DAYLIGHT
PHYSICAL HEALTH
Research Brief

PARTNERSHIP INITIATIVE
INTEGRATED DESIGN LAB
at the Center for Integrated Design

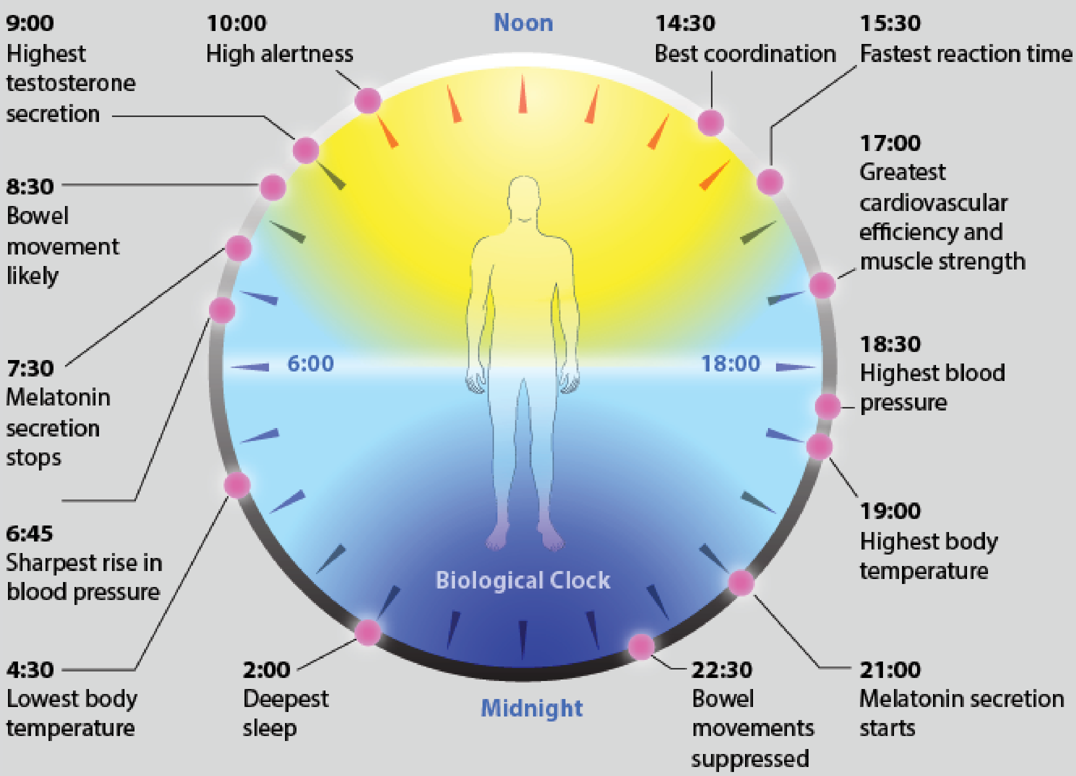

Figure 1:
Daily physiological effects of a typical circadian rhythm system. The inverse daylight-melatonin relationship is highlighted, with melatonin secretion stopping in the morning and resuming in the evening when the sun has set.

Source: https://cpapvictoria.com.au/blog/sleep-apnoea/circadian-rhythm-disorders/

Keywords:
daylight, physical health, circadian rhythm, melatonin, cortisol, physiological health, circadian disruption, sleep

CONTENT OVERVIEW

DAYLIGHT + PHYS. HEALTH SUMMARY

Daylight has many important physiological impacts on building occupants. These impacts predominantly manifest through light that enters the eye, though some come from light that is absorbed by the skin. In addition to contributing to eyestrain, daylight influences and properly sets the circadian rhythm, which has numerous impacts on physiology and physical health, both directly and indirectly.

