# Designing with Circadian Stimulus

The Lighting Research Center proposes a metric for applying circadian light in the built environment

BY MARIANA G. FIGUEIRO, KASSANDRA GONZALES AND DAVID PEDLER

Lighting for the circadian system is quite different from traditional architectural lighting design. Generally speaking, the latter approach has focused primarily on visibility and related concerns such as reduction of glare and shadow, color rendering, safety and the appearance of the space. While not unconcerned with these factors, designing for the non-visual effects of light, such as circadian entrainment and alertness, involves different lighting design objectives and, therefore, metrics that are different from those currently used by lighting designers.

All living organisms on Earth exhibit circadian rhythms, which are biological cycles that repeat themselves on a daily basis and are regulated or *entrained* by environmental signals, the most important one being the natural, 24-hour, light-dark cycle. In humans and the vast majority of animals, patterns of light and dark reaching the back of the eyes are converted to neural signals that promote synchronization of the body's "biological clock" with the local time on Earth. Without this synchronization, research has shown that we may experience long-term decrements in physiological function, neurobehavioral performance and sleep, and are put at a higher risk for cardiovascular disease, diabetes and certain forms of cancer.

Lighting characteristics affecting the circadian system, as measured by acute melatonin suppression and phase shifting of dim light melatonin onset (i.e., the time in the evening when melatonin levels start to rise), are different from those affecting visibility. The Lighting Research Center at Rensselaer Polytechnic Institute has been developing metrics and tools to help designers and specifiers understand and apply circadian light in the built environment. We have proposed a metric called circadian stimulus (CS) that has played a key role in the field of lighting design for healthy buildings.





## CALCULATING CS

When specifying lighting for the circadian system, it is important to consider light level, spectrum (color), timing and duration of exposure, and photic history (previous light exposures). An important first step in establishing whether a lighting system will deliver a prescribed amount of CS is to determine the spectral irradiance distribution of the light incident at the cornea. From this spectral irradiance distribution it is then possible to calculate circadian light (CLA), which is irradiance at the cornea weighted to reflect the spectral sensitivity of the human circadian system as measured by acute melatonin suppression after a one-hour exposure, and CS, which is the effectiveness of the spectrally weighted irradiance at the cornea from threshold (CS = 0.1) to saturation (CS = 0.7).

Our research with Alzheimer's disease patients, office workers, teenagers and healthy older adults shows that exposure to a CS of 0.3 or greater at the eye, for at least one hour in the early part of the day, is effective for stimulating the circadian system and is associated with better sleep and improved behavior and mood. We have developed a CS Calculator[1] to help lighting professionals select light sources and light levels that will increase the potential for proper circadian light exposure in buildings at the right time—that is, during the early part of the day. This tool is offered to facilitate calculations of CLA and CS for several example light source spectra as well as user-supplied light source spectra.

Here are some considerations to keep in mind when designing with CS:

- *Request the SPD of the light sources under consideration, and be careful not to rely exclusively on their CCTs.* While light sources with higher CCTs (5000-6500K) will generally provide greater CS, that is not always the case. It is possible, for example, that a 3500K source will deliver less CS than a 3000K source. Moreover, two light sources rated for the same CCT might provide very different CS values depending on their SPDs. The physiological reasons for this shift have been studied and are described elsewhere.
- *Design for vertical (≈ corneal) illuminance ($E_V$) at the eye, not just horizontal illuminance ($E_H$) on the workplane.*
- *Choose luminaires that provide the best $E_H$ to $E_V$ ratio.* We compared the efficacy of three different distribution types (direct-indirect, direct and indirect) by consulting various manufacturers' IES photometric data files, ultimately determining that a direct-indirect optic provides the best ratio of $E_V$ at the eye to $E_H$ at the workplane. Direct-indirect luminaires are generally superior, but keep in mind that differences occur even within this type (**Figure 1**). Note, however, that these relationships will change depending on the design criteria and

