

Circadian Adaptive Lighting

A Landmark Paradigm Shift with Unprecedented ROI Potential

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DSI / BURNETT ... humanizing light

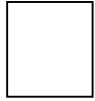
Executive Summary and White Paper

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April 2012

RETURN on INVESTMENT (ROI) can be defined as the monetary and/or marketing benefits derived from having spent time and money on developing or revising a system.

For decades, both the installation and operating costs associated with electric lighting systems has been considered an ongoing monetary expense when it comes to ROI. Accounting for up to 22%¹ of yearly business expense, rising energy costs are driving the growing acceptance of modern building science solutions which employ electronic lighting sources and daylighting technologies for the purpose of reducing ongoing operating costs. However the shift towards energy efficient lighting practices can only be thought of as a first step towards reducing ongoing business related costs. A lighting strategy which has the potential to reduce healthcare premiums and related healthcare burden will be a paradigm shift with direct financial benefit. In 2011, the Kaiser Family Foundation report calculated the average business contribution for family health care premiums alone to be \$10,944.00 per employee per year. Recognized as Circadian Adaptive Lighting this new lighting strategy has the potential for creating a health promoting built environment while fostering lean bottom line yearly expense. In the coming years ahead, the effectiveness of this strategy will be evident in three areas: a.) measurable enhanced sleep efficiencies, now recognized as instrumental in health promotion, preventing disease and major contributor in the healing process, b.) measurable lower allostatic load index scores, a biomarker and non- invasive health assessment used to determine physiological dysregulation in the workplace now also recognized as an indicator of disease trajectories², 3.) and for business owners, an overall reduction of expense line items including: employer health care premiums, costs associated with medical and employee errors, and the escalating costs associated with workplace accidents and fatalities especially among shift work populations. A lighting strategy which is supportive of the human need for both ambient light and darkness levels suitably designed to impact the human circadian system will be the way forward in transferring lighting costs from a line item expense to a valued investment asset.

A recent *Reuters* business online article revealed a survey by the National Business Group on Health (NBSG) which cites research documenting skyrocketing healthcare costs climbing at over 7% per year with no end in sight. The article goes on to state that “beginning in 2012, US employers are expected to pay an **increase** of over \$12,000.00 per employee per year in health related costs”. If providing the right lighting strategy can play a role in reducing those costs, then the case for a circadian-correct lighting system is a very compelling story..... whose time is now.



Overview and Benefits Of Circadian Adaptive Lighting

The continuing scientific discovery linking ambient light to human health, disease, and wellness is one of the most exciting stories of the decade. Research in the fields of chronobiology, photobiology, and scotobiology has made the case clear for how environmental light directly impacts the human body and brain. In fact, the 2002 discovery of specialized non-visual ocular cells responsible for capturing ambient environmental light signals involved with aligning the human master biological clock was cited by the prestigious journal SCIENCE as one of the most important breakthroughs of the year.³ Translated into a practical understanding and application, this discovery has a direct impact on the way modern day buildings are designed, constructed and lighted.

As important as this discovery has been for the scientific community, the movement from knowledge to applied practice by the design and architectural communities has been hampered due to a failure to communicate. Currently there is neither common language nor lighting terminology to establish an open understanding between design professionals and scientific disciplines. With plain language, this paper hopes to bridge the gap between science and applied lighting design by presenting a user-friendly perspective of the human circadian system and how this impacts the design of our built environments.

The term *circadian* means “about a day” and refers to the synchronized nature of the innate human rhythms of body and brain functions throughout a 24 hour day. Keeping it running smoothly is a collection of cells located deep within the brain identified as the Master Biological Clock. Science has also established the existence of multiple organ-based time keepers located throughout the body including red blood cells. In nature, solar light and dark signals drive the master biological clock with a synchronized balance of bright light during the daylight hours, darkness at night, and a perfectly timed cycle of changing wavelength dominance throughout the 24 hour day. Ambient temperature conditions are also a key signal driving and influencing pacemaker clocks.

The “clocks” are responsible for keeping body and brain functions synchronized with changing environmental conditions in order to ensure survival. The principle or major biological clock is the suprachiasmatic nuclei and is located within the brain. Peripheral or secondary clocks are located in major organs and can have either 24 hour regularity (Circadian) or shorter than 24 hour (Ultradian) or feature longer (Infradian) patterns of occurrence. An example of this is a woman’s 28 day menstrual cycle.

Ongoing scientific research is now demonstrating that ordinary ambient electric lighting is also capable of direct influence upon the master biological clock and the circadian system; an important human life system which impacts all of our daily functions and lifelong biological processes. It is both a major biological and neurohormonal system comprised of the sleep / wake cycle and the innate circadian rhythm.

Practical and wide spread acceptance of built environmental lighting strategies capable of circadian influence, calls for an open line of communication between the scientific research community who define and establish the light and health connections, the medical community who ensure the health promoting benefits, and the design community who will apply the knowledge in a manner embracing the intent of the Hippocratic oath “first do no harm”.

Termed *Circadian Adaptive Lighting*, the proposed lighting terminology and recommended application guidelines have the potential to dramatically impact all aspects of business expense and profitability due to the interconnection between human health and the built environment now demonstrated to entrains, align, and directly influence the human circadian system.

For the professional lighting and architectural communities the connection between built environmental light to human health is an amazing discovery with untapped potential for new business growth and worldwide market development. In the very near future, this will be realized with the opportunity to provide clients with more: homes where clients feel better, office buildings where employees work more efficiently, schools where kids learn more effectively, and hospitals where discharge rates are accelerated and preemies gain weight faster simply because design professionals understood the light and health connection with more than just passing lip service.

For the lighting manufacturer, the strategy of Circadian Adaptive Lighting will be an opportunity to develop new products while tapping into the global marketplace including: healthcare, manufacturing, light commercial, institutional, hospitality, medical tourism, governmental and residential. The ROI potential is significant due to one overarching fact; humans need a balanced diet of both light and controlled darkness. The case for new and updated light sources which provide for critically timed and dynamically active light is proving to be paramount for the most basic of all human survival needs- health. The forward thinking manufacturer will embrace this fact and deliver electric light thru innovative sources and specifically designed circadian correct luminaires.

For the controls manufacturer, the move towards dynamically-adaptive lighting environments is even more relevant as the circadian-correct protocol is predicated on precisely timed and controlled shifts of light and darkness operational on astronomical governances. And to make the circadian story even more appealing, scientific research is also demonstrating the need for critically timed ambient temperature conditions which vary throughout the 24 hour cycle.

For the employer, healthcare provider, school administrator, and hotel marketing executive, the potential for this type of precisely controlled ambient built environment is unprecedented for both human health benefits and immediate monetary ROI. With circadian correct dynamic ambient light levels likely to provide for enhanced employee productivity and performance, reduction in on-the-job accidents, reduced medical errors, decreased health related costs, higher student achievement scores on standardized tests, and more satisfied brand-loyal guests the benefits are tremendous and far outweigh the initial costs. One only has to look at the cost of insomnia as this negative health condition plays directly into employee productivity calculations. In fact a 2007 Journal of Occupational Environmental Medicine study estimated that the economic US burden of health care costs associated with lost productivity due to employee insomnia to be \$136 Billion per year.⁴ If the correct lighting strategy could play a small role in reducing this one economic burden alone then the ROI timeframe of circadian correct lighting related costs are immediate.

To understand how and why ambient light would play an important role in reducing the business and health related costs associated with poor human health and reduced productivity, one first has to comprehend the most basic understanding of the critical nature light plays in human existence and survival.

