Advances in Environmental Biology, 9(23) October 2015, Pages: 31-39

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Identifying Daily Lighting Environment to Enhance Occupant's Psychophysiological Wellbeing for Healthy Green Building Design

[1]RatnaKala Sithravel, [1*]Rahinah Ibrahim, [1]Nur Dalilah Dahlan, [2]Normala Ibrahim and [3]Enoch Kumar Perimal

[1]Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
[2]Department of Psychiatry, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
[3]Department of Biomedical Science, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 28 September 2015
Accepted 15 November 2015
Available online 24 November 2015

Keywords:
Circadian Rhythm,
Psychophysiological Wellbeing,
Daily Lighting,
Healthy Green Building,
Integrated Design Management,
Sustainable Design Informatics

ABSTRACT

Background: The increasing indoor lighting threats on humans need careful tackling, to enhance each occupant's psychophysiological wellbeing in the micro built environment. Insufficient periodic light stimuli and inappropriate oscillation of indoor light exposure on the retina affects circadian rhythm synchronization. **Objectives:** The purpose of this article is to identify the key determinants in lighting that influences circadian rhythm in order to enhance occupant's psychophysiological wellbeing in healthy green building design. This is a survey article presenting literature findings, selected principles and applications of daily lighting for healthy green building design implementation. **Results:** Results of this survey include identifying the fundamental daily lighting characteristics and its impact on circadian rhythm. This article also proposes the potential design criteria for designing healthy green buildings. The findings precede the discussion on recommending integration of daily lighting in healthy green building design process. After the introduction of the background problem, this article will present the results from the literature survey on healthy green building design with daily lighting before discussing the potentials for design integration to occur. **Conclusion:** Finally, recommendation from this article leads towards daily lighting characteristics for regulating one's personal circadian rhythm that enables enhancement of the occupant's psychophysiological wellbeing within a healthy built environment.

© 2015 AENSI Publisher All rights reserved.

To Cite This Article: Sithravel, R., Ibrahim, R., Dahlan, N. D., Ibrahim, N. and Perimal, E. K., Identifying Daily Lighting Environment to Enhance Occupant's Psychophysiological Wellbeing for Healthy Green Building Design. ***Adv. Environ. Biol., 9(23),*** *31-39, 2015*

INTRODUCTION

Scholarly advancements have highlighted there are many physical, chemical and biological properties in the indoor environment affecting human's wellbeing, despite complying with standards and guidelines in real-world practice [1]–[3]. Roulet *et al*. (2006) study on 160 buildings in nine European countries, statistically proved there were more unacceptable buildings (red) than acceptable buildings (green) with regards to comfort, perceived health and energy use. The rising complaints and feedback of unsatisfactory indoor environment is a result of occupants being exposed to a relatively young 'man-made' environment where important dose-response considerations and the humane linkage with the matured nature have been missed [5], [6]. Additionally, the industrialized and modern society has also transported humans from an outdoor environment to spend about 80% to 90% of their lifetime indoors for shelter, work and delight. This consequently lessened occupants' opportunity to work closer to windows, besides reducing the individual's exposure to required brightness and natural daylight. Screening the interiors with filaments of tints and shading devices that helps prevent internal heat gain and glare, together with installations of relatively dim artificial illuminance, is proven to decrease one's natural ocular light exposure by 40 to 200 times [2], [3], [7]–[11].

According to Veitch, (2008), the modern society is lacking sufficient exposure of light per day. Her scholarship highlighted an average person in San Diego only spends 4% of each 24 hours of his life in illumination greater than 1,000 lx. Astonishingly, more than 50% of the individual's time is spent in illuminance levels between 0.1 to 100 lx; besides the additional 38.6% of time spent in illuminance levels below 0.1 lx when

Corresponding Author: Prof. Dr. Rahinah Ibrahim, Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
E-mail: rahinah@upm.edu.my

sleeping, driving at night, etc. This is alarming because San Diego is known for its people's culture of spending lots of time outdoors, and having lots of exposure and experience with sunlight. Moreover, findings from Gunay, O'Brien, & Beausoleil-Morrison, (2013) proved the benefits of having natural daylight exposure incorporated into building design. The scholarship highlighted occupants preferred to sit closer to windows and enjoyed natural daylight exposure for health concerns, as the installed fluorescent lighting caused eyestrain and headaches. The view and visual relationship with the external environment also improved the occupant's workspace satisfaction, with greater contentment observed when workstations were orientated adjacent to the window, rather than in front or behind it [13]–[16]. Hence, this article queries the direction of the building industry in moving forward efficiently with proper indoor lighting to cater for occupant's wellbeing.

Apart from merely satisfying visual needs and comfort, light entering the human eye is equally essential for human's non-visual biological effect [11]. Here, we question the indoor lighting design installed in buildings to cater for the modern society, which have moved towards a continuous '24 hour's service-led economy workforce'. Lifestyle changes of living a reversal of the natural day-night life due to employment at night and work commitments, needs complementing lighting for wellbeing. Occupants' in health care facilities and 24 hours service-based organizations are particularly affected, as they are exposed to prolong hours of poorly designed artificial lighting for continuous work productivity. These occupants face insufficient periodic light stimuli, together with inappropriate oscillation of indoor light exposure on the retina, leading to adverse consequences on their alertness, performance, safety, sleep quality and health [11], [14], [17], [18]. This is because ocular light is a potent zeitgeber (time cue) in entraining one's circadian rhythm, and activating one's central and autonomic nervous systems [19]. Since humans are diurnal species, the routine light-dark solar cycle dictates one's activity-rest pattern, and synchronizes his neuroendocrine, physiological and psychological temporal functions into a 24 hours circadian rhythm [20]. Absence of sufficient ocular light causes one's circadian pacemaker to be desynchronized, ultimately leading to numerous psychophysiological disorders [11]. Therefore, this article emphasizes on occupant's psychophysiological wellbeing with regards to the physical indoor lighting environment. This survey article proposes to distinguish the key lighting determinants that influence occupant's circadian rhythm; because, there is a need to enhance occupant's psychophysiological wellbeing in the micro built environment, against its increasing indoor lighting threats.

