine the timing of DLMO. There was a significant difference in circadian phase for participants in the dim-light (n=13) and blue-light (n=12) groups, but no significant difference between groups.

Quantifying Impact of Lighting on K-12 Students' Performance and Well-being

LHRC researchers completed a field study (sponsored by the U.S. Green Building Council) to quantify daytime light exposures of K-12 students and determine whether circadian light exposure can promote entrainment and improve scholastic performance in school.

Methods

- Twenty-two students participated in the study at Smith Middle School in Chapel Hill, NC.
- Daily light exposures were measured using a personal circadian light meter called a Daysimeter, a device developed by the Light and Health Research Center.
- Half of the students wore orange-tinted glasses during school hours to prevent short-wavelength, circadian-effective light exposure.
- Researchers collected salivary melatonin samples to determine the students' dim light melatonin onset (DLMO).
- Students completed standardized performance tests twice daily during school hours and self-reported sleepiness.

Results

- Students wearing the orange-tinted glasses had DLMO delayed by 30 minutes and experienced worse circadian entrainment and increased sleep latency.
- Standardized test scores indicated that students wearing the orange-tinted glasses had lower scholastic performance levels.

Short-wavelength (Blue) Light, Sleep/Wake Schedule, and Circadian Phase in Young Adults

LHRC researchers examined the effects of an advanced sleep/wake schedule and morning short-wavelength blue light on circadian phase among young adults with subclinical features of delayed sleep phase disorder (DSPD).

Methods

- 12 men and 13 women (ages 18-30 years) with late sleep schedules participated in the study.
- Participants wore Daysimeters to measure circadian light exposures and rest/activity patterns.
- Participants kept their normal sleep schedules for the first week of the study. They kept a fixed, advanced sleep schedule (1-2.5 hours earlier) the following week and, upon waking, one half of the participants (blue-light group) were exposed to one hour of short-wavelength (470 nm) blue light from a light box.

Results

- After six days of the advanced sleep/wake schedule, both groups showed significant circadian phase advance.
- Light/dark exposures associated with early sleep schedules were sufficient to advance circadian phase in young adults.

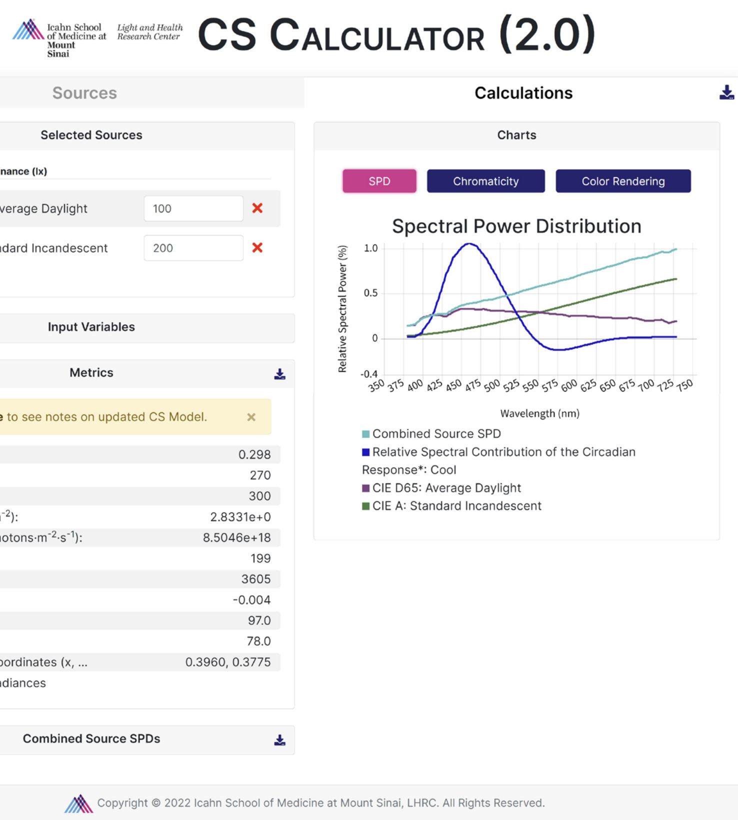
Resources

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/



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3. Figueiro MG, Rea MS (2010) Evening daylight may cause adolescents to sleep less in spring than in winter. Chronobiol Int 27, 1242-1258