

Research has confirmed that light and human health are strongly interconnected. If light is not carefully implemented, both the visual system and the circadian system can result in a series of health problems. For instance, the circadian system is linked to sleep disorder, SAD, depression, may alleviate Alzheimer, and lately found as probable cause of breast cancer. The visual system is linked to tissue damage, migraines, and eye strain. It is clear that healthy lighting has to address the needs of the circadian system as well of the visual system.

The lighting designer is facing a new responsibility and a new level of achievement in the profession - the healthy lighting. "Healthy Lighting" is a relatively new terminology, that encompasses "Quality Lighting" with its aesthetics, performance, and life cost issues, but adds a new feature - human health.

The lighting needs of the visual system and of the circadian system are so different and even contradictory that it seems almost impossible to design for healthy lighting.

Mark Rea (2002) provides an excellent summary of the research findings for the circadian and the visual systems. Table 1 shows this summary.

Let's analyze the lighting characteristics given in Table 1 from the perspective of a lighting designer.

**The quantity** of light needed for the visual system is very moderate compared to the needs of the circadian system. Besides, the visual system operates as a spot light requiring optimal light level at the task. By the law of diminishing returns, increasing further the illuminance on the task will not improve the visual performance. At the same time, the circadian system requires 10 times more light "at the eye" and a vision field, focal and peripheral, completely filled with light. This raises legitimate concerns for

visual discomfort caused by over brightness and of spaces lighted as integrated sphere, without light and shadow patterns.

<b>Lighting characteristics</b>	<b>Application Vision</b>	<b>Circadian day shift work</b>	<b>Circadian night shift work</b>
Quantity	Low (300-500 lux on task and ~100 lux at eye)	High (~1000 lux at eye)	High (~1000 lux at eye)
Spectrum	Photopic (peak sensitivity 555nm)	Short-wavelength (peak sensitivity 420-480 nm)	Short-wavelength (peak sensitivity 420-480 nm)
Spatial Distribution	Distribution important (task luminance, contrast and size determine visibility)	Independent of distribution (illuminance at eye)	Independent of distribution (illuminance at eye)
Timing	Any time	Subjective morning	Periodically throughout the shift
Duration	Very short (less than 1s)	Long (1 - 2 h)	Short (15 min) pulses

**Table 1:** Summary of research findings on visual and circadian systems

**The spectrum** for the visual system has its peak at 555 nm, resulting in a generally warm light. The peak sensitivity for the circadian system is at 465 nm, perceived as bluish light. Lighting efficiently for the circadian system will make spaces appear cold and blue, and generally unacceptable to the visual system.

**The spatial distribution** is important to the visual system. The geometry of eye, task, light source, contrast, and size of the task, all define the visual system’s performance. The circadian system only cares about the retinal illuminance. In fact, it can be compared to a giant photocell, monitoring for large amplitude light/dark signals. However, the lower area of the retina, where the image of the sky is formed, is more sensitive to light and thought to contribute more to the circadian system.

**The timing and the duration** will be discussed together as they are interconnected, especially for the circadian system. Timing for the visual system is not important. The visual system responds fast and the response is similar from one time to another. However, timing and duration for the circadian system are of major importance. Circadian system is bulky and slow in response, and even though is able to integrate light stimuli; it needs a prolonged time exposure to light. Circadian system will respond to light only at certain times in the 24 hours cycle, usually when the lowest body temperature occurs (5am) or when transition in melatonin level occurs (6-8 am and 6-9pm). Circadian system is the most sensitive to light during the night and becomes “numb” during the day. Notice from Table 1, that the timing and duration to light exposure for day-shift is different from the night-shift. For day-shift a stable high level of light (light pulse) will boost worker's alertness and performance. For night-shift, when continuous production of melatonin occurs, periodical light pulses are the most effective way to communicate with the circadian system.

Peter Boyce et al (1997) conducted an interesting study on graveyard shift workers' alertness and performance. They found that light can be dimmed down after a light pulse is administered, preserving the suppressed melatonin level. Therefore, lighting for the circadian system can be also energy efficient. Further, this study shows that not only the dosage but also the direction of the light stimuli is important. Starting with high level of light and dimming down light is more effective for the circadian system than starting with low level of light and then increasing the light level. The findings of this study have direct implications for designing a healthy lighting.

Based on the discussed above, here are some important characteristics of the circadian and visual systems:

The circadian system is an oscillatory (dynamic) system, with several processes intensifying and weakening sequentially. Most likely modulated stimuli such as

modulated light will be the most effective to regulate the circadian system. The visual system is more static and performs at its best under stable lighting conditions.

The circadian system is slow to respond to light stimulus, but it will be in the same way slow to respond to the lack of light stimulus, therefore allowing the use of alternate dimming of light and the realization of energy savings.