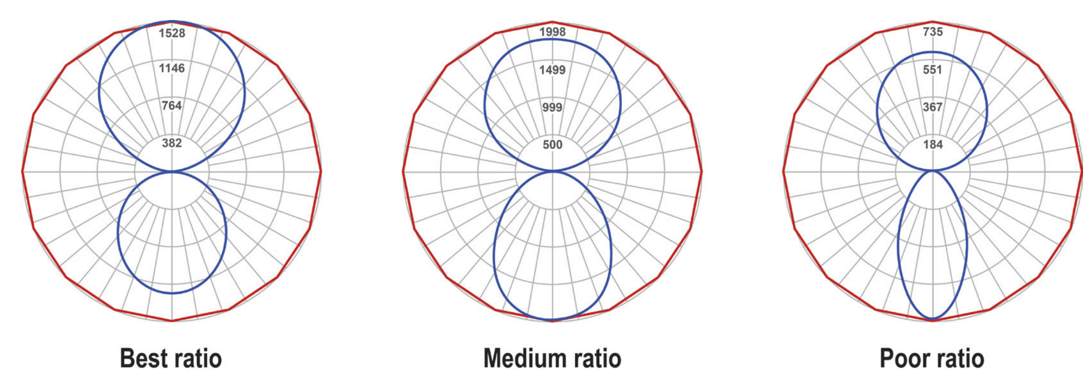


Figure 1. Photometric distribution of selected direct-indirect optics obtained from manufacturers' IES photometric data files, showing the variability in $E_H$ to $E_V$ ratios.

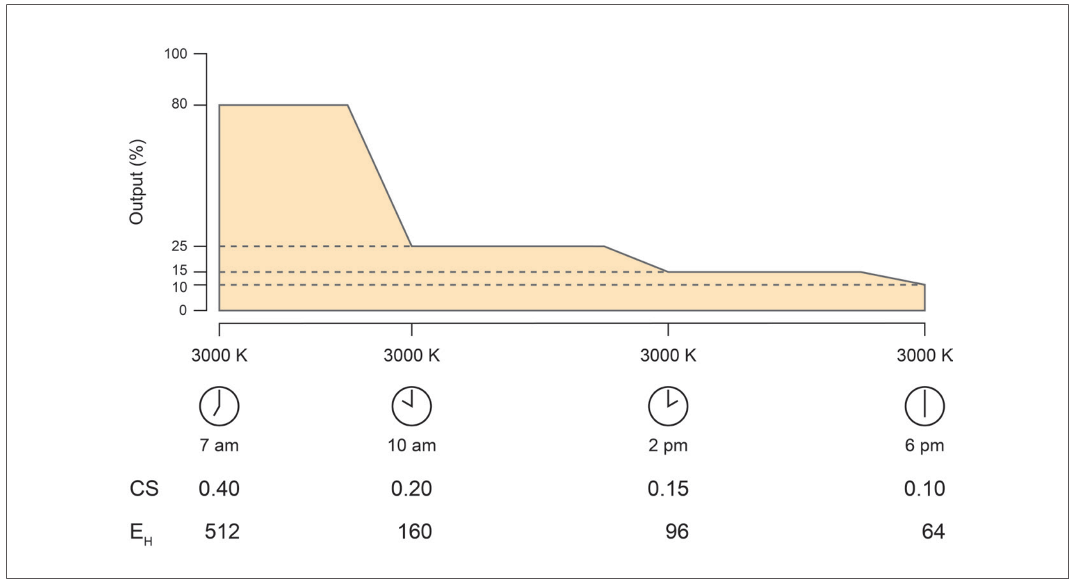


Figure 2. Changes in CS values can be achieved by simply increasing or decreasing the system's light output while keeping the same CCT. The schedule shown here is a specific example and not a general prescription.

the space being illuminated.