METHODOLOGY

This article focuses on one of the three progressive constructs in defining healthy green building design, which aims to enhance occupant's psychophysiological wellbeing. Here, the development of Daily Lighting is discussed by comprehensively identifying the key determinants in lighting that is influencing human's circadian rhythm holistically. Evidence from the literature have been reviewed and sorted into 3 sub-construct i.e. zeitgeber strength (light); sleep-wake cycle (reset) and circadian pacemaker (timer), to illustrate the triangular relationship of the key determinants in synchronizing circadian rhythm.

LITERATURE REVIEW

Visible light is the only portion in the electromagnetic spectrum that is detectable and absorbable by the photoreceptors in human eye to initiate the seeing process. It is a small portion sandwiched between the ultraviolet (UV) and infrared (IR) electromagnetic field; within the wavelength of 380 nm to 760 nm [18], which then expanded to 360 nm to 800 nm [17]. The latter enables optimal comparisons between the visual and circadian effects of light, as the wider range befits current detectability limits in the commercially available spectroradiometers designed with different operative wavelengths ranges in the UV and IR fields [17]. The sun (solar system) is our natural source of light, whilst fire light, oil lamp, candles are combustion sources of artificial light; and incandescent lamps, discharge lamps, LED mechanisms are electrical sources of artificial light developments. The human vision gets initiated when retina detects any of these optical radiations. Its electromagnetic signals are then transduced into neural impulses for various information processing by the brain [15], [21], [22]. Literature has claimed retina is known to be an extension of the brain, as it consists 3 types of photoreceptor cells namely cones, rods and the 3rd novel photoreceptor i.e. intrinsic photoreceptive Retina Ganglion Cell (ipRGC) [11], acknowledged for its definite visual and circadian spectral sensitivity functions. Each photoreceptor is highly sensitive to a specific wavelength and colour range, in order to influence the various physiological variables and neurobehavioural measures e.g. circadian rhythm, core body temperature, hormone secretion, cognitive function, immune response, alertness and reaction time [23]. Furthermore, each one of the photoreceptors is represented by its own single opsin curve indicating the spreads of its peak sensitivity (Figure 1).

The cones form the basis for current lighting standards that merely relates to human's vision during the day enabling photopic vision (V_λ). Its maximal sensitivity peaks at 555 nm, falling under the green-yellow wavelength range; and is neither sensitive to extreme red nor extreme blue wavelengths. This photoreceptor only operates during daytime, permitting good visual acuity and enables detection of colour visibility when the luminous flux bleaches the rods until saturation [23]. Contrarily, the next photoreceptor - rods, only activates in

Advances in Environmental Biology, 9(23) October 2015, Pages: 31-39

darkness, enabling scotopic (V'_λ) vision at night. Its maximal sensitivity peaks at 505 nm. Under insufficient light conditions, rods dominate the visual operation, causing poor visual acuity and inability to distinguish colour visibility [11], [15], [17], [18], [23], [24]. As for ipRGCs, it contains melanopsin photopigment, which is associated with nocturnal melatonin suppression for circadian function. Its circadian sensitivity (C_λ) spectral peaks around 460 nm to 480 nm, indicating dominance in the short (blue) wavelength range [17], [22], [23], [25], [26].

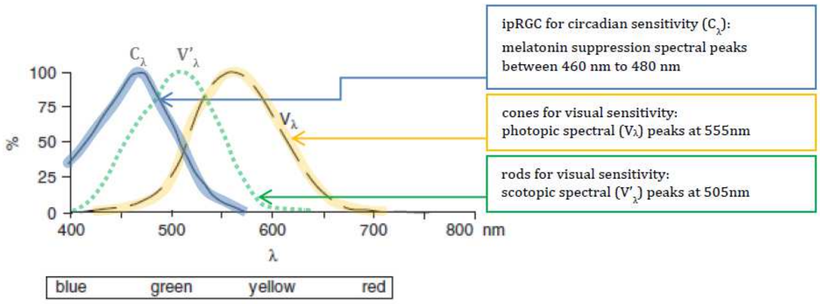

Fig. 1: Single opsin spectral sensitivity curve of each of the photoreceptors, adapted from source [11].