I. General Physiological Impacts

Light impacts physical health in one of two ways: either by falling on the skin or through reaching the retina and impacting individual endocrine, hormonal and metabolic states (Edwards 2002 4). Critically, the physiological effects of light depend "on light entering directly into the eye, not reflected off the work plane (van Bommel 2006 263). Daylight in particular is better-suited to influence health than artificial cool white or energy-efficient fluorescent lighting since daylight is what human bodies evolved to respond to (Edwards 2002 3). Edwards notes, "natural light has the highest levels of light needed for biological function" (Edwards 2002 3) because "daylight provides the richest spectral, usable light, and it eases some of the stress to the eye (Edwards 2002 18). The spectral characteristics of daylight are critical to consider because "many functions, including the nervous system, circadian rhythms, pituitary gland, endocrine system, and the pineal gland are affected by different wavelengths of light" (Edwards 2002 4). Daylight that enters the eye "mediates and controls a large number of biochemical processes in the human body. The most important findings are related to the control of the biological clock (circadian rhythm) and to the regulation of some important hormones through regular light-dark rhythms (van Bommel 2006 260).

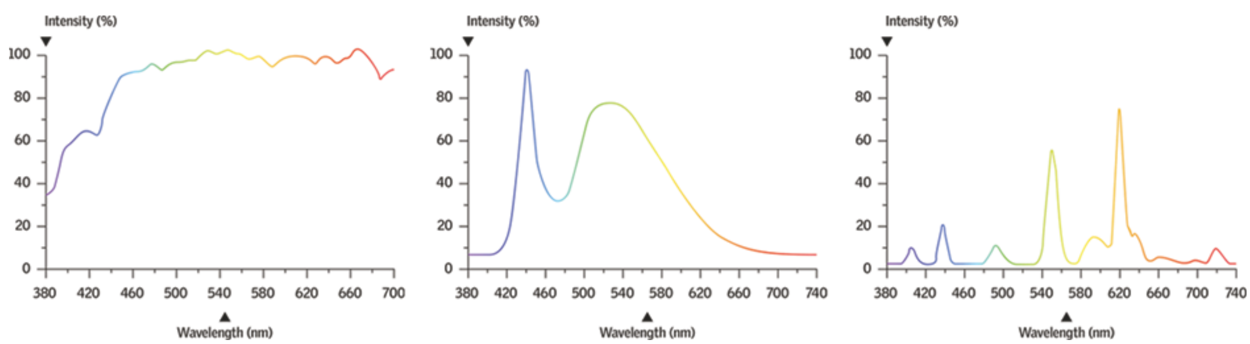

Figure 2: Comparison of spectral distribution of daylight, LED, and fluorescent light sources. Daylight provides a wider array of spectral diversity than artificial light sources, highlighting its importance in regulating health.
Source: https://www.velux.com/article/2016/daylight-natures-prescription

II. Pain + Healing

Daylight has been shown to decrease pain and improve healing rates. According to Ulrich, "patients experience less pain when exposed to higher levels of daylight" when compared with lower levels of daylight (Ulrich 2008 80). This may be because "sunlight exposure increases levels of serotonin, a neurotransmitter known to inhibit pain pathways" (Ulrich 2008 80). By decreasing experienced pain, daylight has been found to decrease the amount of pain medication taken per hour (Joseph 2006 6, Ulrich 2004 20) which may be why daylight has been linked to decreases in length of stay for patients (Joseph 2006 6, Ulrich 2004 20).

III. Headaches, Eyestrain, Other Issues

Headaches + Health Impacts

Daylight contributes to improved health outcomes for a variety of conditions. Increased amounts of time spent outside is associated with decreased nearsightedness, and it is suggested an important factor for this is the intensity of daylight (Aries 2015 11). The proper use of daylight in buildings "decreases the occurrence of headaches, SAD (seasonal affective disorder), and eyestrain," (Edwards

Headaches, Eyestrain, Other Issues cont.

