

LIGHTING FOR HEALTH AND ENERGY SAVINGS

• PATIENT ROOM •

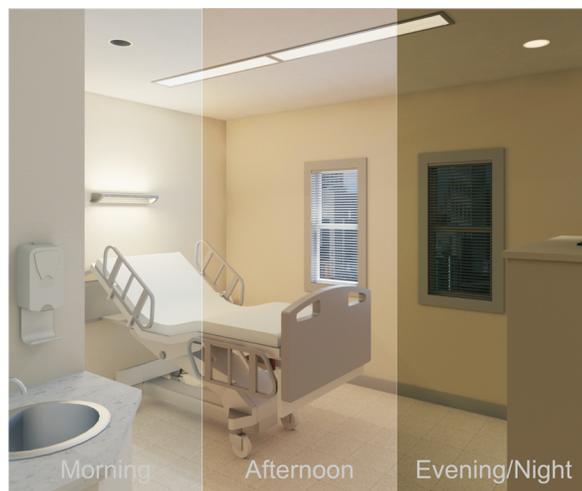
Guidance Document

The recommendations in this document are based on the findings of a Light and Health Research Center (LHRC) study that investigated lighting design techniques for promoting health and well-being while minimizing energy use in hospital patient rooms.

Goals

There are two goals when specifying lighting for patient health and energy savings in hospital rooms:

1. Establish a target circadian stimulus (CS) during the daytime to promote improved sleep quality and psychological well-being in hospital patients, potentially speeding recovery time.
 - a. Deliver a daytime CS of 0.3 at the patients' eyes.
 - b. Provide multilayered circadian-effective light in the morning and circadian-ineffective light late in the day to maintain circadian regulation and visual comfort for the patient.
2. While meeting visual and comfort requirements, maximize the ratio of CS to lighting power density (LPD), measured in $W\ ft^{-2}$, and thus minimizing energy use.



Findings

- Providing high levels of CS can require more energy than is required to maintain recommended [1] ambient/general lighting in patient rooms (horizontal illuminance [E_H] of 200 lx), but is roughly equivalent to the energy required to achieve recommended examination light levels (E_H of 500 lx).
- The most effective lighting solutions for providing the target CS to a patient sitting upright while minimizing energy use were:
 - Adding a supplemental overhead layer of narrowband short-wavelength (blue) light to the spaces' general ambient lighting.
- Installing an array of at least two high-lumen, low-wattage 2x2 troffers to deliver an E_H of 500 lx and a correlated color temperature (CCT) of 3000 K or higher.
- When designing lighting for a patient room, it is important to consider several options:
 - Employ overhead luminaires with a vertical illuminance (E_V) to E_H ($E_V: E_H$) ratio of at least 0.75:1.
 - Employ overhead luminaires with wide, diffuse distributions and high luminous efficacy.
 - Avoid luminaires with printed images (e.g., nature scenes, clouds) on the lens as the primary light source in the patient room, as they have a very high power demand when configured to deliver sufficient light for circadian stimulation.
 - If not using supplemental blue light, provide an average E_H of 500 lx on the patient bed.



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

Background

Circadian disruption is a common problem for hospital patients and can result in reduced sleep duration, which can delay recovery time.

Providing the recommended CS during the daytime can improve patients' sleep quality and mood.

The daytime light levels required for circadian entrainment (similar to those required for patient examination) are often higher than those recommended for general ambient lighting, and therefore have the potential to increase lighting power demand.

Hospitalized patients often experience heightened levels of depression, stress, and anxiety as well as poor sleep quality resulting from their respective health conditions and the nature of the hospital environment [2] [3] [4] [5]. Electric lighting in hospitals often remains static throughout a typical 24-hour period and, especially in patient rooms, delivers light levels that are too low for circadian stimulation during the day or too high for avoiding circadian disruption during the evening and night. These lighting conditions can severely disrupt sleep, as was found in a study [6] evaluating sleep quality among intensive care unit patients who showed a reduction of average sleep-time from a minimum normal duration of 8 hours to as little as 6 hours, with only 3 hours of that sleep occurring at night. Given that sleep quality is a key factor in health outcomes and recovery time, it is important for patients to achieve an adequate duration of consolidated sleep with low sleep-onset/offset latencies [7]. Recent research [8] has identified methods for using electric lighting to improve patient recovery by entraining their circadian rhythms to the natural 24-hour light-dark cycle, which can also improve sleep quality and psychological well-being while in the hospital.



