The effect of artificial lighting and controls on patient outcomes in behavioral health facilities

by

Gabriella Faith Radina

B.S., Kansas State University, 2022

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

GE Johnson Department of Architectural Engineering and Construction Science
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2022

Approved by:

Major Professor
Fred Hasler, P.E.

Copyright

Abstract

Mental illness has been somewhat of an enigma for much of human history. Lack of understanding mental illness led to inhumane treatments in psychiatric hospitals. During the era of inhumane patient treatment, it was theorized that the built environment could influence patient behavior and reception to treatment. Subsequently, design recommendations for mental health treatment facilities in the 18th century were centered around daylighting allowances which has significant benefits including regulating hormones and mental health. With the advent of artificial light sources, humans can control how much light they consume, which can be deleterious to biological systems including the circadian system.

This report provides design recommendations for patient rooms, group rooms, and corridors in an adult, behavioral health, inpatient hospital setting with an LED lighting system. The design recommendations are based on studies that examine the impact of lighting on various mental illnesses (depression, eating disorders, bipolar disorder, and schizophrenia) within a lens of the biological impact of current lighting solutions. To ensure proper circadian entrainment, a circadian lighting system should be installed. In patient rooms, an exam luminaire above the bed may be provided with supplemental lighting throughout the room in the form of downlights. Controls may be provided outside of the patient room. Task lighting in patient and group rooms should be provided via wall surface-mount touch-controlled fixtures. Additionally, group rooms should have lighting that is controllable by patients via dimming or multi-level stepped dimming. Corridors must consider patient viewing, so cove lighting along the perimeter of the ceiling provides uniform ceiling distribution while eliminating glare. Throughout a behavioral health facility, wall- recessed wayfinding luminaires installed 2’ above the finished floor with a light source at 2700K should provide evening illuminance. Melanopic lux measurements can be a

useful way to quantify the impact of lighting on biological processes. The lighting designer should discuss the spectral power distribution with the manufacturer to ensure that the blue wavelength light decreases as correlated color temperature decreases. Providing appropriate lighting solutions can decrease the length of patient stays and increase staff productivity.

Table of Contents

List of Figures

List of Tables

Acknowledgements

First, I would like to acknowledge my major professor, Fred Hasler, for guiding and advising me through my bachelors and master's degree, thank you for believing in me. I would also like to acknowledge my committee, Julia Keen, Kimberly Kramer, and Derek Clements. Thank you for supporting me and answering my many questions. Finally, I would like to acknowledge Angi Xanders who first introduced me to this topic and allowed me to help her with lighting design for a behavioral health floor, thank you for helping me find a topic I am passionate about.

Dedication

To my parents, Wade and Annette Radina, to whom this report is dedicated. You have always exemplified discipline, kindness, and determination. To my sister, Amelia, for helping me laugh and have fun throughout this process. To Ben Brokesh for your never-ending patience and understanding. And to all the teachers, friends, and family who offered words of encouragement, a shoulder to lean on, and an ear to listen.

Without all of you this would have been an insurmountable task.

Chapter 1 - Introduction

Attitudes about mental health have evolved throughout centuries creating a more understanding environment and an atmosphere for change in treatment. Additionally, there is increasing demand to develop treatments and facilities dedicated solely to mental illnesses. For centuries, it has been theorized that architectural design influences behaviors and emotional well-being within a space. Most existing treatment facilities inhibit patient recovery and staff effectiveness. Patients in inpatient and outpatient facilities often find themselves in built environments that feel institutional and would be unsettling to healthy individuals. Thoughtful design can reduce stress, pathological behaviors, and aggression (McCuskey Shepley & Pasha, 2017). Approaches to behavioral health design continue advancing as architects and designers learn more about the triggers and treatments for mental illnesses. Design encompasses all facets of architecture, interior design, and engineering processes. The World Health Organization (WHO) and Center for Disease Control (CDC) have both published data emphasizing the need for thoughtfully designed treatment facilities. Dr. Tedros Adhanom Ghebreyesus, Director-General of the World Health Organization, has stated,

"It is extremely concerning that, despite the evident and increasing need for mental health services, which has become even more acute during the COVID-19 pandemic, good intentions are not being met with investment. We must heed and act on this wake-up call and dramatically accelerate the scale-up of investment in mental health, because there is no health without mental health."

According to the CDC, more than 50% of people in the United States will be diagnosed with a mental illness during their lifetime (Center for Disease Control and Prevention, 2021). Mental illness and health status can change throughout a person's lifetime due to changes in stress, life circumstances, economic and political transitions, and isolation or loneliness. Mental illness is an all-encompassing term referring to depression, eating disorders, attention deficit disorder, bipolar disorder, schizophrenia, and many more. Currently, 1 in 25 Americans lives with a severe mental illness like schizophrenia, bipolar disorder, or severe depression (Center for Disease Control and Prevention, 2021). Continual improvements in design can decrease the seriousness of mental illnesses, and the time patients must remain hospitalized. Integrating more design methodologies can improve the global economy and overall community health (McCuskey Shepley & Pasha, 2017).

1.1 Objective

This report aims to apply current research data to propose a design of LED lighting and controls for adult patients receiving psychiatric treatment in a hospital inpatient setting in the United States. Specifically, the design aims to create lighting scenes that aid recovery and reduce the length of stay for adult patients hospitalized for psychiatric disorders including depression, bipolar disorder, bulimia, and schizophrenia.

1.2 Scope of Report

In chapter 2, this report will analyze the history of psychiatric care and design to provide context for how societal norms and attitudes developed. Next, chapter 3 will explain the physiological perception of light to describe how the human eye and brain perceive light. This is crucial in understanding how patients and hospital personnel interpret the design. Next, chapter 4 will analyze the impact of optical radiation (light that impacts processes) on biological processes through its influence on circadian, neuroendocrine, and neurobehavioral regulation. Chapter 5 analyzes symptoms, diagnoses, and the link between light for sleep, depression, bipolar disorder, bulimia, and schizophrenia. Chapter 6 will propose lighting design recommendations for behavioral health facilities, including patient rooms, group rooms, and corridors. Finally, chapter 7 will summarize the conclusions drawn throughout the report.

Chapter 2 – The History of Psychiatric Care and Design

Observations by physicians have been shaping societal views of mental health since 4 B.C., when Hippocrates and Plato first developed hypotheses about mental disorders (McCuskey Shepley & Pasha, 2017). These views have directly impacted architectural approaches to treatment facility design. More knowledge and research have clarified the link between hormones, personal experiences, environment, and the development and severity of mental illnesses. This chapter will discuss the approaches to treatment, legislation, and design. The context provided in this chapter will establish the importance of continued research and the design recommendations provided in this report.

2.1 Treatment

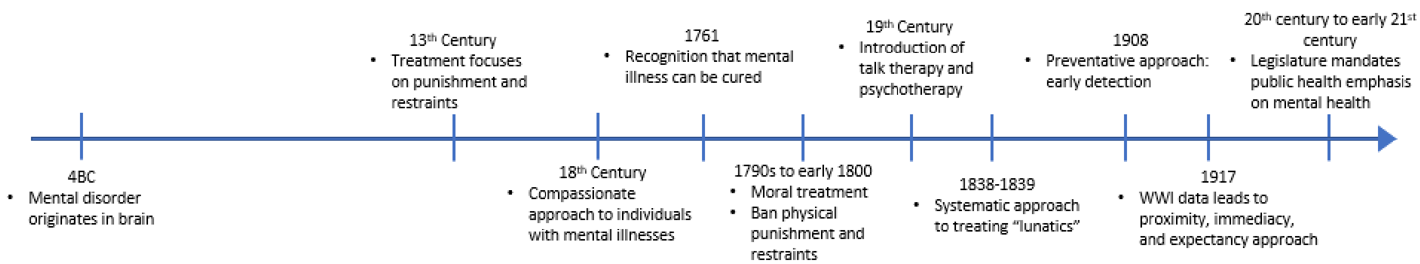

Figure 1. Timeline of Approaches to Treatment

Hippocrates and Plato first hypothesized that mental illness was due to disease in the brain or an imbalance between the mental, physical, and spiritual self. These hypotheses fueled the view that mental health is inorganic and separate from one's being. As a result, treatment facilities from the Middle Ages to the 1800s were jail-like and described as "mad cages." Poorly trained nurses and a general belief that mental illness patients could not feel pain led to a dependence on physical restraints. In addition to physical restraints, extreme temperatures were used to control the patients with the belief that extreme conditions could shock the patients back to sanity. Around the 1800s, many places in Europe began to transition to a more general hospital setting for treatment. By the end of the 19th century, there was a better understanding of mental illness, improvements in medicine, and better-trained nurses, but overcrowding continued the reliance on physical restraints (McCuskey Shepley & Pasha, 2017). Unfortunately, custody and security were still the emphases of care.

The 20th century saw a shift in care due to an increase in understanding about mental health because of the treatment of World War I troops. The principles of proximity, immediacy, and expectancy became the basis of mental health treatment. This encourages treatments available near where the patient lives, provided immediately after the crisis, and with expected recovery. These principles led to laws to reinforce treatment plans. The 1950s saw the development of pharmacological agents, which created significant improvements in severe psychiatric conditions and reduced the need for restraint and constant observation (McCuskey Shepley & Pasha, 2017). The remainder of the 20th century and early 21st century saw improvements to treatment and efforts to decrease mental health's social stigma. Fortunately, changes and enhancements in treatment have corresponded to legislation to standardize care and continually improve patient and staff circumstances.

2.2 Legislation

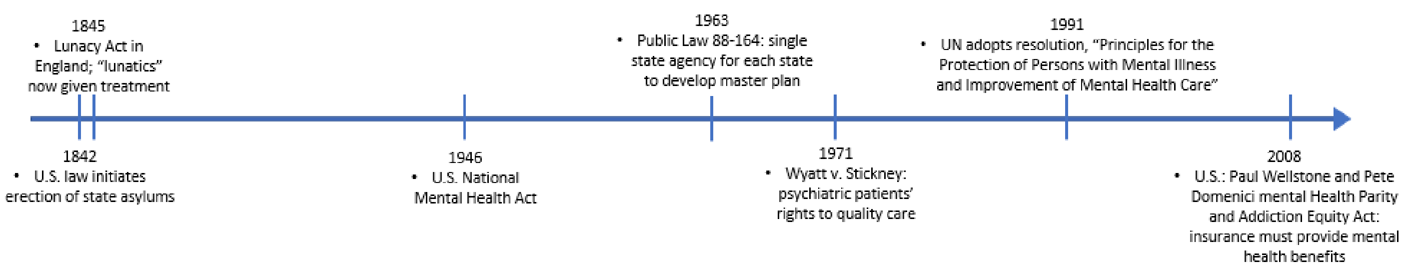

Figure 2. Timeline of Legislation to Support Mental Health

Legislation to support mental health in Europe and the United States began in the mid-19th century. In the United States, laws were passed to initiate the erection of state asylums in 1842 (McCuskey Shepley & Pasha, 2017). These amenities created separate treatment facilities for those diagnosed with mental illness; however, state asylums were still implementing physical restraints and extreme condition treatments, creating inhumane situations. After World War II, the United States created the National Mental Health Act. This act was signed into law in 1946 by President Harry S. Truman and provided funds to create the National Institute of Mental Health (NIMH) (Public Law 79-487). Its' intention was to improve:

"the mental health of the people of the United States through the conducting of researches, investigations, experiments, and demonstrations relating to the cause, diagnosis, and treatment of psychiatric disorders; assisting and fostering such research activities by public and private agencies, and promoting the coordination of all such researches and activities and the useful application of their results; training personnel in matters relating to mental health; and developing, and assisting States in the use of, the most effective methods of prevention, diagnosis, and treatment of psychiatric disorders." (Public Law 79-487)

Funds were provided for Community Mental Health Centers (CMHCs) in 1963 with Public Law 88-164, which contributed to the principles of proximity, immediacy, and expectancy. Alongside these governmental fund allocations for improvements, lawsuits created precedence for the treatment and expectations for patients, staff, and families. *Wyatt v Stickney* (1971) acknowledged psychiatric patients' right to a quality physical environment that supports their unique treatment plans. In a Joint Hearings before the Subcommittee on the Handicapped in 1985, it was found that patients and staff in behavioral health facilities were subject to injury and unacceptable living conditions. The Paul Wellstone and Pete Domenici Mental Health Parity and Addiction Equity Act of 2008 required American insurance policies to provide mental health and substance abuse benefits (McCuskey Shepley & Pasha, 2017). Additionally, an increase in social awareness has led to the creation of mental health policies in schools and businesses. The allocation of funds for facilities has also led to more research and considerations for design.