2002 17) and may also help those suffering from migraines by reducing the amount of flicker typical with electric fixtures, though it's worth noting that high contrast light (glare) may contribute to increase migraines (Boyce 2003 46). For children in school, daylight provides physiological benefits in less dental decay (cavities), improved eyesight, increased growth, and improved immune systems (Edwards 2002 17). The fact that "workers in windowless factories have more headaches, faintness, and sickness compared to workers in factories with windows," also suggests that access to daylight has important impacts on physical health (Edwards 2002 36).

Eyestrain

Eyestrain is the most direct effect of light to the visual system (Boyce 2010 12) because of the many contributing factors of light: "too little light, too much light, too much variation in illuminance between and across working surfaces, [glare], veiling reflections, shadows, and flicker (even when not perceptible)" can all cause eyestrain (Boyce 2010 12). "Daylight will usually provide more than adequate illuminance on the task and is certainly free of flicker, but is prone to produce excessive luminance," due to difference in light levels in the sky and on interior walls (Boyce 2003 46). Eyestrain symptoms include "irritation of the eyes, evident as inflammations of the eyes and lids; breakdown of vision, evident as blurring or double vision; and referred effects, usually in the form of headaches, indigestion, etc." (Boyce 2003 46). Because of the myriad of conditions that can cause eyestrain, it's particularly problematic given that "regularly occurring eyestrain is inimical to productivity, not only for its effect on visual capabilities, but also because of the way it may alter people's behaviors" through coping mechanism like walking around or talking with coworkers (Boyce 2003 46). However, studies have shown that reports of eyestrain were significantly reduced by "people whose workstations received large proportions of natural light" (Aries 2015 11).

IV. Light on the Skin

At the most basic level, light on the skin can result in sunburns and skin tanning, but it is also important for the production of Vitamin D (Edwards 2002 4, Joseph 2006 8). Vitamin D is important because it helps with metabolizing calcium in the body, decreasing levels of tooth decay and factoring into the ability to recover after falling since "vitamin D is necessary for the absorption of calcium into bones and other body tissue" (Edwards 2002 18, 33).

V. Impact on Sleep

Interestingly, exposure to daylight during the day has been shown to impact office workers' sleep quality later in the evening, which may then have additional impacts on health (Boubekri 2014 609). Boubekri showed that workers with greater daylight exposure slept an average of 46 more minutes per night than workers in the same office without daylight exposure (Boubekri 2014 609). Impacts to sleep are important for health because lack of sleep, both in quality and quantity, is linked to "a range of significant short-term impairments such as memory loss, slower psychomotor reflexes, and diminished attention" (Boubekri 2014 604). Additionally, "sleep quality is an important health indicator that may have effects on, and interactions with, mood, cognitive performance, and health outcomes such as diabetes and other illnesses" (Boubekri 2014 604). "Insufficient sleep and reduced sleep quality have been associated with higher even levels of cortisol, impaired glucose metabolism, increase in appetite via decreased leptin and increased ghrelin levels, and higher body mass index, as well as increased fatigue and deterioration of performance, alertness, and mental concentration, which can lead to increased error rates and subsequent risk of injury" (Boubekri 2014 609).

VI. Hormone Response

Melatonin

One of the key ways daylight impacts the physiological systems is through the regulation of hormones such as melatonin, cortisol, and serotonin. Melatonin is perhaps the most important hormone influenced as this is a central component of the circadian system, to be discussed later in the brief. At the most basic level, light suppresses melatonin production (Lucas 2014 1, van Bommel 2006 257, Edwards 2002 6, Joseph 2006 4, Ulrich 2008 90). This is important because "melatonin levels in the body determine a person's activity and energy level. High melatonin levels cause drowsiness, while low melatonin levels correspond to an alert state of consciousness" (Edwards 2002 7, Joseph 2006 4). Additionally, "melatonin is involved in a variety of diseases, including cancer, insomnia, depression, dementia, hypertension, and diabetes" (Aries 2015 14). "Light absorbed by the eye controls the production of the hormone melatonin, which affects sleep, mood, body temperature, puberty onset, and tumor development." (Edwards 2002 6).

