Is the world finally waking up to circadian lighting?

Ben Townsend highlights the growing awareness of the health benefits of circadian lighting, while exploring some of the latest photonic technologies illuminating the field

Chromaviso

Circadian lighting is increasingly being deployed within the healthcare sector, for example in this Neonatal Intensive Care Ward at Uppsala University Hospital, Sweden

Once upon a time, our sleep-wake cycle revolved around the rising and setting of the sun. And while this has become somewhat obscured by the artificial glow of the modern world, the drums of our circadian rhythms – the 24-hour clocks inside us that regulate our sleep and energy levels – beat ever on.

Now, the risks of ignoring our affinity with sunlight are growing ever clearer.

In October 2023, a survey[1] published in *Frontiers in Photonics* by the Circadian Light Research Center, involving 248 scientists and 2,697 peer-reviewed publications, concluded that artificial lighting should support circadian rhythms. It also said that LED lights with high 460-495nm blue content should be labelled as "harmful" if used at night – a fair suggestion considering the survey identified associated risks such as obesity, diabetes, sleep disorders, and even breast cancer. This figure is important – the photoreceptors in our eyes that regulate our circadian rhythm reach their peak sensitivity at around 480nm, meaning that short-wavelength light in this region can suppress the level of melatonin – our sleep hormone – in the blood, and disturb a good night's rest later on.

Standing outside during the peak of a nice, sunny day though, it's hard to imagine this being a problem. But many people working in industries such as healthcare, commerce, and production only receive light during the day from artificial sources, while those stuck at home during winter – especially in the Nordic countries – get very little sun at all. Not that the season always matters, considering how much time we spend inside – Americans spend 87% of their time indoors, according to The US National Human Activity Pattern Survey. And of course, night shift workers are especially at risk from poor lighting. In 2019, studies[2] confirmed that night work can even be carcinogenic, with other risks including heart disease and dementia.

Enter circadian lighting

Also known as human-centric or tunable lighting, circadian solutions provide light at different intensities and spectrums, from bright, blue-enriched light in the daytime to warm, dim light in the evening, in an attempt to mimic natural light cycles and re-synchronise our body clocks. These LED solutions are usually made from a combination of natural and artificial light sources and are described by their correlated colour temperature (CCT), ranging from about 2,400K (warm shades) to 6,500K (cool shades).

But while circadian lighting has been around for a while, with basic research starting in the 60s and 70s, it hasn't quite caught on in today's $120 billion[3] lighting industry. Martin Moore-Ede, director of the Circadian Light Research Centre and lead author of the *Frontiers in Photonics* paper, says: "Despite the health concerns… less than 0.5% of the lighting sold today modifies spectral content and intensity between day and night."

So where is it? Why isn't there an artificial sun in every home, office, school, and bathroom? Well, Dr Pranciškus Vitta, a Professor at the Institute of Photonics and Nanotechnology in Lithuania, claims it has partly to do with awareness.

"How do you convince someone that circadian lighting is beneficial?", he says. "The effect of circadian lighting is not very straightforward to measure. Studies show that if you spend entire months under circadian illumination, in the long run, your health and your cognitive abilities can improve, you can concentrate better, you

can sleep at night, and so on. But if you spend one day in the best illumination, it doesn't mean that by the end of the day, you will feel any different from the day before."

What's more, we're still not entirely sure of what's going on inside of us, as Dr Vitta explains: "There are gaps, not in physics or engineering, but in neuroscience and medical science. It's still not clear from a neuroscience perspective how circadian rhythms work. It's very difficult to get reliable academic feedback from human research. The subject is not a technology – it's a person who needs to spend time under certain conditions."

Indeed, according to a study[4] published last year in Neurobiol Sleep Circadian Rhythms, "In order to improve our understanding of circadian rhythms and their role in disease states, there is an increasing need to perform well-controlled circadian studies on humans in a more natural setting."

Space-based opportunities

What better way to test circadian lighting than on humans confined in the darkness of space, then? In 2007, engineering firm Bionetics built a circadian solid-state lighting assembly (SSLA) for the International Space Station (ISS) based on research into the lighting systems and wavelengths needed to support plant life in the cosmos.

Bill Wells, the Director of the Space and Engineering Division at Bionetics, which is now the exclusive provider of circadian lighting to NASA, says: "We recognised they were having issues with the old fluorescent lighting systems on the International Space Station. They just had just plain fluorescent bulbs before. The units were dying; they were flickering, and as NASA had expressed an interest in circadian lighting, I said [Bionetics] could build a new system using LEDs."