2.3 Design

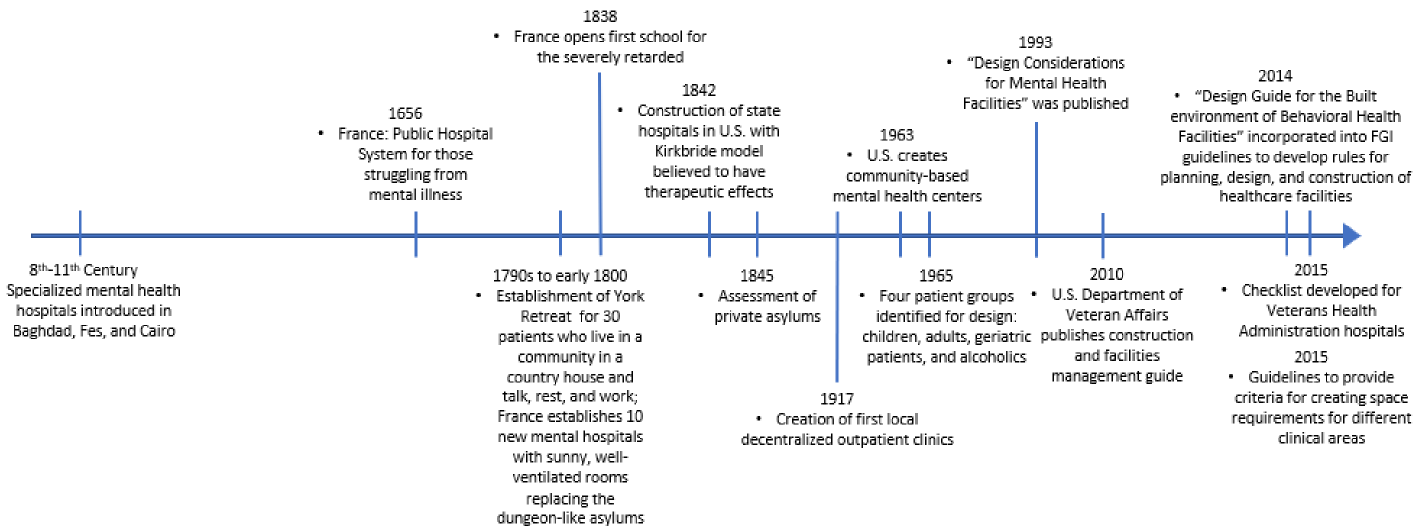

Figure 3. Timeline of Approaches to Facility Design

In the 8^{th}-11^{th} century, specialized mental hospitals were introduced in northern Africa and the Middle East. These were the first facilities to provide specialized treatment and observe different mental illnesses. Their discoveries gave the insight to create spaces that supported those struggling with mental illness. During the era of physical restraints and harsh conditions, the York Retreat (York, England) was established in 1796 by William Tuke, which pioneered ethical treatment. His grandson, Samuel Tuke, wrote "Practical Hints," published in 1815. This publication recommends that security be achieved through direct observation rather than physical restraints. This principle is still implemented in behavioral health design. Additionally, "Practical Hints" recommends access to daylit spaces and fresh air (McCuskey Shepley & Pasha, 2017). Providing access to spaces with different functions (i.e., group therapy, isolation, cafeteria, gym) creates a sense of autonomy in the patient that can improve treatment (S. Root, personal communication, December 10, 2021). At the end of the 18^{th} century and beginning of the 19^{th} century, hospitals began separating the psychiatric wards from the rest of the hospital. For most of the 19th century, there was a common belief that 70-90% of insanity cases were curable with the contingency that patients were treated in specially designed buildings. The Kirkbride model was used in the 19th century to construct state hospitals in the United States. This model recommends creating separate wings of the hospital to maximize daylight and ventilation and providing separate wards for patients based on their mental state. For example, violent patients were kept in a separate single-story ward. Patients needing seclusion and privacy were also kept in a single-story ward. Each ward contained patient sleeping areas, dayrooms, dining rooms, bathrooms, housekeeping, and storage rooms. This remains a traditional approach to design. In the 20th century, four patient groups were identified as needing different types of design: children, adults, geriatric patients, and alcoholics. Treatment facilities for these groups include hospitals, halfway homes, and rehabilitation centers. The “Design Considerations for Mental Health Facilities” was published in 1993 by the American Institute of Architects, which created standard expectations for design. In 2014, the “Design Guide for the Built Environment of Behavioral Health Facilities” was incorporated into the Facility Guidelines Institute’s (FGI) standards to develop guidelines for the planning, design, and construction of healthcare facilities (McCuskey Shepley & Pasha, 2017). The basis for these documents is Evidence-Based Design (EBD).

Today, design is often grounded in EBD or Planetree design suggestions. EBD is patient-focused design and concentrates on sleep and recovery. There is a heavy emphasis on science informing design, but there is currently a lack of input from lighting designers and experts (S. Root, personal communication, December 10, 2021). As suggested by “Practical Hints” in the 17th century, daylight remains the preferred form of illumination with a recognition of the mental and physical health benefits of daylighting (McCuskey Shepley & Pasha, 2017). Daylighting controls come in the form of blinds enclosed in glass with staff only controls so they are tamper-resistant. Similarly, a Planetree approach focuses on patient-centric design. This method considers a home-like approach to create a comfortable and inviting space to promote healing (S. Root, personal communication, December 10, 2021). This directly affects artificial lighting, emphasizing choice and impacting luminaire selection to create a warm, home-like atmosphere. To intentionally select appropriate luminaires, it is important to understand the human visual system.

Chapter 3 – The Physiological Perception of Light

Light travels by photons propagating electromagnetic radiation (DiLaura et al., 2011) and is often described as a wave or particles. A combination of these theories is commonly accepted for describing the visible portion of the electromagnetic spectrum (Figure 4) (IES Light and Human Health Committee, 2018). Daylight is the primary source of illuminance perceived by humans and animals. Advances in technology have created artificial sources that increase exposure to light or optical radiation (this includes ultraviolet, visible, and infrared radiation) (IES Light and Human Health Committee, 2018). Light inputs from natural and artificial sources relate directly to ocular circadian, neuroendocrine, neurobehavioral, and therapeutic responses. Circadian responses relate to the sleep-wake cycle. Neuroendocrine responses relay brain regulated hormone responses created by nerves and gland cells. Neurobehavioral responses relate to how the brain influences emotion and behavior (IES Light and Human Health Committee, 2018). A fundamental understanding of the human perception of light and the functions of the various structures of the eye assist in the explanation of the health and biological implications of light exposure.

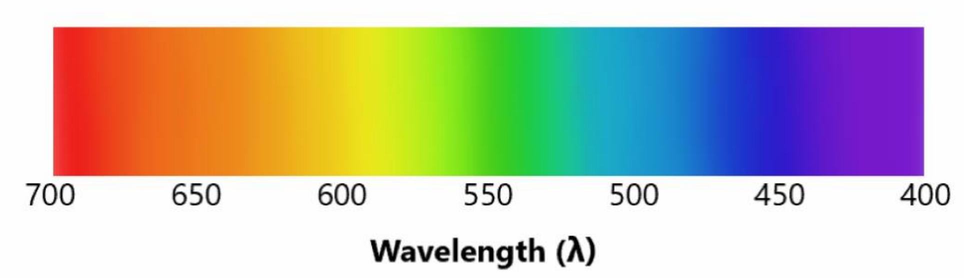

Figure 4. Visible Light Spectrum

400 nm – 700 nm consist of the visible light portion of the electromagnetic spectrum

3.1 The Mechanisms of the Eye

The eye captures optical radiation via retinal photoreceptors and converts them to neural signals (IES Light and Human Health Committee, 2018). The main layers of the eye and brain are the retina, the lateral geniculate nucleus, and the primary visual cortex (DiLaura et al., 2011). To create an image, optical radiation must be processed through the eye and converted into an electrical impulse for the brain through phototransduction within the photoreceptor (Kremers et al., 2016). Many specialized structures within the eye facilitate this process.

3.1.1 Anatomy of the Eye

The anatomy of the eye consists of components that maintain eye shape, focus light, and connect to neural pathways for visual comprehension. Additionally, these optical structures are responsible for controlling the amount of optical radiation that enters the eye and manipulating it using mechanical, chemical, and neural processes to create an image in the brain (DiLaura et al., 2011). These processes allow the eye to function at varying light levels.

The sclera (Figure 5a) is known as the white of the eye. It contains many blood vessels and provides a thick outer layer that is durable and protects the eye. The choroid is a thin layer in the sclera that is dark and brings the blood vessels to the eye's interior. The epithelium comprises the innermost layer of cells that helps absorb the light because it has a low reflectance (DiLaura et al., 2011).

The cornea (Figure 5b) sits on the outside of the eye and is a thin, transparent extension of the sclera. It does not have blood vessels, but it is packed with pain receptors that help protect the eye. The primary light-based purpose of the cornea is to help focus the light into the eye. Because it is so round, it is responsible for 2/3 of the eye's focusing power. Additionally, the lacrimal glands continuously produce tears that moisturize the cornea creating a better visual interface (DiLaura et al., 2011).

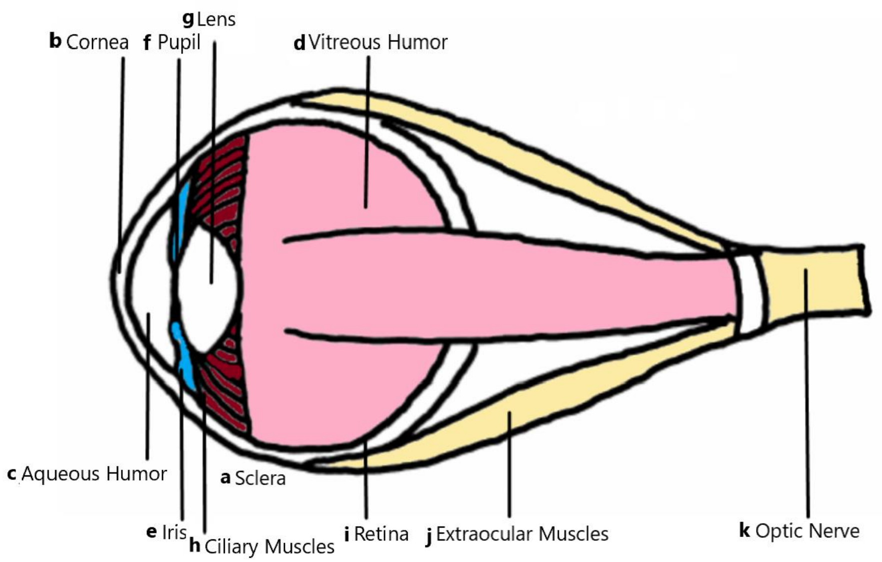

Figure 5. Diagram of the Eye Adapted from (DiLaura et al., 2011)

(a) The sclera or white of the eye surrounds the eye and is coming towards the reader. **(b)** The cornea is a thin, clear extension of the sclera that has pain receptors to protect the eye and controls the focusing power of the eye. **(c)** In front of the eye is the aqueous humor which is a clear watery substance that is absorbed and regenerated continuously and exerts pressure on the eye. **(d)** Behind the eye, is the vitreous humor which is a jelly like substance. **(e)** The iris is the colored portion of the eye and controls the dilation and contraction of the **(f)** pupil which controls how much light reaches the back of the retina. **(g)** The lens behind the pupil helps focus light onto the retina. **(h)** Ciliary muscles control the bulging and flattening of the lens. **(i)** The retina contains three layers of cells that communicate the information to the brain. **(j)** Extraocular muscles control the movement of the eye. **(k)** The optic nerve delivers optical signal to the brain.

The aqueous humor (Figure 5c) is directly behind the cornea, a clear and watery substance that is constantly absorbed and generated. Comparatively, behind the lens is the vitreous humor (Figure 5d) which has a more jelly-like consistency and is not as clear as the aqueous humor. Comparatively, the vitreous humor is not regenerated; thus, the aqueous humor determines the amount of pressure exerted on the eye's structures (DiLaura et al., 2011).

The iris and pupil sit behind the aqueous humor and control the amount of optical radiation that enters the eye. The iris (Figure 5e) is the colored portion of the eye, and its expansion and contraction control the dilation of the pupil (Figure 5f), thereby controlling how much light reaches the retina. The pupil constricts and dilates in response to light and the size of the object in the field of vision (DiLaura et al., 2011).

The lens (Figure 5g) is directly behind the pupil and helps focus the light onto the retina. It is convex and almost entirely translucent. The lens is very flexible in youth but hardens with age making it more difficult to adjust to different light intensities. When the lens is relaxed, it bulges out, increasing curvature and refracting potential. Muscles control the lens through tensioning and separate the front and the back of the eye. Radial zonule fibers pull on encasing tissues and flatten the lens. Ciliary muscles (Figure 5h) surround the lens and oppose the pull of the zonule fibers. These muscles play the most significant role in controlling the bulging or flattening of the lens (DiLaura et al., 2011).

In the back of the eye, the retina (Figure 5i) serves as the end of the optical pathway and the beginning of the neural pathway to create a visual response. Optical radiation reaching the retina impacts: pineal melatonin production, morning cortisol production, subjective alertness, heart rate, core body temperature, pupil constriction/dilation, and circadian clock gene expression (IES Light and Human Health Committee, 2018). The retina is functionally considered a part of the brain because of its structure, function, and complexity. The retina lines the entire back of the eye and contains three layers of nerve cell bodies (IES Light and Human Health Committee, 2018) (Figure 6).

The outer nuclear layer of the retina is made of photoreceptors (rods and cones). It sends all the photic information to the brain via cells in the retina’s outer plexiform layer (OPL). In general, rods outnumber cones about 20:1. Rods are responsible for sight in diminished light levels (less than .001 cd/m^2) called scotopic vision and contain the photopigment rhodopsin with peak sensitivity at 507 nm. Cones are responsible for photopic (daylight) vision and contain the S (short), M (medium), and L (long) photopigments responsible for color vision. During the times between photopic and scotopic light levels called mesopic vision, both the rods and cones are operating (IES Light and Human Health Committee, 2018).

