# Circadian Rhythms

This is an opinion paper by a lighting designer on the current cacophony on light and health.

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Approximately every decade, new research or analysis reiterates warnings about the influences of people's chosen environments on their health and wellbeing. In lighting, the recent spate of proceedings plies circadian rhythms. Coincidentally, the convergences of commercial-grade potent light emitting diodes (LEDs) in varying whites and colors, the advancements of organic LEDs (OLEDs), the emergences of cost-effective digital controls, and surges in backlit device display uses have led to an increased interest in the influence of all manner of light on circadian rhythms. The negative health implications for people exposed to backlit device displays and lighting in the built environment appear to be serious and escalating. It is time to recalibrate how and when we dispense light.

**Background**

Lighting has long been known to affect people's circadian rhythms, affecting most people in a similar manner. Daylight and dark in their most natural states for one day (one rotation of Earth) have reliably set or entrained circadian rhythms for millennia. In the $20^{th}$ century, much study focused on how the presence or absence of daylight and manmade light affected circadian rhythms. Most recently, research honed in on the specific spectral, intensity, and duration-of-exposure characteristics of light that most influence circadian rhythms.

Device-display backlighting, built environment lighting criteria, and the lighting solutions for these applications will never be the same.

**Clarity of Purpose**

Because lighting influences health, wellbeing, comfort, and productivity, and because its natural manifestation is considered uncontrollable and its manmade manifestation is considered energy-intensive, it has always been impossible to resolve its adoption in a manner that is satisfactory to all people.

This paper will discuss some lighting issues, criteria, and related lighting techniques relevant to circadian rhythms of most relatively healthy people. Some techniques or timing and duration-of-exposure aspects may be inappropriate for those with certain disorders, such as Alzheimer's. Some people's responses will lie outside the curve of those considered typical.

Any solutions suggested or implied should not be considered in isolation from the context of the full lighting problem and the assignment of criteria priorities on any project. The matter of light used exclusively as a drug is left to health care professionals in this paper. Device display and built environment lighting should now be acknowledged by users, designers, owners, developers, hardware providers, and software providers for their influences on circadian rhythms. This acknowledgment should consequently influence device display and built environment lighting solutions.

Statements herein are the author's real-world situation interpretations of a variety of references (see References, pp.7-8) [1-14] A number of popular press articles offer anecdotes and practical experiences on lighting and circadian rhythms. [15-17]

Reference is made to color temperature (the "whiteness" of the light source), reported in Kelvin or K: the higher the K-value, the bluer-whiter the appearance of the light. Therefore, 2200 K to 6500 K is a visible range from candle-flame-white to crisp blue-white. Additionally, for electric light sources, reference is also made to color rendering, which is a score or rank of how well colors, such as skin tones, clothing, cars, and room surfaces appear under the light source. Color rendering is reported in terms of Color Rendering Index (CRI). The higher the CRI-value, the better the colors are rendered. A value of 100 represents the maximum CRI and is considered "perfect." Along with CRI, a value known as R9, which is defined as the light source's ability to render a specific saturated red, is also reported. A value of 100 is the maximum R9 value, considered "perfect."

**Summary of Findings**

Two areas of study are significant for the purposes of this paper: the influences of electronic device displays on circadian rhythms and the influences of daylight and electric light sources on circadian rhythms. Many of these studies directly or indirectly converge to one conclusion: timing and duration of exposure to "blue" light of virtually any intensity/level profoundly impact circadian rhythms.

**Implications**

"Blue" light is light of approximate wavelength 450 nm to 480 nm of the visible spectrum. The light might be saturated exclusively with these wavelengths, appearing deep or royal blue. More typically, the light might consist of a number of disparate groups of wavelengths, including those somewhere in the range of 450 nm to 480 nm. This light would then take the appearance of "white" light.

Within the context of a typical day, exposure to blue light is beneficial at wake-up and through midday. The benefits of blue light, however, diminish by afternoon. By evening, blue light is detrimental, extending a person's wake time until well after bedtime and perhaps causing sleeplessness. A preponderance of evidence suggests that exposure to blue light in the evening and overnight hours is unhealthy (see References, pp. 7-8).

