LED professional Review

www.led-professional.com

ISSN 1993-890X

LpR

The Global Information Hub for Lighti chnol Design

Jan/Feb 2021 | Issue 83

CREE® XLAMP® LEDs

CREE® HIGH-BRIGHTNESS LEDs

CREE® J SERIES® LEDs

WE STARTED THE LED LIGHTING REVOLUTION —AND NEVER STOPPED.

MORE RELIABLE.
MORE PERFORMANCE.
MORE OPTIONS FOR MORE APPLICATIONS.

SEE THE COMPLETE PORTFOLIO AT: CREE.COM/LED-COMPONENTS

CREE

Vitasolis™ | Optisolis™ | 2-in-1 Tunable LED

NICHIA

Light **so** Good

The Light **so** Good LED range delivers optimum performance in human centric lighting. **Vitasolis™** is state-of-the-art spectrum technology that stimulates human activity, while **Optisolis™** provides a natural light source on a spectrum that's the closest match to sunlight. Plus, Nichia's **2-in-1 tunable LED** enables development of compact tunable white luminaires with superb color mixing.

For more information

visit us at **nichia.com**
or contact us via
info_de@nichia.eu

Reboot With Plenty of Opportunities

The beginning of the year is always a good time for reorientation in our private and business lives.

With this Jan/Feb 2021 LpR issue, we want to set an impulse for a reboot and so have compiled some interesting topics for you that will accompany us in the lighting sector this year.

In his LpS Digital lecture, Mark Ridler talks about his view of the Circular Economy and how this important topic will be incorporated into lighting projects. Then we had an in-depth conversation with Patrick Durand, who was able to explain the advantages of Bluetooth Mesh and its practical implementation concepts. One focus, of course, remains ”healthy light” and the orientation of lighting solutions to human needs. Here you will find several TOP contributions from projects to business and product solutions. With Double Dynamic Lighting we also present a new approach to dynamic lighting design - a study conducted by the University of Aaalborg. Besides design and applications, technology is the driver for lighting innovations. We present dynamic lighting solutions, MicroLED displays, simulation support, UV-LED curing and LED testing. All areas that can provide us with new impulses in technological sectors.

But perhaps more important than the introduction, I want to wish you a Happy New Year with lots of new impulses and, above all, good health for you and your family.

PS: Call for Papers for the LpS Digital 2021 is now open. Take the opportunity to submit your idea for a paper or present your latest innovations http://www.LpS-Digital.global.

Yours Sincerely,

Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting, LpS Digital & Global Lighting Directory
Photonics21, Member of the Board of Stakeholders
International Solid-State Lighting Alliance (ISA), Member of the Board of Advisors

RÖHM

Almost too beautiful just for the road – lighting design with PLEXIGLAS®.

What does PLEXIGLAS® have to do with car design? For over 60 years, PLEXIGLAS® molding compounds have been a driving force behind the auto industry. Why? Because the multifaceted ways in which PLEXIGLAS® can be formed open up virtually endless possibilities for design. One shining example is crystal-clear or colored PLEXIGLAS® whose top light-guiding properties and color stability make for innovative automotive lighting systems. For more inspirational PLEXIGLAS® products, go to **www.plexiglas-polymers.com.**

PLEXIGLAS®

THE ORIGINAL BY RÖHM

Overview about Circular Economy Approaches in Lighting Designs and Projects by Mark Ridler, Head of Lighting at BDP, London, United Kingdom

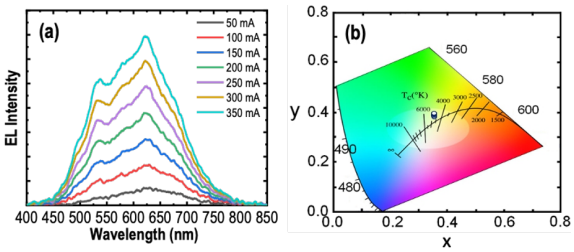
Patrick DURAND

Carry YU

DOUBLE DYNAMIC LIGHTING

Ellen Kathrine HANSEN

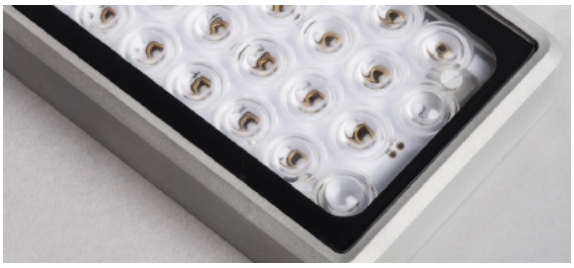
MICRO-LED DISPLAYS



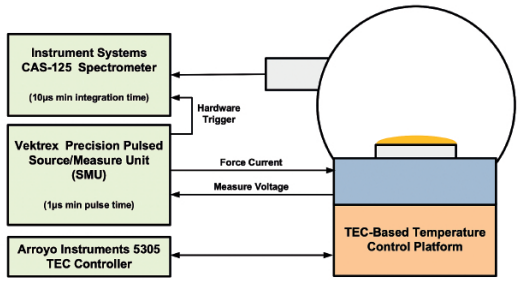
SIMULATION

UV-LED CURING

DYNAMIC LIGHTING



LED TESTING



ADVERTISING INDEX

Henrik CLAUSEN

Henrik has worked in the lighting sector for almost 30 years, collaborating with architects, interior designers and specialist lighting designers. From 1996 to 2004 he held the position of Managing Director of Fagerhult Lighting in Denmark, after which he founded the Fagerhult Lighting Academy, based in Copenhagen. There, he has held the positions of Director, Head of Research and International Development Director. He has also been an associate professor in Lighting Design at the Aalborg University in Copenhagen since 2016. Henrik regularly contributes to international conferences, speaking on various issues related to lighting, primarily addressing the human and emotional aspects of light and lighting design. He is also a sought after guest speaker at various universities across the globe.

From Kelly to Double Dynamic Lighting

I am a great admirer of Richard Kelly, the world's first real Lighting Designer.
Kelly did his fundamental work by introducing a simple, yet powerful classification of light – not by describing products or installation – but by describing how you experience light. He published his idea in his college paper, essay "Light as an Integral Part of Architecture" in 1952 and there he introduced his three principles of lighting design:

"Focal glow" is the spotlight on the modern stage. It is the pool of light at your favourite reading chair. It is the shaft of sunshine that warms the end of the valley. It is candlelight on the face, and a flashlight on a stair... Focal glow draws attention, pulls together diverse parts, sells merchandise, separates the important from the unimportant, helps people see.

"Ambient luminescence" is the uninterrupted light of a snowy morning in the open country. It is fog light at sea in a small boat, it is twilight haze on a wide river where shore and water and sky are indistinguishable. It is in any art gallery with strip-lighted walls, translucent ceiling, and white floor. Ambient light produces shadowless illumination. It minimizes form and bulk.

"Play of brilliants" is Times Square at night. It is the eighteenth-century ballroom of crystal chandeliers and many candle flames. It is sunlight on a fountain or a rippling brook. It is a cache of diamonds in an opened cave. It is the rose window of Chartres... Play of brilliants excites the optic nerves, and in turn stimulates the body and spirit, quickens the appetite, awakens curiosity, sharpens the wit...

Light & Communication, nature as a reference in lighting design.
That's the title of one of my books about lighting, published in 2009. The overall idea is to use nature as a reference when you describe different lighting scenes, that creates different moods that again supports different emotions.

In the first section I tried to explain the need for a common frame of reference. Stories may be one way, using nature as our common reference may be another. The reason I choose the latter is that we all have a common heritage, we - the human species - evolved outdoors and our vision, along with the other sensory systems are made to perfection for outdoor use in daylight. Why not use this common genetic stored reference when we specify lighting solutions and present our lighting designs? Let me give you an example:

There is nothing like walking along a path in the forest that leads us towards adventure and mystical discoveries. We can walk for hours, never getting tired. Our senses are filled to the brim. There are high variances in luminance levels and the sizes of the light spots that hit both vertical and horizontal surfaces of all shapes and colors. Our senses have a great time loading data into our entire system. We simply love it!

Using nature to describe what I want to achieve has been an efficient tool for me talking about Light, Lighting and Lighting Design through the years.

I understand if you think: This all sounds very nice, but where is the evidence?
– Its right here! The *"Double Dynamic Lighting Concept"*.

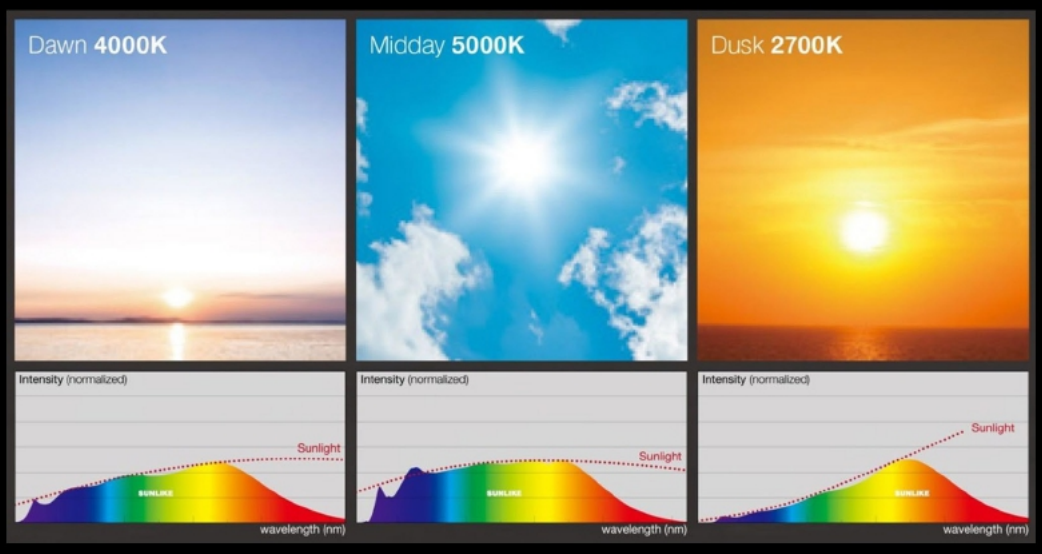
For many years we lacked the evidence that lighting really influences people's emotions. However, since 2002, when the Photosensitive Ganglion cells in our retina were discovered and their control of our sleep/wake cycle documented, we have had scientific proof of the biological effects. But it was only after a four-year research project, recently published by LEUKOS, that we have scientific evidence that lighting design influences our feelings and our emotions.

We have always known it –- now we can prove it. So let's all get better at explaining the difference good lighting can make for people. ■

H.C.

Working inside a cave ?

SunLike



We bring you the Sun

SEOUL

APPOINTMENTS

New Head Of Light Bureau

As Light Bureau, part of AFRY, takes the next step to grow even further internationally, **Paul Traynor** takes over as the new Head of Light Bureau, as of 1 January 2021.

Traynor is the founder of UK-based Light Bureau which joined AFRY (then ÅF Lighting) in 2017, growing the team to about 100 lighting experts. The whole lighting design offer of AFRY later assumed the brand Light Bureau.

"This is more than I imagined would happen three years ago when AFRY acquired Light Bureau, but the more I have thought about it, the more I value the opportunity of working with a great business to develop the brand to which I am forever committed. Beginning with binding the cultures in our different territories, I want to see us all motivated by doing great projects and growing together," says Paul Traynor.