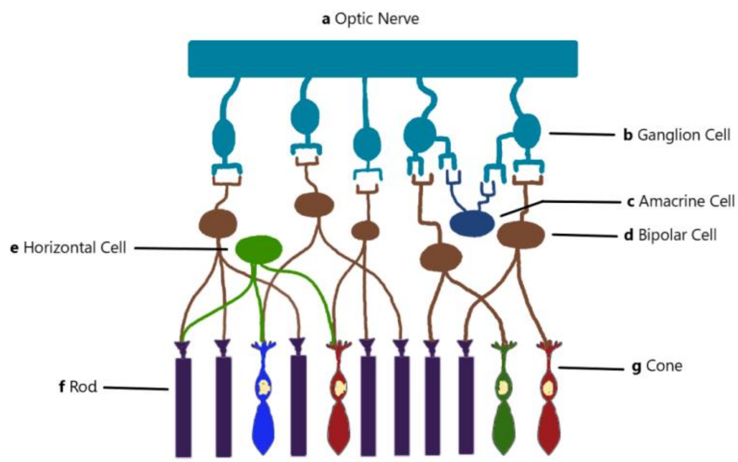

Figure 6. Retinal Wall Cells Adapted from (White & Olabisi, 2017))

The **(a)** optic nerve receives information from the **(b)** ganglion cells. **(c)** Amacrine cells help regulate signals between the ganglion cells and the **(d)** bipolar cells. Signals from the bipolar cells are delivered to the **(f)** rods and **(g)** cones. **(e)** Horizontal cells help regulate signals among the photoreceptors and the bipolar cells.

The retina's inner nuclear layer comprises bipolar, horizontal, and amacrine cells that are responsible for signal processing functions (Figure 6). Bipolar cells collect information from the photoreceptor cells, while horizontal and amacrine cells transmit the data to the ganglion cells (DiLaura et al., 2011).

The layer closest to the vitreous humor is the ganglion cell layer. The visual signal leaves the retina as a ganglion axon spike which is activated when light hits the retina (ON discharge) or when the light is extinguished (OFF discharge). To separate the ON/OFF signals through the ganglion cells to the brain, the inner plexiform layer (IPL) is divided into two sublaminae called a (OFF) and b (ON) (IES Light and Human Health Committee, 2018). There is evidence that the intrinsically photosensitive retinal ganglion cells (ipRGCs) function as a fourth type of photoreceptor and impact circadian, neuroendocrine, and neurobehavioral responses in the hypothalamus (DiLaura et al., 2011) which will be discussed in more depth in the next chapter.

The axons from the ganglion cells join in the midline at the optic chiasm in the back of the eye and create the optic nerve, which is comprised of roughly 1.5 million fibers (Figure 7) (the number of ganglion cells in the eye). Each eye has an optic nerve (Figure 5j), and they join and cross at the optic chiasm and then feed into the lateral geniculate nucleus (LGN) (Figure 7). From here, the axons travel to the middle of the brain, and then a smaller number of fibers continue to the back of the brain, where eye movement and pupil size are controlled (DiLaura et al., 2011).

3.1.1.1 Cranial Response

Once the retina has converted the optical radiation into an electrical signal, it is passed along the primary tract of the optic nerve to the primary visual cortex in the back of the brain via the LGN and then through the secondary optic tract to the superior colliculus (IES Light and Human Health Committee, 2018). The left and right fields of vision are kept separate, with the right field of vision interpreted by the right brain and the left field of vision interpreted by the left brain. Inputs from the LGN are then processed in the visual cortex at the back of the brain, which creates perception and allows vision (DiLaura et al., 2011).

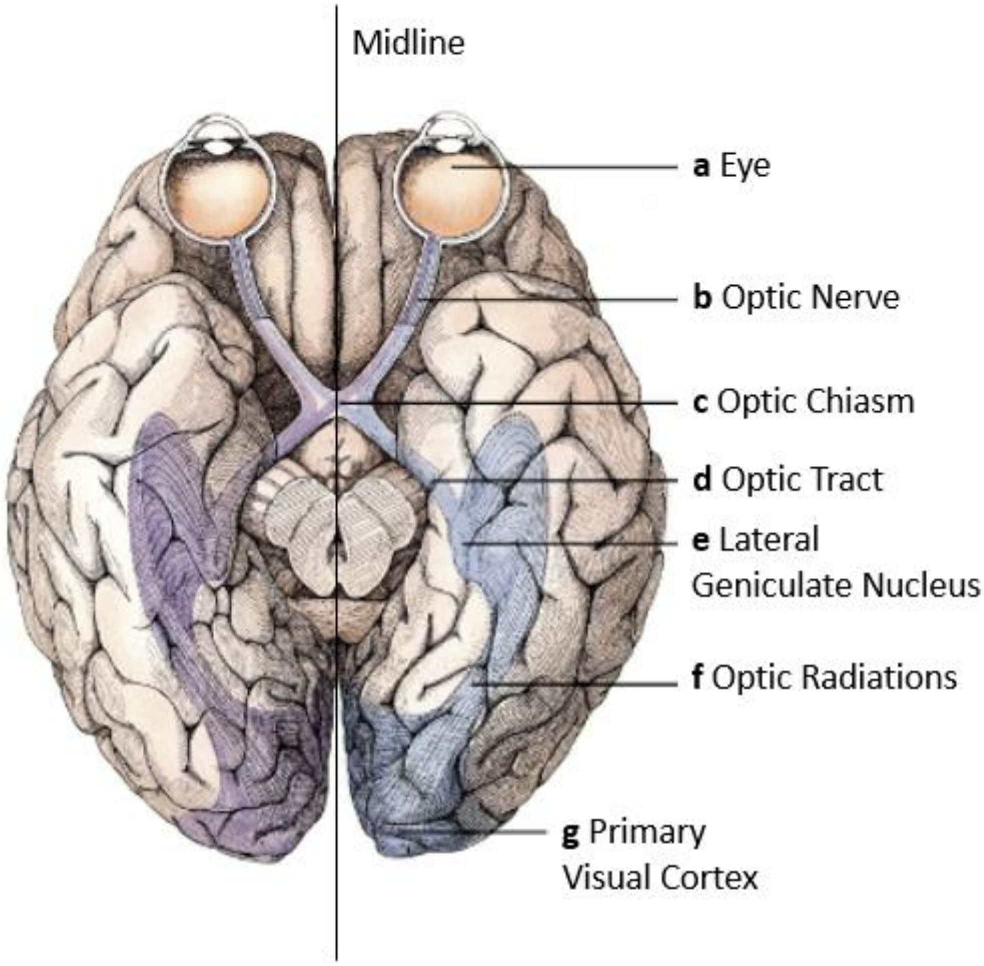

Figure 7. Neural Pathways Adapted from (DiLaura et al., 2011)

Visual optical radiation taken in by the **(a)** eye is converted into electrical signals by the retina. Signals from the left and right eye travel through the **(b)** optic nerve and meet at the **(c)** optic chiasm. The optic chiasm turns into the **(d)** optic tract which carries the signals to the **(e)** lateral geniculate nucleus which feed the **(g)** primary visual cortex via **(f)** optic radiations. The primary visual cortex controls eye movement.

3.2 Color Vision

The ability to decipher color varies in the animal kingdom and relates to photoreceptors in the retina. Color vision in vertebrates requires photoreceptor cells called cone cells that can decipher the incoming light as it hits the retina and then connect with neural mechanisms that compare the responses of the cone cells and create a color signal. Animals with color vision (including humans) have photoreceptors with differing spectral sensitivities capable of analyzing light waves at differing intensities (Surridge et al., 2003). These adaptations can be traced to the difference between diurnal and nocturnal primates (Kremers et al., 2016).

There is a correlation between diurnal animals (like humans) and nocturnal animals and their ability to perceive light. Nocturnal animals often have only two types of photoreceptors causing poor color vision at low light intensities. Comparatively, diurnal animals have evolved to have three photoreceptors allowing them to see more colors (Surridge et al., 2003). The presence of three photoreceptors is called trichromacy and demonstrates many evolutionary advantages.

3.2.1 Evolution of Trichromacy

Primates (humans included) have evolved to have trichromatism, which gives a survival advantage. It is believed that the evolutionary drive of trichromacy in primates is the ability for better color discrimination, especially in the red/green portion of the visible light spectrum, which allows for better recognition of fruit against green leaves. Photopigments are located in the photoreceptor of the cone cell. Duplication from two photopigments to three resulted in trichromacy (Kremers et al., 2016). The three requirements to be a trichromat are the expression of the gene that allows a unique chromatic signal to be produced, the addition of another opsin (light-sensitive protein that makes up the visual pigment, rhodopsin) gene, and the evolution of neural circuitry to isolate the color information (Surridge et al., 2003).

3.2.1.1 Chromatic Signal Gene Expression

The retina has two types of photoreceptors, rods and cones. There are three different types of photopigments in the cone photoreceptor. The three photopigments are sensitive to different wavelengths in the visible light spectrum. These photopigments are called S (short), M (medium), and L (long). The X chromosome has a single gene that encodes different M and L photopigments, while the S photopigment is determined by an autosomal (non-sex chromosome) gene. The M photopigment evolved via duplication of the L gene on the X chromosome (Surridge et al., 2003). Table 1 shows the relationship between photoreceptor, photopigment, and maximum spectral sensitivity. In dichromats, only the L and S photopigments are present, which creates a lack of ability to distinguish reds and greens (this is described as red-green colorblindness when a mutation causes the M photopigment to disappear). The presence of all three photopigments is called routine trichromacy. Each photopigment has a different spectral sensitivity defined by the likelihood of a photon of wavelength (λ) being converted into a neural signal (Surridge et al., 2003).

Table 1. Photoreceptors based on information in IES TM-18-18

Photoreceptor	**Photopigment**	**Maximum Spectral Sensitivity (λ_{max})**
S	Cyanolabe	440 nm
M	Chlorolabe	535 nm
L	Erthylabe	565 nm

Each photoreceptor translates into sensitivity to one type of photopigment molecule most closely corresponding to red (L), green (M), and blue (S). This nomenclature is misleading because maximum wavelength sensitivity, λ_{max}, does not necessarily correlate to colors recognized by these names (Figure 8) (Surridge et al., 2003)

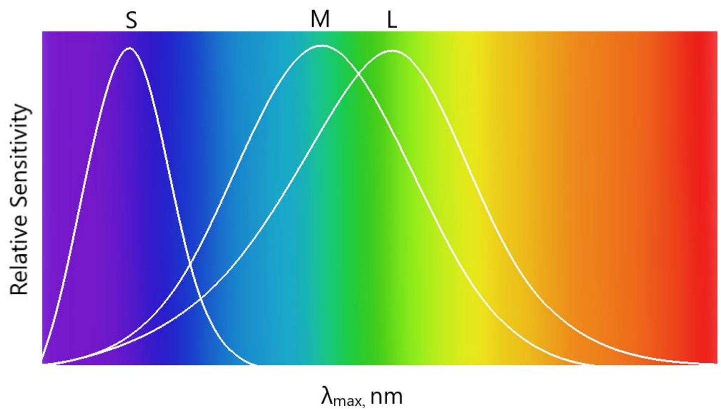

Figure 8. Photopigments Peak Spectral Sensitivity

3.2.1.2 The Opsin Protein

Photopigments are comprised of an opsin protein and a retinal prosthetic group (Surridge et al., 2003). Opsin is a protein that is light sensitive (IES Light and Human Health Committee, 2018). Mutations through duplication increased the opsin gene number and single point substitutions created spectral sensitivities resulting in diversification and trichromacy. Both of these phenomena are extremely common over an evolutionary timescale and allowed the opsin protein to differentiate into the S, M, and L opsins (Surridge et al., 2003).

The cone opsin protein has 364 amino acids where just a few amino acid changes can affect the spectral sensitivity and account for variations in pigment sensitivities called "spectral tuning." Spectral sensitivity or absorption maximum is based on the amino acid sequence within the opsin protein and its interface with the chromophore (the part of the molecule that absorbs photons) (IES Light and Human Health Committee, 2018). Spectral tuning is incredibly moderate along primate lineages, creating minimal variations from individual to individual and generation to generation (Surridge et al., 2003).

3.2.1.3 Neural Pathways

Neural pathways evolved to organize optical radiation inputs. Optical radiation enters the eye, is captured by retinal photopigments in the cone cells, and then converted into neural signals to be transmitted to the brain (IES Light and Human Health Committee, 2018).

Mammals that are not primates, perceive inputs through pooling (Figure 9). Pooling works by combining the outputs of many cone cell photopigments before transmitting the information to the brain via retinal ganglion cells in the optic nerve; however, this simplistic approach to organizing inputs causes a loss in spatial recognition. Additionally, if there were to be mutations that created a new photoreceptor, it would likely not be possible to distinguish a separate chromatic signal without simultaneous evolution to neural connections (Surridge et al., 2003).

Comparatively, primates can communicate individual colors and data from photoreceptor cells because of midget retinal ganglion cells (Figure 9). The evolution of these midget ganglion cells likely gives the ability to see fine patterns – a skill completely separate from color vision. When M and L opsins started appearing in primates, these cells along the optic nerve individually connected the cone cells to the brain, where the detection of separate M and L opsins (red-green signals) takes place (Surridge et al., 2003).