**The Blue Appeal – Literally and Figuratively Cool**

People are eager to expose themselves to blue light. Blue and blue-white light emanating from devices and light sources has a cool appearance. That is, the appearance is both "cool" in effect (hip, chic, modern, edgy) and in visual perception (crisp, bright, even dazzling).

Electronic devices seemingly facilitate if not forge a frenetic life. Device display screens can wreak havoc on the rhythms of life. Research and life experiences bear out the link between our electronic device display screens and our disrupted circadian rhythms. Exposure to relatively bright blue-white display screens during pre-sleep and sleep phases disrupts circadian rhythms and manifests undesirable conditions in users, including difficulty waking, drowsiness during the normal wake phase, and sleep patterns in which both going to bed and rising are pushed ever later.

Display screens are perhaps most insidious. These constitute a relatively large amount of exposure time and consume a significant field of focused, attentive view. In other words, they pummel the eyes from wake time until sleep time with intensities and wavelengths of light meant for synchronizing the wake phase and stimulating alertness early in the day. Display screens in tablets, smartphones, electronic readers, video and music players, televisions, laptops, PCs, and other appliances exhibit default blue-white settings that range from 5000 K to 6500 K. These color temperatures are appropriate from the morning to the mid-afternoon hours of the wake cycle. During the late afternoon and early evening, however, warm-white reduced-brightness display screens are more appropriate for entraining circadian rhythms and supporting sleep at bedtime, because they contribute to “winding down.” During late evening, still warmer-white and even dimmer display screens are appropriate. At bedtime and during the sleep phase, absolute black-out conditions are appropriate. There should be no exceptions, though a midnight toilet run or baby check will be least disruptive when any associated path light or display backlight is tuned to nearly single-wavelength reddish-orange at very dim output.

Electric lighting also influences circadian rhythms during both day and night. Historically, electric lighting default color temperatures were 2400 K to 3000 K. Dimming to 2200 K and even lower was cheap and easy, making electric lighting minimally disruptive during the nighttime. Recently, however, color temperatures from electric light sources are typically 3500 K to 6000 K. This is because research in the fields of human vision physiology and light source chemistry converged on “bluer light better sight”, a finding that has manifested an explosive use of blue or bluest-white light for applications both day and night. Marketing ploys tied to the “S-over-P ratio” (scotopic over photopic) or the “mesopic range” of vision have resulted in a flood of office, industrial, pedestrian, and street lighting installations using the bluest-white light. This approach also happens to “best save the Earth”, because the bluer-white sources tend to be five to twenty percent more efficient than their warm white counterparts. However, the over-generalized use of blue light could be likened to a hypothetical scenario in which the car companies took a 100 mpg engine and installed it in every vehicle made, regardless of vehicle size or function, and regardless of the engine’s ability to accelerate to maneuver through traffic or power an emergency vehicle quickly to a scene. Common sense should dictate a moderate approach that does not sacrifice one attribute for another. In the case of lighting and circadian rhythms, the business-as-usual, low-cost, easily-maintained, and one-size-fits-all models are not optimally effective. Indeed, the literature already suggests that some recent cool-white LED installations are likely unhealthy.

Daylighting is the ultimate elixir in circadian rhythm entrainment. Unfortunately, in a world of pervasive use of electronic devices, any exposure to daylight is serendipitous and short-lived. Daylight is less available at the right times of the day to many people. People must significantly increase engagement in outdoor activities. Indoor access to daylight (building design and use patterns) must change.

**What to Do**

Consistency in scheduled exposure to the right wavelengths and the right intensities over the right durations is paramount to setting or entraining circadian rhythms. Research identifies the various wavelengths of light that are respectively beneficial to the wake, pre-sleep, and sleep phases. Light levels (illuminance) which affect luminance (brightness) are also known to influence circadian rhythms, with lower levels appropriate during the pre-sleep phase and no light during the sleep phase. Consistent times and durations of sleeping and waking are known to benefit circadian rhythms.