Cortisol

Daylight also stimulates the production of the cortisol because cortisol production is triggered by the secretion of melatonin, affecting the break down of carbohydrates, protein and fat; the development of white blood cells; the activity of the nervous system; and the regulation of blood pressure (Edwards 2002 6). Cortisol plays an important role in governing alertness by increasing "blood sugar to give the body energy and enhances the immune system… [it] increases in the morning and prepare the body for the coming day's activities" (van Bommel 2006 260).

Serotonin

Lastly, daylight exposure increases serotonin levels, which is known to "inhibit pain pathways" (Ulrich 2008 82). Aries also notes that "the rate of production of serotonin…[is] directly related to the prevailing duration of bright sunlight. Serotonin in the brain[is] affected by acute changes in the light intensity." (Aries 2015 14).

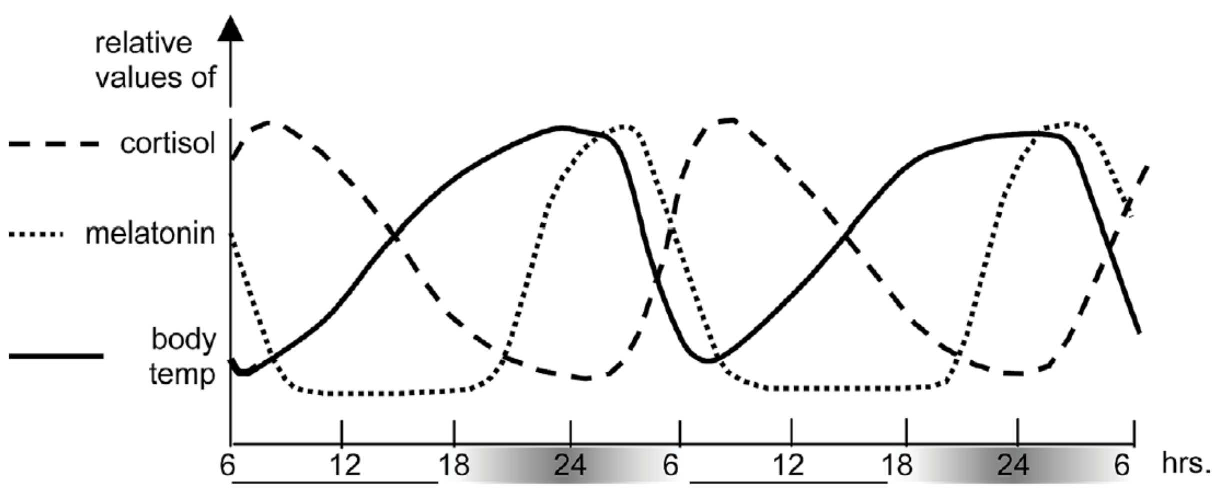

Figure 3: The cyclical pattern of melatonin, cortisol, and body temperature over the course of two days.
Source: van Bommel 2004

VII. Circadian Rhythm

What is circadian rhythm

Regulation of the circadian system is one of the largest ways light impacts the physiological health. Circadian rhythms “are the daily rhythms that repeat approximately every 24 hours and are driven by an endogenous clock. Nearly all behavioral and physiological parameters exhibit circadian rhythms and thus circadian clock synchronization is paramount to the body’s efficient and appropriate functioning. The neurobehavioral (e.g. sleep/wake cycle) and neuroendocrine (e.g. hormone production) axes are thus influence by optical radiation both directly (acute effects) and indirectly, via circadian clocks that drive and coordinate the rhythmicity in these systems” (Figueiro 2008 1). Lucas notes that circadian rhythms are “a feature of nearly every physiological, metabolic, and behavioral system” (Lucas 2014 1). However, one of the most visible manifestations of the circadian system is the sleep-wake cycle through the ability of light to impact the secretion of melatonin from the pineal gland (Bedrosian 2016 118). “The timing of the periods of light (or darkness) and their duration plays an essential role” in biological functions and physiology (van Bommel 2006 465). Daylight is critical to maintaining proper circadian alignment because the “human body clock is usually slightly longer than 24 hours and thus needs a daily morning light signal to reset the clock to entrain with the Earth’s 24-hour rotation rhythm and the changing photoperiod” (Aries 2015 16). Though the maintenance of circadian rhythm is critical to physical health, it is important to note that “the impact of optical radiation on the neurobehavioral and neuroendocrine responses is not exclusively via the circadian system” (Figueiro 2008 2).