"I'm so pleased that Paul will lead Light Bureau as the award-winning lighting design offer now aims to grow even further internationally. Paul is an internationally recognised lighting designer with a proven track record as a leader. Having worked extensively internationally and as former President of the Professional Lighting Designer's Association, Paul's profile is ideal to help to realize Light Bureau's ambitions," says Malin Frenning, Head of Division Infrastructure at AFRY.

Paul TRAYNOR

Zlatan Idnert who has been Head of Light Bureau this past year will continue his commitment as Head of Efterklang, part of AFRY, and focus on its continued growth in existing as well as international markets. ■

Filix Lighting Welcomes New MD

From February 1st 2021 **Martin Valentine** will join FILIX lighting following a growth strategy aimed at better supporting the global lighting community. Martin will join as the Managing Director of the new UK office and as Global Lighting Solutions Specialist to boost business development and support specifiers.

He arrives at FILIX with 35 years of experience in the lighting industry with an in-depth knowledge of lighting design, business and product development gathered at organisations such as AECOM, Abu Dhabi Municipality and Ligman. Aside from his core roles, supporting lighting designers and engineers internationally, Martin will through his membership and involvement in organisations such as SLL, IALD and IES interface with the lighting community and continue to work on education and industry-wide research. His experience and knowledge across multiple areas of the industry will bring Filix Lighting a much-needed boost to continue growth.

Martin VALENTINE (left)

Founded in the 1980s; FILIX Lighting was originally an electrical engineering company. After years of catering key stakeholders we became the first importer of LED technology to Croatia, working directly with Osram. With the development of LED technology and changes in the industry Filix harnessed their engineering knowledge and began the development of their first outdoor and underwater LED lighting solutions. ■

Foundry London Welcomes Steve Owens

Steve Owens joins Foundry London as Associate Director. Previously, Owens has designed lighting in collaboration with Foundry London on several projects.

A designer from a diverse background with over 20 years' experience, delivering high-end restaurant and commercial interior projects, to individual bespoke pieces of furniture – including at the late Sir Terence Conran's Benchmark, where he was Director and Head of Design. ■

SLL President's Medal Winner Announced

The SLL President's Medal was awarded to **Henrik Clausen**. Outgoing winner Jim Shove referenced Henrik's career in lighting to date, including his time as Managing Director of Fagerhult Lighting in Denmark and his time as a board member of the Danish Illuminating Society. Henrik has dedicated much of his career to lighting education, founding the Fagerhult Lighting Academy in 2005. He is head of Fagerhult research, leading and expanding on studies relating to light and human health.

In 2015, Henrik was appointed Associate Professor of Lighting Design at Aalborg University, Denmark. He has also published two books, All you need to know about Lighting and Light and Communication. Henrik regularly contributes to conferences and events, as well as delivering guest lectures at universities internationally.

Henrik was very touched to receive the SLL President's Medal, which is surprisingly the first medal that he has received in his illustrious career. In accepting the award, Henrik gave thanks to the SLL and its membership. His main area of interest now is to keep up with the scientific community on applied lighting research and deliver this back to the lighting community in an accessible, easy, and entertaining way. Fagerhult Lighting Academy established in 2004, aims to gather, refine and distribute information regarding light, lighting and lighting design.

Henrik Clausen

"Thank you so much, all my colleges in the UK through the years. I would never have received this recognition without you guys – and all the other fabulous Fagerhult colleges around the world. I am very, very grateful and proud!" Henrik Clausen, Director at Fagerhult Lighting Academy. ■

HUMAN CENTRIC LIGHTING

NICHIA Unveils Advanced Tunable LED Pairing with 'Circadian Tune' Functionality to Enhance Body Clock Management

NICHIA, the world's largest LED Manufacturer and inventor of the high-brightness blue and white LEDs, announces a new and improved Circadian Tunable LED offering. This new tunable LED pairing has been developed to enhance the regulation of your Body Clock by combining both the stimulation and calming doses, in addition to color tuning.

This Circadian Tune technology harnesses NICHIA's expertise in developing a unique Phosphor Converted Cyan, among other semiconductor processes and packaging techniques. The supplementary component is the inclusion of NICHIA's newly launched LEDs with TriGain® technology, a potassium fluorosilicate (PFS) based phosphor technology licensed to NICHIA through a strategic partnership with GE Current.

Most existing human-centric lighting systems mainly work by changing CCT (correlated color temperature). Some have started using individual "energizing" or "calming" LEDs, including NICHIA's VitasolisTM. However, NICHIA's new Circadian Tune LED products will raise the bar to also address efficacy, color quality and increased Melanopsin Stimulation, the light that explicitly targets melanopsin-containing neurons in the retina of the eye. These neurons, called Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs), are connected to a region of the brain responsible for regulation of the 24-hour circadian cycle along with associated reflexive neuronal and hormonal responses to the presence of light.

Sensitive to a particular range of wavelengths, melanopsin photoreceptors reach peak light absorption at wavelengths around 490nm. By utilizing NICHIA's Phosphor Converted InGaN Cyan, NICHIA's Circadian Tune LEDs are optimized at the most sensitive wavelength of ipRGCs. Indeed, this approach provides a higher performance through its unique combination of lumens per watt (lpW), TM30 and Melanopic Ratio (MR) than other human-centric lighting solutions.

NICHIA's Phosphor Converted Cyan outperforms a pure InGaN die based cyan in many ways. As highlighted by Phosphor Engineer Sadakazu Wakui at the recently-held Phosphor Global Summit 2020, the Phosphor Converted Cyan delivers a higher lumens per watt (lpW) performance versus a traditional pure InGaN cyan. Additionally, the PC Cyan provides the same forward voltage (VF) as standard white LEDs, as well as the same z-height for optical matching. Couple this unique PC Cyan and NICHIA's Warm White LEDs with TriGain® technology, the system can achieve a CRI of 90+, with high TM-30 values, while delivering a lpW performance equivalent to that of an 80 CRI LED. A balanced human circadian lighting system is achieved with simply no loss in efficacy.

Using NICHIA's new Circadian Tune technology, the high MR and cooler CCT will reduce fatigue and provide greater alertness to help office workers remain in an awakened state of mind or help night workers complete their shifts effectively. At a low MR and warm CCT, the focus switches to relaxation, prompting a feeling of safety and initializing a transition to sleep. A sense of time is therefore introduced when both proper melanopsin stimulus and variable CCT is being applied.

"New Circadian Tune LED products are truly innovative. Through an optimization of efficacy, color quality and Melanopsin Stimulation, we can better target ipRGCs. Additionally, the utilization of a traditional 80 CRI warm white for the relaxing portion limits the color quality of the system. To overcome these limitations, NICHIA has introduced this Phosphor Converted Cyan and Warm White TriGain® pairing," explains Satoshi Okada, General Lighting Business Planning Manager of NICHIA Japan.

"NICHIA introduced VitasolisTM in 2019, a range of LEDs geared to suppress fatigue and boost vitality. The Circadian Tune LED pairing builds on these innovations to offer a more dynamic and tunable solution to the global lighting industry."

LEDs with TriGain® technology are available now in NICHIA's 757 series, the industry's first and leading mid-power LED. The new unique Phosphor Converted Cyan will be available within the first half of 2021.

Reach out to NICHIA at info@nichia.com. ■

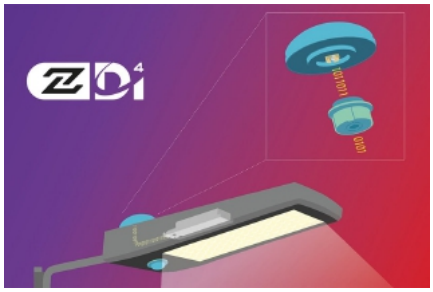
SMART & IOT

Zhaga and the DALI Alliance Add Sensors and Controllers to Zhaga-D4i Certification

The joint Zhaga-D4i certification program from the DALI Alliance and the Zhaga Consortium has already qualified a number of Zhaga-D4i Book 18 outdoor luminaires with Zhaga receptacles and D4i components. Now, certified D4i control devices with Zhaga connectors can also be submitted for Zhaga-D4i certification. Eligible devices include light-level or occupancy sensors, as well as control nodes that can communicate wirelessly with external networks.

This ecosystem of lighting products enables smart, future-proof LED luminaires with IoT connectivity. Certified Zhaga-D4i products can carry the dual logos of Zhaga and D4i which together indicate plug-and-play interoperability of sensors, communication nodes and luminaires.

”Bringing control devices into the Zhaga-D4i program will enable a certified ecosystem of interoperable products from multiple vendors, which will be welcomed by the lighting market,” said Paul Drosihn, DALI Alliance General Manager.



”With the Zhaga-D4i certification program, decision makers in outdoor road lighting can combine the long-lasting nature of the lighting infrastructure with the rapid changes in digital communication and sensor technology,” said Dee Denteneer, Zhaga Secretary-General.

Zhaga-D4i luminaires have a powered Zhaga receptacle, which can accommodate a D4i-certified sensor or communication node with a corresponding Zhaga baseplate. Also, Zhaga-D4i luminaires use LED drivers meeting the D4i requirements, including the availability of DALI luminaire, energy and diagnostics data.

D4i enables DALI in intelligent, IoT-ready luminaires. By taking care of control and power requirements, D4i makes it much easier to mount sensors and communication devices on luminaires.

Smart Zhaga-D4i luminaires are ideal platforms for the IoT, capable of gathering information from on-board D4i sensors, and providing data via DALI for performance monitoring, asset management, predictive maintenance and many other tasks. Communication and data exchange with an external network can take place using a D4i control device with wireless communication capabilities. ■

General Assembly Approves Transfer of Zhaga Books 18 and 20 to IEC

The Zhaga General Assembly has decided in November 2020 to transfer the Zhaga Books 18 and 20 to the IEC. Sharing Zhaga specifications with global standard development organizations is included in the Zhaga mission and has the goal of increasing global acceptance of Zhaga specifications. The Zhaga Books 18 and 20 define smart interfaces between outdoor and indoor luminaires and sensing and/or communication modules. The exclusivity period of one year allowing only Regular and Associate members to access the Zhaga Books 18 and 20 has expired.

The Zhaga mission includes the active sharing of Zhaga specifications with other global and regional standards development organizations with the end goal of gaining increased global acceptance of the Zhaga specifications. In the past, already Book 7, 10, 12 and 14 were shared.

The transfer of the Books 18 and 20 to IEC were approved by the Zhaga General Assembly in November 2020. The next steps will be to formalize the arrangements with IEC. This means in detail the conclusion of a liaison agreement and the identification of a working group in IEC.

Assuming typical procedures within the IEC, books 18 and 20 can be adopted as IEC standards in about 2-3 years. ■

DALI Alliance Joins IP-BLiS to Improve IoT Integration Across Smart Commercial Buildings

The DALI Alliance has joined IP-BLiS, the ”IP Building & Lighting Standards” market interest group to support convergence towards using Internet Protocol (IP) transport and security mechanisms to simplify deploying, provisioning, and securing complex building systems.

IP-BLiS was launched in June 2020 by BACnet International, KNX Association, OCF, Thread Group and the Zigbee Alliance.

Together, these standards organizations support the widespread adoption of a secure, multi-standard, IP-based infrastructure as the backbone in commercial buildings for lighting and building-automation solutions.