**The Problem**

When manmade light became a commodity in the early 20th century, its application quickly devolved to lowest-cost installations: the poor practice of designing the lighting with the lowest initial cost that yielded the greatest quantity of light. Consequently, non-specialized applications of electric lighting have long taken the form of mundane, overly-bright, static white light with limited manual dimming available. Today 3500 K, 4000 K, 5000 K, and 6000 K <80 CRI LEDs are now, unfortunately, considered "the industry standard". They seem to populate every light fixture indoors and out and paint our world with a hazy blue-gray veil. These LEDs are reminiscent of the halcyon days of mercury vapor and quartz metal halide popular half a century ago. To most people, these must represent the best of such a novel technology as LEDs. Manufacturers are filling luminaires with these lamps of insomnolence. These will last the lifetimes of many people now over 40 years of age. This is undoubtedly a waste of Earth's resources and a serious burden on the human health and psyche.

3500 K, 4000 K, 5000 K, and 6000 K LEDs in architectural lighting and the 5000 K and 6000 K default backlighting settings for almost all device displays, are only circadian-appropriate from approximately 7 a.m. until 3 p.m. (intended body time). Some studies suggest stretches of exposure to these color temperatures at the wrong time of the circadian cycle, even at relatively dim levels, might be linked to lack of sleep, poor performance, and even some forms of cancer.

**Strategies**

The status quo, therefore, appears to be detrimental to human health. As a general rule, the lighting for device displays and the lighting for architectural applications must become more sympathetic, if not tailored, to circadian rhythms. The means to the end may be simple depending on the level of execution and the anticipated degree of success.

There are likely two basic strategies for advancing more appropriate lighting solutions – one based on static lighting and a second based on dynamic lighting. Both can be applied to architectural lighting and display screen backlighting. Static lighting might, arguably, offer some incremental improvement over status quo, especially when combined with common sense actions. Static lighting rivals the simplicity and cost of the current status quo lighting, and can be put into effect with more appropriate decisions about lighting. Dynamic lighting offers the promise of cycling lighting that is tuned to circadian rhythms. While static lighting may be effective in entraining circadian rhythms, it may not be as effective as dynamic lighting. Additionally, appropriately-designed architectural lighting, arguably, may be effective in entraining circadian rhythms, but it may not be as effective as appropriately-designed device display screen lighting. Architectural lighting, for the most part, is socialism. With the exception of private living quarters, most architectural lighting is designed for and used by a rather broad constituency and the lighting that works best for one individual using the setting may have limited or no positive effect for another. Device display screens, however, are typically uniquely used and the backlighting of each screen can be tuned accordingly.

A static lighting approach involves settling on a "least disruptive" fixed color temperature of white light and can offer the option of automatically dimming this lighting through the day to correspond to circadian rhythms. Here, selecting, specifying, purchasing, installing, and dimming a single color of white light is convenient and less costly than dynamic lighting. The real challenge, then, is determining which color temperature of white light to select. Whether choosing the lighting for an architectural purpose or for a device display screen, a selection should be made that is *least* disruptive to circadian rhythms throughout the day-night cycle. 2700 K and 3000 K light sources are therefore the most attractive candidates. Variants with CRI values of at least 90 and R9 values of at least 60 are likely to exhibit broader or stronger red wavelengths, so they may be better suited to later-day and evening hours of use. This warm white, high-CRI, high-R9 light may, for example, make schools and offices less frenetic and stressful, make health care facilities more approachable and better healing environments, and make many roadways and walkways calmer and less circadian-intrusive. This lighting approach could even potentially contribute to decreased polarization between humans in our frenzied, stress-laden world.

Anecdotal evidence suggests that 2700 K and 3000 K lighting work well for most people throughout the day. For too many commercial and institutional installations, "best" efficiency as the primary goal now overrides other more noble lighting goals. The most conveniently available, cheap, efficient lighting has, for years, been 4000 K. Now, with the advent of LEDs, 5000 K and even bluer-white light is usually selected. Sadly, the vicious cycle of supply-demand perpetuates these poor choices. 5000 K and 6000 K screen backlighting has long been de rigueur for device display screens because these screens offered the brightest appearance. However, the practical appeal of this use has vanished due to vast improvements in screen brightness. Furthermore, scientific and empirical evidence now suggests the amount of exposure people receive to the light shone by these devices at the wrong time of the day is significantly harmful.