Within the past two decades, both scientific and medical discovery have established the critical role of one component of the circadian system; SLEEP. The process of sleep is vital for maintaining and providing for human health, wellness, and development including disease control and prevention. Additionally, the quality and quantity of sleep is now directly linked with memory, cognition and learning⁵. Although explained in detail later in this report, a summary

version of how sleep and the circadian system are connected to ambient light and business benefit follows:

- The human circadian system is fundamental for all other human systems to function and survive.
- Sleep is a vital component of all human biological, physiological, anatomical and neurohormonal systems as well as the health and viability of organs and neuronal structures.
- The process of sleep occurs throughout the entire 24 hour period.
- The act of sleep produces varying degrees of fatigue and alertness depending upon the timing, quality, and quantity of sleep received.
- The act of restorative sleep naturally occurs during the night darkened hours while key biochemical changes, which bring about the act of sleep at night, are fortified and/or dampened during the light-filled daylight hours.
- Efficacious sleep periods provide for system wide health and wellness, resistance to disease, sustained growth and robust age-related adaptations all of which contribute and determine the downstream monetary costs of health insurance, health care expenses, and business costs directly attributable to fatigue and loss of attention.
- Within the general population to obtain a quality sleep at night, humans need both a light-devoid ambient environment during the evening hours AS WELL AS a bright light-filled daytime environment in order to provide for the biochemical changes which bring about the act of sleep, the human health and alertness benefit the process of sleep ensures, and the behavioral response a quality sleep provides with measurable improvements in productivity and performance, increase cognition, and enhanced memory.



Definition: Circadian Adaptive Lighting

Epigenetic design ***Circadian Adaptive Lighting*** is the applied circadian-correct lighting strategy best describing the integration of natural light and dynamic electric light sources controlled by advanced lighting controls systems coupled with integrated shading options for the purpose of meeting one or all of the following objectives:

Provide built environmental lighting support for medically prescribed primary and secondary treatment for disease and health related conditions such as Alzheimer's, depression, and cardiac conditions. Additionally, this lighting strategy would be particularly useful in medically supervised sleep diagnostic centers as well as providing lighting solutions for medical practitioners interested in customizing individual patient adjuvant treatments for existing disease conditions such as cancer, mental illness and metabolic disorders.

Provide circadian-correct lighting support sensitive to occupant need for dynamic light levels which are necessary to maintain both the homeostatic sleep propensity and circadian rhythm. Areas for application include: hospital based NICU, ICU, and psychiatric wards, as well as, long term care facilities where innate circadian systems are negatively impacted by the aging process. As an inducement for sleep without pharmacological intervention, this lighting protocol would also serve as an excellent geriatric non-prescriptive means for achieving a quality sleep.

Provide critically timed circadian-correct lighting interventions designed to address specific populations in a critically demanding field where extra attentiveness is paramount for worker and public safety. The purpose of this type of lighting strategy is to

Epigenetic Design is an emerging design practice which bridges the gap between scientific discovery and energy efficient design application for the purpose of creating health promoting built environments. Application methods are firmly established on a medically relevant working knowledge of how genetic expression, human physiological, neuroendocrine, and behavioral response is impacted by the built environment; the primary stimuli of which is LIGHT.

promote optimal health, performance, alertness and enhanced memory for anyone working or learning in an indoor daytime environment where access to windows are limited and/or the existing light levels are minimal. Especially useful for night shift environments, nursing stations, and safety-critical control centers, this strategy also provides for the delivery of wavelength spikes of alerting light during critical time periods to further enhance sleep efficacy and promote the secondary health benefits of light.



The Case for Circadian Adaptive Lighting

Historically the design specification of electric light sources has been predicated on the need for visual acuity and task enhancement. With ongoing scientific discovery the path is becoming clear for the inclusion of a second light level guideline: a circadian-correct light level designed to enhance, support, or shift the circadian system of anyone who occupies the spaces we design. With the advent of two electric light source systems now demonstrated to be capable of affecting the human circadian system (electronic solid state LED technologies and fluorescent lamps) we now have unprecedented potential to combine both visual acuity lighting solutions coupled with critically timed wavelength light shifts designed to impact the circadian system.

Established peer review scientific and medical research in the fields of sleep medicine, chronobiology, and photobiology have opened the door for the practice of lighting design and architecture which supports a synchronized dynamic shift of ambient light levels throughout the 24 hour day.⁶ The consequences of not maintaining this alignment are well documented and relevant to any windowless environment or where room light levels are below light levels necessary for circadian entrainment and /or phase shift cross over. Recommendations for specific light levels and key spectral wavelengths which impact human health are currently in discussion by leading scientists, medical research facilities, and governments worldwide. Basing the decision to act on existing but yet still emerging scientific data, the German government has set forth a goal of September 2013 for a first draft of establishing light levels (Illuminance recommendations as measured in measured in LUX or foot candles) levels suitable for circadian entrainment within the built environment. The decision to act in advance of conclusive scientific study is thought to be a proactive measure against the rush of manufacturers to bring blue- rich light sources to the market

with the potential to do both ocular and circadian harm. We the design and lighting community must be ready to apply the necessary light levels and lighting practices once established when called upon. The integration of the terminology of the proposed Circadian Lighting and application guidelines will be but the second step as the first and most important aspect for correct application is a working understanding of how light impacts human health and wellness.

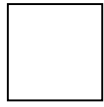


Connections: LIGHT and the Human Animal

As the earth rotates on its axis around the sun, it's easy to observe naturally shifting light levels as they go from a bright dominant blue daylight condition to a muted red-shifted wavelength presence prior to an extended darkened period we call night. Our human nature takes note and responds accordingly. Biologically speaking, man is an earth-bound diurnal mammal who sleeps during darkened conditions and awakens upon the presence of bright light refreshed and relaxed in order to eat, seek shelter and eliminate waste during the daytime hours. Coordinating the many processes of reoccurring activity throughout the body and brain, the circadian system governs biological rhythms which occur seasonally, weekly, daily, hourly and minute-to-minute.

The two major biological functions comprising the circadian system are the sleep/wake cycle and the alignment circadian phase, known as the circadian rhythm. An endogenous (built-in) rhythmic balancing process between brain chemicals and metabolic functions, the human circadian system is responsible for most of our humanly functions such as urine flow, appetite, sex drive, sleep, wound healing, growth, disease resistance and cellular repair. It also plays an important role in other body wide systems including the skeletal, endocrine, immune, nervous, and reproductive and digestive systems. Each system is impacted or directly influenced by the circadian system thus indirectly under the direct influence of the light /dark signals derived from either the earth's rotational spin around the sun or electric light sources. It is this fact that now has the scientific and medical communities reaching out to other professions because electric ambient environmental light has now been demonstrated to be equally capable for driving the circadian system. For the A/E/ID and lighting professional, the importance of this discovery is becoming increasingly clear; the design element of light is no longer an aesthetic attribute or defining architectural feature. Light and darkness are primal human needs now compromised by a failure to understand how the built

environment contributes to the health and wellness of all who occupy the spaces we design and construct.



Examining the Human Circadian System

Since early human history, man has long appreciated the relationship between earthly light and our humanly existence. Only since the last quarter of the 20th century has modern science begun to fully evaluate the circadian system and explore its impact on human health, disease and wellbeing. The human circadian system is present in every cell of our body and brain and the command seat is situated in a small region of the brain behind the eyes. This amazingly simple system functions like a giant control center keeping all of our biological, physiological and psychological processes on track, while at the same time priming the body and brain for an optimized healthy state. Establishing the pace for this master control system is dependent on both internal and ambient environmental signals called **zeitgebers**, a German word meaning ‘time givers’. Although numerous other factors, including the timing of food intake and ambient temperature conditions also contribute to the alignment or entrainment of the human circadian system, the primary signal is environmental light. In addition to natural and electric illumination sources environmental light capable of circadian system influence are extraneous light sources such as: kinetic fire sources, electronic computer screens, phone displays, illuminated alarm clocks, TV screens and even aquarium lighting. Specifically, the three types of light signals which impact the circadian system are: dynamic wavelengths of bright blue-dominant daytime light present during the morning hours, dynamic long red wavelength dominant light present during the late afternoon and early evening hours, and regularly occurring periods of darkness at night.^{7 8}

The circadian systems’ internal timing mechanism or pacemaker which coordinates the zeitgebers with all of the other human systems including the immune, skeletal and reproductive system, and is located in a small brain region behind the eyes comprised of approximately 20,000 specialized cells.⁹ Collectively known as the biological clock or master pacemaker, the suprachiasmatic nucleus (SCN) has inherent timing accuracy and the unfailing ability to coordinate and influence most all human functions including sleep, wound healing, and health.¹⁰ The SCN is known as the master pacemaker or biological clock because it controls or influences the secondary pacemakers found within each of the major organs throughout the body¹¹. The zeitgeber of environmental

light has been demonstrated to be the primary influence for entraining or aligning the SCN and the entry point of the signals is found in the eye.¹² Unlike the photosensitive rods and cones necessary for vision, the circadian system non-visual cells are unique and recently discovered.