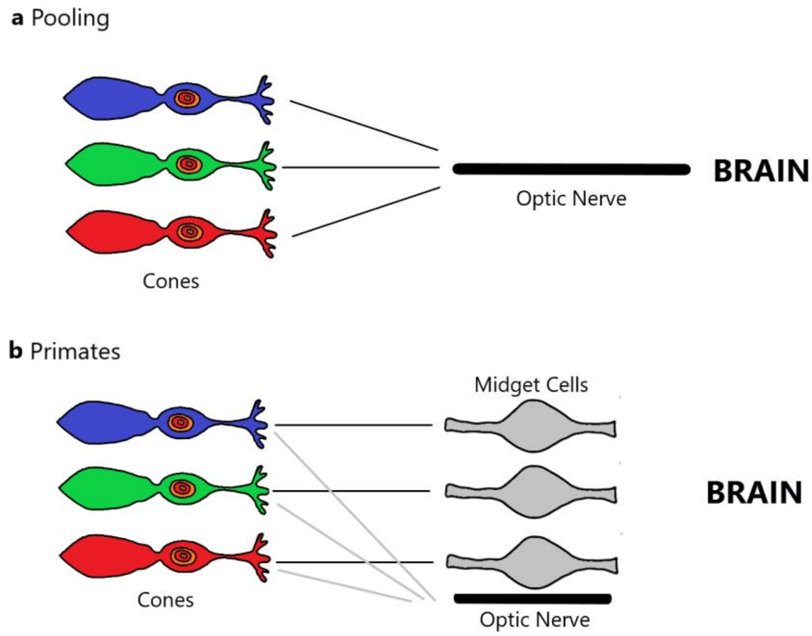

Figure 9. Pooling and Separation of Neural Pathways Adapted from (Surridge et al., 2003)

(a) Nonprimate mammals pool the inputs from the cones in the retina which causes a loss of detail in vision **(b)** Primates, like humans, separate inputs through the use of midget cells along the optic nerve allowing for clarity in visual details

Brain processes and functions tie directly to interpreting inputs from the optic nerve and impacting biological processes (Bogin, 2020). Inputs from the optic nerves are processed in the brain and create reactions and impacts on the body's circadian, neuroendocrine, and neurobehavioral systems.

Chapter 4 – The Impact of Light on Biological Processes

Optical radiation reaching the retina is responsible for visual and biological responses. This is an essential consideration in design where the environment, like the lighting system, can influence fragile patient conditions. The field of chronobiology (study of the influence of light on physical and mental health) has grown rapidly in the past ten years (IES Healthcare Committee, 2020). Optical radiation is converted into neural signals through the process of phototransduction. Neural signals affect the body's neurobehavioral (sleep/wake cycle) and neuroendocrine (hormone production) systems. Studies with people who are blind have determined that rods and cones are not the primary photoreceptor for circadian, neuroendocrine, and neurobehavioral responses. For decades studies have sought to determine which photoreceptor is responsible for driving biological responses. The mammalian eye contains special photoreceptors called intrinsically photosensitive retinal ganglion cells (ipRGCs) that are different from visual photoreceptors and specifically regulate circadian, neuroendocrine, and neurobehavioral responses to optical radiation. ipRGCs receive information from rods and cones through bipolar and amacrine cells to regulate non-visual responses (IES Light and Human Health Committee, 2018).

4.1 Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs)

Intrinsically photosensitive retinal ganglion cells (ipRGCs) were discovered in 2002 (IES Healthcare Committee, 2020) in humans and primates with action spectroscopy. Action spectroscopy is a methodology that determined the underlying photopigment, melanopsin, by comparing the efficacy of different electromagnetic radiation wavelengths. Melanopsin, in the ipRGCs of the retinal ganglion layer, is light sensitive and mediates circadian responses. ipRGCs can respond to optical radiation even though they are physically or chemically isolated from other neurons because they are functionally independent from other photoreceptors. For primates, rods, cones, amacrine, and bipolar cells' inputs combine with ipRGCs' photosensitivity to create signals for circadian and pupillary regulation (IES Light and Human Health Committee, 2018). Thus, ipRGCs are the primary photoreceptor for mediating circadian and neuroendocrine regulation. The ipRGC has thinly branching dendrites (fibers that carry signals to the neuron cell body) that terminate in the OFF sublayer of the inner plexiform layer. Although ipRGCs make up just 0.2-0.8% of retinal ganglion cells, the dendrites of the cell cover nearly the entire retina, so melanopsin is present throughout the retina. ipRGCs communicate with the lateral geniculate nucleus (LGN) in the brain, which relays information to the visual cortex (IES Light and Human Health Committee, 2018).

4.2 Cranial Processing of ipRGC Inputs

Optical radiation is transmitted from the retina to the suprachiasmatic nucleus (SCN) (Figure 10) of the anterior hypothalamus of the brain via the retinohypothalamic tract (RHT) (Figure 10). The RHT is comprised of nerve fibers composed of retinal ganglion cells that are widely distributed in the retina, which allows the capture of photic input from a large area of the eye. The integrity of the RHT pathway is vital for collecting light-dark signals that impact circadian, neuroendocrine, and neurobehavioral responses. A second photic pathway from the geniculo-hypothalamic tract (GHT) (Figure 10) terminates in the SCN as intergeniculate leaflet (IGL) lesions (Figure 10). This pathway overlaps with the RHT pathway, but while it does not play a role in photic entrainment with light-dark cycles like the RHT, these IGL lesions impact the re-entrainment after phase shifts (shifts in the timing of melatonin production) (IES Light and Human Health Committee, 2018).

The daily 24-hour light-dark cycle resets the internal clock. Optical radiation impacts circadian rhythm through the main biological clock, the SCN; however, mammals have peripheral clocks in the liver, heart, and other organs that dictate timing for tissue-specific genes. These tissues can maintain synchronicity with each other but receive external inputs from the SCN that control endocrine and automatic systems. The SCN ultimately drives circadian rhythms through pineal melatonin production (high at night and low during the day). Exposure to appropriate light-dark cycles impacts all organ functions, directly impacting human physical well-being and mental health (IES Light and Human Health Committee, 2018).

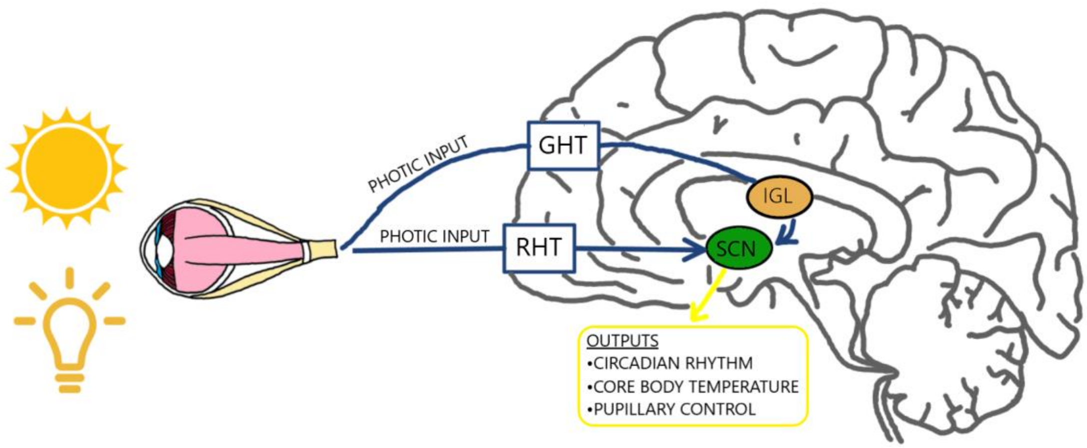

Figure 10. Cranial Pathway of ipRGC Inputs

Optical radiation is processed by ipRGCs and follows the GHT or RHT in the optic nerve. RHT signals are processed directly by the SCN. GHT signals are processed by the IGL and impact phase-shifts. The IGL terminates in the SCN. The SCN is responsible for photic entrainment and controlling circadian rhythms, core body temperature, metabolism, and pupillary control.

4.3 Circadian Rhythm Impact

The most important role of optical radiation is the resetting of the circadian clock. Animals are on annual and daily cyclical schedules. The endogenous circadian clock (the SCN) ensures physiological and behavioral events are harmonized with the surrounding environment (including other individuals in the social group) and internally with each other (IES Light and

Human Health Committee, 2018). In fact, ten years ago it was theorized that circadian rhythms controlled 10% of genes in the human body. Today it is believed that circadian rhythms control over a third of the genome and half of drug-response pathways (IES Healthcare Committee, 2020). Thus, suggesting circadian rhythms could substantially impact psychological and physical health. Research indicates that chronic circadian disruption may cause higher susceptibility to obesity, heart disease, cancer, and depression (IES Healthcare Committee, 2020)

Circadian rhythms are not set on exactly 24-hour cycles (IES Healthcare Committee, 2020). Environmental cues like light-dark cycles, food, exercise, social cues, and sleep ensure the biological processes are reset and synchronized with external stimuli each day. Specifically, optical radiation from light-dark cycles impacts resetting and synchronizing (IES Light and Human Health Committee, 2018). Daily clock resynchronization is crucial as the environment changes. Significant impacts to resynchronization include the quantity of optical radiation, spectrum exposure, timing, duration, patterns, and prior optical radiation exposure. People who are completely visually impaired demonstrate the crucial role optical radiation plays in circadian clock setting. These individuals have internal clocks that run on a 23–25.1-hour cycle. Without input from optical radiation, the internal biological clock does not remain entrained on a 24-hour cycle (IES Light and Human Health Committee, 2018).

Studies have shown that human circadian phototransduction exhibits spectral opponency, meaning that different sources of polychromatic white light stimulate the circadian system differently. Analyses of optical radiation have found that wavelengths between 450 nm and 550 nm (blue wavelength light) cause the strongest stimulation of circadian and neuroendocrine responses (IES Light and Human Health Committee, 2018). This is beneficial in the morning, as bright, blue wavelength-rich light from the sun keeps animals awake by suppressing melatonin production, which is the hormone that causes sleepiness. Exposure to light levels as low as 0.1-0.5 footcandles (fc) at the cornea of specific monochromatic wavelengths can suppress melatonin production in healthy individuals. This reveals the sensitivity of this system. Additionally, photic history can impact light sensitivity, so the eye and brain will experience increased sensitivity to higher illuminances after a period of dim lighting. Conversely, after a period of high optical radiation, the response from the ipRGCs and subsequent suppression of melatonin production in the presence of blue wavelength light is minimized (IES Light and Human Health Committee, 2018). This demonstrates that rather than absolute exposure, the ipRGCs controlling the circadian system are reacting to changes in optical radiation.

4.3.1 Timing

Timing and light intensity impact circadian clock resetting. Studies have shown that levels as low as 30-50 fc on the horizontal of broadband spectrum white light can cause phase shifts in the circadian pacemaker (the SCN). Dose (light intensity) response studies identify the effects of light exposure on subjects for specific periods of time. These studies have identified the correlation between optical radiation and alertness, attention, and brain activation, thereby proving that optical radiation plays a crucial role in cognitive stimulation and behavioral reactions to the environment. For example, in an average eight-hour sleep cycle, optical radiation exposure (before the minimum core body temperature is reached) between 6:00 p.m. and 6:00 a.m. causes a phase delay (resulting in sleep occurring later than normal) with a maximum phase delay at 2:00 a.m. Exposure in the morning between 6:00 a.m. and 6:00 p.m. causes a phase advance, but maximum advances occur in the biological night (IES Light and Human Health Committee, 2018).

4.4 Drawbacks to Current Studies

It is important to note that studies surrounding circadian rhythm entrainment and phase-shift have been conducted in a laboratory setting on healthy individuals. There is a lack of evidence in real-world settings on the impact of optical radiation on humans. As a result, these findings can inform design decisions but by no means guarantee similar outcomes. In real-world applications, photic history will likely impact sensitivity to different light levels making it difficult to predict exact illuminances that will impact the body's neurological systems (IES Light and Human Health Committee, 2018). The IES has concluded that standard terminology of lux and footcandle are not adequate for determining the best light practices to influence circadian, neuroendocrine, and neurobehavioral regulation because of evidence that different wavelengths can have a significant impact on hormones and mood (i.e., blue wavelength light). Additionally, the IES states that with research regarding circadian rhythms and artificial lighting still in its infancy, it cannot make recommendations that support circadian rhythm entrainment. Unfortunately, a metric of optical radiation that can directly relate to biological influences has yet to be determined. Regardless, the current knowledge and inferences can be implemented with some level of confidence that this will benefit patients.

4.4.1 Melanopic Lux

Traditionally, illuminance (the amount of luminous flux incident on a surface) is measured with the International System of Units (SI) unit of lux or the imperial unit of footcandle. These measurements are taken considering photopic (daytime) vision and do not consider the biological effects of light. Measuring melanopic lux provides designers with a way to quantify the impact of artificial illuminance on biological systems (Lucas et al., 2013). The concept of melanopic lux has been incorporated into the International WELL Building Institute

Standards. WELL uses Equivalent Melanopic Lux (EML) as a recommended alternate metric to traditional lux (*Circadian Lighting Design | WELL Standard*, 2020). Chapter 6 – Design Recommendations will go into more depth for applying melanopic lux in design.

