DAYLIGHT: NATURE'S PRESCRIPTION FOR HEALTH, PRODUCTIVITY, AND SLEEP

Daylight enlivens interior spaces, saves energy and provides us with important time cues. It is a source of sensual delight that most of us would not want to miss in our everyday lives. To fully understand the importance of natural light, however, one must take into account how daylight directly affects our biology; an impact that goes far beyond vision.

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Photography by Daniel Blaufuks

THE NATURAL SCIENCE of physics tells us that daylight is the only visible part of the electromagnetic spectrum. It is organised into wavelength bands represented by familiar colours, each of which contains a different amount of energy. The short wavelengths (380–492 nm) represented as violet-blue bands are the most stimulating for biological response, so we only need a relatively small amount of them. The long red wavelengths are a less powerful source of energy but needed for providing biotic counterbalances throughout the 24-hour daylight/dark cycle. It is the blue bands that stimulate alertness, while the red wavelengths trigger relaxation and the act of sleep. Overall, daylight is the only source of light that provides the perfect blend of wavelength distribution at the right times of the day in order to keep us healthy throughout our lifespan.

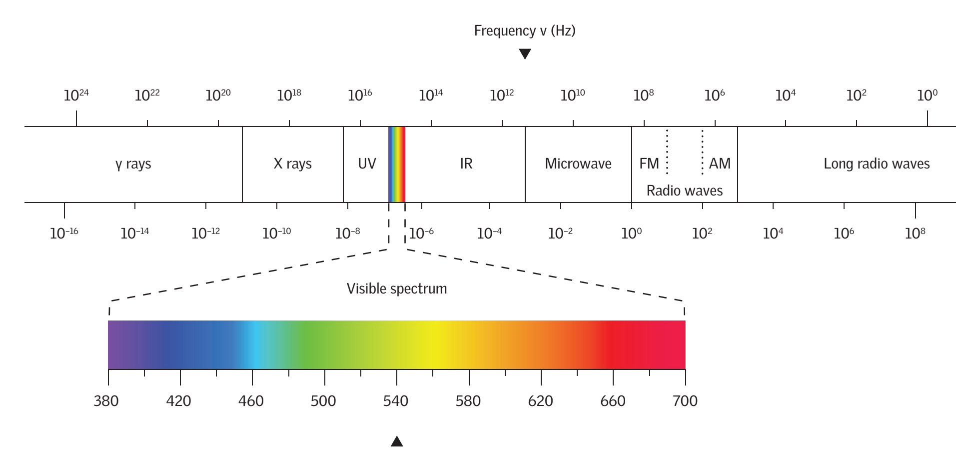
Although modern light sources try to replicate natural daylight distribution, they fall short as the primary signature of daylight – a consistently high distribution of all wavelengths throughout the day. Additionally, natural daylight provides evolutionary mandated qualities of light intensity, duration, timing, location and, the all-important dynamic, motion – something that our current electric light sources do not provide. The artificial spectral wavelength distributions, by contrast, are static and missing entire bandwidths due to the way the light source and luminare are manufactured. It is important to note that every cell in our bodies, including those that comprise organs, muscles, glands and even blood cells[1], responds to exposure to ambient light and darkness, also that provided by electric light, via the circadian system. This innate biological system, as you will soon learn, provides the means for how we are able to function and survive on the planet we call home.

Daylight: delivery system for biological stimulation

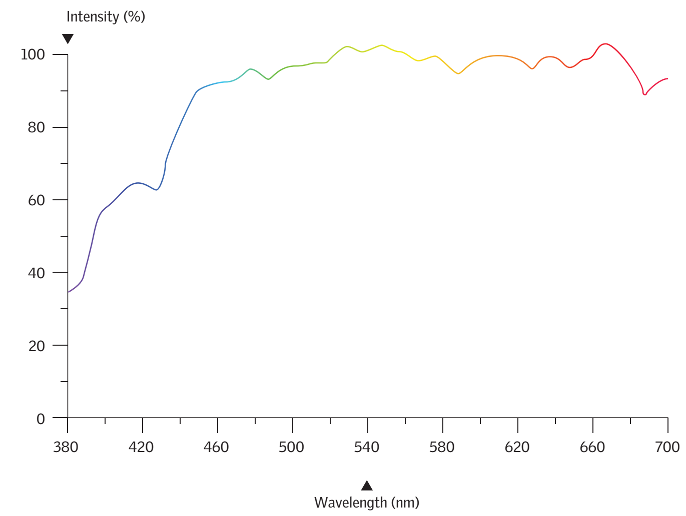
Daylight can be described as the preferred delivery system for encoded organic information that initiates, governs and controls all life functions necessary for our survival.

