C5 - Full Spectrum Lighting

All life depends on light. The quality of light impacts the quality life.

Background

We take daylight for granted, yet almost all forms of life depend upon light to survive.[1] Daylight is derived from the thermal radiation of the sun, filtered directly through the atmosphere and reflected from the sky due to scattered molecules in the air. It forms a continuous spectrum of wavelengths ranging from Infrared (IR) down to UVB (300nm). (The UVC produced by the sun's radiation is filtered by the atmosphere.) It provides heat and energy for life, but also energy to kill certain bacteria. The wavelengths of the humanly visible spectrum range from 700nm (Red) down to 400nm (Violet) encompassing all the colours of the rainbow (ROYGBIV).

Other sources of light might include fire, candles, kerosene lamps, various incandescent bulbs, and lately Light Emitting Diodes. On their own, none of these sources provide the same spectrum as natural sunlight.

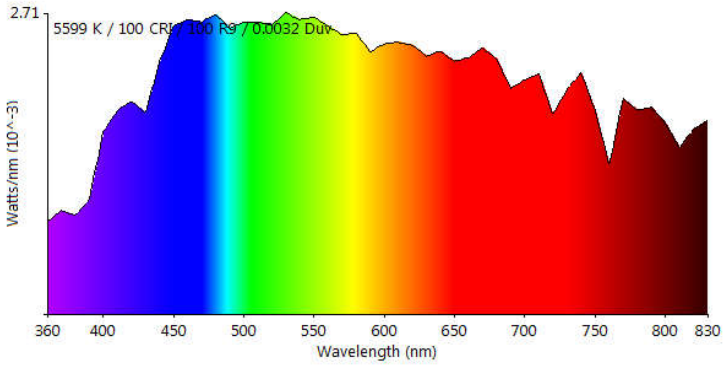

Figure 7. Typical Spectrum of Sunlight

Sunlight provides the energy for photosynthesis, which plants use to create sugars, which in turn provide energy to the living things that digest them. Different parts of the spectrum play key roles in different parts of the plants life cycle. This is why many plants struggle to grow under artificial indoor light.

Sunlight also provides the key synchronising mechanism for biological clocks, whether in plants or animals. These clocks control various functions within the organism, whether it be preparing the plant for sleep (petals folding up at the end of the day), or the preparation of the stomach for digestion.

In a human (and all vertebrates), sunlight is received by photoreceptor cells in the retina, and historically our only interest in light was how it impacted our vision. Recent research has shown that there are additional photoreceptors that control hormone production, independent of vision, making the impact of light quality much more complex.

Light is perceived not only by the eye, but also by the skin. The photoreceptors in the eye take the form of Rods and Cones (responsible for vision) and ipRGCs (intrinsically photosensitive retinal ganglion cells) which are responsible for physiological and behavioural responses to light. There are at least five distinct types of ipRGCs that we now know of. These ipRGCs respond differently to light depending upon the Rod and Cone behaviour and the physical pathway, intensity and persistence[2] of the light source. Adding to the complexity of the spectral functions of these sensors, is the fact that they "report" to different regions of the brain. These target areas also therefore have different reactions to light, depending upon spectrum, intensity and duration. Thus these ipRGCs control the production of hormones which the body uses to regulate various critical internal functions.

[1] Deep in the ocean, some life forms (bacteria) can convert thermal energy into food using chemosynthesis.
[2] Some reactions are long lasting, others are transient.

It has now been shown that exposure to adequate natural light is a key component in a sense of wellbeing and motivation for people working indoors.

Additionally, the efficiency of the retina is improved when energy is available in the full spectrum, and this aids visual acuity and reduces strain.

It is important to understand that the natural light spectrum changes throughout the day and depends upon season, latitude, cloud cover and pollution.

White Light and Colour

Our ability to perceive colour accurately depends upon the presence and intensity of the various spectral components of the light source. A white light can be made up of two or more discrete wavelengths, the sum of which can appear white if mixed with the correct intensity. Such a source may appear white, but completely fail to render red or blue, or it might over emphasise a colour and inaccurately accentuate it.