Beginning in the late 1990's a new type of ocular photoreceptor cell, the *intrinsically photosensitive retinal ganglion cells* (ipRGC) was discovered.^{13 14}

Long understood to be important for visual acuity and pupillary light reflex, the new findings demonstrated that a small 1 – 3% of the 1.3 million ganglion cells in each eye were also maximally sensitive for non-visual light signals and considered to be part of the circadian system. Collectively, the ipRGC cells are receptors for light signals with specific search criteria such as light timing, intensity, duration and spectrum of the available ambient light. It is widely recognized that the ocular ipRGC are the first line of entry for ambient environmental light signals to play a role in circadian entrainment, but continuing discovery has been changing how we understand the involvement. In the first part of the 21st century when the new role for the ganglion cells was first made, most scientists at the time thought that this was the only photoreceptor to direct light information to the SCN¹⁵. Recently, a landmark study from Johns Hopkins University has uncovered a second entry point with access to the SCN; a small portion of the dim light activated rod cells. In addition to the non-visual ipRGC cells which send bright light information to the SCN, Dr. Hattar's work has demonstrated that a small portion of the rods (visual photoreceptors located in the periphery of the retina) also provide input to the SCN¹⁶. But instead of collecting bright light information, these specialized rods are isolating dim light signals such as found when the sun wanes and night approaches. This type of light is usually long wavelength and red dominant. The scientific consensus is now understood to be that along with a small percentage of input from the cones and rods, the function of the ipRGC is to transduce bright, blue-dominant light information

OCULAR PHOTORECEPTORS

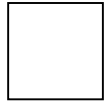
A photoreceptor is a specialized neuronal cell located in the eye which receives light information and changes (transduces) the photons into bioelectrical signals which are then processed by the brain. There are three primary photoreceptors located within the eye:

RODS - primarily responsible for dim light and peripheral vision, they number approximately 120 million in each eye and are also involved with circadian entrainment

CONES – primarily responsible for color vision as well as attention to fine visual detail, they number approximately 6 million in each eye

ipRGC - recently discovered, these cells are responsible for collecting specific light wavelength dependent information and transducing that signal in a process called ocular phototransduction. The master biological clock (SCN) utilizes this critical information for circadian system processing and circadian rhythm entrainment. These cells are also involved with stress response and the pupillary light reflex. There are approximately 40,000 ipRGC cells in each eye

for further processing in the SCN while red dominant light wavelengths are now thought to be critical for maintaining the robust nature of the ipRGC cell itself during the regeneration process.



An Integrated Two-Step Circadian System

NOTE: The human circadian system is comprised of two processes; the restorative sleep/wake cycle and the endogenous circadian rhythm. Although commonly used interchangeably, a correct review of how the circadian rhythm and the separate sleep /wake cycle are unique while yet complimentary and supportive of the other is necessary for a comprehensive understanding of the complex nature of the circadian systems relationship to environmental lighting practices.

CIRCADIAN RHYTHM

As part of the circadian system, the circadian rhythm (from the Latin *circa diem* meaning about a day) is a reoccurring biological 24.2 hour cycle which provides timing stability and alignment with environmental changes for anticipating and aligning activities between brain chemicals, genetic expression, cellular activities, physiological development and the automatic rhythms of the autonomic system. These include our cycles of body temperature, cardiovascular function, and the endocrine systems' production of hormones such as melatonin and cortisol. The autonomic rhythms, once thought to be beyond outside influence, are tightly controlled by the circadian system and are now understood to be impacted by environmental light stimulation and behavioral influence^{17 18} The circadian rhythm also plays a major role in coordinating other biological cycles located throughout the body and brain. These include the ultradian rhythms which occur less than every 24 hours and include our timing cycle for urination, bowel activity, and nostril dilation.¹⁹

The circadian rhythm is state dependent, meaning that environmental stimuli including signals from within our bodies such as digestive activity, as well as, derived from the built or natural environment such as light and temperature are the regulating or entraining factor by which the 24.2 hour circadian rhythm maintains its course through a 24 hour rotation of the earth. As a cyclic wave with varying degrees of amplitude (intensity or strength of reaction response) the circadian rhythm has phased timing rhythmicity and age related wave amplitude strengths which

will lose a percentage of strength or robust nature as a result of the normal aging process. We are not born however with a fully entrained circadian rhythm thus the reason why newborns sleep in excess of 18 hours per 24 hour period. It is only after spending time within an environment richly filled with light and other sensory stimuli that the rhythm will establish a consistent pattern. For humans this alignment ability is stabilized and firmly established usually between 4 and 6 months of age.

- An example of how an in- depth understanding by both the medical and design community of the connection of the circadian system's alignment with ordinary room signals such as light, motion and ambient temperature can be utilized to dramatically impact mortality rates among newborns one only has to examine a 2008 study. Here researchers discovered the connection to effective pediatric life-saving design interventions through awareness of how the light and temperature entrained circadian system is involved with the process of breathing, temperature regulation and motion detection. Simply by instructing young mothers of 4 – 6 month old infants to keep the children's sleeping rooms cool (72 degrees or under) while keeping a circulating fan oscillating nearby whenever the child is sleeping or napping, researchers demonstrated a whopping 94% reduction in the opportunity of SIDS (Sudden Infant Death Syndrome) to claim another life.²⁰ Infant mortality from SIDS primarily occurs within the first four months of life and is now thought to be a failure of the yet developing brain to produce the necessary signals needed for maturing lungs to development and function properly. As a result, young babies die unexpectedly by suddenly stop breathing, usually while sleeping or taking a nap. It is my thought that if all new mothers, pediatric medical professionals and residential design practitioners were made aware of how the Epigenetic Design practice techniques for nursery design featuring a ceiling fan, large windows which allow ample daylight during napping times, automated blackout window treatments blocking light trespass at night, and integrated light and HVAC controls which automatically lower lighting levels and room temperatures as an adjuvant protocol for mortality prevention, this then would become the accepted standard and the value of an applied CIRCADIAN ADAPTIVE LIGHTING strategy becomes more than just a design modality; it would literally save lives. Ideally this strategy would be applicable for any space where infants would be sleeping including: NICU's, hospital nurseries, and infant daycare centers.

SLEEP /WAKE CYCLE

The second component of the circadian system is known commonly as the sleep /wake cycle and involves the complex process of sleep. Sleep is both a regularly occurring innate restorative drive necessary for human survival but also a willfully timed act which usually occurs at night. The process of sleep is a 24 hour homeostatic balance of genetic and brain chemical activations and response which trigger a series of body wide responses resulting in a number of necessary functions critical for human survival.

The critical timing of the process is known as the Homeostatic Sleep Propensity (HSP) which is the need for sleep as a function of the amount of time elapsed since the last adequate sleep episode²¹. The HSP imposes a harmonizing balance and monitors the strength or amplitude of two inverse waves of continuing biochemical and physiological response patterns which are tied to the ever changing cycle of light and dark on a rotating planet. The HSP controls the timing, amplitude and direction of the two waves and is instrumental in maintaining the balance between the need for sleep and the innate waxing and waning circadian rhythm. The HSP inverse cycle of a decreasing “circadian phase” and an increasing need for sleep is coordinated with the 24.2 hour circadian system which, in turn, drives the timing of the brain chemicals and biological functions which govern sleep. The overwhelming need for sleep, is known as “sleep pressure” and is based upon the amount of time elapsed since the last adequate sleep episode plus the amount of activity and light exposure experienced during the daylight hours. During specific episodes of neurohormonal chemical activity which are critically aligned between transition times of daytime light levels and darkened evening hours, the circadian system coordinates the sleep wake cycle with the endogenous circadian rhythm in order to impact all areas of our human existence; physiological development, cellular growth and repair, wound healing, disease progression, weight management and mood.