A recent study [9] by LHRC researchers investigated circadian-effective light exposure among hospitalized multiple myeloma patients. It was demonstrated that providing a CS of 0.3 for up to 3 hours in the morning improved clinical depression ratings compared to an experimental control condition providing a CS of 0.1 during the same time interval. Nocturnal melatonin levels (a marker of the circadian system) were maintained high in the intervention group while it was significantly reduced in the control group, suggesting that the latter was experiencing circadian disruption from staying weeks in the hospital.

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 was also 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 circadian entrainment is fast gaining interest among lighting specifiers and manufacturers.

One drawback to this approach is that delivering high levels of circadian-effective daytime light often requires more energy than is needed for general ambient illumination or typical visual performance tasks (though it is equivalent to the energy needed for patient examination). Delivering high levels of circadian-effective morning light may also overlap with the timing of peak energy demand in the hospital. Therefore, the LHRC recommends providing patients a minimum of 2 hours of high CS exposure in the morning while minimizing energy consumption by following the steps described in this document.

Specifications

Provide a CS ≥ 0.3 to the patient for at least 2 hours in the morning to promote circadian entrainment, and reduce CS for the remainder of the day to allow for recovery, rest, and sleep.

Time of Day	CS
Morning	≥ 0.3
Afternoon	0.2
Evening/Night	≤ 0.1

Design to reach CS targets for the patient in an upright position with gaze directly forward. Also consider the patient gazing upward at 45° above horizontal (when reclined) especially when evaluating the possibility of discomfort glare from overhead luminaires.

Designs should strive to be at least within the light gray zone which is ideal for reaching the daytime target CS value between 0.3-0.4, while staying below ASHRAE guidelines for a maximum LPD of 0.68 W ft⁻². The median LPD was derived from the entire set of LPD values for each lighting condition evaluated for the study.

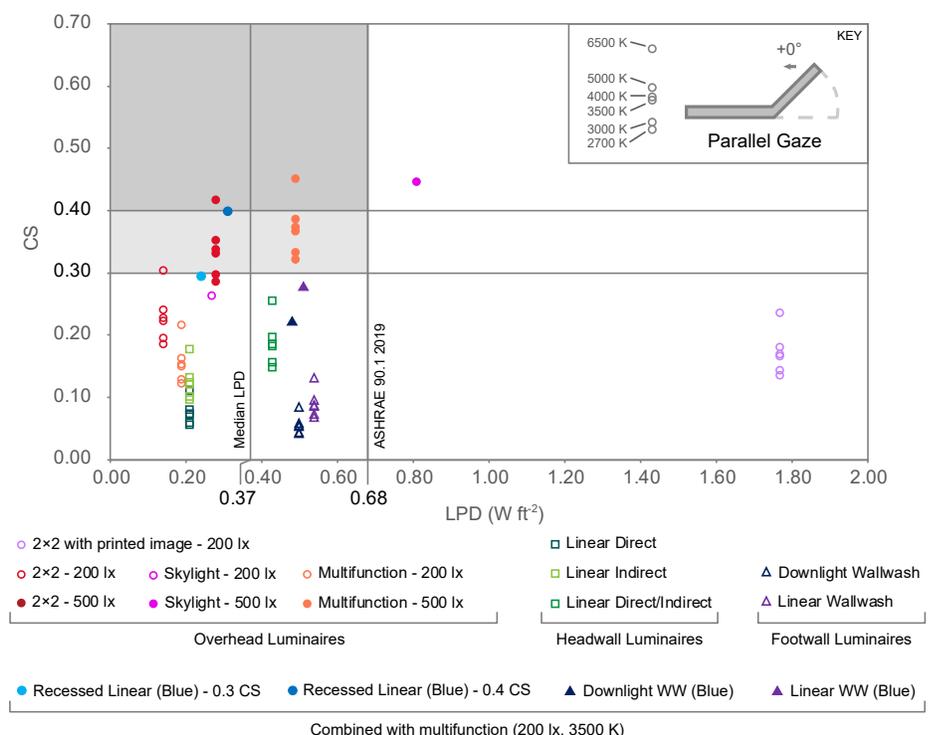
To facilitate circadian entrainment and patient recovery, the LHRC recommends providing CS ≥ 0.3 for at least 2 hours in the morning, CS ≤ 0.2 in the afternoon, and CS ≤ 0.1 in the evening and nighttime.