The industry has historically used a measurement called "Colour Rendering Index" which is unfortunately somewhat misleading. The CRI of a light source measures how accurately it renders 8 pastel colours (R1 - R8). It does not include any information about saturated colours Red, Yellow, Green and Blue (R9 - R12) or skin and natural tones (R13 - R15).

The spectrum of a fluorescent lamp source is an example of a light source with two main peaks in the green and orange wavelengths. The light appears white because the various wavelengths "pull" the combined spectrum onto the Black Body Locus curve, a curve that represents the spectrum that is emitted from a hot (glowing) black body. This light source is unable to render reds (R9=-5%) or blues (R12=60%) and yellows (R10=59%) with any accuracy. However, such a light source is exceedingly common and is described as having an excellent colour rendering index (CRI=84). In fact it is completely unable to render certain colours with any accuracy at all!

Such a light source may also fail to stimulate the relevant ipRGCs in the retina, and therefore fail to elicit the same behavioural responses that you might expect from natural light.

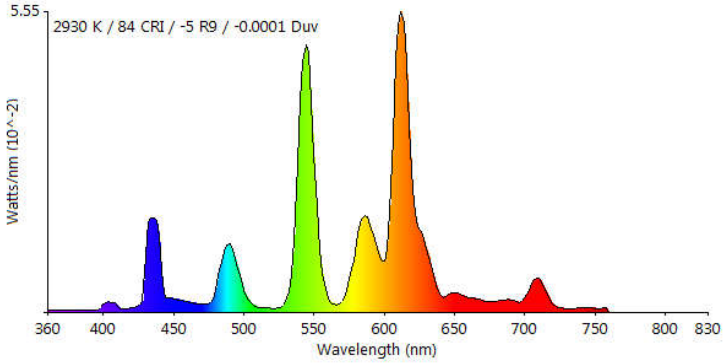

Figure 8. Spectrum of Typical Fluorescent Lamp

It has been shown that people working under a natural light source (or full spectrum light source) have improved feelings of wellbeing, mood and motivation, and thus increased productivity, accuracy and performance.[3] As a result, exposure to a natural light source is now a requirement for "WELL" rated buildings along with Biophilic designed working spaces.

[3] Human Spaces: The Global Impact of Biophilic Design in the Workplace

It seems we can do no better than to try to mimic natural light. To target some nominal colour temperature with a particular colour rendering index is far too simplistic and misses the point of how we interact with light.

Similarly, to simply change the colour temperature to provide circadian stimulus also misses the point, as it is the light's wavelengths and intensity, not simply the colour temperature, that trigger the biological impacts.

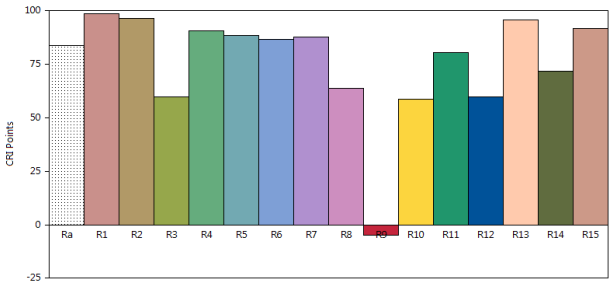

Figure 9. Colour Rendering of Typical Fluorescent Lamp

In many medical applications, accurate colour rendering is critical to detect cyanosis, jaundice, various dermatologic conditions and colour based diagnostic tests. A well designed full spectrum light source will render colours with about 97% accuracy, regardless of what colour temperature it is "tuned" to.

The Germicidal Aspects of Natural Light

One of the key discoveries of Full Spectrum Lighting is the ability for natural light to kill harmful bacteria.

It has long been known that sunlight provides a cleansing function, and this may be assumed to be due to the presence of UV light. However recent research[4] has shown that some wavelengths of visible light are also highly effective in sterilising bacteria (MRSA, vancomycin-resistant enterococci or VRE and MDRA).