Spectral Sensitivity

For the circadian system, it is not just about the quantity of light reaching the eye, but the quality of that light as well; circadian responses have a different spectral (wavelength/color) sensitivity than visual responses. While “maximum visual sensitivity lies in the yellow-green wavelength region,” “maximum [circadian] sensitivity lies in the blue region of the spectrum” (van Bommel 2006 257). Van

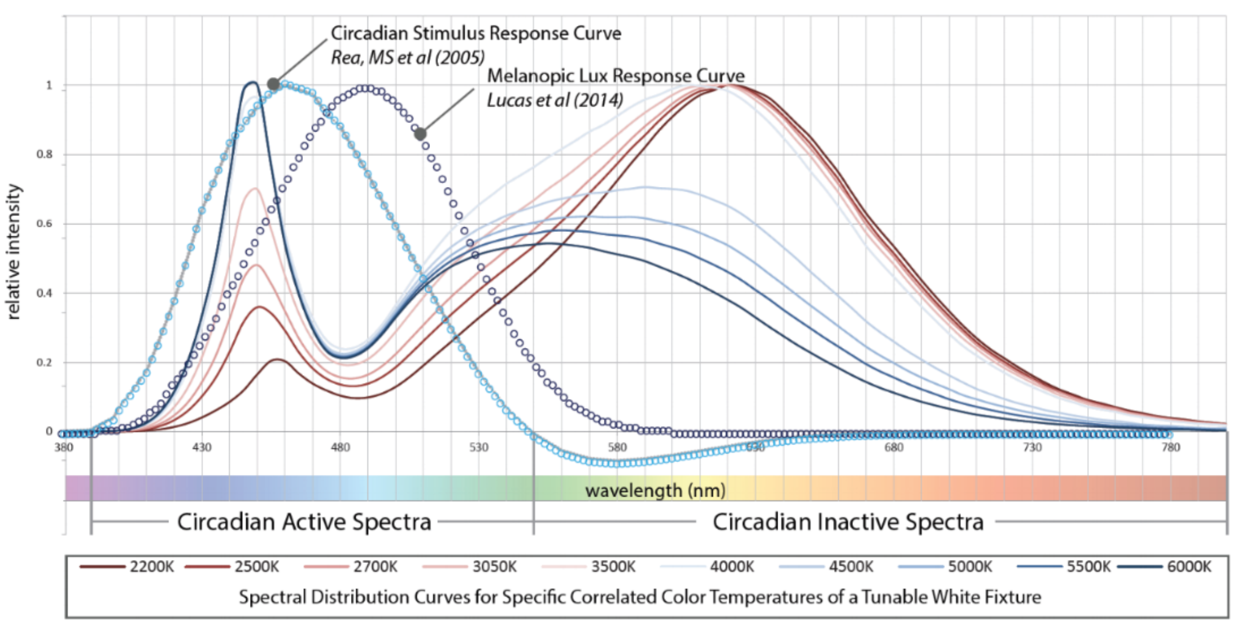

Figure 4: Circadian spectral sensitivity compared to typical spectral distribution of color temperature light fixtures.
Source: https://www.circa-dies.com/circadian-impactful-design/

Circadian Rhythm cont.