Besides the differing sensitivity range demonstrated by each of the photoreceptors, light entering the eye causes two distinct effects. First, it affects one physically for visual needs, by responding to visible light characteristics. The visual pathway triggers when the rods and cones capture optical radiation entering the eye. Both the photoreceptors then transduces its signal through nerves that connects directly with the visual cortex at the rear of the brain, in order to detect the visual information and operate its visual system [11], [17]. Photometric and colorimetric measurements are the fundamental methods used to quantify visual spectral light [17], [18], [23], [27]. As for the second effect, it affects the individual psychologically and physiologically for circadian needs by responding to circadian light characteristics. Here, circadian light is responsible for stimulating and regulating the 'non-visual' human biochemical functions, processes and rhythm [17]. The circadian pathway is triggered when ipRGCs detects the optical radiation, which directly transduces the 'circadian' photic information through its axons forming the retino-hypothalamus tract (RHT) and finally to the Suprachiasmatic Nuclei (SCN) [11], [22]. The SCN then orchestrates the pineal gland to regulate neuroendocrine responses that stimulates physiological responses like resetting the circadian pacemaker, suppressing melatonin, managing metabolic state, alertness and performance [11], [15], [17], [28]–[30].

Hence, these variations highlight the requirements of visual sensitivity is not the same with circadian sensitivity. Inevitably, it points out current lighting standards are inexact a representation of the true circadian needs. Since this article focuses on the relationship of lighting with circadian rhythm synchronization, evidence from literature are deliberated to get a holistic understanding over its relationship. This article categorizes the findings as zeitgeber strength, sleep-wake cycle and circadian pacemaker.

3.1 Zeitgeber Strength (Light):

There are 5 fundamental interconnected measurements used to quantify zeitgeber's strength for circadian function i.e. Quantity, Spectrum, Spatial Distribution, Timing and Duration; that works towards suppressing melatonin and phase shifting [14], [21], [31]. Similar to scholar Wirz-Justice, (2007), this article defines zeitgeber as the periodic external light stimuli (time cue) that mediates the process of entrainment (optimal synchronization with the environment) in humans.

Quantity:

This measurement relates to the intensity of the available ocular light to trigger circadian rhythm synchronization. The brighter the light, the faster it suppresses melatonin levels. Exposure to natural daylight (high-level intensities between 2,000 lx to 10,000 lx) throughout the day, is considered sufficient to regulate one's circadian pacemaker and melatonin level [14]. However, due to occupant's lifestyle of spending more time indoors, prior scholars have indicated healthy circadian function requires high level of intensities of at least 1,000 lx at eye level, to achieve its maximal peak photosensitivity [11], [32]. To work towards this agenda, Rea *et al*., (2002) highlighted indoor lighting that meets international photopic standards of about 500 lx [33] is insufficient for circadian regulation, unless the individual is exposed to morning bright light to overcome circadian disruption.

Spectrum:

Different light sources have its own spectral power distribution (SPD) property that indicates its peaks at certain wavelength. The correlated colour temperature (CCT) of each light source also plays a role to stimulate circadian function differently by contributing to different melatonin suppression levels [14]. Studies have indicated using ‘cool-white’ and ‘daylight’ (higher CCT) fluorescent lights are beneficial as it increases occupant’s alertness level, improves one’s mental activity, reduces drowsiness, fatigue and daytime sleepiness [32], [34].

Spatial Distribution:

Regulating circadian function and evaluating visual comfort and performance relies more on the illuminance that strikes at human eye level [11], [17], [27]. This is because the angle of ocular light to activate the photoreceptors, needs certain consideration. Certain evidence claim the lower part of retina has greater sensitivity towards circadian regulation and greater melatonin suppression, as compared to the upper part of retina. This could be due to the way human eye is framed, where the eyelid protects relatively more of the upper part of the eye rather than the lower part, hence making the lower part to be more susceptible to the high levels of selective and angular sky light illuminance [35]. Contrarily, there are others who believe the photoreceptors for circadian regulation appear to be randomly distributed throughout the entire retina [14]. Since there is no one single theory, it is adequate to comprehend - sufficient amount of circadian light characteristics is required to reach eye level, and this should be complemented by the indoor lighting design.

Timing:

Light exposure at different times of the day is able to pose phase advance or phase delay shifts on the circadian pacemaker. However, the magnitude of the shifts depends on the timing of the light-dark oscillation on the retina [14]. Scholarships have proven, continuous adjustments in the timing of 24 hours lighting is able to shift one’s phase towards an expected direction, irrespective of any fixed sleep routine [14], [27], [31].

Duration:

Circadian sensitivity involves a series of neurotransmissions and stimulation of biochemical responses to reach homeostasis - especially in balancing the melatonin hormonal rhythm. Hence, it requires relatively longer period of zeitgeber stimulus as compared to the visual system that responds in fraction of seconds [14], [17], [26]. Prolonged exposure of bright light at night ceases melatonin production and causes disruption to the natural circadian rhythm. Hence, care is needed when designing lighting for night shift workforce [11], [14].

3.2 Sleep-Wake Cycle (Reset):

Sleep-wake cycle is regulated by the human brain and it has been estimated that humans spend about one third of their lives for sleep [36]. The region of the brain that is responsible for this cycle are hypothalamus anterior to promote sleep, and hypothalamus posterior to produce neurons for wakefulness [20]. Entrained sleep-wake cycle is an adaptive behaviour in relation with the 24 hours light-dark solar cycle. Since, humans are diurnal species, individuals are adaptively and biologically programmed to be awake during the day and asleep at night [22]. This process is important because it acts as a powerful reset button in one’s daily restoration life, coordinating one’s activity-rest pattern and day-night cycle [17]. Under entrained conditions, sleep-wake cycle remains stable with respect to a given activity-rest ratio and light-dark cycle. But in the absence of zeitgeber, sleep period shifts later by each day, following the frequency of free-running endogenous circadian pacemaker [20]. Besides resetting for restoration, sleep-wake cycle also maintains a regulatory effect on the neuroendocrine (hormone and prolactin) growth. It is proven that certain ‘growth hormones’ essential for bodily tissue repairs are only secreted during sleep (after the first occurrence of delta activity), henceforth, giving the body an opportunity to repair its wear and tear caused by activities during one’s waking hours [Moorcroft, (1993) in 50]. Additionally, sleep also improves one’s cognitive process (ability to retain information) and helps the brain to organize, consolidate, incorporate and store information [50].