The use of IP as the common networking protocol allows IT systems and building services, including lighting control, to operate on a secure, all IP-based configuration. As a result, building operators can expect end-to-end addressing and security; easy connectivity between previously-isolated applications; limitless scalability; better, faster and lower cost integration; and great flexibility and choice of both physical transports and applications.

”On behalf of all the leading lighting companies that comprise our membership, we are excited to join IP-BLiS and help to address the complexity and connectivity roadblocks in smart buildings,” said Paul Drosihn, General Manager of the DALI Alliance. ”Internally, our team is making strong progress towards our first DALI over IP specification, which will enable DALI networks with wireless connectivity, as well as IP addressing and security.”

IPBLiS
STANDARDS JOINING FORCES
DALI® Alliance

”DALI, as the leading digital lighting-control protocol, joining IP-BLiS is highlighting once again the importance of making commercial buildings more responsive to the needs of users by promoting a secure, multi-standard, IP-based harmonized IoT solution, which is fully in-line with the vision of IP-BLiS. With DALI as a new member, we see IP-BLiS confirmed in its previous activities and success in the IP-BLiS roadmap for the future,” said Casto Cañavate, Chair of IP-BLiS.

While IP-BLiS speaks with a unified voice to promote IP-based networking with common transport and security requirements, the organization will not create its own standards. Each participant is responsible for specifying its own technology. This allows companies to decide which solution or solutions work best for their business and use cases.

Similarly, IP-BLiS seeks to align security requirements for the industry, rather than reinventing them. Security issues are discussed in an IP-BLiS blog entitled ”Common Myths About IP Networking for IoT.”

About IP-BLiS: IP-Building and Lighting Standards (IP-BLiS) is a multi-party liaison between existing standardization organizations

- BACnet International, DALI Alliance, KNX Association, Open Connectivity Foundation (OCF), Thread Group and Zigbee Alliance - who are working together to promote the move to a secure IP infrastructure. IP-BLiS is an initiative that envisions to make commercial buildings more responsive to the needs of users by promoting a secure, multi-standard, IP-based harmonized IoT solution. The IP-BLiS liaison parties, through collaboration and cooperation, will educate and influence the market regarding application framework standards over IP for commercial building connectivity through marketing and communications. - www.IP-BLiS.org

About the DALI Alliance: The DALI Alliance (also known as the Digital Illumination Interface Alliance or DiiA) is an open, global consortium of lighting companies that drives the growth of lighting-control solutions based on internationally-standardized Digital Addressable Lighting Interface (DALI) technology. The organization operates the DALI-2 and D4i certification programs to boost levels of cross-vendor interoperability. As lighting continues to evolve and converge with the IoT, the DALI Alliance is also driving the standardization of wireless and IP-based connectivity solutions. - www.dali-alliance.org ■

Mira Release 2.5 - Wireless Technology Reaches New Levels of Stability and Scalability

LumenRadio – a global leader in reliable wireless communication – release version 2.5 of Mira which introduces many stability improvements for larger, and more stable networks. With Mira version 2.5 LumenRadio double down on their promise of "Wireless Without Worries!" – pushing the limits of stability and scalability even further.

Wireless technology experts LumenRadio take their unique reliability to a new level with the new release of Mira – their wireless technology for reliable device-to-device mesh connectivity – cementing their position as the most resilient and Future-Proof connectivity solution on the market.

Johannes Arvidsson, Product Owner at LumenRadio explains Mira 2.5: "We've gone back to the drawing board on implementations which are part of the very core of the network stack. By optimizing radio timing, clock synchronization and routing layers we take Mira to new levels of stability and reliability. Doing this while also not impacting current consumption, keeping it to our world record levels, is an achievement that we're very proud of." Johannes continues: "Our customers are constantly working on scaling up their wireless solutions to cover greater areas and more devices, a trend that is consistent with what is happening in the IoT space in general. It is only natural that Mira follows this development, now and in the future."

Also coming in this release are two "quality of life" features:

Snappier BLE beacons:
To achieve a fast response between devices and phone applications, a very low BLE beacon interval may be necessary. Due to constraints in the concurrent time slicing between Mira and BLE beacons, previous versions of Mira were limited to only sending 5 beacons per second. Mira now supports double that amount, 10 advertisements per second, enabling even more responsive commissioning and maintenance, for a better user experience.

Easier network restarts:
Mira version 2.5 introduces a feature to make scheduled network restarts less intrusive on running applications. Previously, the best practice in order to achieve short restart/rebuild times was to fully reboot all nodes in a network simultaneously whenever a network restart was necessary. This can be a problem for any device running critical applications which needs to be kept running. This is where the rejoin function comes in. It enables only the root node being forced to reboot in the same scenario. All other nodes can use the rejoin function instead of rebooting the entire chipset, all while still achieving a short restart/rebuild time.

Mira version 2.5 also reintroduces support for the MKW41z chipset, enabling us to deliver the best Mira ever across all our platforms.

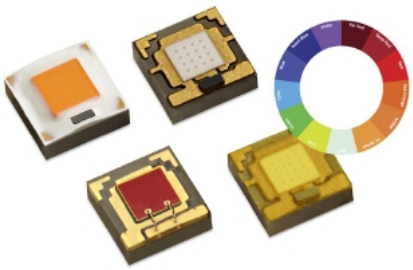
With these changes Mira strengthens its position as the most resilient and robust wireless IoT solution. Going forward we will keep our commitment to continuously improve in that area, but also turn our sights to the monitoring and management of Mira networks. For more information see https://lumenradio.com. ■

AUTOMOTIVE

17% Flux Boost in Key Colors for LUXEON C and CZ Color Lines

Lumileds announced breakthrough flux delivery from the PC Amber, Lime and Royal Blue emitters in its LUXEON C and CZ Color Lines, the lighting industry's broadest lines of

color LEDs. The incredible 17% leap in flux of PC Amber in LUXEON C LEDs supports more efficient, safer, and easier to design lighting for first-responder vehicles, tow trucks and construction vehicles



17% brighter PC Amber, 10% brighter Lime and 4% brighter Royal Blue on LUXEON C - LUXEON C and CZ color lines provide the highest performance and most color options in the lighting industry

Lumileds unique Lime LEDs deliver the industry's highest efficacy of any LED – 149 lm/W – and are a critical element for the very best tunable white and color mixing solutions. Royal Blue benefits from a 4% increase in flux performance supporting broader use in entertainment and architectural applications.

"The LUXEON color lines are known for having the greatest color selection and now they provide even higher luminous output so fixtures will require fewer LEDs to achieve their target brightness in a smaller overall footprint," said LP Liew, Product Marketing Manager at Lumileds.

The LUXEON C and CZ Color lines provide flawless color mixing, enabled by the same focal length on every color to prevent halos and ensure uniform output levels across light beams. The LUXEON CZ Color LEDs feature a dome-less design to deliver narrow beam angles and 50% higher punch than competing LEDs. The low dome on LUXEON C provides the highest light extraction from a very small source, which results in more compact fixture designs. The LUXEON C reaches luminous output of 110 lm in PC Amber, 149 lm in lime and 552 mW in Royal Blue when driven at 350 mA. LUXEON CZ delivers 88 lm in PC Amber, 138 lm in Lime and 432 mW in Royal Blue at 350 mA.

Both color lines feature small overall footprint of 2.0 x 2.0 mm for dense packing, low thermal resistance that reduce heat sink requirements, and hot testing to ensure color consistency in real-world operating conditions. Colors of the LUXEON C and CZ lines include Violet, Royal Blue, Blue, Cyan, Green, Lime, Mint, PC Amber, Amber, Red-Orange, Red, Deep Red and Far Red. ■

UV LIGHT

Osram Enters UV-C LEDs Market Offering Their First Products

The longer the coronavirus pandemic lasts, the more important it is to stay safe and healthy in everyday life. Hygiene measures, such as wearing a facemask or socially distancing, help safeguard against the spread of germs. But light in the right wavelength also makes an enormous contribution to fighting viruses. UV-C light can eliminate 99.9 percent of viruses and bacteria on surfaces, in the air and in drinking water. As one of the world's leading manufacturers, Osram Opto Semiconductors now enables particularly small and robust disinfection applications with its LEDs, while also driving the industrialization of these special light sources forward. The Oslon UV 3636 marks the beginning of a comprehensive portfolio in the UV-C LED sector.

LED technology makes extremely space-saving disinfection applications possible. Osram's Oslon UV 3636 (inset) marks the beginning of Osram's UV-C LED portfolio

Irradiation with UV-C light causes chemical bonds in the RNA or DNA helix of the pathogens to break down. As a result, they are no longer able to multiply and are thus rendered harmless. UV-C light has been used for many years to disinfect air or water - but often with very large lamps based on conventional light technologies. A major advantage of modern, LED-based UV-C solutions is the compact size of the light sources. Thanks to their space-saving dimensions, the LEDs can be installed easily on the final application for direct interaction with the substance being sanitized such as: significantly reducing germs in faucets and disinfecting the air in air conditioning systems before it is blown into car interiors. The direct integration of the light sources also has the advantage of ensuring that the high-energy, short-wave UV-C light does not reach the surrounding area, and therefore, does not pose a risk to people. In addition, unlike conventional lighting technologies, LEDs are very robust and insensitive to external shocks.

Oslon UV 3636, Osram's first UV-C LED, is available in a low- and a mid-power version and features compact dimensions of 3.6 mm x 3.6 mm. With a wavelength of 275 nanometers, both versions are ideal for disinfection applications. The low-power version achieves 4.5 milliwatts at 30 milliamperes. The mid-power version impresses with 42 milliwatts at 350 milliamperes.

"Thanks to their compact footprint and different optical power classes, UV-C LEDs enable completely new designs and applications," explains Christian Leirer, Product Manager for UV-C at Osram Opto Semiconductors. "The Oslon UV 3636 is the first product in a series of innovations from Osram Opto Semiconductors in the UV-C range. A high-power UV-C LED will be launched in early 2021."

Osram has been active in the UV area for many years and developed in-depth knowledge of UV technology from participating in various research projects with partners from industry and research. Particularly noteworthy are the UNIQUE and UV-Power project, as well as IPCEI on Microelectronics. ■

UVC Disinfection Solution – Edison Opto

Recently, due to the global outbreak of COVID-19, the people's demand for anti-epidemic and sterilization of anti-virus products has risen, ranging from portable sterilization equipment, home appliances sterilization, and public health sterilization. With the rise of environmental awareness and in response to the Minamata Convention, UV lamps containing mercury will gradually be replaced by LEDs. In the future, in the post-epidemic era, UVC LED products will continue to grow steadily in the sterilization, and purification and water treatment markets.

Edison provides complete UVC series products (EDILUV series) and customized services. In November, it developed and completed various power packages for 275 nm UVC, including 3535, 5050 & 7070 products, and the emission power after packaging is between 3 80 mW, and can be matched with different optical designs to achieve the best sterilization effect. The third-party unit test report shows that the sterilization effect can be as high as 99.99% in

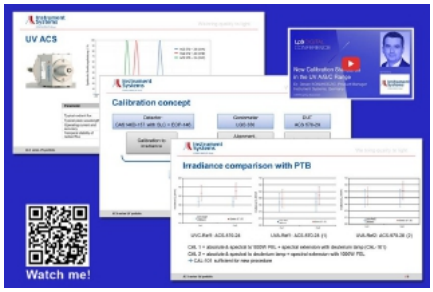
the application of water sterilization and air sterilization.