The circadian system responds readily to bluish cool light and high light levels. The visual system prefers warm light and lower light levels. Therefore, a spectral and intensity modulation will be necessary to accommodate the requirements of both systems.

So what are the odds that the same lighting will work for both systems?

Luckily, there are interfaces between the circadian system and the visual system that will allow this to happen. These interfaces are: the perceptual constancies and the square law curve for adaptation to illuminance levels. The IESNA Lighting Handbook defines the perceptual constancies as “fundamental attributes of surrounding objects that are constant over a wide range of lighting conditions”. In this case we are interested in two of the attributes, the color constancy and the lightness constancy. The color constancy is preserving the familiarity with a color (color recognition) under different light sources with different spectral distribution. This will allow the cycled modulation from bluish light (for the circadian system) to warm light (for the visual system) preserving the features of the surrounding objects. The lightness constancy is basically the appearance of a white paper as always lighter compared to a piece of black charcoal, even if the charcoal's luminance is much higher than the paper's luminance. The lightness constancy reinforces the other interface, the square law curve for adaptation to illuminance levels. What the square law curve represents is the adaptation of the eye to changes in illuminances. For instance, a measured illuminance of 50% of the original illuminance is perceived as bright as about 70% of the original level. This “lag” in brightness perception will allow the dimming of light after a light impulse has been administered for the circadian system, without disturbing the operation of the visual system.

So what luminaires to use for healthy lighting?

Healthy lighting will need sophisticated lighting controls that will time activate a simultaneous light modulation in intensity and spectral distribution. Traditional energy efficient light sources such as fluorescent and metal halide will need an array of dimmable luminaires operating an array of lamps of different spectral distribution (SPD). This arrangement will result in expensive and cumbersome lighting systems. Besides, fine tuning to the needs of the circadian system will be almost impossible.

A much simpler (and yes, less expensive) lighting system will be using Light Emitting Diodes (LED) as the light source. LED is a new paradigm of light source, where individual LED modules synergize and work together for fine tuning the lighting characteristics. While the mix of rare phosphors for the fluorescents occurs inside the lamp, the external mix of several narrowband LEDs will result into changing the color rendering (CRI) and the spectral distribution (SPD). Additive RGB (red, blue, and green) LED can provide white light modulation. Also, white LEDs are on the bluish side with excellent circadian (biological) efficiency. White LED combined with amber LED can satisfy the visual system through a spectral modulation. By far, the greatest advantage of LED lighting system for designing healthy lighting is in its integral controls allowing synchronized with the circadian system changes in the light characteristics.

So what are the design guidelines for healthy lighting?

Day-shift work healthy lighting guidelines:

Increase the illuminance in spaces of low light levels or no daylight contribution. Use indirect lighting to illuminate the ceiling. Use blue light, preferably from RGB LED. The lighted in blue ceiling will result in illuminance predominantly on the lower retina without visual discomfort. To accommodate the visual system, have warm color finishes on the walls or at the task surfaces. Inter-reflections will result in warmer light for the visual system.

### Night-shift work lighting guidelines:

Continuously modulate lighting to maintain defined melatonin level. Start the cycle with high illuminance (15 to 20 min.) and cool bluish-white light, and then progressively dim down the light levels while simultaneously shifting to warmer light (20 to 30 min.). Ramp the dimming down, so it is unnoticed to the visual system. Shift the light spectrum also unnoticed to the visual system. To restart the cycle, jump up instantaneously (in a blink) on high illuminance level, to give directionality of the cycle. Additional research will be needed to find the threshold sensitivity of the visual system and define better “unnoticed” change in light condition. Additional research will be needed to define what level of suppressed melatonin during the night will provide acceptable levels of alertness and performance. Perhaps suppressing the melatonin completely during the night (and upsetting the circadian system) is not necessary. The dosage of light pulses (for how long what amount of light) and the interval between light pulses during the night need also to be defined. Finally, don’t just light for the retina, light lower surroundings reflected in the upper retina with interesting bright/dim patterns. In order to preserve perception constancies, light the space just with cool or just with warm light at any given time. Provide additional interest in the space by using warm/cool pattern finishes.

This is an exciting time for lighting designers. Providing people with healthy lighting is of the greatest benefit to all. Let there be Light, a healthy human light.

### References:

- Boyce, P.R., Beckstead, J.W., Eklund, N.H., Strobel, R.W., and Rea, M.S.1997. *Lighting the graveyard shift: the influence of a daylight-simulating skylight on the task performance and mood of night shift workers*. *Lighting Research and Technology*, 29 (3), 105-142.
- Rea, M.S. 2002. “*Light-much more than vision*”. *Light and Human Health: EPRI/LRO 5<sup>th</sup> International Lighting Research Symposium*: Pal Alto, CA: The Lighting Research Office of the Electric Power Research Institute, 1-15.