Despite the fact scholarships have linked sleep-wake cycle with day-night cycle, according to scholar Wirz-Justice, (2007), an individual’s timing and structure of sleep and waking pattern is more dependent on the interaction between his phase shifts and sleep homeostatic process; and it is not a matter with day-night cycle.

Phasing:

As explained under zeitgeber’s strength, timing of light exposure poses phase shifts on the circadian pacemaker, resulting to different timing of sleep-wake cycle. Some are accustomed to sleeping early (Advance Sleep Phase Disorder); whilst some late (Delayed Sleep Phase Disorder (DSPD)), and this comes without affecting their sleep architecture and quality [37]. The first group is categorized as the early morning ‘larks’ chronotype, where one sets early to bed and rises very early in the morning. This group commonly faces lifestyle consequences of unable to stay awake to engage in social activities in the evenings due to high urge to sleep early. As for the latter - late night ‘owl’ chronotype, the individual experiences sleep onset and offset times that are relatively delayed compared to conventional timing. This group usually stays up late due to inability to sleep early and faces extreme difficulty in waking early or suffers excessive daytime sleepiness when forced to rise early in the mornings. Both chronotypes portray one similarity i.e. change in sleep-wake cycle is not a consequence of abnormal circadian pacemaker function or desired personal choice, but rather due to phasing i.e. the inability to follow conventional sleep-wake times. Therefore, phasing makes one's biochemical rhythm to be in time-free condition, running parallel with his circadian pacemaker, but opposing the socially accepted light-dark cycle.

Sleep homeostasis:

Sleep homeostatic process refers to an increase in sleep pressure as the waking hours increases with respect to the last adequate sleep episode experienced [20]. The longer the individual has been awake, the stronger his desire and need to sleep, and the greater the likelihood of him falling asleep [51]. Sleep homeostasis usually peaks at two distinct periods, first at early mornings due to sleep inertia; and secondly at post-lunch dip hours around 2pm to 4pm [30]. The dip in alertness at the mentioned periods is proven by the numerous human errors and accidents registered due to increased fatigue over time and acute-chronic sleep deprivation [22].

3.3 Circadian Pacemaker (Timer):

Human's endogenous master circadian pacemaker (timer) or commonly known as the biological clock, is located in the Suprachiasmatic Nuclei (SCN) in the hypothalamus region of the brain [38]. This pacemaker enables the ticking of the 'internal' biological time in a continuous and autonomous rhythm. In an entrained condition, this timer resets and repeats its cycle daily forming the timing for circadian rhythm, with an average intrinsic period of about 24.2 to 25 hours [22], [28], [38]–[40]. Similar to sleep-wake cycle, the entrained 24 hours circadian rhythm is a consequence of one's behavioural adaptation with the external light-dark stimuli [41]; and together with his internal diurnal system (representing the continuous rise and dip in hormone production and neurotransmitters) [20]. On the other hand, if the pacemaker is isolated from environmental zeitgebers, it runs into a free-running mode, with the timing of circadian rhythm extending from 28 hours to over 30 hours daily [20], [40].

Besides managing its endogenous ticking, the pacemaker also regulates the sleep-wake cycles in appropriate phases to match the light-dark cycle [20], [22]. Additionally, it organizes and orchestrates the timing of all other daily physiological functions and biochemical processes [25]. The most potent is the secretion and suppression of melatonin and cortisol hormones [36]. Both melatonin and cortisol, exhibits its own diurnal timing pattern, and their levels tend to run in opposition to each other [42].

Melatonin:

This hormone is secreted in the pineal gland, regulated by the circadian pacemaker in SCN, and is synthesized by the ipRGC photoreceptor in retina [14]. It is an important biomarker especially in indicating circadian disruption [42], [43]. It primarily synchronizes the internal hormone environment with the external light-dark cycle. In an entrained condition, it depicts a diurnal rhythm, where it gets synthesized and secreted (onset) during dark period at night to decrease nocturnal core body temperature and induce sleep; and gets suppressed with the existence of light in the morning to reduce sleepiness [11], [14], [36]. This internal management role promote alertness during day and sleepiness during night [14], [17], [22], [25], [44]. Interestingly, the timing of circadian pacemaker can be easily estimated by monitoring the rhythm of melatonin production over time [43].