He continues: "We flew it up to the station and the crew loved it. It was only supposed to be up there for about a month but they said, 'Hey, we'd like to keep this!"

The SSLA featured a 'pre-sleep' mode with a large blue component to inhibit melatonin production, followed by amber light to increase melatonin and induce sleep. It was replaced with a newer, more energy-efficient version in 2016.

The project was inspired by research conducted by the National Space Biomedical Research Institute, which found that excess blue light at the wrong time could disrupt the circadian rhythm.

"The ultimate issue," Wells explains, "is that you have a sunrise on the international space station every 80 minutes. So [the astronauts'] circadian rhythm – their biological clocks – are all whacked out.

NASA

Top: Astronaut Mark Kelly on the International Space Station with Bionetics' circadian solid state lighting module (upper left) and an old fluorescent light (upper right) Bottom: The circadian solid state lighting module installed in crew quarters on the ISS

"Circadian lighting can stabilise natural rhythms, reduce stress and fatigue, improve sleep, counteract depression, and lower medication usage"

They really never know what time it is. Sleep issues have a large effect on your mental capacities and stability. So if you're having sleep issues over, say, a long period – let's say a trip to Mars – you can get a little wacky. This could mean [astronauts] get into unsafe situations."

Wells says that circadian lighting will be critical to the future of human activity in space. "As we continue our space exploration activities, you're going to have humans that are going to be in space longer, be it on a Moon base, Mars, or anywhere where you're going to have an abnormal circadian rhythm clock other than Earth."

Bionetics is developing the lighting systems for the new Orion capsule, which is part of NASA's Space Launch System – the new rocket that's going to send astronauts back to the moon. "Our interior lighting system will be with the crew on the Artemis 2 mission, which is slated for launch about a year from now. We're also working with Blue Origin, which is building a commercial space station," says Wells.

He adds: "We're going to see these moon bases start to come to fruition, and we're going to be getting to Mars. And then there are these other commercial space stations which we're going to see quite a few of over the next few years – all of this is going to provide opportunities for circadian rhythm [lighting] implementations."

Lighting up healthcare

Back down on Earth, the healthcare industry is one that's benefitting from circadian lighting. Chromaviso, for example, is a firm developing customised, ergonomic and circadian lighting for the healthcare sector that automatically controls and adjusts the lighting throughout the day to mimic natural light.

"So much is at stake when designing lighting for large indoor environments," says Torben Skov Hansen, Chief Technical Officer. "We're in a pursuit to educate lighting specifiers to apply more light during daytime and less light at night, at a different spectrum to conventional lighting."

"At night, we're guests in nature, so the problems we've caused by lighting up large

parts of the earth is something we have to work intelligently to counteract. Not for aesthetic reasons, but to ensure a positive path for biodiversity."

Explaining the effect of the firm's circadian lighting solutions, Mette Kuhlmann Frandsen, Chief Marketing Officer, says: "You experience a gentle sunrise, the light intensifies around midday and becomes bright white light, and towards the late afternoon and evening, it becomes more subdued and warmer. At night, the lighting corresponds to biological darkness, either completely off or with very low intensity and without blue light to avoid disrupting the body's natural circadian rhythm."

Chromaviso now has more than 3,000 installations in hospitals, nursing homes, and psychiatric facilities across the Nordic countries. The firm says its lighting solutions stabilise the circadian rhythm, reduce stress and fatigue, improve sleep, counteract depression, and lower medication usage in nursing home residents – many of whom have dementia – hospital patients, and staff.