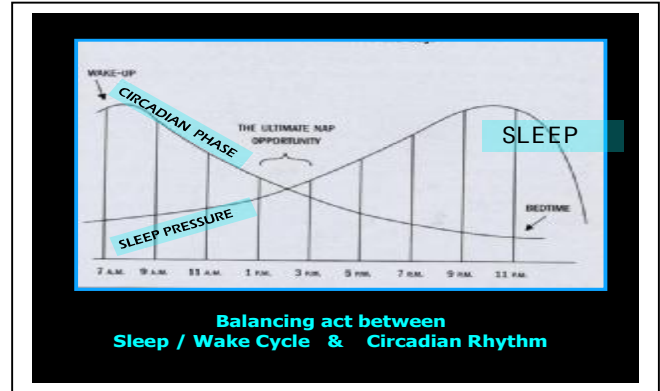
Among sleep professionals the circadian rhythm within the context of sleep is referred to as the “circadian phase” and is a movable hallmark of our diurnal nature. It is responsive to ambient light levels for either phase advancing (shifting the naturally occurring sleep period forward) or of phase delay. Without a perpetual well-balanced oscillation cycle between the circadian phase and the sleep pressure wave the circadian system is desynchronized and the potential for illness and disease occur. It is important to remember that both the circadian phase and the sleep pressure wave intersect at two critical time periods throughout the 24 hour day. The timing of

these intersections naturally align with the changing natural light and temperature zeitgebers and serve to realign the 24.2 hour circadian system to the 24 hour rotation of the earth. It is also during these junctures where critical biochemical transition activity occurs within the body and brain.

Depending on genetic predisposition for either alertness during the morning hours or alertness late into the evening hours, we experience the HSP as follows: After the sun has risen most individuals notice the circadian phase as an innate descending shift to remain awake and alert. Prior to the sunrise period we naturally experience this phase as a growing need to arise and become

active. Conversely, under sleep pressure influence, upon awakening prior to the sunrise period we experience a decreasing need or pressure to remain asleep. After the sunrise period we experience an increasing need throughout the day to return to the sleep state. This need or pressure to sleep intensifies the longer we remain awake. An example of this is when try to keep our eyes open late into the evening hours after a hard days of activity in the bright daylight. In summary one can say that process of preparing the body for sleep at night starts the moment you wake up in the morning so that you can fall asleep later that night. It is important to remember however, that as an innate feature of our humanness, sleep acquired during the day is never as effective nor restorative as that of sleep acquired during the darkened evening hours. Several well documented studies have noted the fact that sleep periods during the daylight hours are shorter and less consolidated than night-time sleep.^{22 23}

Another factor to consider when discussing the sleep wake cycle, circadian rhythm and the homeostatic sleep propensity is that of the aging process. In addition to the obvious outward signs of aging, the brain also undergoes a degradation of previously robust cycles and the important role biochemical play within those cycles. Recently there has been significant research examining the age related impacts on a key sleep biochemical, the hormone melatonin and the resulting affects this has on the homeostatic sleep propensity. One well-documented study examined the relationship between the waking melatonin levels of older study participants (average age 67) as compared to younger subjects (average age 24) and how the later waking times of the older participants was due to an increase of a biochemical which is ideally diminished upon waking.



The researchers go on to state: “Consequently, the older subjects were waking at a time when they had higher relative melatonin levels, in contrast with younger subjects, whose melatonin levels were relatively lower by wake time. Our findings indicate that aging is associated not only with an advance of sleep timing and the timing of circadian rhythms but also with a change in the internal phase relationship between the sleep-wake cycle and the output of the circadian pacemaker. In healthy older subjects, the relative timing of the melatonin rhythm with respect to sleep may not play a causal role in sleep disruption”²⁴

SLEEP

Although the exact purpose of sleep is still being debated, we do know that both the body and brain use the process of sleep for necessary cellular repairs and restoration of the primary energy currency for our cells; adenosine^{25 26} The “restorative process” occurs while we sleep in order to enable an effective return of activity the following morning. During the actual process of sleep, brain wave activity shifts oscillation rates in regularly occurring cycles of 90 – 120 minutes throughout the sleep period. It is here that the design of the sleeping environment is important as the phases or differing stages of brain wave activity associated with sleep can be influenced and disrupted by light-at-night, as well as, a warm room and other design features of the space. As much as we’d like to consider sleep as an inevitable biological process it is one of the few functions that is also controlled by “willed behavior” and directly influenced by lifestyle, behavior, and ambient conditions. Without realizing it we can impact the process of sleep simply by turning on the TV or working on the computer during the nighttime hours as this light will also contribute to light at night (LAN) now examined as a determinant to the overall sleep process.

There is also a unique fact about our sleep habits which we do not actively control; our genetic predisposition for the timing of when we go to bed at night. The innate preference to stay up late or go to bed early is due to a variant on a gene called PER; individuals who naturally prefer the ‘early to bed and early to rise’ routine are identified as PER 4/4 commonly called larks while those who instinctually go to bed late and sleep till mid-morning are identified as PER 5/5 and known as owls.^{27 28} Throughout our lifespan the hourly requirement for sleep will undergo several age-dependent changes ranging from 18 hours of sleep needed for newborn development to an ideal 7-8 hours for average young adults. For adults an overly lengthened (more than 9 hours) or

shortened (less than 6 hours) sleep period is now shown to be correlated with a number of negative health impacts such as excessive daytime fatigue, impaired memory and concentration, poor judgment abilities and low attentiveness levels.²⁹ Additionally, ineffective sleep periods are also now shown to be directly related to major disease promotion and progression including heart disease, kidney disease, diabetes, and major inflammatory diseases such as rheumatoid arthritis and fibromyalgia.³⁰

An efficacious sleep period is dependent on several environmental timing cues as well as behaviors which provide for the correct biochemical response which aid in promoting sleep. Achieving a quality sleep is predicated on getting adequate amounts of bright light during the day and limiting light exposure during the normally darkened evening periods. Additionally, the more physically active one is during daylight hours within an ‘enriched environment’ the more robust the sleep process and thus the better the sleep experience.^{31 32} According to Wikipedia “Environmental enrichment concerns how the brain is affected by the stimulation of its information processing provided by its surroundings (including the opportunity to interact socially). Brains in richer, more stimulating environments, have increased numbers of synapses, and the dendrite arbors upon which they reside are more complex” Built environments providing for occupant access to natural views, optimized lighting, and varying ambient conditions throughout the day, all contribute to an enriched environment and an enhanced sleep period.

In order for the process of sleep to be efficacious, including maintaining an undisturbed sleep period throughout the night, two components are necessary for driving the circadian system leading to a good night sleep; engaging mental and physical activity the previous day and receiving ample amounts of bright light during the previous daylight hours.^{33 34} In fact, science has demonstrated the importance of daytime light on circadian system needs by recognizing a minimum of 1000 LUX to drive an average adult circadian system.³⁵ This is important to note because without receiving ample amounts of high light levels, especially during critical morning hours, the pineal gland cycle of darkness derived melatonin production will slow down to a value of 25.1 hours instead of maintaining a cycle of 24 hours.³⁶

It is a rather unfortunate reality of living in the 21st century where most indoor workers are not routinely exposed to these high light levels as work environments rarely provide levels which support the circadian system. In the US, many modern office buildings rarely exceed 500 LUX for general lighting needs, while in Denmark the government has mandated that office spaces be

illuminated with a meager 250 LUX in an effort to conserve energy. For employees working in light levels sufficient for visual acuity, but yet totally inadequate for circadian needs, the concern is that these workers are not fully biologically awake and that their circadian systems are never fully aligned so that in essence they are biologically asleep. To call attention to the need for higher daytime light levels, the term *biological darkness* has been coined by a prominent German researcher, Dr. Till Roenneberg, to describe conditions of low indoor ambient light levels insufficient to drive the circadian system. Critical of the European standard limiting indoor light levels to 200 LUX during the work day in order to conserve energy costs, worldwide research professionals are now urging governments to consider and establish a unified circadian standard of acceptable light levels deemed effective for providing sufficient light to suppress daytime circulating melatonin, and a maximum dim light threshold for light at night (LAN) in order to promote sleep and the health promoting benefits it provides. Currently the debate is centering on establishing 1000Lux as a base line lighting level necessary for daytime melatonin suppression however the exact timing and duration for the application of this light is still being investigated.

