Circadian lighting for designers and manufacturers

Circadian-effective lighting to promote circadian entrainment requires designers to create a CS schedule that mimics the daily pattern of light and dark that provided by the solar cycle. As indicated in the UL Design Guidelines, the circadian lighting design process includes six essential steps:

Step 1: Establish a circadian-effective lighting design criterion (e.g., CS = 0.3)
Step 2: Select a luminaire type (e.g., direct/indirect)
Step 3: Select a light source (e.g., 3000 K LED)
Step 4: Perform photometrically realistic software (e.g., AGi32) calculations for the building space
Step 5: Calculate CS from the vertical illuminance at the eye (EV) and the light source's spectral power distribution (SPD)
Step 6: Determine whether the lighting system meets the circadian-effective lighting design criterion; repeat steps 2 – 6 if necessary

Step 1- CS criterion is dependent on:

Chronotype & sleep/wake cycle

Occupants are the most important considerations in circadian lighting design and the establishment of a design criterion CS for Step 1. Are you designing for one person, a small work group, or a large open office? What are their ages? Age-related changes to the eye can render CS prescriptions for elementary school students to be inappropriate for office workers or seniors in eldercare environments. It is also very important to take into account where, when, and how the occupants use the space. If it's an office or other kind of workplace, do the occupants always work in the same spot or do they move around? Do they work evenings or shifts? When do they sleep, and what kind of light exposures do they experience when they are not in the space? Establishing these parameters helps designers to determine appropriate CS exposures and the timing of their delivery.

Time of day

Target CS depends on the time of day or night. As learned previously, at the right spectrum and brightness, light can delay the onset of the body's hormones, specifically melatonin which is released at night and in dark conditions. If this occurs, the body will not be synchronized with the solar day which can cause negative short-term and long-term effects. Proper circadian designs will provide a CS ≥ 0.3 in the morning and even afternoon hours, and provide a CS < 0.1 at night to not disrupt the circadian system.

Duration of exposure

Humans are far more sensitive to light stimulus at night than in the middle of the day. Experiencing high levels of light later in the day and in the evening will delay circadian phase, causing us to fall asleep later than our usual bedtime, leading us to sleep-in or feel tired on waking the next day. Conversely, experiencing high levels of short-wavelength light early in the morning will reset the master biological clock, advancing our circadian phase and helping to entrain our circadian system to the solar day. Because the circadian system free-runs at a period that is longer than the solar day, we need light early in the day to maintain regular bedtimes. Longer light exposure durations are also more effective at suppressing melatonin.

Light history

While it is well-accepted that exposure to higher light levels results in greater melatonin suppression at night, research also shows that a one-day light exposure of 200 lux suppresses melatonin to a greater degree when it is preceded by 3 days of dim light (< 1 lux) compared to 3 days of the same 2000-lux source [21]. While the visual system's response to light is virtually instantaneous, the circadian system's response to light is cumulative [22].

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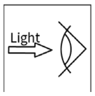
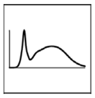
Steps 2 & 3- Light source components contributing to CS:



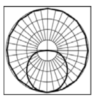
Illuminance at the eye, or vertical illuminance (Ev)

Existing lighting practice is concerned with how much light gets to a work plane, also known as horizontal illuminance (Eʜ). Circadian design, however, is concerned with the amount of light that gets to the eye, which is known as vertical illuminance (Ev). The internal circadian clock in the brain interprets signals from the photoreceptors in the eye to use as cues for determining what time of day it is. The circadian system is particularly sensitive to amount of light.



Spectral power distribution (SPD)

The circadian system is also sensitive to spectrum (i.e., color). All light is composed of a combination of wavelengths. The circadian system is "blue sky detector"; light containing more power in short wavelengths (blue) will have a greater impact on the circadian system than longer wavelengths (red).



Intensity distribution

Typical light fixtures mounted near the ceiling shine light downward onto the workplane. For circadian effectiveness, lighting designers should aim light toward the eye as well. This can be done with direct/indirect fixtures, fixtures mounted to vertical planes, or light that washing vertical planes. Since light on the workplane is important for visibility, use fixtures with a vertical-to-horizontal illuminance ratio approaching 1:1. Alternatively, provide separate layers of light within a space.

Steps 4, 5, & 6- Calculating CS:

Calculate vertical illuminance at the eye for the space (Step 4). The checklist at right provides a comprehensive overview of the components of circadian design, the tools required, and the desired outcomes. Lighting design software and manufacturers' published photometric data files (IES, or *.ies) are especially valuable tools for Step 4, as they permit simulated predictions of illuminance and lighting power density (LPD). When designing only for vision, the lighting design process stops at this stage.

In Step 5, use the CS calculator, including vertical illuminance data from Step 4, combined with source SPD. (https://www.lrc.rpi.edu/cscalculator/)

Step 6 involves iteration of steps 2-5 to achieve target CS. If the lighting design does not meet the criterion CS, adjust some of the components shown in the checklist at right. Successful lighting designs grow from a dynamic interchange between architects, lighting designers, and manufacturers; several iterations may be required with input from any of these stakeholders to achieve optimal CS performance.

Information about the room	Facility and room type
	Occupants
	Area of room
	Ceiling height
	Room reflectances: Ceiling, walls, floor
	Room layout (location of occupants)
	Work plane height (to find horizontal illuminance)
	Eye level height (to find vertical illuminance)
Circadian Lighting Solutions	Lighting systems and CS schedules
	Static vs color-tunable lighting systems
	Desired CCT
Fixtures	Retrofit or new design
	Fixture type(s)
	Personal lighting device
	Intensity distribution
	Orientation of fixture: direct vs indirect
	Mounting height
	Maximum lumen output
	Initial wattage
	Fixture spacing
	SPD
	Number of fixtures
	Light loss factors (depreciation factors)
Computer design	Lighting design software
	IES file(s) for fixture(s)
	CS calculator
Applied design	Illuminance meter
	Spectroradiometer
	Tape measure
	Installation of test fixtures
	Control system: Dimming and/or color tuning
	Daysimeter
	CS calculator
Results	Average EV
	Average CS at occupant locations
	Average EH
	Maximum LPD
	Energy usage

References

UL Design Guidelines: https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=36592

Lighting Research Center’s CS Calculator: https://www.lrc.rpi.edu/cscalculator/

[21] Smith KA, Schoen MW, Czeisler CA (2004) Adaptation of human pineal melatonin suppression by recent photic history. *J Clin Endocrinol Metab* **89**, 3610-3614.

[22] Figueiro MG, Nagare R, Price LLA (2018) Non-visual effects of light: How to use light to promote circadian entrainment and elicit alertness. *Light Res Technol* **50**, 38-62.