- *Light level and spectrum are two sides of the same coin*. Lower light levels will achieve relatively lower CS values unless compensated for by an SPD with more power at shorter wavelengths. If you have design restrictions such as energy codes or fixed $E_H$ levels, choose a light source that will emit more short-wavelength light to account for those restrictions. We found that when targeting an average $E_H$ of 300 lux, for example, an SPD emitting more short-wavelength (CCT of 6000K) light was needed to achieve a target CS of 0.3, whereas for a target average $E_H$ of 400 lux, an SPD emitting less short-wavelength (CCT of 4500K) light was capable of reaching the same CS. We are currently developing a resource that will help designers match light levels and SPDs to achieve the desired CS. As **Figure 2** indicates, changes in CS values can also be achieved by simply increasing or decreasing the system's light output while maintaining the same CCT.
- *All-day light matters too*. While morning light is important for circadian entrainment, light at other times can elicit an acute alerting effect from people, which may not be the desired outcome. People should not be kept in darkness at any time of day. But if the space is also being used in the evening, its lighting system should be dimmed or its SPD should be adjusted to emit less CS. Lighting control schedules such as the one shown in Figure 2 should be part of the design process and will change depending on the application.
- *Carefully consider who will be occupying the space*. Lighting control schedules for schools will be different from those for nursing homes, for example, because children tend to be night owls and older adults tend to be larks.
- *Think about layers of light*. In cases where site-specific design restrictions prevent CS targets from being met, saturated blue (e.g., peak wavelength = 470 nm) LEDs can be used to boost CS. A relatively simple design solution would be the installation of luminous workstation partitions to deliver extra CS to a space's occupants (**Figure 3**). For the post-lunch dip in the afternoon, when CS may not be the required design criterion, a red luminous partition could be employed to provide an alerting effect, in a manner similar to a cup of coffee, without raising the occupants' CS (**Figure 4**). Various studies have shown that red light, which does not suppress melatonin at night, can have an acute alerting effect on objective and subjective measures of alertness.





Figure 3. Luminous workstation partitions can be employed to deliver extra CS to a space's occupants.

Figure 4. To provide alertness during the post-lunch dip in the afternoon, red luminous workstation partitions will provide an alerting stimulus without raising CS.