The adjustable positions of patient beds (from fully reclined to sitting upright) and patients' gaze directions must be taken into account for considerations of CS and discomfort glare. Since bed positions are variable, the LHRC recommends targeting a CS of 0.3 for the lowest amount of light from headwall or overhead luminaires received at the eyes of patients in a fully upright position.

To ensure CS is being delivered while minimizing energy use, the LHRC recommends maximizing to the greatest extent possible the ratio of CS to lighting power density (CS:LPD), measured in W ft⁻². Though numerous lighting products and configurations can be used to meet these performance specifications, the following Design Process section points specifiers to products and strategies that are most likely to maximize the CS:LPD ratio.

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 shows the CS:LPD performance of lighting configurations using seven commercially-available overhead, footwall, and headwall luminaires with two E_H targets: (a) "general" (200 lux) and (b) "examination" (500 lx on the patient bed). These lighting conditions were analyzed at six* CCTs (2700, 3000, 3500, 4000, 5000, and 6500 K) with the bed in a 45° reclined position and two patient gaze directions (45° above horizontal and directly forward, parallel to the floor.) Also included are four combination designs using a multifunction luminaire at 200 lx and 3500 K supplemented by a layer of blue light from overhead recessed linear luminaires or footwall wallwashers.



*An artificial "Skylight" luminaire was available with a combined CCT of 7000 K, whose SPD was only included for this luminaire type in the analysis.

Design Process

Step 1 Model your space

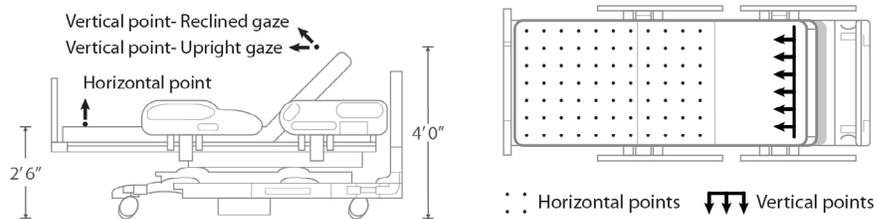
Build a 3D computer model of the patient room in a photometric simulation program and arrange vertical and horizontal illuminance calculation points

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

Take into account the height of the bed, which may vary between manufacturers, when determining E_H and E_V calculation point heights above the floor.

Use a photometric simulation model of the patient room to calculate E_H on the patient bed as well as E_V at the eye. Arrange horizontal calculation points in a 6"×6" grid on the bed, as well as vertical points along a line 4'-0" above finished floor (AFF) pointed in the direction of the eye of a patient gazing upward at 45° above horizontal (reclined) and looking directly forward (upright). Using the resulting vertical illuminance, together with the source's spectral power distribution (SPD), calculate CS using the web CS calculator developed by the LHRC:

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



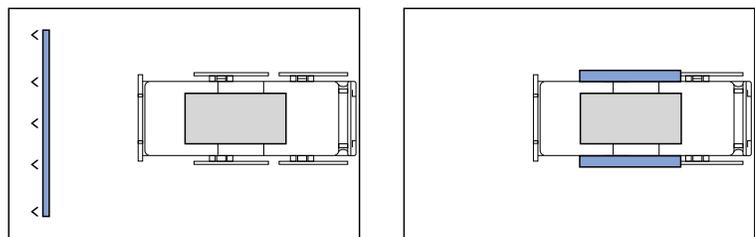
Step 2A Decide if a Supplemental Layer of Blue Light Can be Used

The circadian-effectiveness of the overhead lighting is far less critical if supplemental blue light can be used to provide high CS to patients

Decide early in the design process if you can use an additional layer of blue light to supplement the typical overhead lighting. Separate controls for this layer should be provided in case of emergency and/or for better color discrimination during exams.