For additional information, please visit https://www.edison-opto.com.tw/en/professional-lighting/disinfection-sterilization-lighting-collection or contact us via our contact page at https://www.edison-opto.com.tw/en/contactus/

About Edison Opto: Edison Opto is a professional company with specialized talents in different fields of light, mechanics, heat, and electricity. Edison Opto created the LDMS service program which can be customized for different sterilization scenarios and customer application needs, providing optical simulation, mechanism design, LED packaging development, circuit design, printing services and finished product assembly services can provide customers with a complete one-stop service. ■

New Calibration Standards in the UV A/B/C Range

UV radiation encompasses a very wide wavelength spectrum between 10 and 400 nm and is subdivided in ISO Standard 21348 into three ranges. The UVC range between 100 and 280 nm is currently extremely relevant for air and water disinfection for combating COVID-19. Since the outbreak of the pandemic this has been manifested, among other things, in a sharp increase in the demand for UVC light sources.



The UVA range lies between 315 and 400 nm. Typical applications are UV curing and UV ink printing. Light sources in the UVB range between 280 and 315 nm are used for medical skin treatment. According to their specific field of application, all UV light sources must be precisely measured in terms of radiant flux. This calls for particularly sensitive and reliable measuring equipment.

Instrument Systems offers a complete portfolio for the measurement of UV light sources consisting of high-precision spectroradiometers with very low stray light, PTFE-coated integrating spheres and special calibration standards for the three UV ranges A/B/C.

The most important field of application for UV-LED calibration standards is the monitoring and calibration of UV integrating spheres to radiant flux. With its new ACS-570-UV series, Instrument Systems is the first company in the world to develop temperature-stabilized UV-LED calibration standards that feature radiant flux calibration traceable to the PTB. The ACS series of UV-LED calibration standards is available for the typical peak wavelengths of 280 nm (UVC), 305 nm (UVB) and 365 nm (UVA). The temporal stability of their radiation is exceptionally good and lies at about 0.2% in 12 hours or 1% in 100 hours.

For calibration to radiant flux, an absolute calibration value traceable to a national institute must be available. Hitherto, neither the PTB nor NIST were able to offer such a value for the UVB and UVC ranges. Consequently, Instrument Systems implemented this radiant flux calibration itself. The traceability of UV-ACS to radiant flux is achieved by extremely precise calibration of the spectrometer optical probes used to the irradiance and integrative measurement with a goniophotometer. The extremely low measurement uncertainties (k=2) of only 4.5% (UVC), 3.5% (UVB) and 2% (UVA) for the UV-ACS are comparatively low as in the metrologically unproblematic visible range. With this achievement, Instrument Systems has earned a worldwide position as pioneer in radiant flux calibration in the UVA, UVB and UVC range.

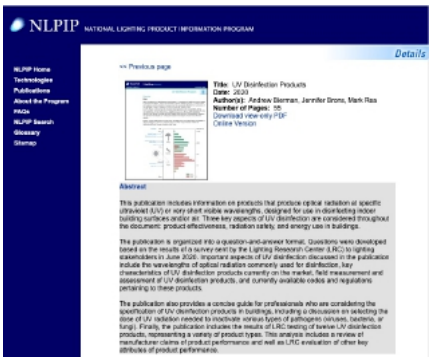
Video: https://www.youtube.com/watch?v=VD76IbiKGfs

About Instrument Systems GmbH:
Instrument Systems GmbH develops, manufactures and markets turnkey solutions for light measurement. Its main products are array spectrometers, imaging photometers and colorimeters. Key applications are LED/SSL and display measurement, as well as spectroradiometry and photometry. Products of the Optronik line for the automotive industry and traffic technology are developed at the Berlin facility. Since 2012 Instrument Systems has been a wholly owned subsidiary of the Konica Minolta Group.

For further details refer to: Instrument Systems Optische Messtechnik GmbH, Kastenbauerstr. 2, 81677 Munich, Germany. Phone: +49-89-454943-0, sales@instrumentsystems.com, www.instrumentsystems.com ■

UV-C Report from Lighting Research Center

This publication includes information on products that produce optical radiation at specific ultraviolet (UV) or very short visible wavelengths, designed for use in disinfecting indoor building surfaces and/or air. Three key aspects of UV disinfection are considered throughout the document: product effectiveness, radiation safety, and energy use in buildings.



Full report: https://www.lrc.rpi.edu/programs/NLPIP/lightingAnswers/pdf/view/LA_UVDisinfection.pdf or https://www.lrc.rpi.edu/programs/nlpip/publicationDetails.asp?id=949&type=2

The publication is organized into a question-and-answer format. Questions were developed based on the results of a survey sent by the Lighting Research Center (LRC) to lighting stakeholders in June 2020. Important aspects of UV disinfection discussed in the publication include the wavelengths of optical radiation commonly used for disinfection, key characteristics of UV disinfection products currently on the market, field measurement and assessment of UV disinfection products, and currently available codes and regulations pertaining to these products.

The publication also provides a concise guide for professionals who are considering the specification of UV disinfection products in buildings, including a discussion on selecting the dose of UV radiation needed to inactivate various types of pathogens (viruses, bacteria, or fungi). Finally, the publication includes the results of LRC testing of twelve UV disinfection products, representing a variety of product types. This analysis includes a review of manufacturer claims of product performance and well as LRC evaluation of other key attributes of product performance. ■

RESEARCH

Repro-light Consortium Concludes

The European research project Repro-light concludes after a three year journey which began in 2017. The consortium set out with the aim of supporting the European lighting industry in moving towards a more sustainable and competitive future. The project harnessed innovative technologies and materials to develop intelligent modular luminaires with matching smart production processes. The main components of these luminaires are interchangeable and configurable for the respective application (e.g. different LED modules and optics), and their software can be updated accordingly. The LED luminaire can change from a disposable object, into a customisable and sustainable product, with a high function value.

This modular 'Luminaire of the Future' provides the right light for our working activities, at the right place and at the right time of the day, adopted to our individual needs (personalized). It improves mood and productivity, and can positively influence our body's circadian rhythm, which has a big impact on our health.

The research demonstrated a demand for improved and personalized lighting in society, and detailed scientific studies with a test population to confirm the positive impacts of such lighting on humans. The life cycle studies showed that there is a big potential to decrease the environmental burden of lighting by a smart and sustainable development and production process, and by careful material management (reusing of components, recycling, waste).

Led by representatives and driving forces from the European lighting industry, as well as manufacturers, experts on lighting sustainability and the social sciences, the Repro-light consortium executed this project successfully, to invoke a sustainable change in the European lighting industry well beyond the lifetime of the project.

The following outlines the achievements and outcomes presented by the consortium members detailing their findings and recommendations.

The Luminaire Manufacturing and Characteristics Specification developed and validated a specific technology model for lighting solutions: TAMLIGHT. An extensive European wide user survey (1100 workers) was done to fully understand the market demands for better lighting. Results derived from this large sample survey identified people in Europe expected better, personalizable and adaptable luminaire solutions in their workplace for the future.

The results produced analysis and definition of the individual and technical requirements for more sustainable and competitive lighting.

The results revealed the importance of connected lighting to realize a Repro-light system. Both wired connectivity and wireless connectivity received the highest ratings as design attributes. Dynamic lighting for changing light in all dimensions (intensity, color, direction) also scored highly along with, exchangeable and upgradable components, and firmware. The results concluded that the rating for these design attributes are driven by strategic requirements for circular economy of Repro-light systems. Efficiency was found to be not the most important design attribute but still attracted a medium-high rating.

Product and Process Design

The consortium partners developed a modular architecture for a continuous line luminaire, which maximises product variants out of a minimal set of components. To bring the full benefit of such a modular system to the customer, a configurator was designed. This allows the configuration of luminaire characteristics freely, generating all necessary technical data and manufacturing data as needed, and has a direct interface to the production line. Further developing the customisable luminaire concept by designing 3D-printed decorative and functional elements that can be manufactured according to the customer's definitions. Investigations were also carried out for components of pointed luminaires in order to support modularity and customisation for such luminaires. Another driving force behind the modularisation was to increase the sustainability by elongating the usage time of the luminaire. However, in collaboration with the environmental assessment specialists, it was found to be not always the optimal approach.

A second luminaire architecture, the Personal Table Light (PTL), was developed to specifically improve workplace lighting and exploit the effects of light on the well-being and health of humans. The PTL achieves exceptional lighting for vision and health at the workplace and is fully personalized by the user via a desktop application. It is a user-centered, intelligent lighting system allowing a very flexible control of the illumination of table surface and back-wall, adjusting illuminance level, color temperature and light distribution. Integrated sensors and control systems estimate the current user activities and automatically adjust the lighting in line with the user's needs.

Smart Production Scheme for Industry 4.0

A fully automated production scheme was developed for continuous line luminaires with 400,000 variations. In contrast to methods of the past, when large quantities were produced for one type of luminaire, LED technology offers the advantage but also the challenge of a large number of variants. Therefore, the aim was to create a modular and thus largely flexible automatic production line.

One of the challenges was the connection between the configurator software and the automated production line, so that in extreme cases up to quantity 1 an automated assembly would still be possible. Several workstations were realized, examined and installed in a semi-automated pilot production line.

Furthermore, the highly customisable 3D-printing production for the morphing of polygonal geometries of bio-inspired shapes, has been integrated into the developed pilot production line to ensure an in-time production and availability of 3D printed components.

The results revealed a well-developed, customisable cost effective production, where the connection between the luminaire configurator, the ERP system, and the assembly line itself provided the key benefit for a smart production line. Thereby allowing automated and cost effective production for LED luminaires irrespective of multiple variants.

Environmental Assessment

The sustainable environmental performance of Repro-light luminaire designs in an industrial setting was assessed using LCA methodology, to consider the production, use and the end-of-life stages. The results showed an impact reduction of approximately 30% in the environmental categories related to climate change, primary energy demand and harm to ecosystems. This is because the electricity consumption in the use phase of the luminaire was reduced due to a novel light management system (daylight and presence control) and higher luminous efficacy. A further significant improvement was achieved in the production stage, since the impact associated with the natural resource consumption (minerals) was decreased significantly by 60%. This was attributed to a new design in the modular architecture of the luminaire to save materials (steel, plastics, etc.) and avoid the use of precious materials with a high environmental burden, such as gold in the LEDs.

The results further supported the luminaire eco-design which was another key focus of the Repro-Light project. The environmental assessment also was carried out in line with the circular economy by means of studies on the LED module exchangeability to know how this new characteristic influences the environmental performance of the luminaire in its life cycle. A key finding notes that additional efforts are necessary at the end-of-life of the design to improve material recovery as a secondary source. This is vital to minimize the virgin material extraction used in electronic components to enhance the circular value of the luminaire.

In summary, the raw material balance (abiotic resource depletion), the metals used for electronics and LED-boards and their recycling rates are mainly decisive (rare earths, as well as gold, silver, copper, nickel, lead and aluminum and their by-metals). A resource shortage is threatening in the case of gold and silver and the rare earths. As far as the toxicity of the materials used is concerned, the mining of rare earths (toxic sludges) and uncontrolled contamination with copper, iron, lead, nickel and silver are crucial.