Obesity, a leading preventable cause of death worldwide is another area where the number of hours of sleep experienced at night contributes to a growing health concern; one with rising worldwide economic healthcare burden³⁷. Obesity is now considered to be reaching worldwide epidemic proportions and according to the World Health Organization there are more than 1 billion overweight adults and nearly 300 million among them are obese. In the US, a 2007 NIH study concluded that 63% of all Americans were overweight, and that by 2030, 86% would be obese or dramatically overweight. The link between sleep and obesity has been demonstrated in several major reports documenting that receiving less, or more than, the recommended 7-8 hours of sleep each night, has a direct bearing on increasing waist lines. One such study conclude that adults receiving 6 hours or less of sleep each night were 35% more likely to gain 11.3 pounds over a 6 year period³⁸. Another study, a 29 year investigation with 68,183 women participants reported that those whose sleep was less than 5 hours per night were a third more likely to gain significant amounts of weight over 16 years.³⁹

And employers with overweight sleepy employees are feeling the hit as health care costs rise with growing waistlines. A 2007 landmark study demonstrated a strong association between body mass index and traumatic workplace injury. Their study investigated 7,690 US aluminum manufacturing workers and found that those who experienced a workplace injury, 85% were classified as

overweight or obese.^{40 41} Examining the link between ambient light levels and obesity, diabetes and glucose intolerance is the topic of several ongoing studies. The most recent, a 2010 study demonstrated that light entrained mechanisms involving circadian system CLOCK genes played a role in regulating plasma triglycerides – a notable hallmark of both metabolic syndrome and obesity⁴².

Light, Brain Chemicals and the Connection to Sleep

Both the circadian rhythm and the process of sleep correspond directly to the release, silencing and circulation of two major light reactive brain chemicals; melatonin and serotonin.⁴³ The well-orchestrated antagonist relationship of expression and suppression between serotonin and melatonin comprise a major role in both the circadian rhythm and the sleep wake cycle.⁴⁴ Both melatonin and serotonin are light reactive and are negatively impacted by lifestyle conditions such as working the night shift and occupying daytime work environments absent from the influence of dynamic bright light shifts.^{45 46}

Two types of brain chemicals play a critical role in maintaining the circadian system; neurotransmitters and hormones. Neurotransmitters are small chemical transport messengers which enable brain cells (neurons) to communicate. They are responsible for turning on or off key reactions setting in motion specific behaviors, physical responses and other chemical reactions within the body and brain. Hormones, a large blood borne chemical messenger, impact all cells within the organism by signaling pertinent information necessary for reproduction, growth, development and disease protection. Key neurotransmitters and hormones are light reactive. Neurotransmitters such as serotonin and adenosine, the chemical which gives the process of sleep its role as a restorative process, are shown to be maximally expressed during the daylight hours while the hormone melatonin demonstrates a pattern of nighttime expression initiated by evening hour dim light onset continuing to darkness without light. When environmental light and darkness signals, from either natural or electric light sources, enter the circadian pathway specific neurotransmitters and hormones turn on or off according to the light information derived. This then sets into motion the chemical reactions which drive our very existence: cellular regeneration, maturation, growth, system wide repair, immune response, skeletal development, reproduction,

and autonomic function. It is the environmental light conditions which are now proving to be the driving force impacting the presence or absence of circulating melatonin and serotonin levels ^{47 48}

MELATONIN

Modern research has uncovered the connection between blue rich white light and the hormone melatonin. Melatonin, a darkness reactive hormone long understood to be instrumental in the sleep /wake process, is now known to be a powerful antioxidant protectant for DNA, as well as, a system wide tumor suppressant.^{49 50} In the presence of even low levels of ambient light-at-night, melatonin expression from the pineal gland is diminished or suppressed. Emerging research further demonstrates the understanding that when melatonin (MT1) levels are not sufficient in the circulating blood stream due to the inhibiting effects of light-at-night (LAN) on the pineal gland, the expression of a key tumor suppressant genes (p53 and p38) are impacted and breast cancer cells are promoted to a progressive state.⁵¹ Several international studies have suggested that LAN is a contributing factor in rising cancer rates due to light trespass and increased light levels within the sleeping area. One such paper demonstrated a 22% increase in breast cancer rates among populations where LAN was the norm.^{52 53} Another international study examining the impact of LAN on breast and prostate cancer, although now highly suspect for incomplete study protocols and data collection, has even gone so far as to call for the elimination of blue-rich white light LEDs from the nighttime environment due to their findings that melatonin is suppressed up to five times more under this light source than exposure from red wavelength dominant High Pressure Sodium light at night⁵⁴.

SEROTONIN

Serotonin, a daytime light reactive neurotransmitter involved with mood, motion and balance control, pain perception and peristaltic movement, is a chronobiologically linked counterbalance to melatonin in the process of sleep, and also plays a critical role in maintaining an overall sense of emotional wellbeing.⁵⁵ Serotonin is involved with overall brain function as it binds to an impressive 14 different receptors found on every cell within the brain, and also plays a role in memory, concentration, reaction times and mood. Serotonin is also light reactive. Recent discovery has demonstrated that lower levels of circulating serotonin occurs in both depressed and non-depressed individuals due to a seasonal light level decreases experienced in the Fall and

Winter months. This has brought about attention to the need for seasonal increase in environmental light levels in order to support fluctuating serotonin levels.^{56 57} Yet another area where the relationship between ambient light and serotonin is being investigated is in women's health. Here the researchers are examining the role daytime produced serotonin has with nighttime optimized estrogen production.⁵⁸

Throughout our lifespan, environmental light is emerging as a key player for driving the circadian system impact on the expression and silencing of key brain chemicals. A 2001 study revealed that specific brain regions responsible for maintaining a healthy level of serotonin throughout our lifespan decreases predictably by 10% per decade with advancing years thus drawing attention to the connection of the circadian system with dementia and other neurodegenerative conditions.⁵⁹ To further compound the problems associated with aging, normally diminished melatonin secretions are also being shown to be exacerbated by low levels of environmental light among elderly populations.⁶⁰ This research demonstrates that the elderly are not getting sufficient day time light exposure in order to suppress melatonin fully during the day. In essence they are never fully awake and are living in an architecturally imposed biological darkness. You can best understand the importance of this latest research by realizing that melatonin production originates within several regions of the body and brain - 85% from the enteric or intestinal area and the remaining portion, identified as MT1, comes from the pineal gland located deep within the brain. Both types of melatonin are important for not only achieving sleep, but also for DNA protection and tumor suppression. When melatonin is expressed from the pineal gland it is circulating freely at night because of two things: prior strong bright light exposure during the daytime hours and a darkened night time environment. These two conditions stimulate the pineal gland to release high levels of MT1 at night. Both environmental light conditions are necessary in order to accomplish one very complex function: to stimulate circulating serotonin while suppressing daytime levels of melatonin. It is the bright light exposure received during the daylight hours which keeps the darkness-produced MT1 melatonin suppressed so that at night it can return with a powerful surge. Without the suppressant effects of daytime high light levels on the "darkness" hormone, the nighttime release of melatonin is very weak or nonexistent. In other words, you need to keep the MT1 heavily suppressed during the daylight hours in order for a robust expression of MT1 at night. The strong nighttime expression of the hormone melatonin and corresponding decreased levels of serotonin within darkened conditions are what keep us asleep at night and functioning with optimal health the next day.