Since the early 20th century, medical science has demonstrated the healing power contained within a good dose of daylight; wounds heal faster, the immune response is strengthened to fight off disease, and emerging tumours are weakened or destroyed. Daylight exposure

Different types of electromagnetic radiation with their corresponding frequencies and wavelengths. Visible light constitutes a relatively small fraction of the electromagnetic spectrum.



Typical captured spectral power distribution (SPD) of natural daylight, with the relative percentage of energy contained within each wavelength. Emerging research is suggesting that for fixed electric light sources, short wavelength radiation should be limited to the 12% range; a typical problem for white LEDs, which emit a much higher proportion of blue short wavelength radiation. Since daylight is dynamic, with constantly changing proportions of short wavelength to long wavelength radiation, the correct emission percentage of short wavelength energy is always the right light, at the right time, in the right percentages.



is now even credited with controlling obesity by enhancing the production of the body's 'good' fat[2,3]. But it is only since the mid-1990s that we are beginning to understand how it all works.

It has long been understood that our eyes are the organ of sight via the reception of visible light by the rods and cones (light/dark photoreceptors). However, since the 2002 discovery of a third ocular photoreceptor, commonly referred to as the circadian system's non-visual receptor or iPRGC cells (intrinsically Photosensitive Retinal Ganglion Cells), we now attribute the eye as being the primary organ of biological timing[4].

Although new discoveries are still emerging, science has conclusively demonstrated that the job of the iPRGC non-visual photoreceptors, via the opsin called melanopsin, is to: send, receive and transmit light signals to the master biological clock, initiate pupillary light response, contribute to pupil size, and regulate the activation and suppression of a key hormone, melatonin, from the pineal gland. This hormone, once thought only to promote the onset of sleep, is now recognised as the primary DNA protectant and the body's major tumour suppressant.

The iPRGCs are also unique in that they are extremely sensitive to the presence of short wavelength light accrued over a long period of time. They capture this information, transduce it (i.e. change its form of energy) and then transmit it to the brain via a specialised path. This neural pathway is called the retinohypothalamic tract and leads directly to the master biological clock. Although we have a number of secondary clocks located throughout the body, the master pacemaker, identified as the suprachiasmatic nuclei (SCN), receives these secondary clock signals along with those from the iPRGC to regulate and control all our biological functions.

The SCN is an important 2.5-billion-year old evolutionary brain structure designed to keep our biotic functions optimised, our daily strength and vitality maintained, and our reproductive viability strong – in other words, to do everything we need to survive and continue our species[5]. This brain formation is comprised of a tiny collection of about 40,000 master oscillator cells located behind the eyes and is responsible for ensuring that our overall biology is correctly aligned with the Earth's light and dark cycles. It also acts as a major input source for delivering neuronal signals to the brain for further processing and direction.

It is important to note that some of our genes are also aligned with the 24-hour pattern of daylight and darkness. Genes with catchy names such as CLOCK, TIME and PERIOD respond to the varying light conditions by either expressing (turning on) or by silencing (not responding) when appropriate). This can be either a good thing or a bad thing, depending on the time of day the dose of light is received.

Circadian system: nature's gift to keep us connected

The circadian system is a complex series of environmental stimuli receptors, dedicated pathways for biotic messaging, secondary timing oscillators and light receptive genes that provide timing protocols for every cell, gland, muscle and organ of the human body, including the brain. At the centre of this network is the SCN (master biological clock), which translates the incoming information into neurochemical and physiological responses to govern and control every aspect of our being, including blood pressure, heart rate, urine output and muscle strength.

Consisting primarily of the circadian rhythm and the sleep/wake cycle, this cadence-producing design supplies us with what can be described as a biological 'perpetual motion machine', using ambient light conditions as fuel.

The circadian rhythm is an innate 24.2-hour biotic timing cadence that must be recalibrated to the Earth's 24-hour rotation cycle. This is necessary for us to be in constant biological sync with the planet we call home. The process of aligning the circadian rhythm to the Earth is called entrainment and is instrumental for controlling a number of functions we sometimes take for granted. These include sleeping at night, puberty arriving in time for our teenage years, and maintaining our daily energy levels, which keep us alert and active throughout the day. This process is accomplished when ambient light is received by the iPRGC cells and the corresponding wavelengths are sent to the master pacemaker. Based on this information, the SCN recalibrates and synchronises the rhythm so that it aligns perfectly with the 24-hour solar day.