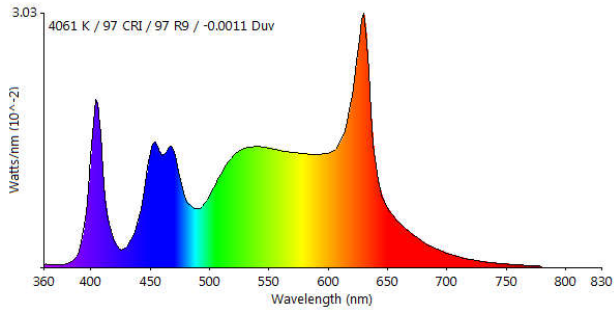

Figure 10. Compuspec's Full Spectrum Germicidal Light

Typical clinical trials have reported an 85% reduction in bacteria in operating theatres and a 73% reduction in the number of surgical site infections.[5]

This presents a huge opportunity for indoor lighting to provide a safe and automatic cleaning function - finding applications in Hospitals (effectively killing Super Bugs), Aged Care Facilities, food preparation and processing areas, ablution areas and schools (mould). Essentially anywhere with the potential for bacteria growth to be harmful to occupants, property or produce.

Mammalian DNA is unaffected by these wavelengths of visible light, making it safe for humans and animals, and allowing its use in general indoor lighting to provide a continual sterilizing effect, or simply to provide a cleaning function when areas are unoccupied.

[4] Initial studies by the University of Strathclyde, Scotland. Supporting studies by the U. North Carolina
[5] Maury Regional Medical Centre, Columbia, Tennessee

Biophilic Design

Biophilic Design is a term describing an innovative way of designing the places we live, work and learn. This design philosophy recognises that we live and operate better in a natural environment.

The benefits of Biophilic Design have been shown to be:

> Improvement in productivity (> 15%), increased concentration levels, improved creativity (15%), enhanced occupant wellbeing and greater staff retention.

Key aspects of the Biophilic Design Philosophy are a strong desire for natural light, along with the inclusion of living plants, bright colours and quiet work spaces.

While it is possible to grow plants under traditional fluorescent light sources, these light sources are a poor solution and usually only provide very limited photosynthetic flux. Full spectrum lighting, on the other hand, not only provides the light spectrum that our bodies crave, but is also the perfect partner for indoor plant growth and renders natural colours with excellent accuracy.

Circadian Stimulus

All living organisms exhibit circadian rhythms, which are biological cycles that repeat themselves on a daily basis. These cycles are synchronised primarily to natural light. Without this synchronisation, research has shown that we experience long-term detrimental effects in our physiology, [6] neurobehavioral performance and sleep patterns, and are put at a higher risk for cardiovascular disease, obesity, diabetes and certain forms of cancer.[7]

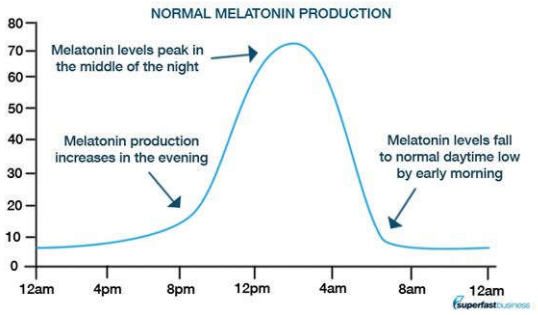

Figure 11. Change of Melatonin Production over a Day

Lighting characteristics affecting the circadian system are different from those affecting visibility. The predominant influence that we are recently becoming aware of has to do with melatonin suppression and onset of melatonin release (sleep), which are controlled by light level, spectrum, timing and duration of exposure, but is highly influenced by blue light. Additional to melatonin, body temperature, cortisol secretion, heart rate, alertness, cognitive performance, psychomotor performance (reaction times), EEG responses and clock gene expression have all been shown to be acutely effected by the eye's secondary optical tracts. These effects occur even in blind people, because of the different pathways involved. Similarly, a closed eyelid still allows sufficient penetration of the blue wavelengths to promote a natural wake cycle. (Thus blue light from alarm clocks will negatively impact sleep.)