Consider a layer of narrowband, short-wavelength “blue” light to supplement the typical overhead lighting. To achieve a CS of 0.3, 8 lx of blue light at the eye (in addition to the multifunction troffer delivering an E_H of 200 lx horizontal at 3500 K) was needed for the patient in the upright position. By far, the most effective means of delivering the supplemental blue light was from the overhead recessed linear luminaires. The linear wallwashers on the footwall were able to provide the additional blue light needed to reach a CS of 0.3 for the patient in the reclined position, which was the only position in which the footwall luminaires could reach the target CS of 0.3. However, the footwall location required 10 times the energy compared to blue light provided by an overhead source. Thus, while adding a supplemental layer of blue light can be very effective, the location of the luminaires can significantly affect energy use and efficiency.

Reflecting blue light off the footwall required as much as 10 times more energy to achieve the same amount of blue light to the eye of the patient compared to the overhead luminaires.



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

If additional layers of saturated blue light cannot be used, specify overhead luminaires with an intensity distribution and CCT that will be most likely to provide a high CS for limited energy use

Look for overhead luminaires with an $E_V:E_H$ ratio of at least 0.75:1.

	Conditions with $CS \geq 0.3$
Looking upward	1.26
Looking forward	0.73

Average $E_V:E_H$ ratio of overhead luminaires for a patient with their gaze upward at 45° above horizontal, and looking forward.

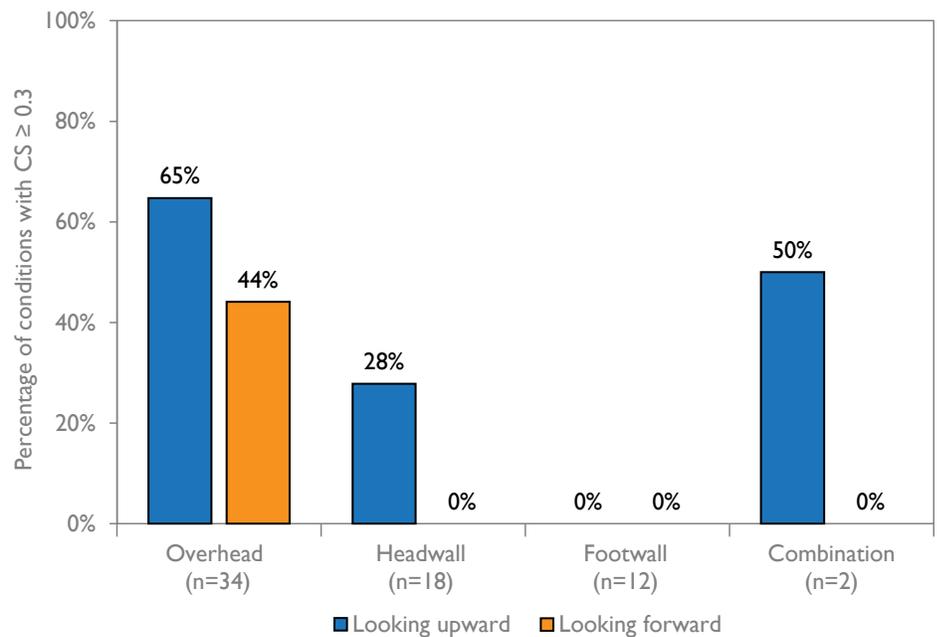
Design for the worst-case-scenario in terms of patient position, but keep in mind the potential for discomfort glare from overhead luminaires when the patient is gazing upward.

Intensity Distribution

The circadian effectiveness of a light source is specified in terms of E_V , or light incident on an observer's retinae, but current lighting standards are based on E_H , or light incident on the work plane. Luminaires with intensity distributions that deliver higher $E_V:E_H$ ratios also generally increase CS:LPD ratios and, thus, improve energy efficiency.