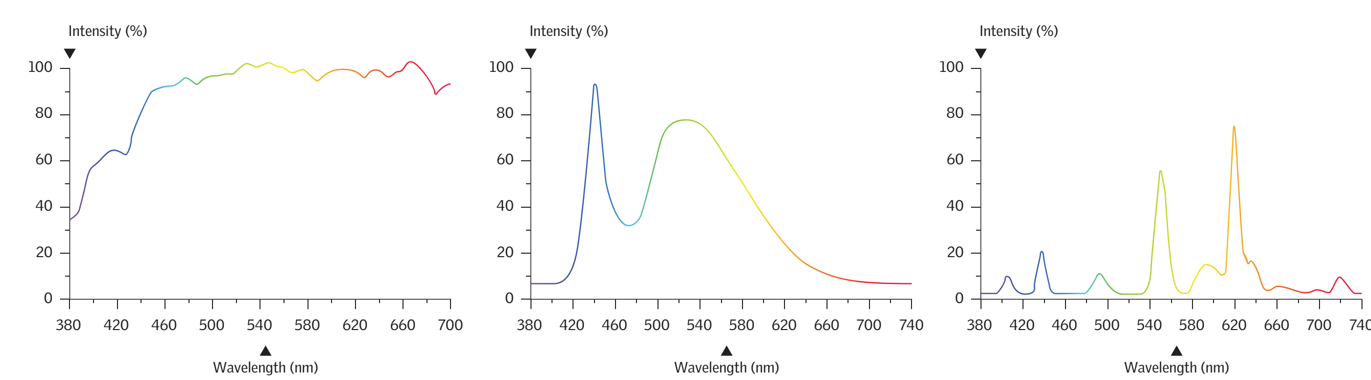
As mentioned already, the circadian rhythm is only a part of the overarching circadian system. Another major component is sleep, a function by which all the daylight received during the day goes to work at night.

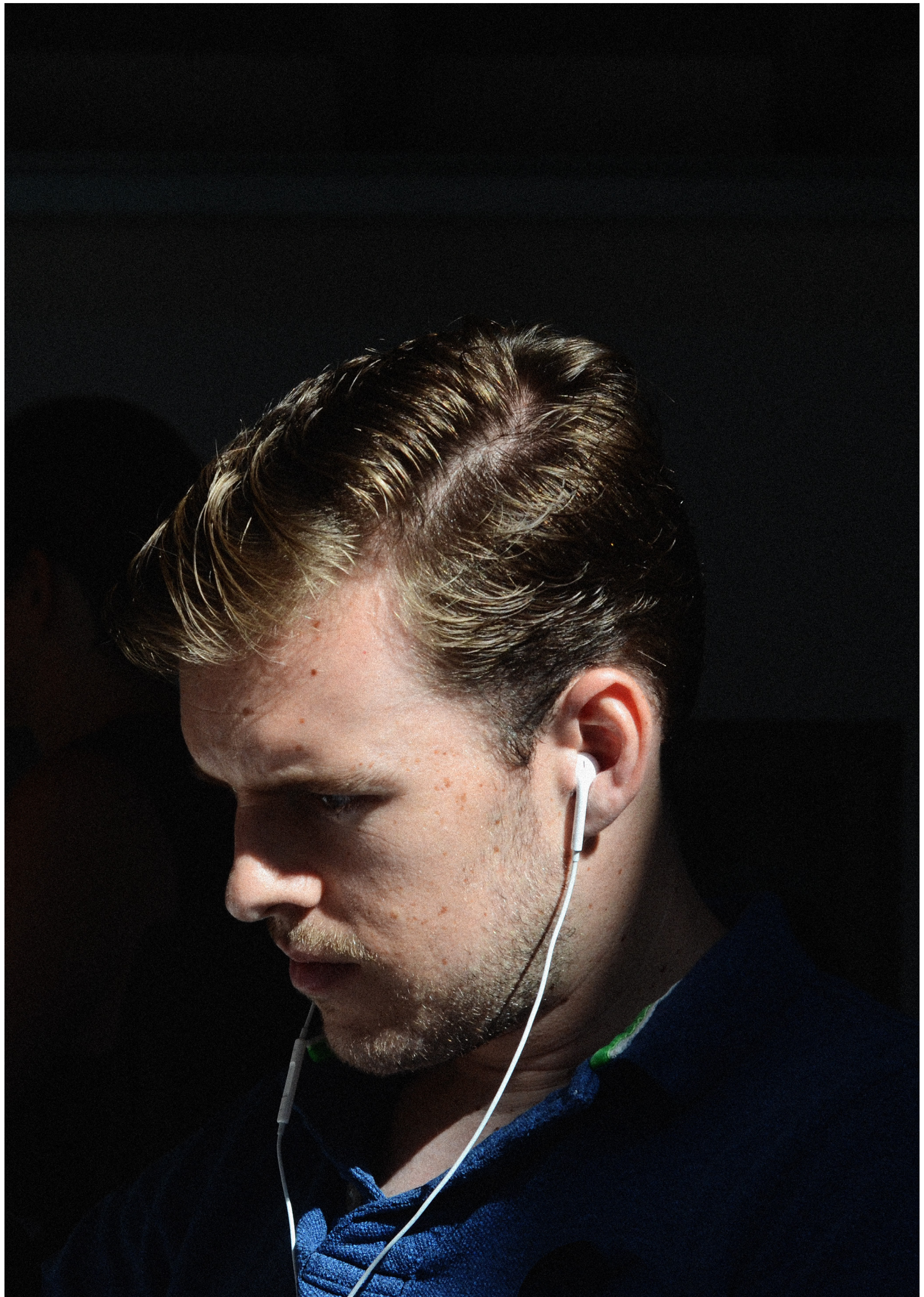
As humans we are naturally diurnal, which means that we are awake during the day and naturally disposed for sleep during the evening hours. Simply explained, sleep is the circadian system's counterbalancing activity, comprised of two parts: the innate process of sleep, which begins about 2 hours before you get up in the morning and continues throughout the day so that the act of sleep can happen at night.