Bommel continues, explaining, “bluish, cool light has biologically a larger effect than warmer colored reddish light. Thus blue morning light has biologically an activating (alerting) effect, while the red sky that we see more often in the early evening has a relaxing effect” (van Bommel 2006 264). In addition to blue light, green light (wavelengths of 555 nm) “elicits non-visual responses...resetting circadian rhythms, suppressing melatonin production, and alerting the brain” (Aries 2015 13). What this means is that the melatonin-suppressing impacts of light are greatest with the cooler, more blueish light in the morning, weakening in the evening as the sun sets and the light shifts to a warmer tone.

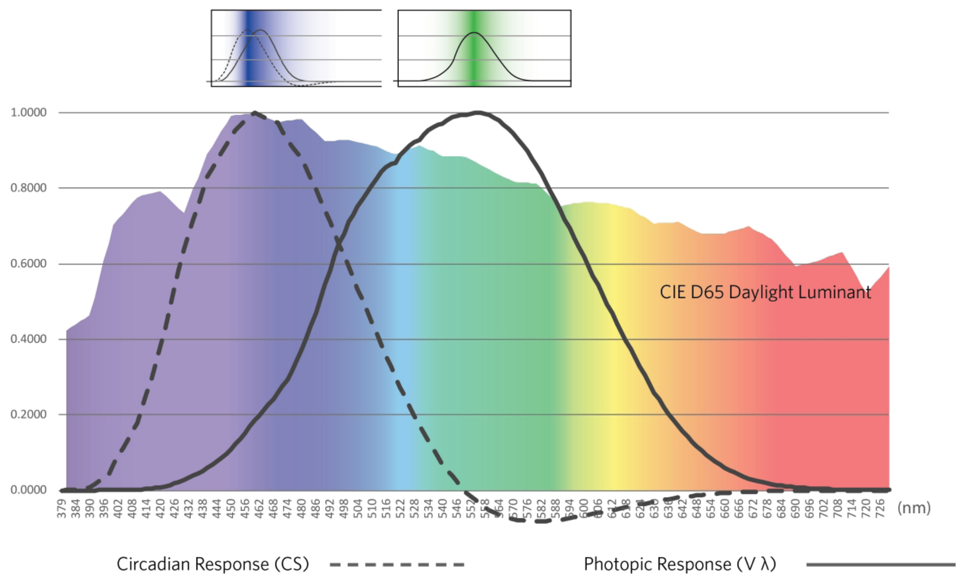

Figure 5: Circadian and visual spectral sensitivity compared to spectral distribution of sunlight.
Source: http://www.metropolismag.com/interiors/healthcare-interiors/why-light-matters-designing-with-circadian-health-in-mind/

Quantity of Light

While the spectral quality of light is critical for regulating the circadian system, the quantity of light is also important, though it is more difficult to precisely determine a “proper” amount of light. This is because the amount needed depends on multiple factors, as Boyce notes, “exactly how much light exposure is sufficient to entrain the human circadian system depends on the amount of light, the spectrum [quality] of the light, and the duration of exposure” (Boyce 2003 22). Additionally, the sensitivity to illuminance levels is still being debated. van Bommel suggests that “lighting levels of at least 1000 lux on the eye are needed for biological stimulation” of the circadian system; however by using more bluish light, the required light levels could be lower due to the photosensitivity of circadian receptors to that spectra of light (van Bommel 2006 464). Bedrosian states that, “in humans, 100 to 350 lux of light is sufficient to suppress melatonin levels, and exposure to just 100 lux in the early night phase delays the melatonin rhythm.” (Bedrosian 2016 114) while Aries notes that “the sensitivity of the human alerting and cognitive response to polychromatic light at levels as low as 40 lx is blue-shifted” (Aries 2015 13). Figueiro also adds that “levels of optical radiation lower than originally demonstrated...and as low as 50-100 lux at the cornea, can impact the circadian systems of humans in laboratory settings” (Figueiro 2008 12). However, she notes that, “the minimum levels of optical radiation necessary to impact the circadian clock in the real world will likely differ from those

Circadian Rhythm cont.

observed under laboratory conditions. Photic history has a profound effect on system sensitivity in that there is increased sensitivity following an interval of dim lighting" (Figueiro 2008 12).