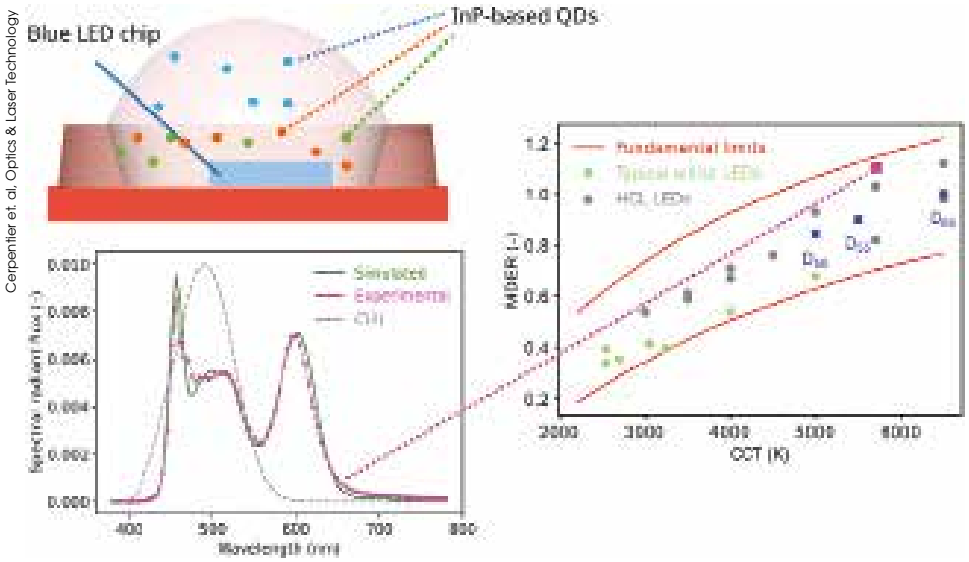
Frandsen adds: "Our solutions have been developed in collaboration with the healthcare sector and its complex working environment, treatment, and care environments, and the effects have been clinically documented."

She describes circadian lighting as a "well-kept secret", adding: "The availability of technology that allows for dynamic and adaptive lighting systems, such as circadian lighting, has only recently become more widespread. The overall awareness of the importance to health of being exposed to the right light at the right time is an emerging trend that works in companionship with trends about better sleep and better work environment, especially for those working around the clock."

Quantum dot-based single-chip LEDs

When it comes to the tech, circadian lighting generally falls into two camps: tunable/dynamic white LED systems, which let you control a light source's colour temperature; and spectrally optimised LED solutions, which are tailored to the circadian rhythm from the offset. The latter is more difficult to make, as it requires delivering the exact hues and intensities of light, at the right times of day needed to stimulate our body clock. Ultimately, this means that despite years of development in LED technology regarding illumination aesthetics, energy efficiency, and costs, it's not quite plain sailing yet.''

"There is still a wide range of challenges for the circadian lighting industry," says Jeroen Cerpentier, a researcher at KU Leuven, Belgium. "The main focus within the lighting industry has always been on visual colour rendering and/or energy efficiency. However, since humans are exposed to artificial light for a significant amount of their time, it's crucial that lighting systems also appropriately affect the biological rhythm, without only focusing on energy efficiency."



Cerpentier et. al. Optics & Laser Technology

Researchers at KU Leuven are designing quantum dot-based single-chip LEDs that can stimulate the circadian rhythm while maintaining good vision performance and efficiency

"Quantum dot-based single-chip LEDs can stimulate the circadian rhythm while maintaining good vision performance and efficiency"

Cerpentier and his team are designing quantum dot-based single-chip LEDs, which they say can stimulate the circadian rhythm while maintaining good vision performance and efficiency.

"For human-centric lighting systems, there are two ways to boost the circadian output," Cerpentier says. "Firstly, the raw power output of the system can be increased; by doing so, the spectral power distribution (SPD) remains equal, but the total amount of energy goes up – the amount of output 'circadian energy' then also increases. A second – more elegant – way of doing this, is by tuning the SPD shape to match the melanopic sensitivity function [how sensitive the human eye is to different wavelengths of light when it comes to regulating the circadian rhythm]."

He adds: "It's been argued that this aligns well with increasing the CCT of the spectrum, but research has shown that even within one CCT, there's a wide range of possible circadian tuning. For industrial lighting, efficiency and visual effects remain highly relevant. This makes designing SPD very challenging."

Cerpentier explains how quantum dots can help contribute to better circadian lighting.

"Quantum dots absorb light and re-emit light, with the cost of losing a limited amount of photons. However, a major advantage is that the spectrum of the re-emitted light is generally a very narrow peak, with the peak location directly dependent on the size of this 'dot' particle.

"This means that by tuning the size of the particle we can create narrow emission at certain wavelengths, allowing for highly flexible illumination. It's clear that this is useful in circadian lighting since emission around the cyan region is required, while also maintaining colour rendering."

He explains that in the study[5], the team optimised the size of quantum dots – and therefore, the emission peak – for three different (cyan, red and green) emitting particles."Our study demonstrated – for the first time – a single chip LED which achieves the highest spectral performance for circadian. EO

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