For all other environmental burdens such as CO_2 pollution (global warming), primary energy consumption, soil acidification and eutrophication, the operation of the luminaires (energy consumption) is responsible for about 98%.

The technological acceptance and usability of the developed workplace lighting solution (Personal Table Light, PTL) has been proven in a field study, and the expected non-visual effects of the PTL have been investigated in laboratory studies with a test group. To achieve the necessary daily light dose, special "light showers" were applied to the study group and the acute effects were measured.

The Repro-light consortium successfully achieved the objectives of the project to offer a luminaire scheme to minimize the ecological footprint of LED lights. Specifically taking into consideration the extraction of raw materials for a circular economy, increased maintenance, reuse and reprocessing, all before the product design stage to avoid waste and environmental pollution.

Looking beyond the state of the art technology developed and analysing the

results and potential impacts (including the socio-economic impact and the wider societal implications of the project so far), Repro-light confirms the demand for an easy to use, customisable lighting system, which was realized with a so-called Personal Table Light (PTL). Currently with patent pending, the PTL has the potential to transform workspace lighting worldwide. The results regarding automation and customisation in production will push lighting manufacturers to a more sustainable and individual modus operandi, including data handling and logistics measures. The results of the life cycle analyses will deeply affect the future luminaire and production designs in the lighting industry.

Further detailed information can be found on the website
https://www.repro-light.eu/downloads

About

Funded through the European Commission's Horizon 2020 work program, the Repro-light consortium consists of leading European experts including; TRILUX, a driving force of the European lighting industry, components manufacturers including BJB, Grado Zero Espace, and Rohner Engineering, innovative members of the lighting industry, Bartenbach and Luger Research, as well as experts in lighting sustainability and Life Cycle Assessment IREC and Mondragon University who are prominent in Social Sciences.

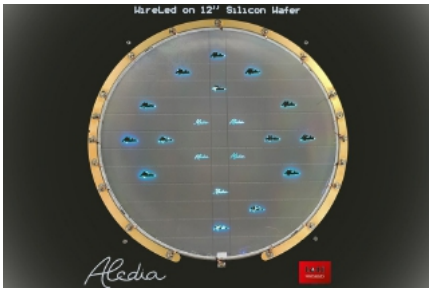
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768780. ■

Aledia Has Produced Its First Nanowire Chips on 300mm Silicon Wafers Using CEA-Leti Pilot Lines

Aledia, a French startup pioneering a disruptive technology for microLED displays, today announced it has manufactured the world's first microLED chips produced on 300 mm (12") silicon wafers. The company, which developed its breakthrough technology on 200 mm (8") silicon wafers over the past eight years, will produce the chips on both 200 mm and 300 mm wafers. The larger wafers provide better economic payoff and cost-effective integration with smaller-node electronics, which are only available on 300 mm silicon wafers. Aledia was spun out of CEA-Leti, a French research institute pioneering micro- and nanotechnologies, in 2012, and the work on 300 mm wafers has been performed by joint Aledia and CEA-Leti teams.

"We believe producing microLEDs on large-area 300 mm silicon wafers is a world's first, and opens this technology to huge potential-volume-manufacturing capabilities," said Giorgio Anania, Aledia CEO and cofounder. "The larger size allows 60-100 smartphone displays to be made on a single 300 mm wafer, versus approximately four-to-six using the present LED industry-standard, 4" sapphire substrate. Thanks to Aledia's unique nanowire LED technology (3D LED), this can be done with commercially available processes and equipment, since it uses standard-thickness (780 µm) silicon wafers."

Traditional planar, "2D" microLEDs are produced by depositing flat layers of gallium-nitride (GaN) crystal on sapphire wafers of 100-150 mm diameter (4-6"), with the majority of production today being on 100 mm (4") wafers. Aledia's microLED technology grows GaN nanowires (GaN crystals of sub-micron diameter) on top of large-area silicon (called "3D"). This 3D nanowire technology does not create any of the stresses seen on 2D chips, which build up as the wafer size is increased, and so allows the use of very large-size wafers. In addition, this silicon-based technology allows production in conventional microelectronics fabs, called silicon foundries, which can be ramped up to high volume production with extremely high yield.



"We are very pleased to have helped Aledia push forward the state of the art of 3D LED manufacturing using our 300 mm silicon processing line. We believe large-area silicon wafers are the best manufacturing platform in the world today for displays, and give big advantages in manufacturability," said Emmanuel Sabonnadière, CEO of CEA-Leti. "3D nanowire micro-LEDs have the potential to make serious penetration into large display markets. CEA-Leti is very active today in supporting the display industry's transition to micro-LED technology."

"We believe the use of large-area silicon wafers and microelectronics foundries are the only way to deliver the huge volumes demanded by end-user markets," Anania said. "For example, if only the large-screen TVs of 60" in diagonal and larger transitioned to silicon nanowire technology to obtain better image quality and lower manufacturing costs, this would require 24 million 300 mm wafers per year, volumes that can only be delivered by the silicon industry and supply chains. Smartphones, laptops and tablets would be on top of that."

Aledia's technology is protected by 197 patent families, making Aledia the leading French startup company in France in filed patents.

This work is sponsored by the EC: Grant Agreement number: 954553 — SPEED — H2020-EIC-SMEInst-2018-2020.

About Aledia:
Aledia develops and manufactures microLED displays and components to equip the 120 billion USD worldwide display market with next-generation technology. Its proprietary 3D microLED technology uses GaN nanowires on large-area silicon that emit light and can be used to manufacture state-of-the-art displays that deliver better performance at competitive prices compared to current OLED technologies. These improvements include longer battery life on mobile devices, better outdoor readability and faster refresh rates, as well as sharper colors. The company is

targeting markets for smartphones, laptops and tablets, augmented reality displays and large TVs. Based in the Grenoble area in France, Aledia has 130 employees. It was spun out of CEA-Leti, the French microelectronics R&D institute, in 2012. - www.aledia.com/

About CEA-Leti (France):
Leti, a technology research institute at CEA, is a global leader in miniaturization technologies enabling smart, energy-efficient and secure solutions for industry. CEA-Leti pioneers micro and nanotechnologies, tailoring differentiating applicative solutions for global companies, SMEs and startups. CEA-Leti tackles critical challenges in healthcare, energy and digital migration. From sensors to data processing and computing solutions, CEA-Leti's multidisciplinary teams deliver solid expertise, leveraging world-class pre-industrialization facilities. With a staff of more than 1,900, a portfolio of 3,100 patents, 10,000 sq. meters of cleanroom space and a clear IP policy, the institute is based in Grenoble, France, and has offices in Silicon Valley and Tokyo. CEA-Leti has launched 65 startups and is a member of the Carnot Institutes network. - www.cea.fr/english ■

EVENTS

LpS Digital – Call for Papers

LpS DIGITAL

LpS Digital has published the Call for Papers. You can now submit your lecture via the LpS Digital website (www.LpS-Digital.global). In addition, exhibitors can also submit their contributions via (submit your exhibits). The partner and sponsor area is also open and they can already make the relevant reservations for 2021.

"For the coming year, we are fully committed to the LpS Digital Event and will be able to offer further interesting and effective collaborations. In addition to the expansion of content, networking opportunities are also being planned. The free content, available 24/7, should give new impulses to the lighting industry and bring new opportunities for the lighting sector. We would like to thank all partners for their cooperation", said Siegfried Luger, LpS Digital Event Organizer. ■

Digital Services Act Latest

The Digital Services Act acknowledges gap in the online product supply chain
The Digital Services Act is a unique opportunity to upgrade our EU rules for eCommerce and make them fit for today's market reality. The current legal framework does not ensure that always within the online product supply chain there is an economic actor who is established in the EU jurisdiction and can be held liable for the breach of EU rules.

"The new Regulation must ensure that only safe, quality and compliant lighting products are placed on the EU market and must prevent the listing or re-listing of non-compliant products," said Ourania Georgoutsakou, Secretary General of LightingEurope. "The European Commission proposal published yesterday acknowledges that online intermediaries need to do more to ensure non-compliant products are not made available to EU customers. We also note the commitment to robust enforcement of the proposed rules, in particular with the introduction of substantial penalties that Member States will now have to establish," she added.

LightingEurope is assessing the new proposed measures and will share its technical expertise with EU institutions to help shape these new measures. LightingEurope's objective is to deliver a positive and fair business and regulatory environment, one that fosters fair competition and growth for Europe's industry and ensures that EU citizens only access compliant lighting products that benefit human comfort, safety and well-being, and the environment.

Background
The European Commission published December 15th its proposal for a Regulation on a Single Market for Digital Services (the Digital Services Act). The draft acknowledges the need to address the availability of non-compliant products online. LightingEurope experts are evaluating the proposals to ensure non-compliant products are prevented from being made available to EU customers. The draft proposals will now be evaluated by the European Parliament and the European Council, who will negotiate and adopt the final version of the text.

For more details, read the position paper: https://www.lightingeurope.org/images/publications/position-papers/Position_Paper_on_non_compliance_of_Products_online_-_20200901.pdf ■

LpS Digital – Conference & Exhibition

LpS Digital is the brand new, unique, and first, digital lighting conference and exhibition available to viewers 24 hours a day, 7 days a week. LpS Digital presents current, high-quality content about lighting technologies, design and applications, and acquaints the viewers with the latest trends in product developments and applications.

Experience the Future of Light

Like the LED professional Symposium +Expo and Trends in Lighting Forum &Show that took place at the Festspielhaus in Bregenz/Austria every year since September, 2011, LpS Digital is meant to approach and support the complete value chain in the global lighting industry. When it comes to Technological Design, LpS Digital's goal is to provide Corporate Managment, Technical Management, R&D and Production/QM within the global lighting manufacturing industry with top notch technical knowhow, primarily on a component level. In terms of Lighting Design, LpS Digital will show best practice for Architects, Lighting Consultants, Electrical Consultants, Lighting Designers, Lighting OEMs, IT/IoT System Integrators and students. The editors focus on Human Centric Lighting, Connected Lighting, Smart Controls, Internet of Things, Light as a Service and much more.

Unique Global Reach in the Lighting Sector

VIRTUAL CONFERENCE
The authors of contributions accepted by the program management will be invited to give a presentation and, if appropriate, to write a qualified article. Each presentation will be announced to the industry and/or design channel contacts and followers immediately after publication.

VIRTUAL EXHIBITION
Virtual exhibitors have the possibility to present their products and/or services. The maximum length of the presentation is 20 minutes. Each product/service video is announced to the industry and/or design channel contacts and followers immediately after publication.

Lighting Industry & Technology Channel

With the Industry/Technology channel, over 30,000 contacts in the lighting sector are targeted and addressed. The opt-in databases are highly selective, highly qualified and address key persons in the respective channel.

- Magazine: 30,000
- Newsletter: 27,000
- Online: 30,000/month
- Twitter: 22,000
- LinkedIn: 11,700

Lighting Design Channel

With the Design channel, over 30,000 contacts in the lighting sector are targeted and addressed.