Role of Daylight

The influence of lighting spectral quality and personal history of past light exposure on circadian sensitivity highlights the important role daylight plays in properly regulating the circadian system. "Exposure to daylight is a very potent means of providing enough light to entrain the circadian system," because "daylight... delivers a high illuminance [level] at the eye that is better batched to the spectral sensitivity of the circadian system than most electric light sources" (Boyce 2003 22). While electric lighting can impact the circadian system, it's "important to note that for most ceiling-mounted electric lighting systems, the illuminance at the eye will be markedly lower than the illuminance measured on the horizontal working plane that is conventionally used in lighting design, but this is not the case for daylight provided through a window" (Boyce 2003 23-4). This is because, as noted earlier, "the biological effect of light," depends on light entering directly into the eye, not reflected off the work plane (van Bommel 2006 33). Night time exposure to light is not the only potential sources of circadian disruption; in particular, "exposure to a low level of daytime lighting is similarly implicated in disturbing circadian rhythms and the sleep-wake cycle," (Bedrosian 2016 112). Figueiro supports this, noting "the higher the exposure to optical radiation during the day... the lower the human circadian system's sensitivity becomes to optical radiation at night" (Figueiro 2008 15). Intermittent exposure to proper light levels at the proper spectral range, as occurs naturally over the day when exposed to daylight, seems to provide more circadian entrainment than simply continuous exposure to uniform light levels (Figuerio 2008 14).

Manifestation of Circadian System

The most visible manifestation of the circadian system is through the regulation of melatonin secretion and its impacts on the sleep-wake cycle (Bedrosian 2016 118), though it is also seen in cycles of "body temperature... urine production, cortex activity, and alertness" as well (Edwards 2002 5). Much of the endocrine system is also affected because "endocrine rhythms are an essential part of physiological timekeeping" (Bedrosian 2016 110) and circadian disruption can lead to endocrine disruption, contributing to a "variety of consequences for health and disease" (Bedrosian 2016 118). "In certain illnesses, the biological regulatory system (circadian rhythm) plays an important role in maintaining the well-being of the individual" (Edwards 2002 33), particularly because "the immune system is highly regulated by the circadian system" (Bedrosian 2015 117). Bedrosian also notes that "several inflammatory diseases, including asthma and rheumatoid arthritis, fluctuate in severity of the course of the day, implicating circadian regulation of inflammatory processes" (Bedrosian 2016 117). The temporal distribution of daylight and its impacts on the circadian system are also likely to impact weight regulation; "having a majority of the average daily light exposure occur earlier in the day was associated with a lower BMI," potentially because ""in addition to altering metabolism via melatonin, circadian disruption may influence body weight through the regulation of other metabolic hormones" (Bedrosian 2016 121). Additionally, "low nocturnal melatonin secretion is associated with an increased risk of developing type 2 diabetes" (Bedrosian 2016 120).

Circadian Disruption + Cancer Risk

The strongest connection between the circadian system and disease has been found linking circadian disruption to increased cancer risk. This has been supported by extensive studies in epidemiological, clinical, and basic research (Bedrosian 2016 118). Though the primary concern is nighttime light exposure, "there is concern that the incidence and rate of development of breast and other forms of cancer are increased when melatonin suppression occurs night after night for a prolonged period," (Boyce 2010 15) particularly when paired with studies showing melatonin-depleted blood increasing the growth rate of breast cancer tumors (Boyce 2010 17).

VIII. KEY REFERENCES

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- "Why Ligh Matters: Designing with Circadian Health in Mind" - *Metropolis Magazine*
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- "Daylight: Nature's Prescription for Health, Productivity, and Sleep" - *Velux*