To ensure higher CS:LPD ratios, it is necessary to evaluate the intensity distributions and location of luminaires in the patient room using photometric simulation software, favoring overhead luminaires that deliver a high $E_V:E_H$ ratio (i.e., at least 0.75:1) when the patient is looking forward. When the patient is looking upward, the $E_V:E_H$ ratio should be even higher.

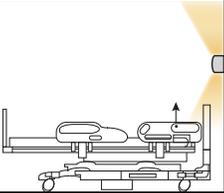
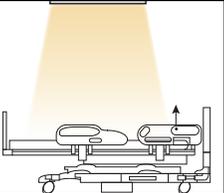
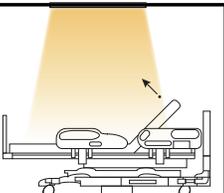
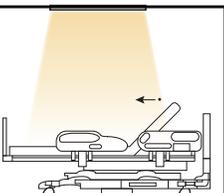
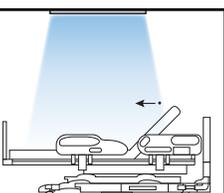
Given the variability of the vertical angle of occupant gaze in this application, the location of the luminaire plays an important role when designing to achieve CS targets in an energy-efficient manner. The bar chart below shows the percentage of lighting conditions (illuminance levels and CCTs) that reached a CS of at least 0.3 from different luminaire locations, and for the patient looking upward at 45° above horizontal, and looking forward.



In the rare instance when the patient is lying flat and gazing at the ceiling, a headwall luminaire with a direct lighting component will likely be the most efficient means of delivering high CS with minimal energy use. In a more realistic scenario with much less risk of discomfort glare, the patient will be reclined at 45° with their gaze either angled upward at about the same angle or directly forward. In this scenario, our analysis found that the direct/indirect headwall luminaire achieved a CS of 0.3, but the CS:LPD ratio was the fourth lowest of the conditions that achieved a $CS \geq 0.3$ for this patient orientation. With the patient upright, the number of headwall luminaire conditions (distributions and CCTs) that provided a $CS \geq 0.3$ was reduced to zero.

While providing high light levels for circadian entrainment is critical in hospital patient rooms, it is also very important to avoid discomfort glare and provide a comfortable and relaxing environment for the patient. Overhead luminaires were the most effective at delivering high CS, but also have the highest likelihood of being perceived as glaring, especially when the patient is in the reclined position looking upward. This can be compensated for by keeping light levels lower (E_H of 200 lx) and using a high CCT (6500 K) or using supplemental blue light from overhead. But, when light levels must be higher (E_H of 500 lx) either for CS or patient examination, also providing higher levels (E_H of 200 lx) of ambient illumination from additional luminaires in the room (either on the footwall, or overhead throughout the rest of the space) can keep discomfort glare to a more manageable level. Specifiers or designers concerned about glare should use well-shielded luminaires or luminaires with large-aperture, low-luminance lenses/diffusers, and reduce contrast between the overhead lighting and the surroundings.

To avoid glare, keep the E_H at 200 lx if you can also supplement with blue light from overhead to achieve high CS levels, or increase the ambient light in the space with additional layers of light and/or light finishes to reduce contrast.

	<p>Patient orientation: Fully reclined Gaze: Upward Luminaire: Headwall Source: Direct/Indirect white light E_H target: n/a</p>
	<p>Patient orientation: Fully reclined Gaze: Upward Luminaire: Overhead Source: Direct white light E_H target: 200 lx</p>
	<p>Patient orientation: Reclined 45° Gaze: Upward Luminaire: Overhead Source: Direct white light E_H target: 500 lx</p>
	<p>Patient orientation: Reclined 45° Gaze: Forward Luminaire: Overhead Source: Direct white light E_H target: 500 lx</p>
	<p>Patient orientation: Reclined 45° Gaze: Forward Luminaire: Overhead + linear accent Source: Direct white light + saturated blue E_H target: 200 lx</p>

Design solutions that can achieve the target CS > 0.3 at varying bed positions and patient gaze direction: (a) For a patient fully reclined, direct/indirect illumination from a headwall luminaire; (b) For a patient fully reclined, overhead white light reaching an E_H of 200 lx; (c) For a patient reclined 45° with an upward gaze, overhead white light reaching 500 lx horizontal (d) For a patient reclined at 45° with a forward gaze, overhead white light reaching 500 lx horizontal. e) For a patient reclined 45° with a forward gaze, combination of overhead ambient illumination (200 lx horizontal) with saturated blue linear luminaires.