Cortisol:

It is the stress hormone that governs physiological alertness, secreted in the adrenal cortex [6], [15], [19]. It becomes highly sensitive to light when the circadian rhythm is desynchronized due to sleep deprivation [22]. Its sensitivity is highly dependent on the transition from dark to light, instead of from light to dark [45], [52]. In fact, contrary to melatonin's rhythm, cortisol has its own diurnal pattern, high during the day (or in summer) and low at night (or during winter). It peaks early in the mornings, elevating in levels within 30 minutes to 1 hour after awakening; and also during late afternoons around 4pm for general activation [6], [19]. Its primary role is to control the blood sugar level in the body, in order to circulate body's energy and enhance immune system [36]. The reason it rises in levels before dawn, is to stimulate the brain to divert body's energy to the muscles, thus facilitating awakening process. Its continuous upswing early in the mornings also prepares the body for its day's activity. After achieving its peak, cortisol gradually declines to a reasonable level, to maintain sufficient blood sugar (energy) over the course of the day. It then hits minimum at midnight, during the individual's resting period. Prolong periods of high cortisol levels is disruptive to one's wellbeing because it makes the body to be too exhausted, leading to inefficient activity deliverables [11]; and degraded immune system [46].

DISCUSSION

The potential design criteria for designing healthy green buildings with the proposed daily lighting integration that promotes circadian rhythm resynchronization is deliberated. Similar with scholar De Groot & Rusak, (2002), this study conceptually defines daily lighting as a 24 hours period of light-dark artificial lighting structure that has appropriate ocular light stimuli and oscillation to support circadian function. The perspective of this proposed daily lighting is discussed over desynchronized circadian rhythm, light exposure and biological alertness.

4.1 Desynchronized Circadian Rhythm:

Desynchronization of circadian rhythm happens when the internal timing of circadian pacemaker is asynchronous with either the external environmental time (light-dark cycle and zietgeber strength), or sleep-wake cycle [44], [48]. According to scholarships [12], [38], [42], [44], desynchronized circadian rhythm is possibly led by the way humans have organized their lives, i.e. to be highly dependable around artificial lighting throughout both day and night, that merely support visual needs and not much of circadian function. Concerns have been raised over the healthy population being inculcated into this disruption due to socio-economic lifestyle transformation i.e. living the night shift life and employment.

It is here that this study noticed a gap. Prior scholars have missed to advocate strongly the swelling risk towards circadian rhythm desynchronization experienced by individuals exposed to sudden lifestyle changes i.e. the burnout lifestyle. These individuals are slightly different from any of the night shifts workers or those experiencing sleep-wake cycle disorders. The present study defines burnout individuals as those whom have been exposed to continuous 30 to 40 hours of wakefulness due to work deliverables and professional responsibility just like the on-call doctors, architects experiencing major submission deadline, students facing final exams, etc. These individuals are subjected to the same cycle of work exhaustion repeatedly; where skipping 1 night's sleep has been part of their adaptive lifestyle. Additionally, they are exposed to insufficient circadian light stimuli for more than 24 hours, and are usually back to normal work routine the following day with no proper recuperation period. Hence, the individual's control of his circadian timing, core body temperature, heart rate, cortisol and melatonin production and alertness will presumably indicate a desynchronized rhythm from the norm. The spill-over effect could lead to temporary tiredness, sleepiness during bright hours and alertness during dark hours [11], increase error rates, memory disruption, cognitive confusion, decline in performance; and a wide variety of serious disorders over time e.g. sleep deprivation, diabetes type II, immune system deficiencies and breast cancer [17], [23], [28]. Therefore, there could be possibilities where frequent disruption in the circadian rhythm may endanger one's psychophysiological wellbeing.

4.2 Light Exposure:

As for the daily lighting characteristics, the following rules of thumb are essential especially in designing for circadian rhythm resynchronization. As highlighted by prior scholars, the intensity of light needs to be higher than 1,000 lx [14], because the standard practice of installation with lower intensity (around 500 lx) is hardly sufficient to stimulate circadian function. McIntyre *et al*. (1989) in [14] proved that 1-hour exposure under a 500 lx 'work surface' illuminance was inadequate an intensity to suppress melatonin efficiently, as its relative response barely reached 40% (Figure 2). Contrarily, the mentioned intensity achieved 100% relative response for visual performance adequacy. This result indicates 500 lx intensity simply supports one's speed and accuracy in processing visual information i.e. merely aiding productivity and not the circadian function. Furthermore, the duration of exposure is also dependable on the intensity, where higher intensity suppresses melatonin faster. Again, McIntyre *et al*.,(1989) in two of his independent studies noted, 25% melatonin suppression was achievable within 20 minutes when the eye level illuminance was sustained at higher than 1,000 lx intensity; whilst it took about 1 hour when lighting intensity was below 500 lx [14]. As a result, the duration needed to suppress melatonin reduces to a third of the time, by doubling the intensity from 500 lx. Hence, there is potential to effectively develop the timing of light exposure for circadian rhythm resynchronization.

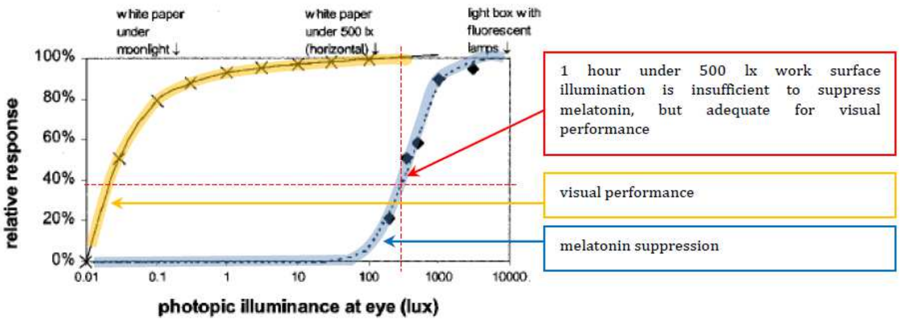

Fig. 2: Representation of how light intensity affects visual performance and melatonin suppression. Adapted from source [14].