A dynamic lighting approach involves settling on a range of color temperatures of white light, then cycling and simultaneously dimming this range throughout the day to correspond to circadian rhythms. Here selecting, specifying, purchasing, installing and controlling a range of color temperatures of white light for architectural purposes is more complicated and costly. However, this technique appears well-suited to entrain circadian rhythms. Short-term obstructions to implementation appear to be lighting power densities, a clearly outmoded hammer, control protocols and systems, and wiring methods. For device display screens, inherent color properties and controllability offer greater more expedient opportunity for convenient, personally-unique circadian entrainment experiences. For dynamic lighting to have positive effect, it will be incumbent on designers to tailor a host of parameters to the user(s).

Common sense actions are implied if not identified in many of the research studies. Some of these include: 1) a schedule that is seldom deviated for waking and sleeping – go to bed and awake at consistent times; 2) allow time for plenty of sleep; 3) eliminate bright-white light exposure a few hours prior to bedtime by turning off televisions ,computers , smartphones, and tablets; and 4) eliminate light exposure overnight – use blackout shades. Other suggestions include: 1) change the background colors of electronic devices to 2700 K or lower for nighttime use; 2) read a book under a dim 2700 K light source; and 3) use only dim orange or red nightlights throughout the night, preferably on occupancy sensors so that they produce light only when a wakened individual is on the move.

Precautions must be taken against using the wrong LEDs and OLEDs for the wrong reasons. Often, valid technical methods and even engineering tricks that are arguably appropriate for a few very specific situations are broadly applied under the guise of efficiency and/or low cost. This is why there is a prevalence of 4000, 5000, and 6000 K, CRI <80 and R9=0 LEDs. Lighting is done ultimately for the benefit of people in need of it, and lighting criteria must be assessed and balanced with that primary focus in mind. Roadways and sidewalks are being re-illuminated to their 1950s and 1960s old polar-blue-white glary selves at alarming rates for what will apparently amount to an interminable time period. At night these areas look gloomy. People walking in them appear gloomy. Discerning vehicle and clothing colors is difficult (therefore, in the event of a crime or accident, accurate color descriptions from very brief visual memories cannot be made and even identifying any specific-color vehicle in the parking lot is challenging). Glare is worse than from the old HID luminaires. It was only a few years ago that roadway lighting bathed our roads in the golden glow of low- and high pressure sodium – questionable sources with, at best, a 20 CRI and R9=0, but a more circadian-appropriate 2200 K. In current times, 4000 K, 5000 K, and 6000 K CRI <80 and R9=0 LEDs are promoted to maintenance crews and city administrators as "best", though in reality this translates simply to "lowest maintenance and energy use". It is still possible to save the same or a greater amount of energy by decreasing baseline light levels as the night wears on and activity decreases and due to the added benefit of significantly better color contrast available from more circadian-appropriate 2700 K or 3000 K >90 CRI and R9 >60 or from 2200 K >80 CRI and R9 >60 LEDs. Replacement cycles are still extremely long, freeing maintenance crews to regularly clean luminaire optics and inspect poles and luminaires for mechanical and electrical integrity. Reduced-glare LED luminaires are available with quality optical-design forethought.

Hospitals have long been over-lighted 24/7 with 4000+ K sources with CRIs between 70 and 80 and R9=0. This is now perpetuated with subpar LEDs, simply because these qualities have been the accepted norm for the last half century. LED suppliers are quick to accommodate long-standing maintenance procedures, however tenuous the rationale. The well-being of patients thus seems less a concern than does easing the performance expectations of the maintenance staff and building management. Medications help numb the physical pain of healing, but the physiological and psychological suffering from suboptimal blue-white lighting that negatively impacts circadian rhythms and compounds anxiety goes unchecked. LEDs are readily available in much more appropriate 2700 K and 3000 K with CRI >90 and R9 >60 at very little cost premium and at efficiencies better than most any traditional light source, including T5 fluorescent. Indeed, as these high-definition LEDs become more popular, their cost will approach that of the suboptimal LEDs and their efficiencies will steadily improve.