- Magazine: 30,000
- Newsletter: 15,000
- Online: 5,000/month
- LinkedIn: 4,600

Benefits for Conference Authors

- Global, highly-qualified target group
- Knowledge transfer at a high level
- Ideal platform for expanding the network

Benefits for Virtual Exhibitors

- Global, highly-qualified target group
- Immediate promotion of innovations and novelties
- Participation in the LpS/TiL Awards
- Highly efficient promotion at no risks

LpS DIGITAL

www.LpS-Digital.global

Supporty by

NICHIA

Bluetooth®

Digital Illumination Interface Alliance

ZHAGA Consortium

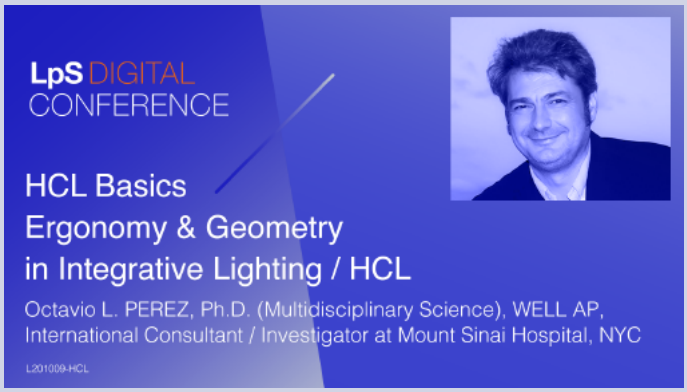
LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

REPRO-LIGHT

austria-architects.com
Profiles of Selected Architects

LpS DIGITAL

Latest conference and exhibition videos published on www.LpS-Digital.global



Latest Trends in Lighting Controls – Towards Bluetooth Mesh

Patrick DURAND, Worldwide Technical Director, Future Lighting Solutions (FLS)

Patrick DURAND
Patrick DURAND is the Worldwide Technical Director at Future Lighting Solutions (FLS) with over 15 years of experience in the solid-state lighting industry. Patrick leads the FLS Technical Marketing team and FLS laboratory teams located in multiple regions around the world with the objective of providing world-class support to lighting OEMs in developing luminaires with the latest SSL technology from the light source to the complete system incorporating the LED driver, optic, thermal management and intelligent control solutions.

Lighting experts repeatedly ask themselves how light control systems should be designed. After a breakthrough in Bluetooth mesh became apparent, we talked to Patrick DURAND who explained the background of the latest trends in the light control sector. In addition, Patrick talked about the basic terms and showed how Bluetooth mesh can be integrated into higher-level building systems. Patrick DURAND is the Worldwide Technical Director at Future Lighting Solutions (FLS) with over 15 years of experience in the solid-state lighting industry.

LED professional: Patrick, thank you very much for the opportunity to do this interview with you on the subject of lighting controls. To start off, we'd like to define and assign the terms correctly. There are interface protocols for LED drivers in luminaires, but on the other hand, we have more complex control units in rooms and buildings working with BMS systems. What is the correct terminology?

Patrick DURAND: It's always a pleasure to discuss meaningful subjects with the LED professional team. Regarding the topic of lighting controls, the key challenge that the industry must overcome is the false perception of complexity. This also extends to common terms that we need to employ in order to clearly communicate solutions to customers such as the lighting OEM or end customers such as the facilities manager. For simplicity, the command to instruct a driver to turn on, off and dim to a specified level whether it is via DALI, 0–10 V, PWM or phase control is a dimming signal. For 0–10 V and phase control, it's an analog dimming signal where for DALI and PWM it's a digital dimming signal.

However, DALI-2 and by extension D4i, have incorporated additional functionality such as energy monitoring and driver diagnostics data that also make DALI-2 and D4i a protocol. Therefore, the dividing line between a dimming signal and a protocol is whether the command can be leveraged for multiple use cases as well as processed and transformed to trigger decisions or send additional data points. As an example, a dimming signal has a singular use case, which is to control the output current of the LED driver. Once the dimming signal is processed and executed, there are no data transformations or additional data points to be returned. Alternatively, the energy metering data from a D4i compatible LED driver that is sent over the DALI bus can be processed and transformed to a Bluetooth mesh data set via a compatible controller and further transformed to a BACnet IP [1] or Cloud compatible data set via a gateway, which can trigger automatic or manual decisions that impact how a building operates.

D4i, Bluetooth mesh, BACnet IP for building management systems and MQTT [2] for accessing the Cloud are all important and available protocols that can interact in order to implement a broad lighting control strategy that is flexible enough to meet the needs of the end customer. The key success factor is how to enable this in a simple and risk-free manner from the project definition phase to the installation and post-installation phase. This is where we've been focusing our efforts, which is to develop a robust pain-free ecosystem.

LED professional: For a long time, it wasn't clear which control system would prevail. Now Bluetooth mesh seems to be the winner. What is your opinion and why has Bluetooth mesh been able to push itself to the fore?

Patrick DURAND: Indeed, the days of the lighting control wild west are nearing their end where Bluetooth mesh is the dominant technology. This can be attributed to three factors. The first factor is that gateways are not required to implement a Bluetooth mesh network. A gateway necessarily introduces an element of complexity and cost that facilities managers want to avoid for most small to medium sized projects. Gateways, which is the case for traditional ZigBee networks, can introduce a potential single point of failure since ZigBee gateways are also managing how the data is communicated within the network. Being able to clearly state that with Bluetooth mesh a gateway is not required for commissioning nor to control the lights resonates with facilities managers. **Figure 1** illustrates a simple gateway-less Bluetooth mesh system via the Silvair [3] platform that includes a wireless sensor interfacing with an LED driver with optional wireless switch and mobile device. Silvair is a key software technology provider that enables Bluetooth mesh implementations and plays a leadership role in defining and updating the protocol.

The second factor is that Bluetooth mesh is a mesh network based on an interoperable standard. Range and reliability are key attributes for a lighting control protocol to be successful where technologies that support the mesh topology have a significant advantage over point-to-point and star topologies. This is due to the fact that in a Bluetooth mesh network, each node can be a repeater to extend the range of the network where the data can take multiple paths to reach its destination, thus increasing network reliability. Furthermore, Bluetooth mesh is defined at the application layer, mean-

ing that commands and properties share a common definition, which enables multiple vendors of Bluetooth mesh devices to communicate with each other. Having the freedom of selecting from multiple vendors and even commissioning platforms is very important for facilities managers to reduce risk.

The last factor is that Bluetooth mesh integrates Bluetooth Low Energy, which is supported on every mobile device, to commission and control luminaires via simple mobile Apps without the need of additional hardware. Convenience, simplicity and a pleasant user experience are key attributes of any successful platform where Bluetooth mesh is ideally positioned for meeting these expectations. Furthermore, Bluetooth mesh has benefited from the global Bluetooth brand, which is synonymous with low-cost reliable wireless technology.

LED professional: What possibilities are there for connecting Bluetooth mesh systems to the Cloud in a cost-effective way?

Patrick DURAND: This is another benefit of Bluetooth mesh. Since the protocol doesn't require a gateway to manage the network, it's possible to develop low-cost gateways in the one-hundred-dollar range. ZigBee [4] gateways, which typically cost several hundred dollars, are essentially Linux-based mini-computers because they require the processing power to also manage the network traffic. With a simplified gateway architecture, Bluetooth mesh can help remove the initial resistance of installing gateways in a project. These lower-cost Bluetooth mesh gateways are expected to launch in the first half of 2021.

Once the Bluetooth mesh gateways are installed and securely connected to the Internet, facilities managers can subscribe to free and/or paid services that bring value to the organization that either reduce cost, enhance revenue, provide convenience or integrate with existing building management systems. And since each gateway can connect to several hundred nodes (sensors, controllers, switches), the incremental cost of the gateway hardware becomes negligible. The key value proposition is that the system is ready to evolve once the need is identified without having to install additional hardware.

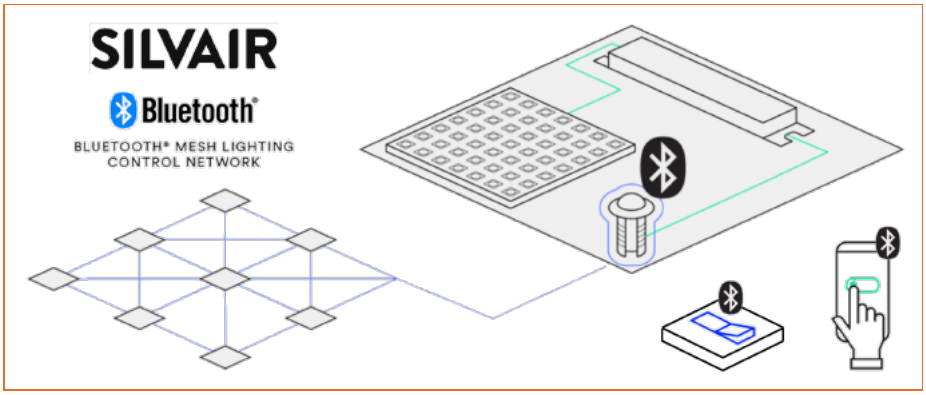


Figure 1: Making Bluetooth mesh function without a gateway via the Silvair platform

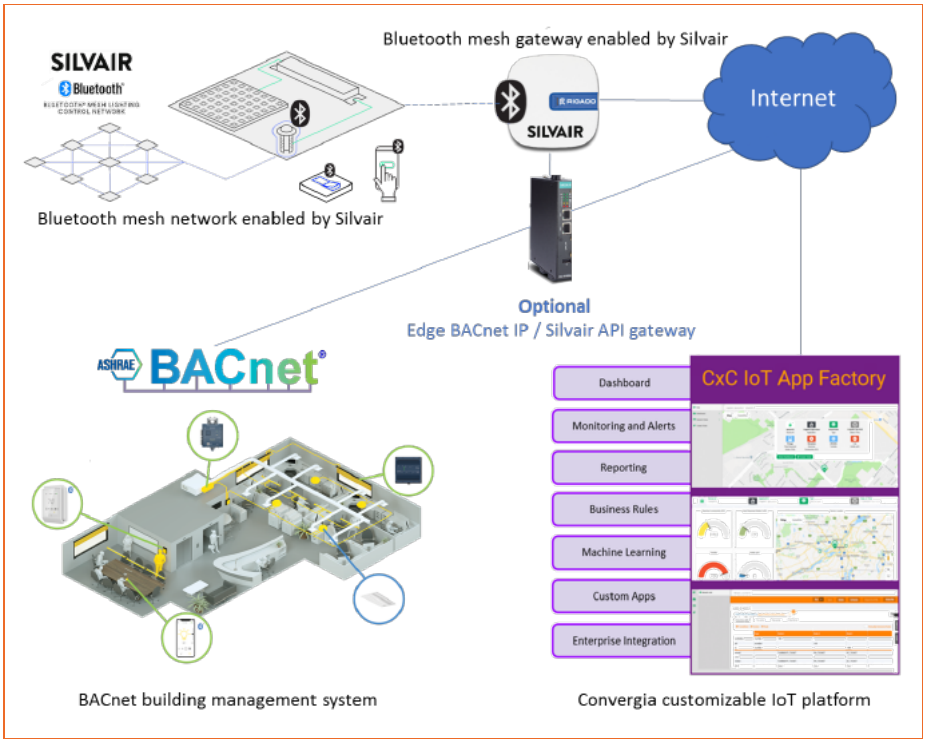


Figure 2: Interfacing Bluetooth mesh to BACnet via the Cloud and/or Edge gateway

LED professional: Could you talk about the connection and integration of Bluetooth mesh systems into BMS systems?