Next, building's stakeholders may query the risk of increasing electricity utilization with higher intensity in illuminance. Alternatively, choosing a light source with an appropriate spectrum could economically deal with the concern. Scholar Rea *et al*., (2002) highlighted using higher CCT sources, complimentarily approves a relatively lower intensity, for achieving the same 50% melatonin suppression. The scholarship proved melatonin was suppressed by half within 1 hour when a source with 7,500K 'daylight' fluorescent illuminance fixed at 1,500 lx at task level was used, instead of the convention 3,000K CCT 'warm-white' fluorescent illumination which required 2,500 lx at task level. In fact, using light sources with higher CCT (cooler colours) also supports the circadian function that peaks at shorter wavelength. This is because higher CCT sources are richer in the blueish spectral, which suppresses melatonin efficiently, to counter balance the reduction in illuminance level [11].

As for timing, scholars Rea *et al*., (2002); van Bommel, (2006); Veitch, (2008) explained, exposure of bright light during the 2nd half of the night, just before the body reaches minimum core body temperature, results in maximum phase delay. This makes the circadian pacemaker and melatonin cycle to peak later than usual, and directly suppressing its level of amplitude that comes after. On the other hand, if bright light is applied early in the morning, after the nadir of core body temperature, a phase advance of both circadian system and melatonin rhythm will occur, representing earlier peak than the norm. Exposure of higher lighting level during daytime and very dark condition during nighttime results in better nocturnal sleep quality - increasing its length and efficiency [10], [Lack & Wright, (1993) and Van Someren *et al.*, (1997) in [14]]. On the other hand, high intensities of nocturnal bright light (5,000 lx) modulates phase shifts amongst night shift workers, hence promoting better daytime sleep [Eastman (1995) in [32]].

As comprehended, melatonin rhythm plays a dominant role in resynchronizing the circadian rhythm. It is acutely suppressed by bright light and short wavelength (blue light) with peak spectral sensitivity around 460 nm to 480 nm. Hence, caution is needed when designing daily lighting as bright light exposure with blue content in the middle of the night can interfere with the rhythm. Alternatively, long wavelength (red light) could be considered [22], [30]. Besides taking care of the melatonin rhythm, there is opportunity for the daily lighting to be effectively designed for cortisol. Since cortisol is more sensitive with transitions from dark to bright, exposure to high levels of polychromatic (white) light specifically in the morning would enable its escalation in levels [52]. Here, future study may explore the usefulness of waking up in 'morning bright light' rather than in darkness.

4.3 Biological Alertness:

There are two different potential ways to manipulate the intensities, spectrum and spectral distribution of light exposure for biological alertness. The first way is to maintain a steady melatonin rhythm. It could be achieved naturally, when the internal circadian timing is in equilibrium with the socially accepted sleep-wake cycle, to promote high level of daytime alertness and nighttime drowsiness. Conversely, to achieve high level nighttime alertness, it is possible to suppress melatonin by exposing the individual to white light or narrow band short wavelength light in higher intensity or higher CCT [14], [22], [30]. The suppression of nocturnal melatonin could subjectively increase alertness to perform certain task for a short duration. However, prolonged exposure may not necessarily enhance performance and may cause retinal damage [14], [19], [22]. Hence, caution is needed in design, because high blue content at night or before bedtime may result in insufficient sleep, thus increasing the risks of depression, type II diabetes and breast cancer. High content of blue spectrum may also shift the circadian rhythm more, because it is known to suppress melatonin twice longer compared to green light source [53]. From the above, the study notes that although the blue wavelength light could be beneficial during the day for boosting attention, reducing eyestrain or fatigue, it may on contrary, impose disruptive effects at night [49].

The second way to retain biological alertness directly is by responding to the brain region associated with alertness. This approach is perceived to be independent from melatonin suppression and renders only short term and specific 'time' alertness. The approach was proposed by Sahin's *et al*., (2014) where at daytime when melatonin levels are relatively low, exposure to specific narrowband long-wavelength (red light) or polychromatic white light (at 2568K) instead of blue light apparently increased noontime alertness and quickened the response time for short term task performance during post-lunch dip hour. These results suggest, perhaps photoreceptors other than the ipRGCs may be contributing to these effects since the ipRGC are not sensitive to low levels of long- wavelength light [22].

CONCLUSION AND RECOMMENDATION

In this article, the focus is on specifically developing the Daily Lighting environment that regulates one's circadian rhythm, henceforth, enhancing the individual's personal psychophysiological wellbeing within a healthy built environment. In light with scholar van Bommel, (2006), future study may want to consider resynchronizing circadian rhythm by fixing it (within a certain period) with proper daily lighting design adoption. This study identifies the benefit of a good daily lighting design for healthy green building to resemble a diurnal pattern that relates to the occupant's biological needs, instead of a static fixed illuminance for all. This study agrees with Frontczak *et al*., (2012), asserting immediate surrounding environment e.g. workspace satisfaction could be perceived to be more relevant and impactful, compared to the overall building, as the lighting conditions could be better controlled individually.