In simple terms, the human body is highly sensitive to blue light (wavelengths around 460nm - 480nm) and such a light source will not only synchronise the internal body clock, but help prepare (or shut down) its internal functions (eating, sleeping, mental activity), depending upon the timing

[6] See Environmental Health Perspectives. Vol 118. Jan 2010. "What's in a Colour"

[7] In 2009, the Danish Government began compensating some female shift workers due to increased cancer risk after the WHO identified shift work as a risk factor for breast cancer in 2007.

and intensity of that source. Thus a natural wake/sleep cycle defined by sunrise and sunset are shown to be optimal.

As a practical example, we provide hospital lighting[8] which, during the evening and night-time, removes critical wavelengths, enabling the patients to sleep (even with the lights on), but simultaneously allows the nursing staff to operate with good visual acuity. Improved patient sleep translates into more rapid recovery and shorter hospital stays.

To simply change the colour temperature of a light source (e.g. from 3000K to 6000K) to provide circadian stimulus is not optimal and misses the point, as it is the light's wavelengths and intensity, not simply the colour temperature, that trigger the biological impacts.

Mental Health and Depression

Light therapy has been shown to help in treating Seasonal Affective Disorder (SAD) and has shown encouraging results with depression and dementia.

This is thought to be related to the body's production of Serotonin, which is normally produced in a daily cycle, peaking around midmorning.

Depression has been linked to low levels of serotonin, but whether this is a cause or effect is still unclear.

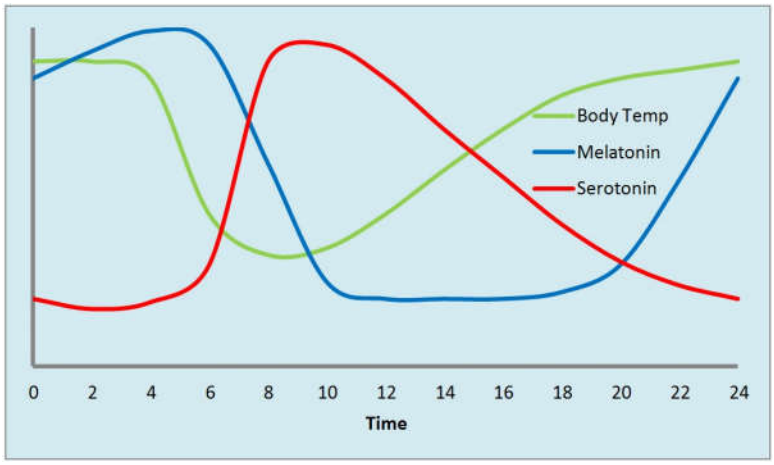

Figure 12. Daily Cycle of Serotonin production, opposite to Melatonin (sleep)

Antidepressant medication (SSRIs) increases serotonin levels by preventing serotonin neurotransmitters being reabsorbed, allowing serotonin levels to remain high in the brain. The appropriate exposure to critical wavelengths of light in the early morning help regulate the release of serotonin and thus increase this natural "happiness" hormone.

Studies have also shown that correct stimulus in the evening can settle patients with dementia and anxiety disorders, allowing less stress and better sleep.

Traditional light therapy involves subjecting the patient to a high intensity light for up to an hour. However, studies have shown that waking to a progressively increasing natural light source has similar or even better effects.

Since light will penetrate the human eyelid and trigger the natural photobiological responses within the brain, advanced lighting systems should be able to simulate an artificial dawn. During this period, prior to the desired wake time, control of both the light level and spectrum is needed. This requires gradually increasing the light level while tuning the spectrum of the light to simulate a natural dawn.

[8] Compuspec IntelliSUN range of Full Spectrum LED Fixtures.