Patrick DURAND: Bluetooth mesh can be considered to be a disruptive technology because it can fundamentally change how lighting controls and, to a larger extent, how building management can work in the next few years. However, for any disruptive technology to be successful, it must first embrace the incumbent technology in a transitional step.

From a building management system standpoint, BACnet is the globally dominant protocol. One additional benefit of low-cost gateways is that they provide the mechanism to bridge Bluetooth mesh and BACnet or other BMS in the Cloud via application programming interfaces (APIs). APIs define how different software platforms can interface via clear sets of instructions on how to send data to another software platform as well as receive and process data from that platform. Alternatively, if the facilities manager does not want to leverage the Cloud, it's possible to bridge Bluetooth mesh and BACnet via an Edge BACnet IP gateway where only one of these gateways is required per building to minimize costs (**Figure 2**). System integrators, IoT services companies and many ESCOs leverage APIs to enable the connection of multiple systems via a single user interface. Future Electronics has partnered with its sister-company,

Convergia [5], to provide system integration services to customers by leveraging the Cloud via their IoT App Factory platform or via Edge BACnet IP gateways.

LED professional: What is the potential of Bluetooth mesh evolution to natively support HVAC functions in future updates to the standard and its impact on IoT services?

Patrick DURAND: When the specification for Bluetooth mesh was initially released in July 2017, only lighting controls was being targeted by the standard. However, with the launch of version 2 of the mesh device properties specification in September 2020, Bluetooth mesh now supports a wide range of temperature and environmental sensors such as ambient temperature, relative humidity, carbon dioxide, volatile organic compounds, ambient noise, pollen concentration and many more.

As a result, cost effective environmental sensors can be developed and placed throughout the building and communicate to the BMS via a low-cost Bluetooth mesh gateway for supporting HVAC functions. As the adoption of Bluetooth mesh grows, the standard itself will surely evolve to support HVAC features more natively, beyond sensors. When this happens, which may admittedly take a few more years, facilities managers may transition from a Bluetooth mesh plus BACnet ecosystem to a Bluetooth mesh plus Cloud ecosystem, which will lower costs and provide more flexibility, rich data sets and increased opportunities to generate value.

LED professional: UV lighting is a growing market area. How can Bluetooth mesh support lighting controls for UV lighting?

Patrick DURAND: In environments like hospitals, schools, gyms, hotels and offices, germicidal UV lighting fixtures are being installed to disinfect surfaces. These luminaires need to be turned off when the room is occupied to prevent overexposure of harmful UV-C rays. Bluetooth mesh can play a critical role in implementing a safe germicidal system. As a starting point, Bluetooth mesh supports networked sensors where if only one of several sensors within a zone detects occupancy, all the luminaires will be turned off. The UV luminaires would only turn on when every sensor within the zone detects vacancy. **Figure 3** illustrates how to simply setup this desired sensor functionality with the Silvair Bluetooth mesh lighting control tools.

The safety aspect of the sensor network can be enhanced with gateway-based scheduling where for high traffic periods during the day, the UV lights will be turned off regardless of the occupancy status of the room. Gateway-based scheduling is important in case of a power failure as the gateway can resynchronize the time from the Internet once power is restored. If there is an interruption in Internet service, the scheduled events can still occur since the Internet is not required to run the scheduled events.

The Cloud can also play an important role in validating the effectiveness of the germicidal system by measuring the energy consumption of the UV luminaires and sending the information to the Cloud. The energy consumption data can then be leveraged to validate that the UV lights were in fact turned on or to detect whether there is a UV luminaire failure, which would trigger an email or SMS text message to the facilities manager or other maintenance team member.

LED professional: How does Bluetooth mesh address last mile ecosystem integrator/installer solutions for lighting OEMs who only want to integrate a hardware sensor/controller device in the luminaire and want to outsource installation, commissioning, and IoT BACnet integration to 3rd parties?

Patrick DURAND: This is a very important question. A significant proportion of lighting OEMs don't have the resources or willingness to invest in creating a team or a network of partners that will install, commission, and optionally support the integration of intelligent luminaires with building management systems or IoT services. These lighting OEMs are simply waiting to receive guidance from the specification on which controller or sensor to include in the luminaire where the installation, commissioning and support of the project is the responsibility of a different organization. It is there that lies the friction to wide market adoption due to the perceived risks.

For Bluetooth mesh to be successful in the mainstream lighting world and to accelerate its success, it's important to provide options with a clear path from installation and commissioning to integration with BMS and IoT services. Convergia, Future Electronics' sister-company, fills the service gaps by providing services for project setup, on-site commissioning, integration with a BMS or IoT services with custom dashboards and reports supporting various business rules and more. It will still take a few more years for a critical mass of specifiers, lighting agents, contractors, installers, system integrators and ESCOs to be made aware and knowledgeable enough to promote and support Bluetooth mesh and its growing ecosystem. However, the road to that inevitable end has begun. We are investing in taking the tangible steps of making this vision a reality.

LED professional: DALI-2, in conjunction with D4i, has a strong presence at the driver and luminaire level. What are your thoughts about this and how do DiiA (DALI Alliance) and Bluetooth SIG [6] cooperate?

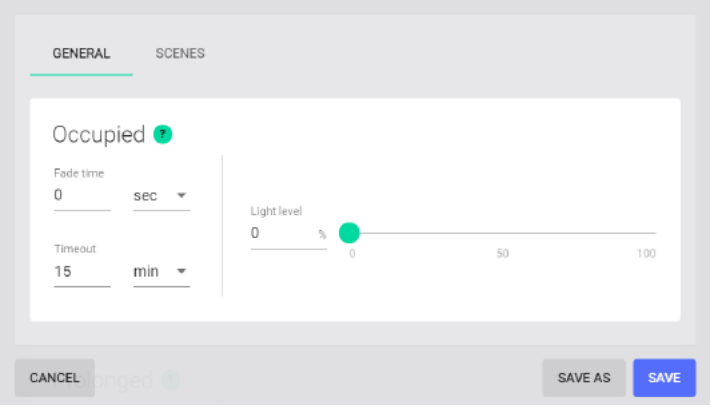


Figure 3: Setup to turn off UV lights when occupancy is detecting via the Silvair Web App

Patrick DURAND: The DiiA (DALI Alliance) [7] and Bluetooth SIG announced their cooperation in May 2020, which was then followed by the launch of version 2 of the mesh device properties specification in September 2020. What the cooperation has achieved is a standardized way of reading the energy consumption, diagnostics and other data from DALI-2 and D4i compatible drivers while also being able to control them (**Figure 4**). Standardizing the interface between both protocols has 2 major benefits. The first is that it accelerates the development cycle for designing compatible in-fixture Bluetooth mesh sensors and controllers that are connected to the DALI-2 or D4i LED driver. The second, which is even more important, is that it ensures interoperability between the 2 protocols, thus eliminating risk that the controller or sensor won't be able to reliably read and control the driver.

Even if the facilities manager is not prepared to invest in interfacing the Bluetooth mesh lighting control system to a BMS or the Cloud, it may still be advisable to leverage D4i LED drivers with compatible Bluetooth mesh sensors and controllers. As an example, it's possible to read and display D4i driver data such as present and cumulative energy consumption directly from a mobile device without requiring a gateway (**Figure 5**). However, the real advantage of leveraging D4i drivers in a project is that it provides the flexibility and option to seamlessly enhance the lighting control system if the facilities manager decides at a later date to implement a BMS or IoT strategy.

Figure 5: Reading D4i energy consumption on mobile device without gateway via the Silvair mobile App

LED professional: Examples of Cloud services have been presented over and over again but it seems that somehow it hasn't gone down well. What is the reason for this and what are the real, practical ways to generate revenue with Cloud services?

Patrick DURAND: The greatest challenge that Cloud services need to overcome is one of habit. For decades, the lighting control technology had typically been 0–10 V, PWM, phase control, or DALI dimming signals, which are cost effective and there are no recurring fees. Therefore, time was required for the industry to accept the concept of lighting as a service (LaaS). What complicates the transition to a LaaS business model is that the lighting world doesn't fundamentally understand the IoT world and the IoT world still requires time to understand the nuances of the lighting world beyond the bits and bytes of data exchange. Progress is being made to bridge the gap but more time is required in some cases.

Ultimately, facilities managers are trying to minimize the risk associated with their decisions, and the greatest risk is that their lighting control investment is not yielding the expected benefits. However, the Cloud itself is ideal in providing data for justifying the investment. As an example, by leveraging occupancy sensors, business objectives can consist of lowering energy costs by turning off the lights in vacant rooms, optimize office layout by converting meeting rooms to office space if the meeting rooms are seldom occupied, evaluate the success of a marketing campaign in a retail store based on foot traffic, and many more use cases. The data stored on the Cloud can be leveraged to track the energy savings, utilization rate of each room in a building, the occupied rate of various departments within a store to make informed decisions that will benefit the organization. The facilities manager can then properly position the benefits of the Cloud system to executive management with the help of data to justify the benefits claims. **Figure 6** illustrates a fully customizable multi-site gas station Cloud-based system implemented by the Convergia IoT App Factory. This solution is able to successfully integrate lighting, HVAC and other functions such as refrigeration in a single dashboard with customized reports, scheduled events and business rules to send out email and SMS text message alerts.

By definition, a Bluetooth mesh Cloud-based system is the least risky approach for the reason that it supports low-cost gateways. The way Cloud services reduce risk is that, once the gateways are installed, if the service is not generating the expected value, the facilities manager can simply cancel the subscription. There are no extra hardware costs that remind the facilities manager of a failed investment. Furthermore, some Cloud-based services are free of charge such

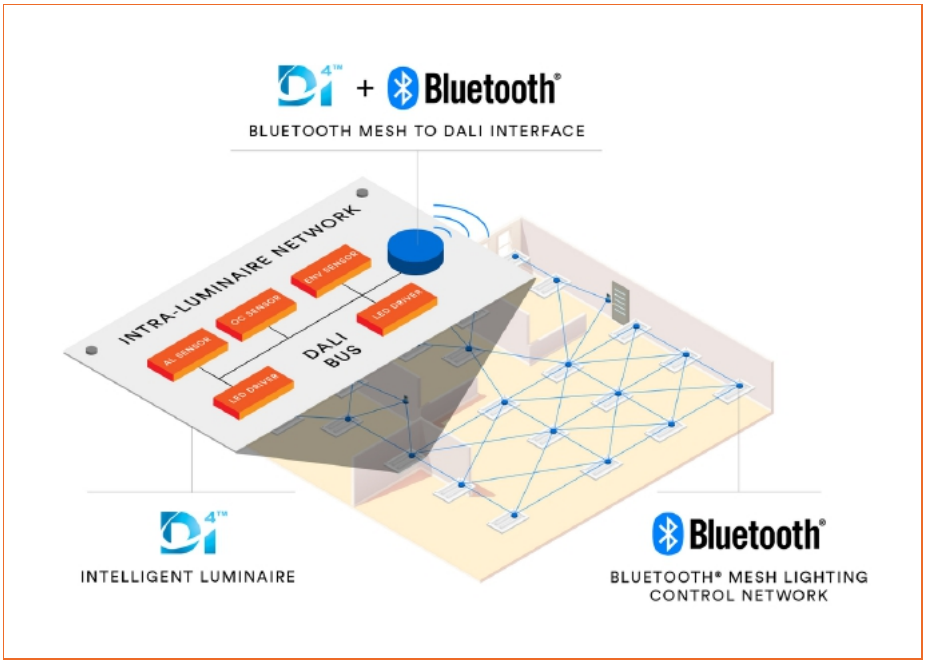


Figure 4: Bluetooth mesh to DALI-2 and D4i interface (courtesy of Bluetooth SIG)