In conclusion, daily lighting design will not only challenge the limitations offered by the standard 500 lx fixed intensity illuminance in indoor spaces, but also the adequateness of having only an average of 8 hours duration of dynamic lighting exposure applied in employment offices to increase employees' productivity. This study supports our intent to further study how architects could promote occupant's wellbeing through indoor lighting design, for improving the occupant's quality of life and a country's human capital economic wealth.

REFERENCES

[1] Bluyssen, P.M., M.B.C. Aries and P. van Dommelen, 2011. "Comfort of workers in office buildings: The European HOPE project," Build. Environ., 46(1): 280–288.
[2] Frontczak, M. and P. Wargocki, 2011. "Literature survey on how different factors influence human comfort in indoor environments," Build. Environ., 46(4): 922–937.
[3] Kamaruzzaman, S.N., C.O. Egbu, E.M.A. Zawawi, A.S. Ali and A.I. Che-Ani, 2011. "The effect of indoor environmental quality on occupants' perception of performance: A case study of refurbished historic buildings in Malaysia," Energy Build., 43(2–3): 407–413.
[4] Roulet, C.-A., F. Flourentzou, F. Foradini, P.M. Bluyssen, C. Cox and C. Aizlewood, 2006. "Multicriteria analysis of health, comfort and energy efficiency in buildings," Build. Res. Inf., 34(5): 475–482.
[5] Bluyssen, P.M., 2010. "Towards new methods and ways to create healthy and comfortable buildings," Build. Environ., 45(4): 808–818.
[6] Boubekri, M., 2008. Daylighting, Architecture and Health: Building Design Strategies, First. Oxford: Elsevier Ltd.
[7] Bluyssen, P.M., S. de Richemont, D. Crump, F. Maupetit, T. Witterseh and P. Gajdos, 2010. "Actions to Reduce the Impact of Construction Products on Indoor Air: Outcomes of the European Project HealthyAir," Indoor Built Environ., 19(3): 327–339.
[8] Singh, J., 1996. "Review : Health, Comfort and Productivity in the Indoor Environment," Indoor Built Environ., 5(1): 22–33.
[9] Steemers, K. and S. Manchanda, 2010. "Energy efficient design and occupant well-being: Case studies in the UK and India," Build. Environ., 45(2): 270–278.
[10] Aries, M.B.C., J.A. Veitch and G.R. Newsham, 2010. "Windows, view, and office characteristics predict physical and psychological discomfort," J. Environ. Psychol., 30(4): 533–541.
[11] van Bommel, W.J.M., 2006. "Non-visual biological effect of lighting and the practical meaning for lighting for work," Appl. Ergon., 37(4): SPEC. ISS., 461–466.
[12] Veitch, J.A., 2008. "Lighting for health : time to light up your life ? Lighting for Health : Time to Light Up Your Life ?," NRC Publ. Arch. Arch. des Publ. du CNRC, 1–30.
[13] Gunay, H.B., W. O'Brien and I. Beausoleil-Morrison, 2013. "A critical review of observation studies, modeling, and simulation of adaptive occupant behaviors in office," Build. Environ., 70: 31–47.
[14] Rea, M.S,. M. G. Figueiro and J.D. Bullough, 2002. "Circadian photobiology: an emerging framework for lighting practice and research," Light. Res. Technol., 34(3): 177–190.
[15] Edwards, L. and P. Torcellini, 2002. "A Literature Review of the Effects of Natural Light on Building Occupants,".
[16] Frontczak, M., S. Schiavon, J. Goins, E. Arens, H. Zhang and P. Wargocki, 2012. "Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design.," Indoor Air, 22(2): 119–31.
[17] Bellia, L., F. Bisegna and G. Spada, 2011. "Lighting in indoor environments: Visual and non-visual effects of light sources with different spectral power distributions," Build. Environ., 46(10): 1984–1992.
[18] Boyce, P.R., 1981. Haman Factors in Lighting. London: Applied Science Publishers.
[19] Küller, R. and L. Wetterberg, 1993. "Melatonin, cortisol, EEG, ECG and subjective comfort in healthy humans: impact of two fluorescent lamp types at two light intensities," Light. Res. Technol., 25 (2): 71–81.
[20] Wirz-Justice, A., 2007. "How to Measure Circadian Rhythms in Humans," Medicographia, 29 (1): 84 – 90.
[21] Bierman, A., T.R. Klein and M.S. Rea, 2005. "The Daysimeter : A device for measuring optical radiation as a stimulus for the human circadian system," Meas. Sci. Technol., 16: 2292–2299.
[22] Sahin, L., B.M. Wood, B. Plitnick and M.G. Figueiro, 2014. "Daytime light exposure : Effects on biomarkers , measures of alertness , and performance," Behav. Brain Res., 274: 176–185.
[23] Goodman, T.M., 2009. "Measurement and specification of lighting: A look at the future," Light. Res. Technol., 41(3): 229–243.
[24] Wurtman, R.J., "The Effects of Light on the Human Body," http://wurtmanlab.mit.edu/static/pdf/286.pdf. .
[25] Rea, M.S., M.G. Figueiro, A. Bierman and R. Hamner, 2012. "Modelling the spectral sensitivity of the human circadian system.," Light. Res. Technol., 44(4): 386–396.