Chapter 5 – Light and Mental Health

The link between light and mental health has been known for centuries. Incorporating daylight into design has had links to shorter hospital stays and increased satisfaction. Artificial lighting has increased the complexity and considerations for designers. The impact of lighting has been explored for anxiety and mood disorders. The overwhelming conclusion is that light has a tremendous impact on the SCN and hormonal processes discussed in Chapter 4. Below, various studies analyzing the impact of light on sleep and the most common mental illnesses in the United States are explored, depression, bulimia, bipolar disorder, and schizophrenia.

5.1 Sleep

Quality sleep is a critical part of the healing process. Unfortunately, treatment centers like hospitals generally create poor environments for quality sleep. Factors like equipment noise, lighting, and other people create a poor sleep environment that can inhibit recovery, diminish mood, and increase stress.

A study conducted in the Netherlands from 2009 to 2010 analyzed the impact of a standardly lit (fluorescent) room or a room with an interventional (fluorescent) lighting system. Both patients and nursing staff were analyzed for the impact of these lighting systems. Measurements considered sleep, alertness, anxiety, depression, and lighting appraisal. The interventional system had a dynamic 24-hour light/dark cycle with low nocturnal light exposure and two hours of high illuminance (1750 lux) light during the day. Additionally, the intervention room had automated gradual changes in illuminance and color temperature (3000-6500K). The illuminance during the day was blue wavelength enriched at 6500 K. Additionally, between 10:30 am and 12:30 pm there was a 45-minute post-lunch illuminance of 100 lux, 3000K on the bed. The study concluded that intervention patients were significantly more satisfied with their lighting than patients in the standardly lit rooms. With interventional lighting, patients' sleep duration increased by 5.9 minutes per day. After the fifth day of hospitalization, patients saw a 29-minute increase in sleep (Giménez et al., 2017).

Focusing on the human wake-sleep pattern concerning healing is critical. This pattern is regulated by a central circadian pacemaker located in the SCN. The SCN uses light-dark information to start and control timing, alignment, and stability of the 24-hour patterns in sleep, physiology, alertness, and mood. Additionally, the timing of light exposure to trigger these reactions is crucial. Most important is access to blue-light-rich daylight especially in the morning, which activates the photoreceptor pigment melanopsin that is particularly sensitive to blue wavelength light (IES Light and Human Health Committee, 2018). Unfortunately, daylight is limited in healthcare facilities, so it must be replicated with artificial light. Unfortunately, standard patient rooms have a horizontal illuminance of 100-300 lux from daylight, but outdoor illuminance is 2000-100000 lux of blue-rich light. Exposure to daylight or blue-rich light has been shown to have benefits on recovery, length of stay, delirium, depression, anxiety, and reduction in the use of pain medication (Giménez et al., 2017).

5.2 Depression

Depression is a common mental illness that affects one in 15 adults every year, with one in six people experiencing depression at some point in their life. Depression is different from sadness or grief. In depression, mood or interest in activities decreases, and feelings of worthlessness are common. To be diagnosed with depression, the symptoms must persist for at least two weeks (*What Is Depression?*, 2020).

Even people living in ideal conditions can be affected by depression. The common risk factors are biochemistry, genetics, personality, and environmental factors. Biochemistry relates to hormones in the brain and can be affected by genetics since depression can run in families. People who are easily overwhelmed by stress and have low self-esteem also run a higher risk of developing depression. Finally, factors like poverty and abuse can increase the chance of developing depression (*What Is Depression?*, 2020).

Depression is very treatable with 80-90% of patients gaining relief of their symptoms. Medication (antidepressants), psychotherapy, and electroconvulsive therapy (ECT) are the most common treatments. Medication can be effective in cases where brain chemistry plays a role in the symptoms. Psychotherapy is often used to treat mild cases of depression and in conjunction with medications for moderate to severe cases. Cognitive behavioral therapy (CBT) is a therapy approach that helps the patient identify negative thoughts and change them so they think about their environment more positively. Finally, ECT is an effective therapy for individuals with major depression who have not responded to other treatments. During an ECT treatment, the patient is under anesthesia and receives a controlled, brief electrical stimulation to the brain. The treatments generally occur two to three times a week for six weeks (*What Is Depression?*, 2020).

Seasonal affective disorder (SAD) is a type of depression associated with seasonal changes. It is brought on by a decrease in sunlight in the fall and winter and generally subsides in the spring. Changes in sunlight cause a biochemical imbalance in the brain as a result of a shift in circadian rhythms. About 5% of adults in the United States suffer from SAD and treatment includes light therapy, antidepressant medications, and talk therapy. Light therapy involves sitting in front of a light box for about 20 minutes a day, typically in the morning, and helps reduce SAD symptoms (*Seasonal Affective Disorder (SAD)*, 2020).

There are theories that a symptom of depression is the perception of a decrease in ambient (general) light. Studies have been conducted to test this theory based on questionnaires distributed to psychiatric patients and patients with age-related macular degeneration (AMD). In a study published in *The Journal of Affective Disorders*, of the participating psychiatric patients, 50 patients were determined to be severely depressed, and 2/3 of those 50 answered "yes" to perceiving their surroundings as dimmer than usual. Among the AMD patients, those who reported perceiving their surroundings as dimmer than usual were 4.5 times more likely to be depressed (Friberg et al., 2008). Thus, it can be concluded that a question about the perception of dimness should be added to questionnaires about depression because patients rarely present to a physician with complaints about perceived dimness of ambient lighting, and lighting designers should consider this symptom by increasing illumination levels and providing dimming controls. Another explanation for the correlation between perceived dimness and depression aligns with typical pharmacological treatments. In the treatment of depression, pharmacological therapies alter the concentrations of serotonin and other neurotransmitters which are present in the central nervous system. There are beliefs that these concentrations may also be present in the optic nerve and, therefore, could explain why this perceived dimness occurs, but more research must be done to draw a decisive conclusion (Friberg et al., 2008).

Light therapy is gaining traction as an effective treatment for SAD. A study conducted in 2020 analyzed published research that proposes that light therapy could also be effective in treating nonseasonal depression. Their synthesis of sources found that light therapy can be significantly more effective than comparative treatments of depression. Depression affects more than 264 million people worldwide of all ages. Depression is generally treated with a combination of antidepressants and psychotherapy; however, relapse rates for both of these approaches 50%. The authors theorize that the use of light therapy with other forms of therapy could increase effectiveness (Tao et al., 2020).

Lighting therapy works by stimulating ipRGCs which release glutamate in the brain's SCN. It is effective in the treatment of SAD. The authors concluded that the light therapy proves most effective in the morning and with a duration of fewer than 60 minutes. Additionally, they concluded that there is no effect of the color (non-white) of the light on the effectiveness of the treatment, so white light is the most effective treatment (Tao et al., 2020).

The IES recognizes the efficacy of light therapy on the treatment on mental illnesses while also recommending that dosages of light therapy be provided in a hospital setting. A hospital setting provides a controlled atmosphere to administer bright light and observe patient responses for any adverse effects (specifically when treating mental illnesses other than depression). Additionally, while the impact of light on biological processes is well documented, a metric to accurately link biological outcomes with a light level does not exist (IES Light and Human Health Committee, 2018).

5.3 Bulimia

Eating disorders can affect anyone and are characterized by a constant and severe obsession with food and eating behaviors. About 5% of Americans experience eating disorders although they commonly develop in adolescents and early adulthood. A wide range of eating disorders can co-occur with other psychological disorders like mood and anxiety disorders and obsessive-compulsive disorder (OCD). Eating disorders include anorexia nervosa, bulimia nervosa, binge eating disorder, and avoidant restrictive food intake disorder (*Get Help With Eating Disorders*, n.d.).

Bulimia nervosa, in particular, generally afflicts women but can be present in any gender. Common red flags for this eating disorder include obsessive discussions about calories, weight, and fat. Focusing on low-calorie foods and then bingeing on high-calorie foods. Some individuals may seek to control weight through vomiting, laxatives, or the use of diet pills. Often these individuals avoid eating in social settings to avoid judgment about food intake (*Get Help With Eating Disorders,* n.d.).

Individuals with severe eating disorders may seek hospitalization for treatment. Studies have involved light preference and how this may enable these disorders. Evening, in particular, constitutes a high-risk environment and increases the probability of binging and purging. Although, this correlation only poses a risk to individuals with restrained eating and not to those who are unrestrained eaters; therefore, preference for dimmer light while eating correlates positively with bulimia for those who are restrained eaters. As a result, bulimic episodes are much more common in months with longer nights, people who are "night owls," and when eating is done alone. One theory for this phenomenon suggests that exposure to dimmer lighting promotes behavioral disinhibition or a pattern of antisocial, impulsive, norm-violating, sensation seeking, and externalizing tendencies and problems. This undermines the individual's self-regulatory control (ability to understand and manage behavior and reactions to feelings and things happening around oneself) and adherence to dietary standards, which creates disinhibited eating (Kasof, 2002). This could be due to decision fatigue and the fact that dinner and evening time are generally a time to relax and decrease focus on goals.

A likely explanation for the correlation between light preference and bulimia is that bulimia is characterized by a discrepancy between high self-standards and low confidence in one's ability to control eating and other behaviors. As a result, this high self-standard with low outcome expectancy fosters a preference for dimmer lighting and decreases self-awareness, promoting bingeing and sustaining self-standard discrepancy and low outcome expectancy, thus creating a toxic cycle. Additionally, dimmer light preference may be an attempt to reduce self-awareness and disengage from actions. Kasof concludes by proposing that perhaps low lighting level can promote relapse or be used as a therapeutic treatment in bulimia cases and other addiction cases (Kasof, 2002).

5.4 Bipolar Disorder

Bipolar disorder is a severe mental illness that causes a change in a person's mood, energy, and ability to function. This disorder causes intense emotional states that occur for days to weeks. These mood episodes are typically categorized as manic/hypomanic (abnormally happy or irritable) or depressive episodes and are accompanied by difficulty maintaining daily routines and social interaction. There are also periods of neutral mood. Mood episodes could occur once in a lifetime or two to three times a year. Although patients can get well without medication, it is impossible to identify which patients will get well without medication and some may seek hospitalization for treatment (*Get Help With Bipolar Disorders*, n.d.).

Studies have shown the benefits of dark rooms in combating manic and hypomanic episodes. An extension of these studies has looked at how different wavelengths of light can impact hypomanic and manic episodes.

Circadian rhythms are essential for regulating mood. Studies show that a regular circadian rhythm is associated with decreased depressive episode relapses for patients with bipolar disorder. Comparatively, a later shift in circadian rhythm was associated with increased depressive episode relapses. Circadian irregularities like advanced phase shifts and increased melatonin secretion are linked with manic episodes. The standard treatment of bipolar disorder to help regulate circadian rhythms is lithium (Yuichi et al., 2021). Installing an appropriate lighting system could increase the efficacy of pharmacotherapy treatments.

Due to these results, a circadian lighting system and light therapy could be beneficial to the treatment of patients with bipolar disorder. Depressive episodes could be minimized, and pharmacotherapy treatments could be more efficient.

5.5 Schizophrenia

Schizophrenia is a complex disease that affects less than one percent of the population but often leads to hospitalization. Active schizophrenia symptoms include hallucinations, hearing voices or seeing things that are not there, a loss or inability to initiate plans, confused and disordered thinking and speech, among other symptoms. During active episodes, patients have difficulty determining real and unreal experiences (*What Is Schizophrenia?*, 2022). In addition, individuals with schizophrenia have difficulty looking forward to future positive experiences (Demmin et al., 2020). This mental illness tends to affect women more than men. Symptoms generally start appearing in the late teens to early 30s and must persist for six months for a diagnosis to be made. Scientists theorize that genetics and environmental factors play a role in the development of this illness. While schizophrenia is not curable, effective treatments can allow patients to live a regular life. In addition, rehabilitation can provide patients with skills to cope with relapse and remission (*What Is Schizophrenia?*, 2022).

Studies analyzing the development of schizophrenia have hypothesized that vitamin D deficiency is a risk factor because of the increased diagnosis of schizophrenia among individuals born in the winter/ spring and individuals with darker skin (Brown, 2011). Vitamin D is an essential nutrient created from UVB rays absorbed from the sun. Sunlight is the primary source of vitamin D, so supplying adequate daylighting could prove beneficial in treating patients with schizophrenia.

Dopamine is one of the primary neurotransmitters impacted by schizophrenia. Studies have shown that blue wavelength light can stimulate dopamine production (Demmin et al., 2020). Increasing dopamine production could help reduce the symptoms of schizophrenia. Therefore, incorporating circadian lighting that provides exposure to blue wavelength light could positively impact the treatment of schizophrenia.

Given what is known about the most common mental illnesses in the United States and their connection to lighting, recommendations can be made. Additionally, the recommendations are informed by the understanding of a hospital environment.

Chapter 6 – Design Recommendations

A hospital setting will be the focus of these design recommendations. Psychiatric wards are separated into low, medium, and high acuity sections. Patients are assigned rooms based on diagnoses and the severity of their condition. Inpatient treatment is reserved for patients with severe issues, but hospital spaces may still be used for those in a partial hospitalization program (PHP; 8 hours per day in the hospital) and outpatient program (OP; 3-4 hours per day in the hospital). Additionally, an adult's average length of stay in a psychiatric setting is 7-10 days, while patients in higher acuity settings stay 10-14 days. Programming that allows for flexibility and growth and considers the patient's treatment plan as the keystone of design requirements are the most successful. The Federal Guidelines Institute publishes programmatic guidelines that recommend square footage for patients for each space type (S. Root, personal communication, December 10, 2021).