Established and Emerging BRIGHT LIGHT Research

Since the late 1980's, science has been actively investigating the ability of electric light to impact the human pacemaker in both a positive and negative affect. Scientists are looking specifically to six differing qualities of light for impacting chemical and physiological functions. These include: delivery source (fluorescent, LED or incandescent) timing of the light interventions, duration of the light intervention, specific wavelength also known as a Spectral Power Density (SPD) the dynamic nature of the light source over the course of the day, and even the kelvin temperature differences between light sources. In 2006 the first research to prove the efficacy of using a dynamic light source, one which simulates the naturally changing wavelength and intensity of light in a characteristic S-shape curve, was developed for human use.⁶¹ Here the researchers demonstrated that dynamic light therapy administered before rising was an effective antidepressant and to be considered an excellent alternative to medication. An example of the 1980's early pioneering work of Dr. Al Lewy and colleagues into treatment for Seasonal Affect Disorder can be cited as the beginning of modern day chronobiology and it's use of light therapy for treatment of depressive symptoms. Prior to this, the use of DDS (Dawn-Dusk Simulation) therapy had been commonly used for a number of years as a treatment protocol for circadian regulation of fish and other contained animal populations to maintain health, growth, reproduction and overall wellbeing.

Overall, worldwide peer reviewed research is uncovering the potential for even small amounts of bright electric light to impact health in both a positive and negative fashion. One of the most interesting studies uncovered that a tiny 2millisecond burst of bright light, administered close to the eye under laboratory conditions is also capable of physiological and neurochemical impacts upon the circadian pacemaker.⁶² This discovery has the potential to dramatically impact the way we help to entrain workers in night shift environments as well as treat various forms of depression.

With worldwide depression rates escalating each year, research examining the use of light has extended into the workplace as seasonal depressive disorder (SAD) and other mental illnesses have overreaching economic and human productivity costs. On September 4th 2011, Reuters, the London news agency, released a summary of a major research project (514 million participants)

where it estimated that 38 – 40% of all European workers within 30 countries were found to be afflicted by mental disorder with depression leading the pack. Additionally the WHO (World Health Organization) has estimated that by 2020, depression and related depressive symptoms, including SAD, will be the second largest contributing factor for the global healthcare economic burden across all ages.

Here in the US, government agencies including the Equal Employment Opportunity Commission (EEOC) and the Administration for American with Disabilities are now regularly reviewing cases where employers are held liable for not providing the correct workplace lighting conditions for those afflicted with SAD and workers experiencing health and mental problems due to inadequate natural light levels within the workplace. In 2010 there were 3,837 cases reviewed nationwide by the EEOC with judgments awarded ordering employers to change the lighting or provide workers with access to daylight and windows. An example is the case presented in 2009 before the 7th Circuit Court of Appeals. Here the court upheld a claim involving a teacher assigned to a daylight-deprived basement classroom on the grounds that the employer failed to accommodate her SAD when it refused to provide her with a classroom with natural light. With research now demonstrating the efficacy of natural daylight as well as electric light sources for beneficial treatment of depressive conditions it is only a matter of time before all employers will be facing the same challenge.

Additionally, several well documented cases have emerged demonstrating how daytime employee alertness and performance behaviors can be improved thru bright light during daylight hours. This is due to the fact that dynamically shifting light, both natural and electric light sources, have a direct bearing on the brain chemicals which are associated with positive work related behavioral outcomes.^{63 64 65} The key findings in these studies are demonstrating that bright environmental light interventions delivered during the daylight hours are just as important for circadian health as is the absence of bright light at night.^{66 67 68}

The timing of even causal environmental light exposure is also demonstrating a vital capacity for negative impact on the circadian system.⁶⁹ In fact, a recent 2010 Harvard study has documented how ordinary household electric light exposure of up to 200 LUX three hours prior to bedtime is capable for directing brain response and circadian impact.⁷⁰ Their findings demonstrate that even

this limited amount of ambient light at night can delay melatonin duration by about 90 minutes. The negative health impacts of light at night (LAN) are sobering as labs worldwide are demonstrating a link between bright ambient lighting conditions, both indoors and exterior LAN with high blood pressure, increased fatigue levels, poor sleep efficiency, abdominal weight gain, diabetes, and cancer.^{71 72 73 74} With an ever increasing encroachment of roadside, highway and retail light into the darkness, it is no wonder that local communities and international governmental bodies are examining the establishment of model lighting ordinances (MLO) which limit the amount of exterior light buildings and roadway lighting can emit after sunset. The MLO guidelines are especially restrictive in residential areas recognizing the growing concern for circadian disruption on all life forms.

Light is color and color is light and the brain recognizes the 'color temperature' of ambient environmental light as it plays an important role in the timing of sleep related hormones and the nighttime drop of body temperature; two key ingredients of the sleep process. One of the first studies to demonstrate this fact was in 1996 study when the researchers demonstrated how ordinary fluorescent light sources of 3000K and 5000K were capable of impacts to urinary melatonin levels and core body temperatures shift. The following year, another study established the importance of seasonal light variances on nocturnal core body temperature thus supporting the importance of receiving light intervention during the darkened winter months especially in northern latitudes.^{75 76} With these connections and including others there is growing speculation linking an environmental light connection between the circadian drop in body temperature, which occurs between 4:30 and 6:00 AM, and the rising light levels of early morning twilight which also coincides with the critically timed drop in body temperature and expression of early morning cortisol, an alerting hormone. It is the combined drop in body temperature and slow rise of early morning cortisol levels which deliver the internal signals for melatonin production to stop resulting in serotonin levels rising a few hours later.

Circadian Desynchronization

Naturally occurring periods of shifting wavelengths of daytime light and darkness at night are an important human diurnal signal directly impacting our ability to sleep at night and remain active during the day. With worldwide resource agencies estimating more than 90 % of our daily lives

reported as being spent indoors away from natural light sources, many scientific researchers are investigating the impact of electric light on the circadian system of workers. It seems that when bright light is present throughout the naturally darkened evening hours, or when bright light is not present during the daylight in high enough light levels to drive the circadian clock this then seems to cause a desynchronized pacemaker leading to negative health related consequences such as profound disease impacts on the cardiovascular system and kidneys.^{77 78 79} With another study demonstrating that over 60% of all workers are now getting their only daily light exposure from overhead ceiling electric light, it is no wonder that the concern for inadequate light exposure is drawing attention. And the impacts of inadequate and/or inappropriate timing of light exposure are not only measurable on the expression of melatonin but they also have a compounding affect on the SCN as well as the HSP and circadian rhythm. Identified as 'circadian desynchronization', individuals with a biological clock out-of-synch are said to be either phase advanced or phase delayed and their sleep timing habits change considerably. Most cases will see individuals falling asleep before or immediately after dinner, awaken about an hour later, stay awake restless and aching for sleep until the wee hours of the morning, get less than 6 hours of sleep each night and then struggle to stay awake the next day. Consequently job productivity, performance, and absenteeism problems are a behavioral result of the failure to maintain the delicate balance of the circadian system. Unfortunately, this condition is a way of life for a growing number of employees who have elected to work the night shift but yet retain a normal diurnal sleep schedule on their days off. In fact, the condition has become so prevalent among shift workers (estimated to be 10% of the night shift population within the US) that the medically recognized disease condition, SLEEP WORK DISORDER is now covered by most insurance carriers⁸⁰.

Recently, scientific discovery has also determined a link between environmental lighting conditions and employee behavioral outcomes associated with alertness, accuracy, and work related accidents among night shift workers, as well as, traditional 9 – 5 day shift employees.⁸¹ Employee decreasing alertness levels and poor job performance, particularly in the delivery of accurate and timely emergency management protocols, is another area where scientific investigation has uncovered staggering costs due to poor circadian synchronization.