CCT & Illuminance

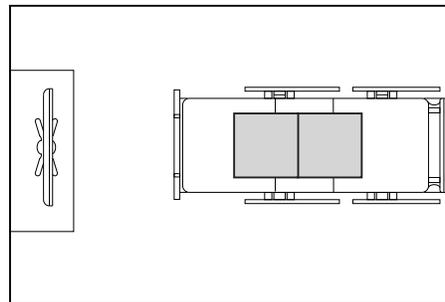
Increasing E_H from 200 lx to 500 lx played a larger role in delivering CS than increasing CCT.

For the same light level, a CCT of 5000 K or 6500 K is more likely to achieve the target CS value than a CCT of 3000 K, though for a more home-like appeal, warmer CCTs may be more desirable.

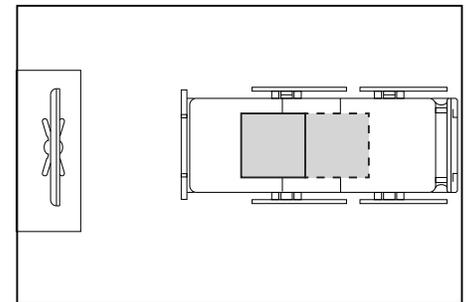
“Optimized spectrum” luminaires such as a simulation skylight may deliver more CS for the same vertical illuminance, they do not always provide a more energy-efficient circadian lighting solution.

Providing the achieved criterion CS value of 0.3 for 2 hours in the morning and reducing levels for the remainder of the day and night (other than for examinations) is the most energy-efficient schedule option that provides adequate morning light for entrainment while meeting established lighting requirements for healthcare settings.

If blue light or high CCTs are not desirable design solutions, the LHRC recommends providing an E_H of 500 lx for at least 2 hours in the morning. In most cases, greater CS was provided by increasing E_H from 200 lx to 500 lx on the patient bed rather than increasing CCT.



Exam mode
500 lux workplane target



General mode
200 lux workplane target

A light source's SPD, rather than simply its CCT, is an important design consideration. To reach a target CS of 0.3 for sources rated at 4000 K, for example, E_v targets can range from 165 lx to 620 lx based on an LHRC study [10] that evaluated a wide selection of commercially available luminaires.

Though higher CCT sources generally reach CS targets at lower light levels, it may be more desirable to have warmer CCTs to make the patient room appear less institutional and more welcoming. Some lighting manufacturers are beginning to offer specialty circadian lighting products with “optimized” SPDs such as the skylight luminaire examined in this study. However, while its SPD was more effective for delivering the target CS, the skylight luminaire's power demand was much higher than most of the other evaluated configurations and its CS:LPD performance was much lower.

CS Schedule

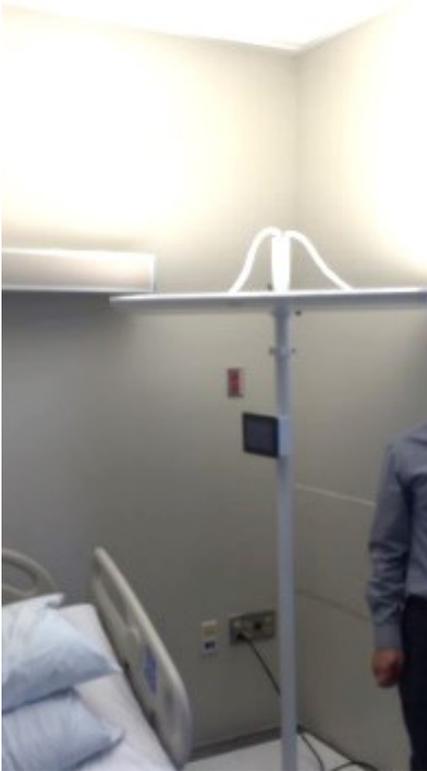
Because morning light is important for circadian entrainment, a tunable-white LED lighting system can modulate CS to provide higher levels during the morning and lower levels later in the afternoon and evening. A static-white LED system is also sufficient if: (1) multiple layers of light are used in the morning for high CS and selectively turned off in the evening for low CS, or (2) light output can be dimmed throughout the day to modulate CS levels. If lighting retrofits or re-designs are too costly, it would be feasible to utilize programmable lighting controls combined with common multifunction troffers to switch between the “exam” mode in the daytime for high CS to the “ambient” mode for low CS in the afternoon/evening. Although this cost-effective solution could utilize existing patient room luminaires to deliver an effective CS schedule, it would not be among the most energy-efficient solutions in terms of CS:LPD.