Patient room environmental issues play a significant role in patient psychology. Personal space and privacy are essential parts of design so that individuals can create emotional attachments and feel ownership of their space. The opportunity to make choices in their environment creates a sense of control (S. Root, personal communication, December 10, 2021). Lighting can help lower psychological stress levels helping patients be more receptive to treatment (IES Healthcare Committee, 2020). Additionally, knowledge about which mental illnesses will be treated can inform lighting considerations.

The Federal Guidelines Institute establishes that luminaires and finishes must be anti-ligature and tamper-resistant so patients cannot hang anything from them that could assist in any form of self-harm or suicide. Additionally, polycarbonate lenses must be used in luminaires because glass lenses can be broken and used by patients to harm themselves or others (S. Root, personal communication, December 10, 2021). This dramatically reduces options for lighting designers.

Research into mental illnesses, treatments, and recommendations from the IES come to similar conclusions regarding environmental design recommendations. Although the original intent was to develop integrative and revolutionary lighting recommendations, the research comes back to a critical issue in treatment: sleep and circadian rhythm entrainment. The link between sleep and mental health has been heavily researched and is evident in patients with severe mental disorders and the general population. With that in mind, the main recommendations of this paper center around circadian rhythm entrainment (especially where daylight is unavailable) for patient rooms, group areas, and corridors because these spaces are primarily used by patients. Circadian entrainment is consequential in healthcare settings for patients (as described previously) and providers (maintain alertness throughout shifts), but recommendations within this report will focus on patient wellbeing (IES Healthcare Committee, 2020). Additional controls allow patients and supervising staff to adjust light levels to accommodate patient healing in conjunction with their diagnosis. While example lighting renderings are provided in this chapter, other solutions and layouts can accomplish the goals and recommendations outlined in this report. There are some special considerations to be made considering light wavelengths (blue wavelength light filtration) and colors which will be explored in more depth below.

6.1 Light Source

Light source characteristics vary, and different types may be appropriate for specific applications. Color rendering ability, cost, life, and efficacy are important considerations for lighting designers especially considering that this has implications for the building owner and facility operator. Below is a summary of considerations to be made in an inpatient hospital setting regarding color rendering, correlated color temperature (CCT), and light source. These conclusions will be considered in conjunction with the design recommendations later in the chapter.

6.1.1 Color

Color rendering has high importance in the healthcare field since diagnoses can differ based on the color of tissues. Additionally, it becomes important for the link between psychology, color, and creating comfort in a mental health care setting. For years color rendering index (CRI) has been used to determine the color rendering properties of a light source. Since its inception, it has received criticism for its simplicity and lack of specificity. Its use has created shortcuts to design and assumptions for best design practices that have created sub-par lighting in spaces. The IES has worked for years to develop a more sophisticated and detailed method for specifying fixtures and describing color rendering. The IES TM 30-20 addresses many issues surrounding the CRI approach. The increased number of metrics (more color samples and measured metrics) incorporate clarity and do not allow the designer to manipulate the results (IES Color Committee, 2018). Ultimately, the adoption of TM 30-20 has created substantial progress in the lighting industry.

Generally, this information has been difficult to find from manufacturers. The initial intention with the TM 30-20 was that as lighting designers began to see how useful it is, the demand would drive the supply of these data. Currently, all the metrics required to compile this data are calculated but are not organized as presented in the TM 30-20. A calculation tool is available with the TM 30-20 that calculates radiant power, local color fidelity, local hue shift, and local chroma shift. IES supplies a library of fluorescent, incandescent, metal halide, halogen, and LED light sources. With the data from cutsheets, the output from the TM 30-20 is attainable and then easily applied. Annex E of the TM 30-20 also provides Table E-2 with recommended specification criteria considering preference, vividness, and fidelity (IES Color Committee, 2018). Requesting TM 30-20 data from manufacturers can increase the accuracy and efficiency of the lighting system.

6.1.2 Lamp Type and Correlated Color Temperature

Light-emitting diodes (LEDs) have swept the lighting industry since their development in the 1990s. The main benefits of LEDs are their energy-saving potential and long lamp life. LEDs produce white light using red, green, and blue diodes or a blue diode filtered through a yellow phosphor. Using a blue diode and yellow phosphor is the most common manufacturing method and impacts the spectral distribution diagram, which shows a dominant wavelength in the blue-light range. Fluorescent and incandescent lamps with dominant wavelengths at about 574nm, which is close to the peak sensitivity of photopic photoreception were replaced by LEDs with dominant wavelengths at about 450 nm (Bauer et al., 2018). This could prove beneficial or detrimental with what is known about the significant impact of blue wavelength light on circadian entrainment. Blue wavelength light can have positive impacts like increasing alertness, but it can also negatively impact phase-shift and circadian entrainment. Many mental illnesses like depression, anxiety, schizophrenia, bipolar disorder, ADHD, and substance abuse are associated with circadian rhythm disruption. The IES and other individuals have created studies that demonstrate the sensitivity of the circadian entrainment system and the role blue wavelength light plays. Lighting designers must question whether the method for creating white light in an LED is detrimental to occupant health.

Correlated color temperature (CCT) tuning can help reduce the amount of blue wavelength light emitted in the evenings allowing designers and owners to utilize LEDs and benefit from their energy savings and life (Bauer et al., 2018). Controls with dynamic CCT tuning can decrease blue wavelength light with a warmer CCT of 2700K. Additionally, sleep LEDs that focus on reducing blue wavelength light emittance may also be available to aid in circadian entrainment (IES Healthcare Committee, 2020). It is important to verify the spectral power distribution (SPD) diagram for various CCTs to ensure a decrease in blue wavelength light emittance. Daytime blue wavelength light exposure can prove beneficial to suppress melatonin and encourage circadian entrainment. Sufficient levels of blue wavelength light are found at a CCT of 4000K. With dynamic CCT controls that automatically adjust CCT throughout the day, the light sources must be controlled together through automatic controls to create a smooth and gradual transition to lower and higher CCTs throughout the day (IES Healthcare Committee, 2020).

6.1.2.1 Lamp Source and CCT Calculations with Melanopic Lux

Melanopic lux is a measurement that quantifies the impact of lighting on biological systems. Lighting calculation softwares like AGi32, DIALux, and ElumTools only provide calculations based on photopic measurements. The International WELL Building Standard has developed a free spreadsheet that can calculate melanopic lux based on calculated lux, lamp source CCT, and lamp source lumens. The Standard only outlines recommended Equivalent Melanopic Lux (EML) for workstations (*Circadian Lighting Design | WELL Standard*, 2020), so a clear understanding of the components of this metric and the occupant activity in a given space is crucial to implement EML. EML has not been discussed by the IES or integrated into building codes. The understanding of EML can provide a clearer picture of how the lighting design will impact biological processes.

6.1.3 Daylight

Daylight considerations are crucial for patient well-being. While this responsibility largely falls to the architect, the whole design team is responsible for understanding and advocating for patient-centric design. One of the issues with daylight design is its variability in intensity and presence. Additionally, it changes spectra and CCT throughout the day with an average CCT of 5000K. A primary concern of daylighting contribution is glare which can be particularly agitating to patients hospitalized for mental illness; however, spectrally selective glazing for fenestration can increase the efficacy of daylight and decrease glare by filtering a greater fraction of non-visible wavelengths (DiLaura et al., 2011). Even given these drawbacks, daylighting in healthcare spaces can be beneficial to patient recovery.

Studies have found that daytime exposure to high illuminances of blue-rich light from sunlight can benefit recovery, length of stay, depression, anxiety, and pain medication reliance (Giménez et al., 2017). As discussed in chapter 4, daylight can enforce circadian entrainment (IES Healthcare Committee, 2020). Additionally, access to daylight can contribute to a shorter length of stay (LOS), reduced pain response, and improved mood. Studies have also found that bipolar patients with east-facing rooms had shorter LOS by 3.67 days than bipolar patients with west-facing rooms. Similarly, patients with depression who had sunny rooms had shorter LOS by 2.6 days. Nurses and healthcare workers with access to daylight also report higher levels of job satisfaction and a reduction in stress (IES Healthcare Committee, 2020).

6.2 Energy Codes

Building energy consumption has become increasingly important to building owners, occupants, and the design team. ANSI/ASHRAE/IES Standard 90.1-2019 is the most recent energy code that provides minimum acceptable levels of compliance (note: some jurisdictions may have adopted more or less stringent standards than the guidelines discussed in this report).

Standard 90.1-2019 outlines lighting energy requirements in section 9. Additionally, the energy code outlines maximum acceptable power allowances in W/ft^2 for various space types based on compliance path. Tables also outline what control methods must be used regardless of the compliance path. It is important to consider and be familiar with jurisdictional energy codes since it could limit what the designer is able to implement.

6.2.1 Controls Sequencing

Under Standard 90.1, healthcare facilities must have a minimum of bilevel controls, local controls, and daylight responsive controls. In addition, building occupants prefer gradual, almost indiscernible changes in illuminance (IES Healthcare Committee, 2020). This is accomplished with dynamic CCT controls that can be programmed to set a different scene throughout the day, each space type lighting system recommendation describes more details regarding specific considerations and control location.

6.3 Space Classifications

The IES has five space classifications within the three patient acuity classes mentioned above (low, medium, and high) with different lighting recommendations related to behavioral health (Table 2). These differing requirements allow for some flexibility with design.

Table 2. Behavioral Health Levels of Security Based on Information from ANSI/IES RP-29-20

Level	Space Description	Lighting Recommendations
Level I	• Staff and service areas • Patients not allowed unless under constant supervision	• All commercial luminaires are accepted
Level II	• Corridors, counseling rooms, and interview rooms • Areas behind lockable doors • Patients not left alone • Highly supervised	• Commercial luminaires accepted IF o Installed at height or location not easily accessible o Good staff supervision • Tamper-resistant luminaires (minimum 6-mm thick polycarbonate covering and tamper-resistant screws) preferred ESPECIALLY IF o Installed in an accessible location o Patients will not be under constant supervision
Level III	• Corridors, lounges, and activity rooms • Not behind locked doors • Patients may be alone unsupervised • Areas may not be visible from nurse station • Consider making nurse station as open as possible	• Tamper-resistant luminaires (minimum 6-mm thick polycarbonate covering and tamper-resistant screws) highly recommended for this level • Tamper-resistant WHERE o Patients could have access to luminaires o Patients will be unsupervised
Level IV	• Patient and toilet rooms • Patients will spend lots of time completely alone or with very minimal supervision	• Patient rooms o Luminaires shall be security-type, vandal-resistant o Provide luminaire over bed only in hospital setting for exams • Toilet rooms o Luminaires shall be security-type, vandal-resistant, wet location-rated, sealed polycarbonate lens
Level V	• Admission and seclusion rooms • Staff is interacting with newly admitted patients • Patients may be highly agitated	• Luminaires shall be security-type, vandal-resistant

Understanding space classifications allows the lighting designer to develop lighting solutions that are safe for the patient and staff.

6.4 Patient Rooms

Patient rooms in behavioral facilities serve slightly different purposes than in a general hospital setting. First, patient rooms in inpatient behavioral health facilities may not be designed with consideration for visiting family (IES Healthcare Committee, 2020) . Usually, family visits are conducted in separate meeting rooms where staff can monitor them. Next, patients are encouraged to leave their rooms to participate in therapy and group sessions to promote their treatment plan. As a result, lighting and furniture are designed to discourage lounging in the room (S. Root, personal communication, December 10, 2021). Finally, patients hospitalized for mental illnesses commonly experience longer hospital stays than general hospitalizations, so creating a comfortable space that the patient can have some control over is important (IES Healthcare Committee, 2020). Creating individualism and patient control can be accomplished through lighting (Figure 11). A sense of control can reduce stress and cause patients to be more open to treatment. In addition, providing personal space and privacy aids individuals in creating emotional attachments and feeling ownership of their space (S. Root, personal communication, December 10, 2021). Additionally, designing lighting to be nonuniform can help create a less-institutional feel and lead to the patient feeling more relaxed (IES Healthcare Committee, 2020). Target illuminances for patient and toilet rooms are found in Table 3 and Table 4.

The first step in design is to define the use of the space. It is not uncommon for facilities to have about 20% of their patient rooms be shared patient rooms (IES Healthcare Committee, 2020). Shared patient rooms (Figure 12) are not appropriate for all individuals but can create an environment where one patient keeps the other safe (S. Root, personal communication, December 10, 2021). In some hospital settings, patient rooms may also be the location of exams, and as such, ceiling recessed direct distribution exam lighting should be provided over the bed. The exam luminaire should be on the emergency critical branch of power. In shared patient rooms, curtains are used to separate the room if exams need to occur. In these scenarios, it is important to place tamper-resistant wayfinding lighting (located 2’ above the finished floor recessed in the wall) so the required illumination cannot be blocked by the drawn curtains (IES Healthcare Committee, 2020). Supplemental ceiling recessed direct distribution lighting around the room in the form of downlights can create more areas of control for the patient. Luminaire housings that shield the light source from the viewer are recommended to decrease glare. Working with the architect and interior designer to select finishes that reduce veiling reflections can reduce patient agitation.