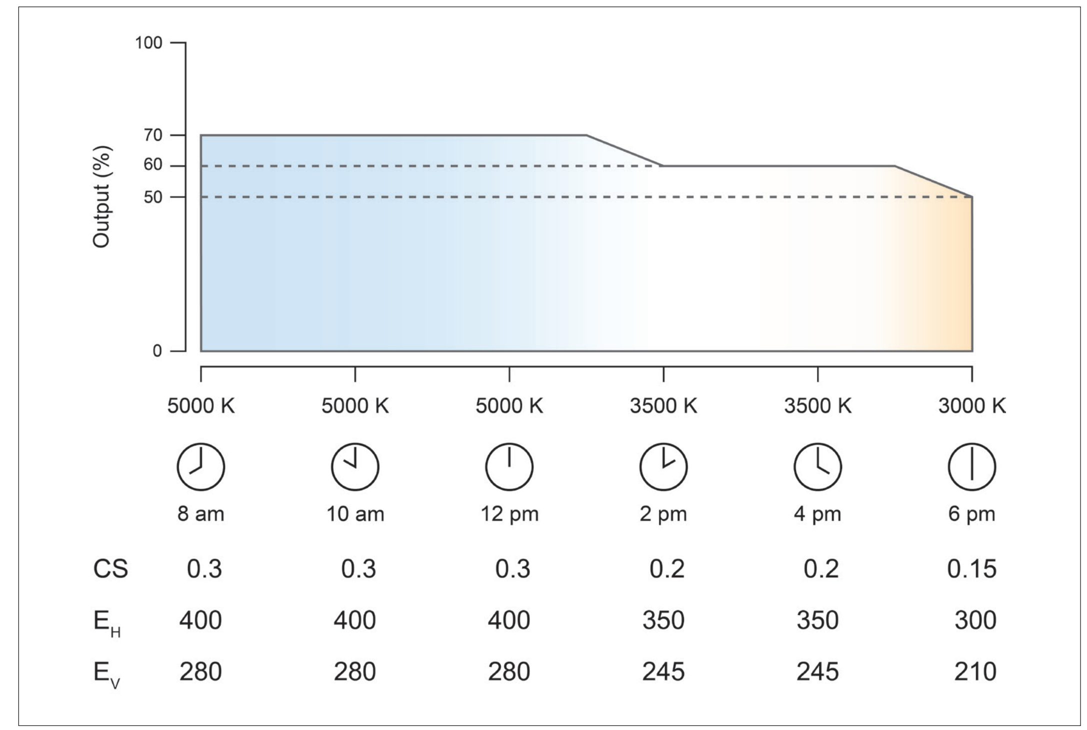


Figure 5. Tunable luminaires can be programmed to deliver customized CS dosage schedules. As with the schedule shown in Figure 2, this schedule should be regarded as a specific example and not a general prescription.

## DESIGN PROCESS

Designers should first decide on the design objectives—that is, whether they want to achieve entrainment or acute alertness—and then formulate a base condition by evaluating the space using our open-access CS Calculator and commercially available software such as AGi32 (Lighting Analysts, Inc.). A software-simulated base condition using existing facility plans, fixture configurations and manufacturers' luminaire specifications can be used for the evaluation. If possible, designers should perform on-site field visits to evaluate the space's current lighting conditions.

Once this base condition is established, designers will have a solid footing for selecting new luminaires, creating a lighting plan, tuning the light in terms of spectrum and light level, and formulating a dosage schedule over the course of the day. The design can be fine-tuned using the CS Calculator, then remodeled and adjusted as necessary while also accommodating IES recom-

Figure 6. Light oases of varying configuration are flexible and affordable solutions for providing CS.

mendations, energy codes and any client workspace specifications.

In an ideal world of healthy buildings, decision makers and designers would be free to propose extensive redesigns with new tunable luminaires programmed to deliver customized CS dosage schedules (**Figure 5**). But designing with CS to achieve healthy outcomes doesn't have to break the bank. In situations where renovations may be impossible due to budgetary or architectural constraints, low-cost and low-impact light oases can be established (**Figure 6**). Such oases can be quite effective when occupants are provided with information on light therapy and the health value of CS, and can be tailored for limited spaces ranging from small offices to submarines.

The tips presented here can help designers create lighting plans to deliver prescribed amounts of CS throughout the workday while also addressing traditional lighting concerns, and thereby create a vital intersection of aesthetics, functionality and health. We hope the tips provided here will lend confidence to start the process. ☐


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### REFERENCES

1. Available at http://*www.lrc.rpi.edu/resources/CircadianStimulusCalculator_30Apr2016.xlsx*


## RP-29 Status Update

The IES Healthcare Committee has recently completed an update to RP-29, the *Recommended Practice for Healthcare Lighting*. The IES Technical Review Committee has completed its review and it is anticipated that within the next two months the IES Board of Directors will endorse the document, forwarding it to ANSI for review and public comment, with publication expected in late 2016 or first quarter 2017.

The IES Healthcare Committee had a balanced group of dedicated healthcare professionals, lighting manufacturers and lighting designers who felt very strongly that this document needed to align with the organization and room naming used by the 2014 FGI Guidelines. By aligning the documents, industry professionals can easily cross reference recommended practices by room types. RP-29 recognizes and identifies the FGI as a guideline resource used for the design of healthcare projects; it is the desire that the FGI will respond with a similar recognition of RP-29 as the Recommended Practice for Healthcare Lighting.

The committee also feels very strongly that lighting professionals working on healthcare facilities have a unique opportunity to impact the health and well-being of numerous people. The document identifies new developments and trends, emerging research and standards, and encourages designers to become part of the conversation in developing innovative ways to improve the lives of not only the facilities, but the people who use and work within them.