Jet lag is a problem experienced by travelers when we travel rapidly across several time zones during transmeridian flights going from east to west or west to east. Traveling along a line north and south within the same meridian does not bring about any noticeable distress. Here science has

demonstrated the biological cause of the symptoms we suffer as due to circadian rhythm and HSP redirection or phase shifts and the chemical changes associated with the shifts and inconsistent periods of sleep.^{82 83} The overwhelming sensation of fatigue, mental confusion and physical exhaustion are but a few of the symptoms of 'jet lag' circadian desynchronization. This is a temporary condition and will correct itself within a few days of arriving at the new destination once the biological clock (SCN) adjusts to the new photoperiods of light and dark, altered feeding schedules, local ambient temperature conditions, and the new geomagnetic location. This aspect of jet lag is now ripe for scientific investigation as recent discovery has uncovered a direct connection for earth bound magnetic signals to be received by the circadian pacemaker thru the blue-light photoreceptor cryptochrome (CRY)^{84 85}



Ambient Light, Shift Work and the Connection to SLEEP

Shift workers comprise nearly 17.7% of the total US working population and a rising concern is now expressed for their personal safety, health and overwhelming percentage (76%) of obesity among night shift workers.^{86 87} Scientific findings have now shown a direct correlation between shift work and health problems associated with insomnia, poor sleep efficiency, worsening of heart and stomach disorders, kidney and liver disease, as well as, obesity and depression.^{88 89 90} Since the early 1950's science has found compelling evidence linking significant negative human health impacts associated with disruption of the circadian rhythm brought about by light-at-night and working the night shift. In fact, numerous studies have provided well documented links between working the night shift and an increase of breast cancer rates in women and prostate cancers in men. This in part was the reason why, in 2007, the World Health Organization took the unprecedented step to list working the night shift as a cancer causation factor.^{91 92} The health consequence of a chronically desynchronized circadian rhythm are numerous including increased prevalence of heart disease, diabetes, obesity, and depression, as well as, monetary and emotional impacts arising from fatigue related traffic accidents, medical errors and decreased performance and productivity and increased mortality .^{93 94 95 96 97}

Another area of investigation which links circadian disruption to worker fatigue is in the area regarding job site accidents and mortality occurrences. Historically, post-accident evaluation data has demonstrated a cause and effect relationship between evening and graveyard shift worker

error and deadly consequences as was the case in the recent airline crash in Kentucky. Here the findings cited employee fatigue and low attentiveness resulting in poor judgment assessment while performing critical thinking tasks during two early mornings time periods. Both pilots in question were found to be sleep deprived having only slept a handful of hours in a 48 hour period. Research has also demonstrated a clear association with worker fatigue and the timing of human error in industrial and technical operations which can affect public safety. In 1988 the landmark U.S. Public Policy Report was the first to link the errors with 'processes associated with sleep concluding that the occurrence of a wide range of catastrophic phenomena are influenced by sleep-related processes' not fully appreciated at the time.⁹⁸ Since then, science has connected the dots between worker error, fatigue and time of incidence with a disruption of the human circadian rhythm; a system inextricably linked with the process of sleep and dependent on environmental lighting conditions.

Additionally, ongoing research is also demonstrating another area for concern regarding sleep deprivation among workers: decreasing employer ROI due to lost productivity. The leading causation factor for productivity related losses has been shown to be worker fatigue and poor sleep. In fact, a recent study has now placed a dollar tag on this as amounting to an average estimated \$1967.00 per employee per year.⁹⁹ Additionally, poor employee sleep and fatigue levels have also been shown to play a role in rising health care costs with one study estimating the average increase to be a minimum of 18% per employee as compared to workers without sleep issues and daytime fatigue levels¹⁰⁰ In 2006, another team of researchers reported 'the analyses revealed that sleep problems go hand in hand with poorer mental health, diminished work productivity and work quality, and greater use of health care services'¹⁰¹. However there is a bright side to these findings; literally.

Since the mid 1990's scientific discovery has demonstrated that the use of critically applied circadian light levels, in addition to providing access to natural lighting, has made significant improvements in increasing sleep efficacy and promoting a more productive behavior.¹⁰² A well- documented 2003 productivity and energy efficiency study had shown a 21% increase in worker productivity brought about by providing natural dynamic light changes throughout the work period.^{103 104} For the bottom line focused employer, a modest investment in circadian emulation lighting interventions may prove to be a cost effective intervention for any employment area. This is especially the case for those workplace settings with a dependence on

a shift work population which are located in a windowless control room under continuous 24/7 operation. A prime example of this high stress work environment is a nuclear facility, emergency management control room, or healthcare 24/7 nursing station in a critical care unit or emergency department.



Preliminary Application Guidelines for Designing with Circadian Adaptive Lighting

As previously stated, the use of epigenetic design Circadian Adaptive Lighting is the applied lighting strategy best describing the integration of natural and electric light sources, interior shading systems, and advanced lighting controls which are knowledgeably programmed to impact, phase shift, align, or enhance the human circadian system in order to influence behavioral and /or metabolic response. In some cases, medical oversight will be a necessary component of this type of lighting strategy. In all cases, for the design and engineering professional, a solid understanding of the human circadian system will be a necessary skill set for specifying this type of lighting strategy. Comprised of three primary focus areas, circadian adaptive lighting practices include:

- **Circadian Restoration-** This type of lighting strategy is designed to be used by the lighting and design professional under the direct guidance of medical supervision. Clinical application include : medically prescribed light treatment using specific protocols suitable for the treatment of health and disease conditions, increasing pre and post birth weights, the clinical treatment of SAD, jaundice, and acute circadian desynchronization¹⁰⁵ The practice of using ambient room-level electric lighting coupled with advanced lighting & shading controls contribute and assist with clinically applied prescriptive application of dosing protocols such as when using light to phase shift, extend or enhanced the patient's desynchronized circadian rhythm. Another example area where this type of lighting would be appropriate would be in assisted care and hospital geriatric wards where medically prescribed intense photoperiods of critically timed blue rich ambient light levels are used as a prescriptive measure. Here the data is emerging for the use of specific wavelength dominated white light during a critical window of late afternoon application for the medically prescribed secondary treatment for symptomatic control associated with Alzheimer's and other neurodegenerative disease conditions.¹⁰⁶
 - Application areas include: hospital patient rooms, sleep diagnostic centers, extended care facilities, and medically supervised athletic training facilities.

- **Circadian Maintenance** – Applying circadian-correct lighting for the purpose of assisting the inherent circadian system is not as easy as it appears. Throughout the 24 hour day the biological clock (SCN) is spectrally sensitive to light/dark patterns resulting in pacemaker entrainment and optimal human functioning and overall health. Additionally, recent scientific discovery has noted spectral sensitivity changes at two critical times during the evening period, both of which require differing light levels to maintain the process of sleep.¹⁰⁷ As we age, the SCN will decrease in both volume and cell density thus contributing to the negative sleep issues faced by both Alzheimer's and dementia patients.¹⁰⁸ Designed to marginally support occupant aging circadian rhythms and homeostatic sleep propensity, the main focus of this type of circadian adaptive lighting practice is to provide supplemental circadian-correct light levels in order to facilitate sleep.¹⁰⁹ The combined use of advanced daylighting technologies with automated dynamic lighting and shading systems is highly recommended. NOTE: Specifying critically timed lighting 'spikes' or periods of specific intense wavelengths programmed to turn on at specific times in order to affect fatigue and alertness levels is NOT the intent of this application method. The primary use of this type of lighting application method is to artificially mimic and /or reinforce naturally occurring cycles of light and darkness within the built environment in order to maintain and/or regain a normal circadian rhythm thus promoting a healthy sleep/wake cycle. Another area for application where the need for gradual dynamic shifts of light has been previously established is in hospital NICU areas (neonatal intensive care units). Research dating back to the 1980's has consistently demonstrated that a continuous cycle of dynamic light changes in the NICU including the introduction of a well- timed darkness has substantial benefit on the developing biological clock of preterm infants.^{110 111 112} Particular attention to rising light levels throughout the day including the shift between red and blue dominate wavelengths, seasonally adjusted timing of darkness onset, timed rising and lowering of blackout shades, and the subsequent subtle color shifts found naturally within the darkened period are necessary considerations for this design application.
 - Application areas include: healthcare patient rooms, hospital ICU and NICU areas, long term care residential quarters and common areas, prisons, hospitality guest suites, commercial spas and relaxation health centers, windowless living environments, and residential environments where relaxation is emphasized.