It is recommended that circadian-rhythm supportive lighting be used. This can be done through circadian tuning (tunable), in which programming dims to warm, decreasing CCT as luminous flux decreases (IES Healthcare Committee, 2020). Programming all light sources to dim-to-warm simultaneously provides consistent CCT throughout the space. While the patient will generally not be spending large amounts of time in their room during the day, daylight harvesting photosensors can help adjust the lighting to maximize daylight use which supports circadian entrainment. Provided wayfinding and nightlights should be shielded from the view of the patient to direct illuminance down. Additionally, these luminaires should provide approximately 0.5 fc of light at 2700K (a lower CCT or red wavelength light would also be advisable) to promote circadian entrainment without compromising safety. Luminaires provided at this level also have a reduced impact on melatonin suppression because light reaching the upper retina does not have as large of an impact on circadian rhythm disruption as light reaching the lower retina (IES Light and Human Health Committee, 2018). For power, the wayfinding nightlights should be placed on the emergency life safety branch (IES Healthcare Committee, 2020).

Task lighting for reading and writing can be provided at the bed with a touch-controlled, wall surface mount luminaire that directs illuminance downward. The patient will entirely control this luminaire through touch. If a desk area is supplied, more ambient illumination should be provided over the desk than over the bed (IES Healthcare Committee, 2020).

Controls need to be accessible for the patient and staff. No occupancy sensors or controls that contain flashing lights should be used. Continuous 0-10V dimming or multi-level stepped dimming (25%, 50%, 75%, and 100% of illuminance options) is recommended (IES Healthcare Committee, 2020) and controls are often located outside of the rooms for staff control especially for high risk patients. Patients should be given on/off switches within the room to control ambient and desk task lighting. Lower risk patients should be provided controls for dimming within their rooms (S. Root, personal communication, December 10, 2021). In the interest of enforcing circadian entrainment, wayfinding should be controlled by motion sensors, so they turn on as the patient gets closer. Additionally, wayfinding and nightlights should be controlled via photosensors so they only operate when the ambient light levels fall below acceptable wayfinding range. Another consideration is integrating luminaire locations with other ceiling features like exhaust fans, curtain tracks, and bariatric lift tracks (IES Healthcare Committee, 2020).

Other considerations for patient room lighting includes blind controls. It is not uncommon for patient room doors to have a small window with a blind between two shatter-resistant panes of glass for observation at certain times. This became a more common request during COVID-19, where observation from a distance became pertinent. These blinds are controlled from outside the room via a slider. Blinds in the patient room exterior windows should be controlled via automatic controls. These blinds are also located between two panes of glass. Controls may not be accessible to the patient depending on the level of acuity. Cords to control blinds pose a health risk to patients. Automatically controlled blinds can maximize daylight harvesting while controlling heat gain like automatically closing the blinds when the room in unoccupied. Additionally, since patients are encouraged to spend time in group areas, the controllability of these blinds may be of little concern (S. Root, personal communication, December 10, 2021).

Toilet rooms (Figure 13) located in the patient rooms should be supplied with nightlights 2’ above the floor and ceiling recessed direct distribution downlights for supplemental illumination. Behavioral health compliant polycarbonate mirrors with an integral light source are commonly used. Additionally, the shower luminaire should be controlled separately.

Table 3. Patient Room Target Illuminance Values (IES Healthcare Committee, 2020)

Space Type	Footcandles (fc) @ ft Above Finished Floor (horizontal)	Footcandles (fc) @ ft Above Finished Floor (vertical)	Max, Avg, or Min Light Level	Ratio	Basis
Exam	75 @ 3	20 @ 4	Average	2:1 (H), 3:1 (V)	Avg:Min
General	20 @ 0	-	Average	4:1	Avg:Min
Night Light	0.4 @ 0	-	Average	-	-
Night Observation	3 @ 3	-	Average	4:1	Avg:Min
Reading	75 @ 3	-	Average	3:1	Avg:Min

Table 4. Patient Toilet Room Target Illuminance Values (IES Healthcare Committee, 2020)

Space Type	Footcandles (fc) @ ft Above Finished Floor (horizontal)	Max, Avg, or Min Light Level	Ratio	Basis
General	10 @ 0	Average	2:1	Avg:Min
Night Light	5 @ 0	Average	2:1	Avg:Min
Shower	20 @ 0	Average	2:1	Avg:Min
Vanity	30 @ C3	Average	2:1	Avg:Min

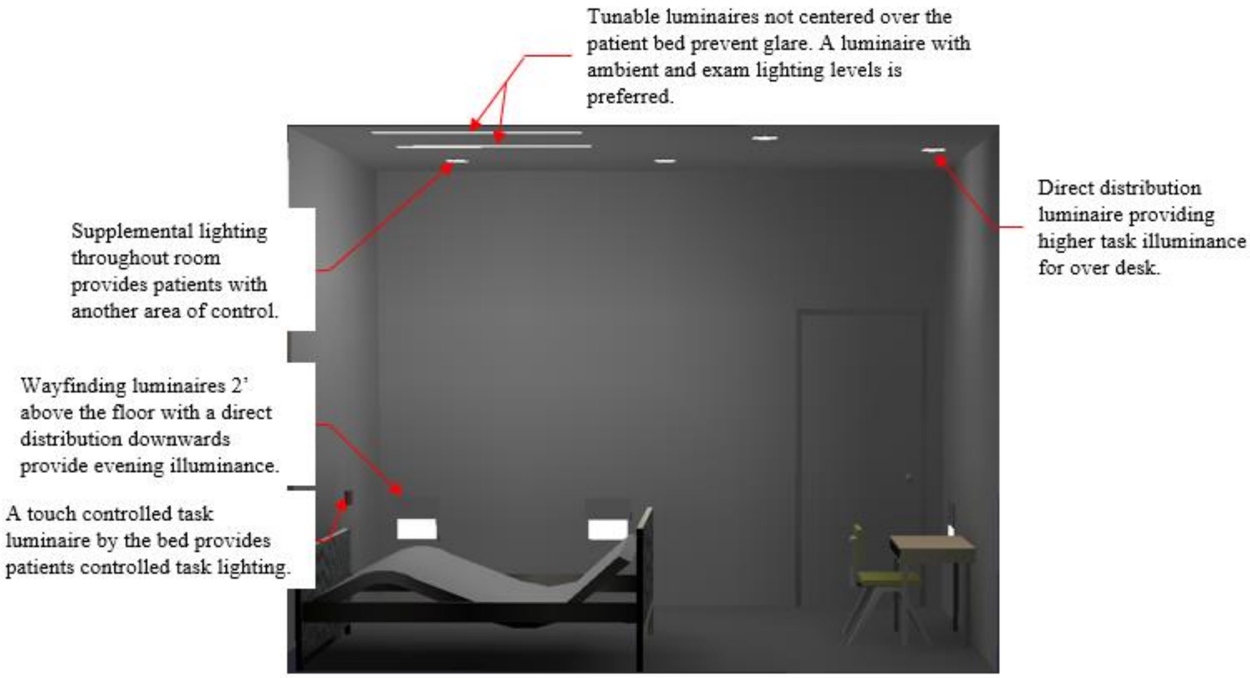

Figure 11. Single Patient Room Rendering

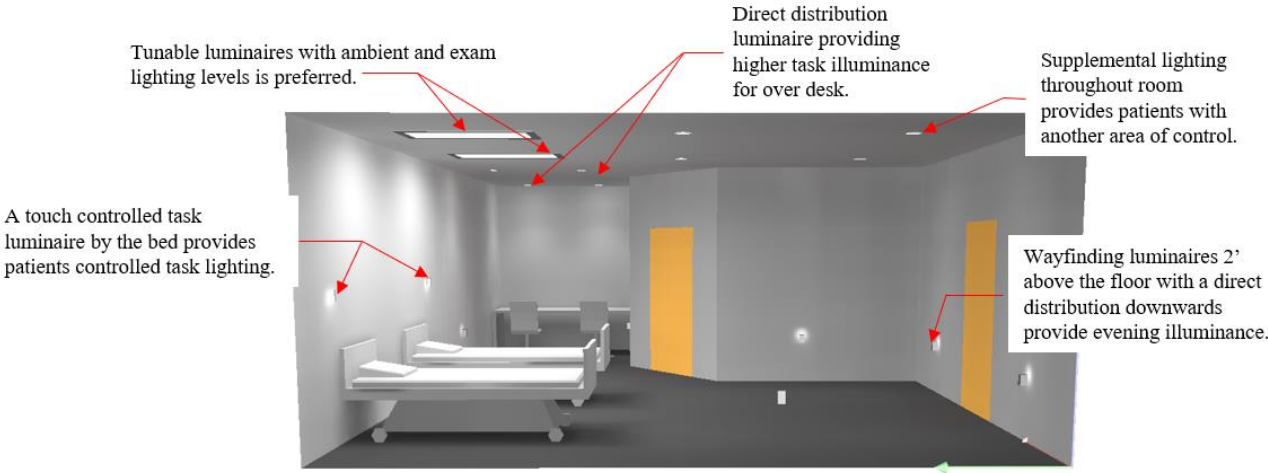

Figure 12. Shared Patient Room Rendering

Figure 13. Patient Toilet Room Rendering

Toilet rooms should be controlled via a vacancy sensor, provided the sensor does not contain any flashing lights. The luminaire over the shower should be controlled separately via an on/off switch (IES Healthcare Committee, 2020).

6.5 Group Rooms

Group rooms are encouraged to be used by patients for group therapy and activities. These spaces are where patients are encouraged to spend time when they are not meeting with therapists individually or receiving other treatment. These rooms encourage collaboration and connection amongst the patients (S. Root, personal communication, December 10, 2021).

Lighting in these areas must be accessible and customizable for the patient(s). To meet the target group room illumination levels, ceiling recessed direct distribution luminaires with dimming controls are recommended (Table 5). These controls should be provided within the space they are serving. Where applicable, daylight harvesting controls should also be provided with overrides located at a nurse's station. As recommended above, circadian-rhythm centric LED lighting should be installed (IES Healthcare Committee, 2020). Task lighting should be provided by wall surface-mounted, touch-controlled fixtures to provide illuminance for reading and writing. As discussed above, these luminaires should be direct distribution to direct illuminance down towards the task. Wall recessed direct distribution luminaires at 2' above the finished floor around the space may also be provided to supply wayfinding in the evening.

Table 5. Group Room Target Illuminance Values (IES Healthcare Committee, 2020)

Location	Footcandles (fc) @ ft Above Finished Floor (horizontal)	Footcandles (fc) @ ft Above Finished Floor (vertical)	Max, Avg, or Min Light Level	Ratio	Basis
General	20 @ 0	-	Average	3:1	Avg:Min
Table	50 @ 0	10 @ 4	Average	3:1	Avg:Min

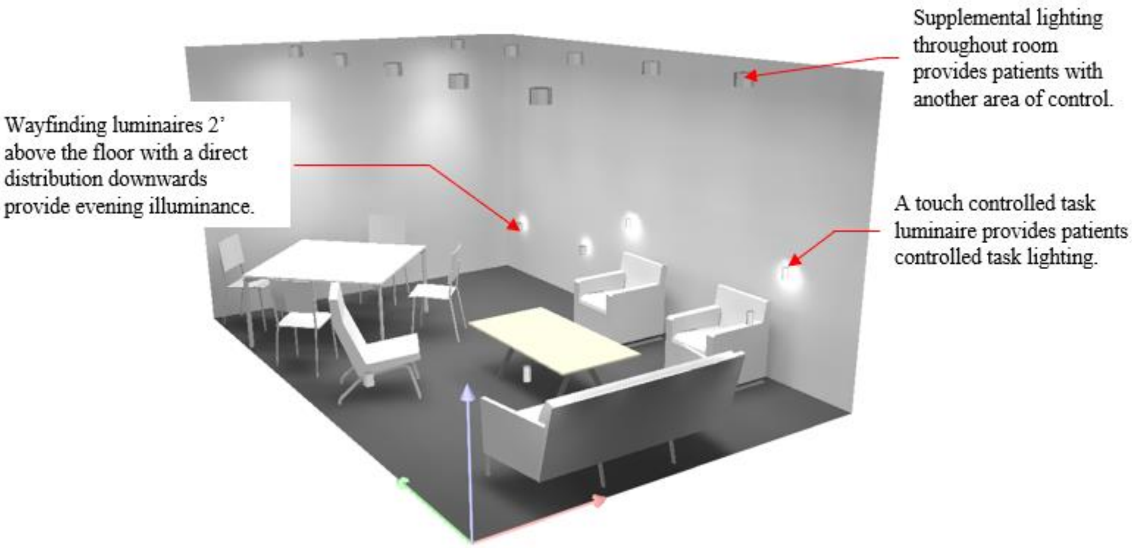

Figure 14. Group Room Rendering

6.6 Corridors

In a hospital setting, some corridors may be public while others are used only by staff. To promote wayfinding, it is recommended that public corridors have an illuminance level of at least 20% of the surrounding areas and for staff-only corridors at least 30% of adjacent areas (IES Healthcare Committee, 2020). Lighting designers must be cognizant of surrounding area recommendations to create light levels that promote wayfinding in corridors (Table 6). Generally, corridors follow the same health risk rating as adjacent spaces. While low-health-risk spaces may utilize wall sconces for wayfinding (IES Healthcare Committee, 2020), it is best to adhere to recessed tamper-resistant luminaires. Another design issue concerns patient viewing. Patients who are transported on a gurney will directly view the lighting and experience excessive amounts of glare (IES Healthcare Committee, 2020). Locating luminaires on the edges of the hallway passage reduces potential eye strain on patients while providing recommended light levels (Figure 15). Cove lighting parallel along the perimeter reduces hot spots on the walls and creates uniform illumination along the ceiling. Additionally, small wall recessed wayfinding and nightlight luminaires 2’ above the finished floor can encourage circadian entrainment (Figure 15). These luminaires should provide shielding to direct illuminance down. Considering circadian rhythms in corridors is essential because of circulation by patients and staff at night. Changes in light intensity and CCT throughout the day can benefit circadian rhythm entrainment. Studies have found that less than six fc of white light will not affect circadian rhythms but will decrease alertness; however, six fc of red light will not affect circadian rhythms but will increase alertness (IES Healthcare Committee, 2020). Wayfinding fixtures with a lower CCT that is more saturated with red wavelengths will encourage circadian rhythm entrainment while not interfering with staff alertness.