[26] Figueiro M.G., M.S. Rea and J.D. Bullough, 2006. "Circadian effectiveness of two polychromatic lights in suppressing human nocturnal melatonin," Neurosci. Lett., 406: 293–297.
[27] Bellia, L. and F. Bisegna, 2013. "From radiometry to circadian photometry: A theoretical approach," Build. Environ., 62: 63–68.
[28] Rea, M.S., M.G. Figueiro, A. Bierman and J.D. Bullough, 2010. "Circadian light," J. Circadian Rhythms, 8(2): 1–10.
[29] Küller, R., 2002. "The influence of light on circarhythms in humans.," J. Physiol. Anthropol. Appl. Human Sci., 21(2): 87–91.
[30] Sahin, L. and M.G. Figueiro, 2013. "Alerting effects of short-wavelength (blue) and long-wavelength (red) lights in the afternoon," Physiol. Behav., 116–117: 1–7.
[31] Appleman, K., M.G. Figueiro and M.S. Rea, 2013. "Controlling light-dark exposure patterns rather than sleep schedules determines circadian phase," Sleep Med., 14: 456–461.
[32] Hoffmann, G., V. Gufler, A. Griesmacher, C. Bartenbach, M. Canazei, S. Staggl and W. Schobersberger, 2008. "Effects of variable lighting intensities and colour temperatures on sulphatoxymelatonin and subjective mood in an experimental office workplace," Appl. Ergon., 39: 719–728.
[33] Newsham, G.R., B.J. Birt, C. Arsenault, A.J.L. Thompson, J.A. Veitch, S. Mancini, A.D. Galasiu, B.N. Gover, I.A. Macdonald and G.J. Burns, 2013. "Do 'green' buildings have better indoor environments? New evidence," Build. Res. Inf., 41(4): 415–434.
[34] Shamsul, B.M.T., C.C. Sia, Y. Ng and K. Karmegan, 2013. "Effects of Light's Colour Temperatures on Visual Comfort Level, Task Performances, and Alertness among Students," Am. J. Public Heal. Res., 1(7): 159–165.
[35] www.osram.com, "Light in its third dimension The discovery," OSRAM. .
[36] Sniecinska-Cooper, A.M., A. J. Shah, D. Dimitriou, R.K. Iles, S.A. Butler and R. Bayford, 2015. "Determination of urinary cortisol, cortisone and 6-sulfatoxymelatonin using dilute and shoot ultra-high pressure liquid chromatography-tandem mass spectrometry," J. Chromatogr. B. Analyt. Technol. Biomed. Life Sci., 978–979: 18–23.
[37] Sharkey, K.M., M.A. Carskadon, M.G. Figueiro, Z. Yong and M.S. Rea, 2011. "Effects of an advanced sleep schedule and morning short wavelength light exposure on circadian phase in young adults with late sleep schedules," Sleep Med., 12: 685–692.
[38] Miller, D., A. Bierman, M.G. Figueiro, E.S. Schernhammer and M.S. Rea, 2010. "Ecological measurements of light exposure, activity and circadian disruption," Light. Res. Technol., 42: 271–284.
[39] Katsuura, T., "physiological anthropology: effects of artificial light environment on humans," encyclopedia of life support systems (eolss). Physical (biological) anthropology, 1–9.
[40] Strogatz, S.H., 1987. "Human sleep and circadian rhythms: a simple model based on two coupled oscillators," J. Math. Biol., 25: 327–347.
[41] Bellia, L. and M. Seraceni, 2014."A proposal for a simplified model to evaluate the circadian effects of light sources," Light. Res. Technol., 46: 493–505.
[42] Mirick, D.K. and S. Davis, 2008. "Melatonin as a Biomarker of Circadian Dysregulation," Cancer Epidemiol. Prev., 17(12): 3306–3314.
[43] Benloucif, S., H.J. Burgess, E.B. Klerman, A.J. Lewy, B. Middleton, P.J. Murphy, B.L. Parry, and V. L. Revell, 2008."Measuring melatonin in humans," J. Clin. Sleep Med., 4(1): 66–69.
[44] Higgins, P.A., T.R. Hornick and M.G. Figueiro, 2010. "Rest-Activity and Light Exposure Patterns in the Home Setting: A Methodological Case Study.," Am. J. Alzheimers. Dis. Other Demen., 25(4): 353–361.
[45] Figueiro, M.G. and M.S. Rea, 2010. "The Effects of Red and Blue Lights on Circadian Variations in Cortisol , Alpha Amylase , and Melatonin," in International Journal of Endocrinology.
[46] Bluyssen, P.M., S. Janssen, L.H. van den Brinkand Y. de Kluizenaar, 2011."Assessment of wellbeing in an indoor office environment," Build. Environ., 46(12): 2632–2640.
[47] De Groot, M.H.M. and B. Rusak, 2002. "Entrainment impaired, masking spared: An apparent genetic abnormality that prevents circadian rhythm entrainment to 24-h lighting cycles in California mice," Neurosci. Lett., 327(3): 203–207.
[48] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), 2012. Effects of Artificial Light, no. March. European Union.
[49] Knutsson, A. and T. Akerstedt, 1992. "The healthy-worker effect: Self-selection among Swedish shift workers," Work & Stress, 6(2): 163–167.
[50] www.csun.edu, Maryam Allahyar, spring 1997
[51] www.howsleepworks.com/how_homeostasis.html
[52] www.jackkruse.com/primal-cortisol-response, Jack Kruse, 2011
[53] www.health.harvard.edu/staying-healthy/blue-light-has-a-dark-side, Harvard Health Publications, Harvard Medical School, 2012.