Known as the Homeostatic Sleep Propensity (HSP) this dual function is a reoccurring neurochemical and physiological pressure rhythm that works counter to the circadian rhythm.

For the architectural community, it is important to understand that the day-

Spectral distribution of daylight compared to LED and fluorescent light sources. Note the lack of energy bandwidth for all power densities as compared to daylight. For human health, well-being, sleep and productivity, we need a light source that contains a full array of all energy bands.





time sleep process happens while we are awake. It is a largely a neurochemical process dependent upon daytime exposure to high light levels in order to maintain alertness throughout the hours leading up to bedtime. The process is also responsible for initiating the alerting stress response in the early morning of the next day. This too is dependent upon the previous days' light exposure and activity levels. Without this response we would not be able to 'jump start' our daily wake cycle, thus leaving us tired and groggy all day unable to function optimally. Daylight naturally provides the right percentage of short wavelength radiation needed to keep the HSP going strong, as well as to suppress daytime circulating melatonin levels thus ensuring a quality daytime sleep process and act of sleep at night.

By contrast, the rejuvenating act of sleep, which is designed to occur between the approximate hours of 10 p.m. and 6 a.m. depending upon age and health, optimises our nervous system for proper brain function and immune system response. This planned biological 'refresh' is also vital for fighting disease and maintaining night-time levels of melatonin, a darkness-derived hormone now recognised as a major breast cancer tumour suppressant, in addition to triggering the act of sleep.

Since both the process and act of sleep are now credited with delivering behavioural benefits, spending our waking hours without the bright light of day to suppress melatonin or the darkness of night to express melatonin, can have noticeable consequences, such as overwhelming daytime fatigue, increased workplace errors, and decline in individual productivity, performance and concentration.

Although the complete neurochemical and genetic purpose of sleep is not fully understood, most scientists now believe that the night-time act of sleep 'defrags' or cleans up those brain areas that convey information from our daily lives and previous days' immediate environment. By compartmentalising and compressing this information during sleep, we start the next day with enhanced memory recall, improved cognition and heightened alertness.

Sleep is also instrumental for optimising our metabolic and immune systems, which we need to fight diseases, control inflammation, control our weight and heal our wounds. Considering these facts, it is understandable that the sleep component (HSP) of the circadian system, with all the health and well-being benefits it delivers, is now recognised as a wellness benefit by employers worldwide[7]. Additionally, the monetary benefits of better sleep are also noted, as many studies are citing improved productivity and performance. The bottom-line factor is now estimated to be USD 1,967 per employee per year simply by getting one hour more sleep each night[8].