- **Circadian Emulation** – The focus of this lighting strategy is to artificially introduce naturally occurring photoperiods during nighttime shift work conditions in order to provide circadian support for the desynchronized worker. The intervention of critically timed photoperiods of enhanced blue wavelength dominant white light for the purpose of enhancing performance and eliciting specific behavioral outcomes is a key factor which, under certain circumstances, would require medical oversight. Since the human pacemaker entrains to the naturally occurring wavelength and intensity of solar light shifts throughout the day, electric circadian emulation adaptive lighting strategy may also be used in daytime settings such as schools and work areas where access to daylight and views is limited or absent. Here the use of circadian emulation would be instrumental in fostering employee and/or student efficacious sleep periods as a secondary means of increased productivity and performance. The use of strategically placed spikes of alerting blue-rich light coupled with alternating cycles of shifting dynamic lighting with appropriate shading controls throughout the day and night are particularly well suited for industries where employee alertness is paramount during all phases of 24 / 7 / 365 operation. This type of critically executed light focus is well suited for factory shift work environments and workplaces such as control rooms, nursing stations and dispensing pharmacies where employee attention to detail is critical for error reduction and emergency performance¹¹³ NOTE: Clinical or medical oversight may play a part in the lighting design specification when the intent is to reduce fatigue, control blood pressure, and other medically relevant health functions within a night shift work environment.
 - Application areas include: industrial and commercial control rooms, nursing stations, office environments, shift work areas, all work related environments, schools, hospital emergency rooms and surgical suites, 24/7 pharmacy departments and all windowless work and school environments.^{114 115 116} Residential kitchens, bedrooms, and bathrooms where the design intent is placed on sleep quality and weight management, are additional areas for consideration.



Suggested Terminology for Circadian Adaptive Lighting

BENYA BURNETT... humanizing light
Deborah Burnett ASID, CMG, LGC
James Benya FIES, FIALD, PE

Classification	Description	Application	Lighting System	Lighting Design Considerations
Circadian Restoration	A medically prescribed light treatment for various health and disease conditions, states and impairments as well as restore chronically desynchronized circadian rhythms	Under the direction of a physician, lighting systems are designed to provide treatment with strict dosing protocols and restrictions. Ideal settings to include hospital wards, ICU units, health care treatment rooms, long term care facilities	Medically prescribed light devices using advanced lighting controls for critical timing, duration, spectrum and intensity <ul style="list-style-type: none">• Daylighting• Shading• Electric lighting systems	Provide surface mounted ceiling luminaires for specific populations Separately light and control each surface in the room including floor, walls, alcoves and ceilings
Circadian Maintenance	Use of lighting systems to enhance natural or existing light levels and to artificially stimulate the circadian system with intent driven enhancement of the natural light dark cycle including appropriate wavelength color shifts throughout the 24 hour period	For use wherever a subtle but pronounced entrainment of the circadian system is deemed necessary such as in locations including: spas, hospitality, medical tourism, confined populations, NICU, ICU, hospital patient rooms, non-work related windowless environments, and residential applications	<ul style="list-style-type: none">• Daylighting• Electronically controlled shading• Electronically controlled HVAC systems integrated with lighting and time of day• Tunable LED systems• Dual lamp fluorescent systems	Perimeter wall washing preferred Daylighting preferred Indirect general light Blackout shading combined with light filtering shading systems preferred Prevent night time intrusion of outdoor lighting
Circadian Emulation	Non-clinical application of advanced dynamic lighting systems within a windowless or low light level environment to artificially emulate a cycle of dynamic light wavelength shifts critically timed for maximum employee or student benefit for enhanced visual acuity, lessen fatigue and increase alertness	Control rooms Nursing stations Office environments Shift work area Schools	<ul style="list-style-type: none">• Daylighting• Electronically controlled shading• Electronically controlled HVAC systems integrated with lighting and time of day• Tunable LED systems• Dual lamp fluorescent systems	

Epigenetic design **Circadian Adaptive Lighting** is the applied lighting strategy best describing the integration of natural and electric light sources, interior shading systems, and advanced lighting controls which are knowledgeably programmed to impact, phase shift, align, or enhance the human circadian system in order to influence behavioral and /or metabolic response.

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Deborah Burnett ASID CMG LGC AASM

Principal, DESIGN SERVICE INC
Partner, BENYA BURNETT CONSULTANCY

International Award Recipient PLDC 2011: for exceptional work in advancing awareness of the Health & Light connection

Deborah Burnett is an internationally recognized registered interior designer, color authority, licensed general contractor, keynote presenter and former National TV personality. She is a leading authority in the practice of Epigenetic Design targeting the connection between human health and built environmental light.

A past national spokesperson for Sylvania Lighting, she serves as a national spokesperson for the American Society of Interior Designers. Her interviews and articles appear in US newspapers and popular magazines including the Washington Times, Health, AARP, and Readers Digest. Her evidence based LIGHT & HEALTH articles appeared internationally in Professional Lighting Design, Mondo Arc, Architectural SSL, DISANO, LUME, and BRIDGE for DESIGN.

General Background

An award winning interior designer, general contractor, product innovator and specialty news and information television personality for over 30 years, Deborah's interest in health promoting environments resulted in developing expertise in the emerging field of health and light. As part of her 16 years of physician level studies, Deborah was accepted into the American Academy of Sleep Medicine and is the first professional designer to work with principal medical and scientific researchers in the field.

Professional Design and Evidence Based Work

Deborah's career in conventional interior design included residential and award winning historic restoration. In 2008 while working with leading research scientists, Deborah designed one of the first documented circadian-friendly homes that used color, light, and simple lifestyle changes to accomplish significant weight loss for the residents with minimum lifestyle impact and intervention.

In 2010, Deborah co-founded the Benya Burnett Consultancy with lighting designer and engineer James Benya to expand her work and circadian understanding to include senior living facilities, resorts and spas, 24 hour control rooms, nursing stations, patient rooms and windowless and low light level environments where an in-depth knowledge of human response to light, color and temperature is essential for overall health and wellbeing. She developed the phrase "humanizing light" and has been retained by two lighting manufacturers to pursue product development in the area of circadian adaptive lighting.

Keynote Presentations and Seminars

Drawing on her skills from popular lectures and television, Deborah's open, down to earth personality and room commanding style have become highly in demand worldwide. A seasoned international keynote presenter at conferences including the prestigious PLDC Berlin 2009, the Health and Light Symposium, Venice Italy 2011, and Madrid PLDC 2011 she is an audience SRO favorite. Other recent programs include LightFair (2006 – 2011) IALD Conference, Healthcare Design (2008 – 2010) NEOCON (2005 – 2010) and CONSTRUCT. In 2010, she was a scheduled presenter at the Harvard Graduate School of Executive Design for her work in the area of design related SLEEP interventions for an aging population. Other presentations have included major US market centers, SURFACES, IINDEX, GLOBAL SHOP and IES chapter meeting throughout the US. She is a recognized ASID Distinguished Speaker and offers over 15 accredited CEU topics for A/E and ID professionals worldwide.

Memberships and Certifications

Professional Member: American Society of Interior Designers
Licensed: Interior Designer, Tennessee
Licensed: General Contractor, Tennessee
Member: American Academy of Sleep Medicine
Chairholder Member: Color Marketing Group
Member: American Society of Photobiology
Member: The New York Academy of Sciences
Member: Illuminating Engineering Society (IES)