Device displays typically exhibit backlighting of 5000 K and 6000 K on full-output at all times. These display screens should be adjusting to circadian rhythms. For example, at some point mid-afternoon, these screens should segue to more circadian-appropriate 3000 K CRI >90 and R9 >60 while simultaneously and continuously dimming. By late evening, a continual warm-white-shift to 2200 K CRI >80 and R9 >60 and progressive dimming through bedtime are more circadian-appropriate. Similar algorithms can be deployed for architectural lighting as LEDs and OLEDs exhibiting the optimal range of color and control of device display backlighting become available.

**References**

1. Wood, B., et al., Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression, Applied Ergonomics (2012), http://dx.doi.org/10.1016/j.apergo.2012.07.008

2. Rea, M.S., Figueiro, M.G., Bierman, A., Bullough, J.D., 2010. Circadian light. Journal of Circadian Rhythms 8, 2.

3. Rea, M.S., Bierman, A., Figueiro, M.G., Bullough, J.D., 2008. A new approach to understanding the impact of circadian disruption on human health, Journal of Circadian Rhythms 6, 7.

4. Leproult, R., Colecchia, E., L'Hermite-Bleriaux, M., Van Cauter, E., 2001. Transition from Dim to Bright Light in the Morning Induces an Immediate Elevation of Cortisol Levels, The Journal of Clinical Endocrinology & Metabolism 86, 1.

5. Figueiro, M.G., Bullough, J.D., Bierman, A., Fay, C.R., Rea, M.S., 2007. On light as an alerting stimulus at night, Acta Neurobiologiae Experimentalis, 67.

6. Boivin, D.B., James, O.J., 2005. Light Treatment and Circadian Adaptation to Shift Work, Industrial Health, 43.

7. Crowley, S.J., Lee, C., Tseng, C.Y., Fogg, L.F., Eastman, C.I., 2003. Combinations of Bright Light, Scheduled Dark, Sunglasses, and Melatonin to Facilitate Circadian Entrainment to Night Shift Work, Journal of Biological Rhythms, 18, 6.

8. Kolla, B.P., Auger, R.R., 2011. Jet lag and shift work sleep disorders: How to help reset the internal clock, Cleveland Clinic Journal of Medicine 78, 10.

9. Figueiro, M.G., Rea, M.S., 2010. Lack of short-wavelength light during the school day delays dim light melatonin onset (DLMO) in middle school students, Neuroendocrinology Letters, 31, 1.

10. Figueiro, M.G., Rea, M.S., 2010. Evening daylight may cause adolescents to sleep less in spring than in winter, Chronobiology International, 27, 6.

11. Sharkey, K.M., Carskadon, M.A., Figueiro, M.G., Zhu, Y., Rea, M.S., 2011. Effects of an advanced sleep schedule and morning short wavelength light exposure on circadian phase in young adults with late sleep schedules, Sleep Medicine, 12.

12. DiLaura, D.L., Houser, K.W., Mistrick, R.G,. Steffy, G.R., editors. 2011. The lighting handbook: reference and application. 10th ed. New York (NY): The Illuminating Engineering Society of North America.

13. Figueiro, M.G. and Rea, M.S., 2012. Short-wavelength light enhances cortisol awakening response in sleep-restricted adolescents, International Journal of Endocrinology, 2012.

14. Figueiro, M.G., et. al., 2006. Does architectural lighting contribute to breast cancer? Journal of Carcinogenesis, 2006, 5:20.

15. Jarvis, Alice-azania. "Coming to a street near you - the lights that keep you awake and could make people ill..." *The Daily Mail* 21 Apr. 2014. *dailymail.co.uk* Web. 11 May 2014.

16. Science News Online (Janet Raloff byline), 2006. Light Impacts: Hue and timing determine whether rays are beneficial or detrimental, Science News, 169, 21, http://www.sciencenews.org/view/feature/id/7375

17. Giuliano, V., 2012. Blue light, sleep, mental alertness and health, Aging Sciences Anti-aging Firewalls weblog, February 27, 2012, http://www.anti-agingfirewalls.com/2012/02/27/blue-light-sleep-mental-alertness-and-health/