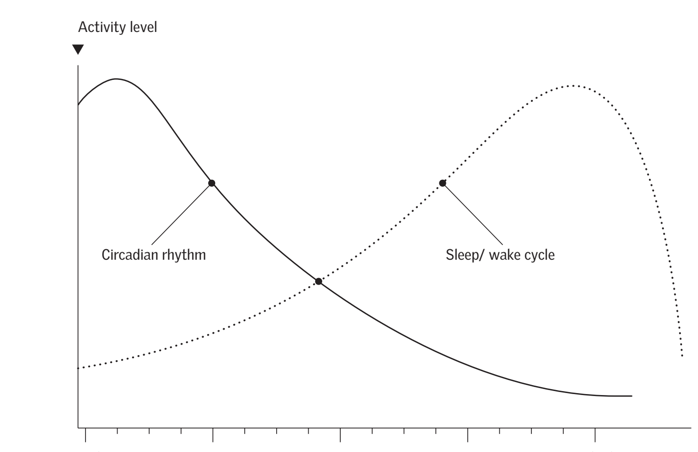
Eyes: designed to use light, not look at it

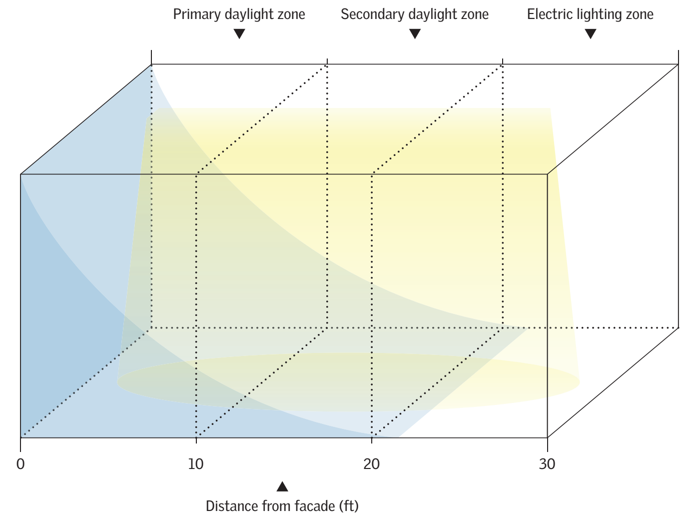
The primary receptors of the circadian system are the eyes. Since the mid-1990s, science has made tremendous advances in the body of knowledge about the circadian system. These include light qualities, received by the eyes, that trigger optimised blood pressure, heart rate, and the negative circadian-related stress response caused by glare.

To understand glare, we first have to understand that the visual process depends upon light capture, while the act of sight depends upon environmental contrast conditions for definition and enhanced visual acuity. Also important to note is that the circadian system plays a role in both vision and sight. Alongside their visual function, the cones and rods of the visual system also contribute information to the biological clock. Furthermore, the response of our pupils to overtly bright light sources is controlled by the same non-visual iPRGC cells that send information about how and when we sleep. In both cases the eye is using light rather than looking at the light itself; to do that would actually cause the biological stress response we recognise as glare.

Here's how it works. Whenever we experience a sudden light intrusion of higher luminous intensity within our direct line of sight, e. g. when looking into a bright light source such as sunlight streaming in through a poorly shielded window opening, the body and brain go into an instantaneous high alert mode. Research tells us that our aversion to overly bright light conditions is actually a whole body stress response in which multiple body sites respond with protective biological reactions. We can begin with the eyes. The pupils are the first to respond and will constrict due to the iPRGC release of a stress-response neurochemical from the adrenal glands, lo-

The Homeostatic Sleep Propensity is an innate rhythm of biological consequence which operates counter to the circadian rhythm in order to maintain our diurnal predisposition of daylight activity and sleep at night.





Daylight through vertical windows provides only limited natural light penetration, thus causing the dependence on electric light sources to provide light necessary for visual acuity alone. Additionally, daylight through windows requires a 'defensive' placement of furnishing and/or light-blocking shading devices in order to reduce the eyes' exposure to direct light and to prevent excessive glare conditions.

cated on top on the kidneys. This initiates a 'whole body alert' that involves blood pressure, heart rate, and muscle coordination. During a glare response, the eyes will also blink or temporarily close, thus reducing visual acuity. Additionally, the visual photoreceptors produce an excessive amount of cellular waste in response to the overtly bright light. Waste builds up behind the retina and causes the sensation of pressure or pain depending upon the intensity and duration of the glare conditions. And, finally, facial muscles contract and shoulders twist slightly, resulting in a change of centre-of-balance that disrupts concentration and causes us to momentarily lose our eye-hand coordination; a devastating consequence contributing to potential workplace injury and increased error rates. If allowed to persist, glare conditions exacerbate existing problems with sleep, migraine and neurological diseases, such as epilepsy and Parkinson's. Furthermore, excessive exposure to glare-producing light sources may introduce a whole-body photosensitivity, which plays a role in a number of health conditions, such as lupus and chronic fatigue syndrome to name but two.