The present recommendations suggest designing patient room lighting following a 24-hour schedule. Providing a CS of 0.3 for 2 hours in the morning and reducing CS throughout the afternoon/evening can have minimal impact on energy consumption when designed strategically and can have significant health benefits to the patient.

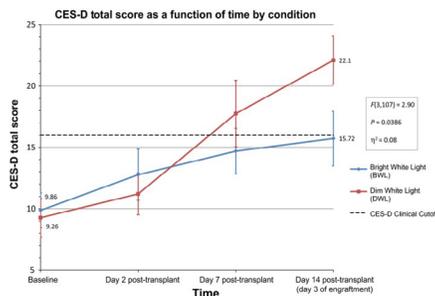
Case Study

Tailored Lighting Intervention to Promote Entrainment in Myeloma Transplant Patients- A Field Study

LHRC researchers completed a preliminary control trial to demonstrate the effects of morning light (CS > 0.3) on clinical levels of depression that occur in over a third of multiple myeloma (MM) patients during autologous stem cell transplant (ASCT) hospitalization.



Free-standing light fixture programmed to the active bright white light setting, placed in a patient room at Mount Sinai Hospital.



Depression scores collected at each time period, showing a significant difference between the Bright White Light and Dim White Light conditions.

Methods

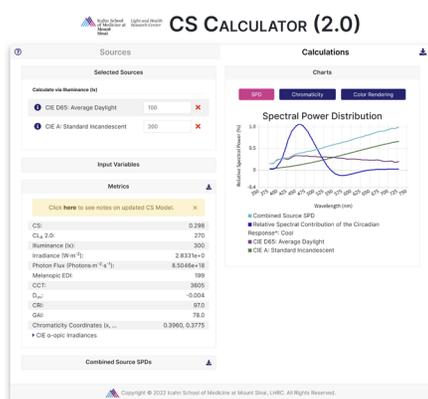
- Forty-four participants undergoing ASCT treatment at Mount Sinai Hospital in New York City met the criteria of the study, which included: first ASCT, 21 years of age or older, and proficient English.
- Participants were randomly assigned to either an active programmed environmental illumination (PEI) intervention (i.e., circadian-active bright white light [BWL]) or a PEI control condition (i.e., circadian-inactive dim white light [DWL]) from 7 to 10 a.m. daily during their hospital stay.
- It has been shown that receiving 30 minutes of circadian-active bright white light per day can reduce fatigue.
- Free-standing light fixtures provided by Acuity Brands were placed next to patient beds and programmed to deliver 1300 lx at the patient's eye (a CS of 0.3) for the circadian-active BWL intervention and 90 lx at the patient's eye (a CS of 0.1) for the circadian-inactive DWL control.
- Overhead, ambient white light was consistent for each of the rooms.
- A Daysimeter (device developed by LHRC researchers to measure personal light exposures) was placed behind the patient bed, on the light fixture, as well as a patient's chest to ensure the correct dose of light was received.
- To assess progression of depression rating, patients completed the Center for Epidemiological Studies Depression Scale (CES-D) before being admitted, on day 2 and 7 after the transplant, and on the third day of engraftment.

Results

- There was no significant difference in CES-D scores for the circadian-inactive DWL condition, whereas a significant interaction between time of assessment and lighting condition was demonstrated for the circadian-active BWL intervention.
- The circadian-active BWL intervention proved to be effective for reducing the development of clinically significant depression in hospitalized patients compared to the circadian-inactive DWL experimental control.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6144249/>

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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