Table 6. Corridors Target Illuminance Values (IES Healthcare Committee, 2020)

Time	Footcandles (fc) @ ft Above Finished Floor (horizontal)	Max, Avg, or Min Light Level	Ratio	Basis
Day	10 @ 0	Average	2:1	Avg:Min
Night	5 @ 0	Average	2:1	Avg:Min

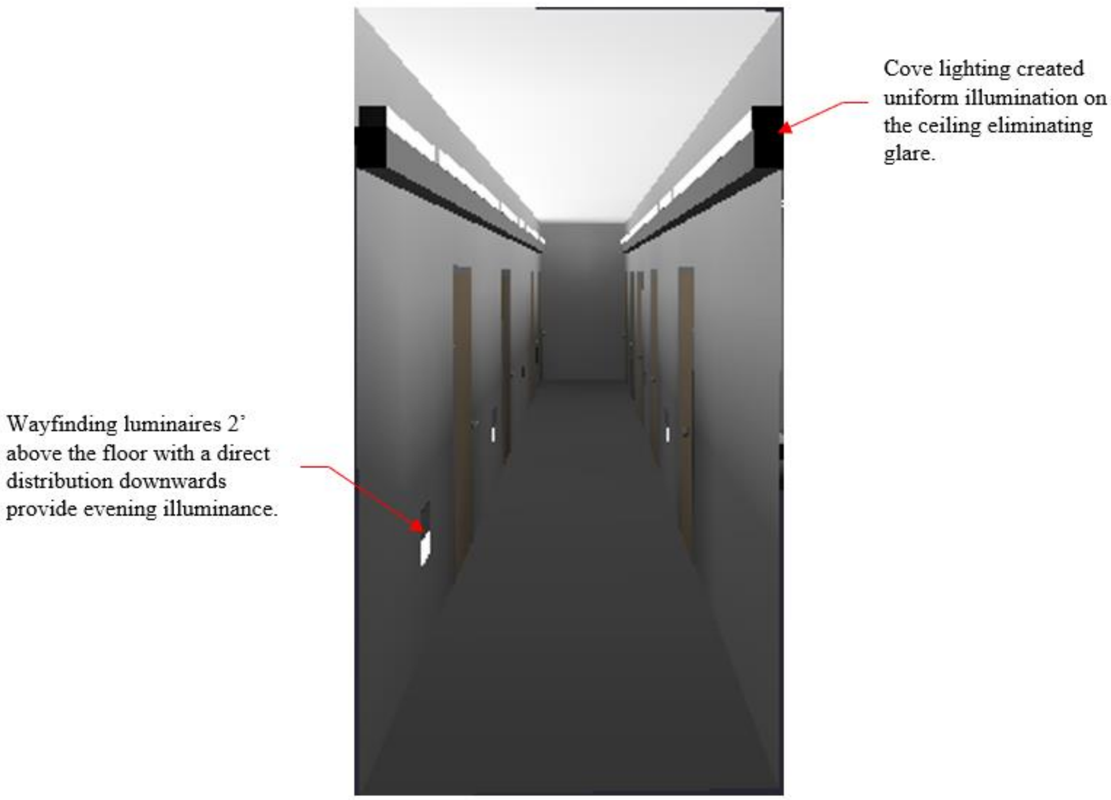

Figure 15. Corridor Rendering

Corridors should be controlled via time clocks with clearly marked overrides provided at nurse stations. Programmed changes in light intensity and CCT throughout the day is beneficial. The emergency life safety luminaires should always remain on but should be dimmed in the evening. The only corridors permitted to be controlled via occupancy sensors are those used only by staff (IES Healthcare Committee, 2020).

6.7 Other Areas

There are many other types of rooms that are present in a hospital psychiatric ward, like dining areas, seclusion rooms, therapist offices, and meeting rooms. These areas should follow similar guidelines to the rooms outlined above. In the dining areas, color rendering may be of particular importance to ensure food is appetizing and appealing to the patients.

Chapter 7 – Conclusions

Environmental design decisions have a significant impact on occupant health and safety. Design considerations are particularly pertinent in behavioral health spaces where patients are at higher risk of self-harm and harming others. The evolution of pharmacological and therapeutic treatments and understanding of mental health has created architectural programming and design that helps aid recovery.

Understanding the visual system helps facilitate a deeper understanding of the interaction of light in a space with a user. Rods and cones are the primary photoreceptors in the eye and aid color vision. Color can play a crucial role in psychology and in helping patients regulate emotions. In 2002, the discovery of melanopsin in ipRGCs gave designers a better understanding of how nonvisual optical radiation impacts biological systems. Studies have shown that melanopsin is incredibly sensitive to illuminances, but photic history likely plays a more significant role in circadian entrainment. Melanopsin also exhibits higher sensitivity to illuminance with a shorter wavelength (blue wavelength light). The SCN regulates hormone production and the entrainment of the endogenous and peripheral circadian clocks. Additionally, it regulates core body temperature, metabolism, and pupillary control.

Circadian rhythms are directly related to sleep quantity and quality. Sleep is a major issue in healthcare settings because it aids recovery, yet patients frequently report inadequate sleep. Circadian rhythm entrainment is often a concern in individuals with anxiety and mood disorders. The co-occurrence of mental illnesses and sleep disorders is extremely common. As a result, it is reasonable to assume that addressing sleep disorders in behavioral health facilities can help patients recover by working alongside pharmacological and therapeutic treatments. While daylight is the preferred method of light exposure to encourage proper circadian entrainment, patients will spend most of their time in an artificially lit environment. Care must be used when specifying luminaires and light sources, to ensure a dynamic CCT. LEDs are constructed with blue diodes that can disrupt circadian rhythms, but dynamic CCT and changes to the SPD have the potential to provide a lighting system that is energy-efficient, cost-effective, and beneficial for patient health.

Circadian lighting and daylight can aid patients in circadian rhythm entrainment and more beneficial sleep-wake cycles. Studies have found that white light levels as low as six fc can create enough task lighting while not inducing a phase shift in circadian rhythms. Likewise, adding red light at low levels (six fc) can enforce alertness without impacting circadian shift.

Lighting design can positively impact patients and staff and create an environment where healing and recovery are supported. The lighting industry must implement more education about the impact of light on patients and healthcare providers. Continual discoveries about biological processes and innovative lighting solutions can significantly benefit patient outcomes.

References

Bauer, M., Glenn, T., Monteith, S., Gottlieb, J. F., Ritter, P. S., Geddes, J., & Whybrow, P. C. (2018). The potential influence of LED lighting on mental illness. *The World Journal of Biological Psychiatry*, *19*(1), 59–73. https://doi.org/10.1080/15622975.2017.1417639

Bogin, B. (2020). *Patterns of Human Growth Third Edition*. Cambridge University Press.

Brown, A. S. (2011). The environment and susceptibility to schizophrenia. *Progress in Neurobiology*, *93*(1), 23–58. https://doi.org/10.1016/j.pneurobio.2010.09.003

Center for Disease Control and Prevention. (2021, August 5). *About Mental Health*. Mental Health. https://www.cdc.gov/mentalhealth/learn/index.htm

Circadian lighting design | WELL Standard. (2020). https://standard.wellcertified.com/light/circadian-lighting-design

Demmin, D. L., Mote, J., Beaudette, D. M., Thompson, J. L., & Silverstein, S. M. (2020). Retinal functioning and reward processing in schizophrenia. *Schizophrenia Research*, *219*, 25–33. https://doi.org/10.1016/j.schres.2019.06.019

DiLaura, D. L., Houser, K. W., Mistrick, R. G., & Steffy, G. R. (2011). *Illuminating Engineering Society, The Lighting Handbook, Tenth Edition: Reference and Application* (10th ed.). Illuminating Engineering Society of North America.

Friberg, T. R., Bremer, R. W., & Dickinsen, M. (2008). Diminished perception of light as a symptom of depression: Further studies. *Journal of Affective Disorders*, *108*(3), 235–240. https://doi.org/10.1016/j.jad.2007.10.021

Get Help With Bipolar Disorders. (n.d.). Retrieved November 26, 2021, from https://www.psychiatry.org/patients-families/bipolar-disorders

Get Help With Eating Disorders. (n.d.). Retrieved November 26, 2021, from https://www.psychiatry.org/patients-families/eating-disorders

Giménez, M. C., Geerdinck, L. M., Versteylen, M., Leffers, P., Meekes, G. J. B. M., Herremans, H., de Ruyter, B., Bikker, J. W., Kuijpers, P. M. J. C., & Schlangen, L. J. M. (2017). Patient room lighting influences on sleep, appraisal and mood in hospitalized people. *Journal of Sleep Research*, *26*(2), 236–246. https://doi.org/10.1111/jsr.12470

IES Color Committee. (2018, July 27). *Technical Memorandum: IES Method for Evaluating Light Source Color Rendition*. Illuminating Engineering Society. https://lightinglibrary.ies.org/document/?contentCode=IES%7CANSI%2FIES%20TM-30-18%7Cen-US

IES Healthcare Committee. (2020, March 23). *Recommended Practice: Lighting Hospital and Healthcare Facilities An American National Standard*. Illuminating Engineering Society. https://lightinglibrary.ies.org/document/?contentCode=IES%7CANSI%2FIES%20RP-29-20%7Cen-US

IES Light and Human Health Committee. (2018). *Light and Human Health: An Overview of the Impact of Optical Radiation on Visual, Circadian, Neuroendocrine, and Neurobehavioral Responses*. Illuminating Engineering Society. https://lightinglibrary.ies.org/CUSTOMERS/view-document.cgi?doc=b1407414-9564-437d-9822-338ff7f9cec2&year=2018&format=pdf&pub=IES&type=3PC

Kasof, J. (2002). *Indoor lighting preferences and bulimic behavior: An individual di€ erences approach*. 18.

Kremers, J., Baraas, R. C., & Marshall, N. J. (Eds.). (2016). *Human Color Vision*. Springer International Publishing. https://doi.org/10.1007/978-3-319-44978-4

Lucas, R., Peirson, S., Berson, D., Brown, T., Cooper, H., Czeisler, C., Figueiro, M., Gamlin, P., Lockley, S., O'Hagan, J., Price, L., Provencio, I., Skene, D., & Brainard, G. (2013). Measuring and using light in the melanopsin age. *Trends in Neurosciences*, *37*. https://doi.org/10.1016/j.tins.2013.10.004

McCuskey Shepley, M., & Pasha, S. (2017). *Design for Mental and Behavioral Health*. Taylor & Francis Group. http://ebookcentral.proquest.com/lib/ksu/detail.action?docID=4862867

Root, S. (2021, December 10). [Zoom Interview].

Seasonal Affective Disorder (SAD). (2020, October). https://www.psychiatry.org/patients-families/depression/seasonal-affective-disorder

Surridge, A. K., Osorio, D., & Mundy, N. I. (2003). Evolution and selection of trichromatic vision in primates. *Trends in Ecology & Evolution*, *18*(4), 198–205. https://doi.org/10.1016/S0169-5347(03)00012-0

Tao, L., Jiang, R., Zhang, K., Qian, Z., Chen, P., Lv, Y., & Yao, Y. (2020). Light therapy in non-seasonal depression: An update meta-analysis. *Psychiatry Research, 291*, 113247. https://doi.org/10.1016/j.psychres.2020.113247

What Is Depression? (2020, October). https://www.psychiatry.org/patients-families/depression/what-is-depression

White, C., & Olabisi, R. (2017). Scaffolds for retinal pigment epithelial cell transplantation in age-related macular degeneration. *Journal of Tissue Engineering, 8*, 204173141772084. https://doi.org/10.1177/2041731417720841

Yuichi, E., Link to external site, this link will open in a new window, Kenji, O., Keigo, S., Kiyoshi, F., Nakao, I., Link to external site, this link will open in a new window, & Tsuyoshi, K. (2021). Association between circadian activity rhythms and mood episode relapse in bipolar disorder: A 12-month prospective cohort study. *Translational Psychiatry*, *11*(1). http://dx.doi.org/10.1038/s41398-021-01652-9