Architectural daylighting solutions: top daylighting is best

For the architectural and design community, continual awareness of the biological aspects of daylight is critically important when it comes to how we justify our daylighting designs. Providing the right daylighting solution is instrumental for enhanced occupant health and well-being; a much larger payback consideration than merely saving energy – and with greater potential. Here's what science is telling us about daylight solutions delivered from above and the side.

Although the research is still emerging, most scientists seem to feel that receiving copious amounts of ambient bright light, with a high luminous intensity of at least 1,250 lux throughout the day, is enough stimulus to sustain the iPRGC (melanopsin) response needed to maintain heath, well-being, and sleep. Daylight provided from above (e. g. through roof windows or skylights in particular) provides the high levels needed and allows for energy-saving daylight harvesting throughout the entire floor plate, regardless of depth. And because zenithal daylight comes with a markedly reduced risk of glare, no light is lost due to window shading devices that would otherwise be needed to mitigate glare conditions.

'Top daylighting' solutions, such as skylights, tubular skylight devices, modular skylight ceilings and interior light shafts, also impact on human biology via continuous dynamic light information. The dynamic pattern of daylight on the floor and that which is broadcasted onto vertical surfaces initiates the eyes' detection of motion within our peripheral visual field. This contributes to the functioning of our circadian system (via the rods' reception of motion) and plays a vital role in determining time passage, enhanced wayfinding ability and heightened memory recall. Additionally, being exposed to dynamic sunlight, and to the ever-changing colour shifts of the skydome via top daylighting features, provides occupants with information about seasonal changes in day length, as well as about the weather conditions outside.

By comparison, 'side daylighting' solutions, such as windows and other facade openings, do not seem to offer the same health benefits. Restricted by a window-to-wall ratio of 50–65%, the side-daylighting solutions are seldom enough to illuminate the adjacent walls, let alone 'bathe' the entire floor plate in natural daylight. A simple guideline to understanding the penetration of daylight into a space through windows is easily accomplished by multiplying the height of the window by 1.5. Thus a 30-foot-wide office space with 12 feet high windows will only provide usable daylight back into the space for a depth of less than 20 feet. Additionally, limited exposure to the skydome, which is often blocked by adjacent buildings and/or window shading devices, reduces light levels. Furthermore, in most cases side daylighting solutions only provide daylight from one cardinal direction, again limiting light penetration even during winter months when low solar angles prevail. However, 'side daylighting' solutions do play a vital role in the process of sleep.

Sleep: the primary beneficiary of daylight

Since the late 1980s, windows with a direct view to the outdoors, and especially those that offer occupants a horizontal line-of-sight to the earth's surface and horizon beyond, have come to the attention of design professionals worldwide. This was mainly due to the positive health and behavioural benefits reported from hospitals, workplaces and schools[9,10]. These include reduced length of hospitalisation, reduced absenteeism and enhanced scholastic test scores. Little is known, however, as to how these benefits, delivered through windows, are biologically produced; mounting evidence is pointing in the direction of sleep.

It seems that the unique benefits provided by windows with outside views contribute to two brain regions where the act of sleep is instrumental for the next day's memory recall and cognitive abilities. Although not completely understood, early research is directing its attention to how viewing the natural environment contributes to the expression of ZIF-268, a gene which initiates a night-time sleep state known as REM (Rapid Eye Movement). It is during this sleep phase that the brain's hippocampus and cerebral cortex prepare for the next day by paring back neuronal synaptic gaps (the brain's 'defragging process' mentioned above) in order to safeguard against a number of negative lifestyle and health-threatening conditions. These include productivity drags, such as excessive fatigue and reduced hand/eye coordination, as well as health-related issues, such as worsening disease conditions and expanding waistlines.

Now for the hard part. How can we, as design professionals, use the biological information contained in daylight to promote architectural daylighting solutions in order to foster occupant health, well-being, and sleep at night? That, dear reader, is up to you. But for me, it seems to work best when I mention that sleep and sexual performance go hand in hand with daylight exposure. I wonder why this is.

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