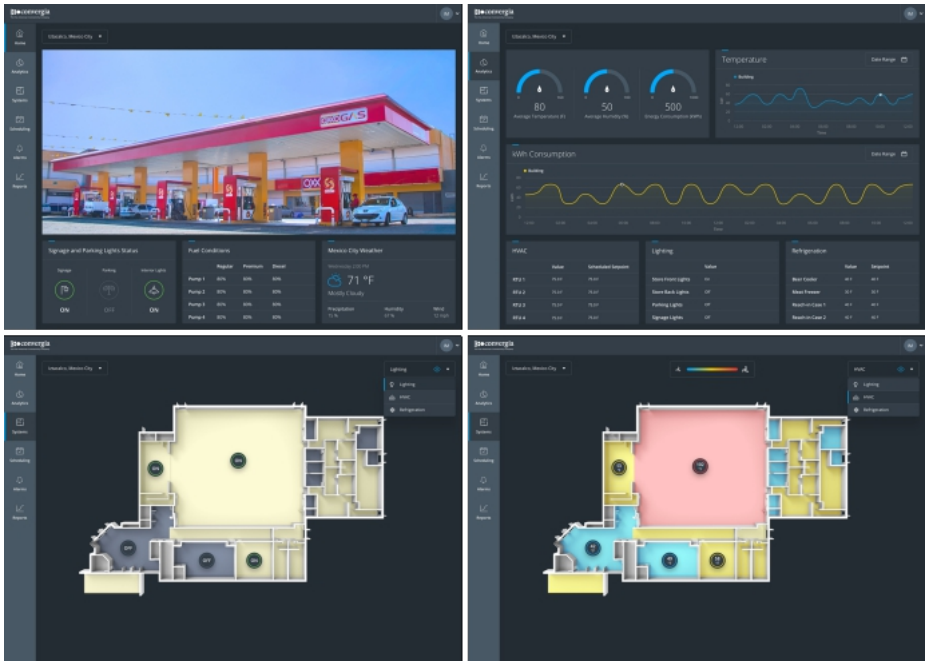


Figure 6: Multi-site Cloud services integrating lighting and HVAC via Convergia's IoT App Factory platform

as server-based scheduling, remote control and remote reconfigurations, which is what Silvair offers as a standard business model to minimize the perceived risk of proactively installing gateways. These basic free services alone can make the purchases of a limited number of low-cost gateways a worthwhile investment.

LED professional: Future Electronics offers a broad range of solutions for lighting controls, especially for Bluetooth mesh. What are the absolute TOP novelties in this field that will be launched on the market?

Patrick DURAND: Once the acceptance of the Cloud becomes more prevalent for lighting controls, the ability to interface a Bluetooth mesh system with other Cloud or building management systems will lead to significant innovation. One example is leveraging the driver diagnostic data from D4i drivers and interfacing with an enterprise ticketing support system such that when a problem with a luminaire is detected, a maintenance worker is automatically assigned to address the issue with details of the problem so that it can be resolved efficiently. Alternatively, if snacks or drinks have been ordered during a meeting, the Cloud system can dispatch the cleaning staff via the ticketing system once vacancy is detected in order to clean and prepare the room for the subsequent scheduled meeting.

A second novel example that is being explored and implemented by several large organizations is addressing the challenge of maintaining social distancing for the safety of occupants in an office, hospital and cruise ship environments due to COVID-19. The Bluetooth mesh standard supports the people counting property for compatible sensors where there are also other technologies that can determine the room occupancy count by the number of cell phone signals in the room. This information can be sent to a Cloud-based system that will inform key individuals via an SMS text message or email who can then politely ask some of the room occupants to disperse if the room occupancy has exceeded a threshold amount.

A third example consists of leveraging the wide range of environmental sensor properties from version 2 of the mesh device properties specification and apply them in an LED greenhouse project. A Cloud-based system can capture temperature, humidity, CO_2, and ambient light data from Bluetooth mesh sensors and interface with greenhouse control and irrigation systems via APIs in order to automate climate control and luminaire light levels to maximize crop yields and profit. There are many possibilities for innovation as long as the value proposition is clear and meaningful. The technology is ready and the market acceptance is increasing.

LED professional: Many thanks for a very interesting exchange!

Patrick DURAND: My pleasure, as always. I'm definitely looking forward to 2021 to see how Bluetooth mesh will penetrate the lighting market in a significant way. Thank you. ■

References

[1] http://www.bacnet.org
[2] http://www.mqtt.org
[3] https://www.silvair.com
[4] https://www.zigbeealliance.org
[5] https://www.convergia.io
[6] https://www.bluetooth.com
[7] https://www.dali-alliance.org
[8] https://www.futureelectronics.com
[9] https://www.futureelectronics.com/en/our-solutions/lighting-solutions

About Future Electronics

Future Electronics **[8]** is a global leader in electronics distribution, recognized for providing customers with global supply chain solutions, custom-tailored engineering services and a very extensive variety of electronic components. Founded by Robert G. Miller in 1968, Future Electronics believes its 5000 employees are its greatest asset, with 170 offices in 44 countries. Future Electronics is globally integrated, with a unified IT infrastructure that delivers real-time inventory availability and access to customers. With the highest level of service, the most advanced engineering capabilities, and the largest available-to-sell inventory in the world, Future's mission is always to Delight the Customer®. For more information, visit www.FutureElectronics.com.

About Future Lighting Solutions

Future Lighting Solutions (FLS) **[9]** is a leading provider of solid-state lighting technologies, engineering expertise and online simulation and design tools. FLS's mission is to facilitate application development and accelerate customers' time to market. FLS's comprehensive portfolio includes a broad selection of LED system components, and integrated solutions that enable our customers to manufacture cost effective, energy efficient lighting applications. FLS provides a comprehensive range of LED light sources, including high-power LEDs, mid-power LEDs, low-power LEDs, CoB, LED arrays, LED modules and LED light engines. FLS's portfolio is completed with a range of optical solutions, LED drivers, passive and active thermal solutions, connectors and controls.

International Solid State Lighting Alliance (ISA)

Who we are?

ISA is a non-for-profit organization consists of regional alliances, association/society, leading companies and renowned universities in global Solid State Lighting (SSL) field.

The Business of ISA members have covered the whole SSL value chain of upstream, middlestream and downstream of global SSL industry such as epitaxy, packaging application, materials and equipment, design system integration and testing etc.

Currently, ISA has 82 members, representing more than 4000 individuals & organizations includes major players (such as Philips, Osram, Smsung, GE Lighting, Cree, Veeco, AIXTRON etc.). The output of which covers more than 70% that of global SSL industry.

The ISA Board of Advisers consists of leading experts and academic "Founder" level experts, such as the inventors of blue LED, yellow LED, Red LED, and OLED. Amongst Professor Shuji Nakamura, the Laureate of Nobel Prize in Physics in 2014 is the Co-Chair of ISA Board of Advisors (BOA) and Professor Hiroshi Amano the Laureate of the Nobel Prize in Physics in 2014 is the member of ISA BOA. The current president of ISA is Dr. Jianlin Cao, the former vice minister of Ministry of Science and Technology, China.

The Mission of ISA

Cooperation with the global resources and efforts, ISA looks forward to fostering a more appropriate "eco-system" for the health development of the global SSL and its application. Echo the needs of the society with more added value services to the members. Strive to improve people's living and contribute a sustainable human society.

The Major Work of ISA

- ISA Technical Committee on Standardization (TCS)
- Global SSL Industry Reports
- International/Regional Cooperation on SSL
- Global SSL Awards (Award of Outstanding Achievement for Global SSL Development; Award of Global SSL Showcase TOP 100)
- ISA-ECC Smart Street Lighting System Specialized Committee
- ISA LiFi Committee
- Global SSL Forums and training workshops
- The Secretariat of the BRICS SSL Collaboration Working Group

Please visit www.isa-world.org for more information

Connect with ISA

If you would like to join ISA or participate in ISA's activities, technical workshops, international seminars etc. please contact the Secretariat at secretariat@isa-world.org.

The Secretariat:
Address: No.1305, Block 2D, Zhongguancun IC Park, No. 9 Fenghao East Road, Haidian District, Beijing, China (100094)
Tel: 86-10-62607581
Fax: 86-10-62607258
Email: secretariat@isa-world.org
Website: www.isa-world.org

LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

LightingEurope Guidelines

Are you ready for the new EU requirements applying in 2021?

LightingEurope supports all companies to understand and apply new and complex rules and helps all authorities to enforce them.

Download our guidelines on

- Ecodesign Regulation (update in Sep 2020)
- Energy Labelling Regulation (update in Sep 2020)
- Radio Equipment Directive
- European Product Registry for Energy Labelling (EPREL)

www.europeanlightingpriorities.eu/guidelines
www.lightingeurope.org

Measuring the User Acceptance: User-centered Methods and Co-creation Processes in Luminaire Development

There is a growing awareness of the value that users and different stakeholders have throughout the process of developing new products or services. Therefore, companies from a wide variety of sectors increasingly rely on user-centred design methodologies [1] to measure the impact of the product or service before launching. This approach makes it possible to receive user feedback during the entire design process and to adapt the products more closely to user needs.

The contribution and impact that user participation can have on innovation processes have already been widely validated [2,3]. Even so, user participation in these processes can be very complex and, if not executed with the appropriate techniques and in a planned manner, consume significant resources [4]. Within the European Project REPRO-LIGHT (Re-usable and re-configurable parts for sustainable LED based lighting systems), different techniques and tools have been used to assess user preferences and explore future luminaire features. These tools have been integrated throughout the different phases of the design process to develop new innovative and sustainable concepts for the LED lighting industry. First, based on the results of a Europe-wide end-user survey on current workplace lighting [5], the prototypes of the new office desk concept called Personal Table Light (PTL) were developed. Then, longitudinal tests were carried out with the participation of real users in a real office environment over several weeks, collecting user acceptance data continuously (e.g. logging data of how users change the workplace light setting, subjective acceptance ratings of different features of the luminaire collected via regular web-surveys). The process was completed with a focus group session with the users who participated in the longitudinal test. This focus group session aimed to establish qualitative acceptance ratings of the product, discuss the obtained results from the longitudinal test and explore the next development steps for the luminaire. This article focuses on the user-centred design participation process that has been carried out during the advanced phases of the REPRO-LIGHT project.

Introduction

The lighting industry is undergoing a profound transformation, where the future of the industry seems to be even more competitive. Companies are proposing new solutions to improve wellbeing, developing more innovative concepts, where sustainability is an additional key element. In addition, the increasingly important Information and Communication Technologies (ICT) place increasingly higher product demands on user integration. Under these aspects, one of the challenges into these new paradigms is to integrate the User-Centred Design (UCD) approach into the current design processes. The UCD concept is a broad term to describe design processes in which stakeholders take part and influence the final solution of the design. Including the user perspective will ensure that innovative lighting designs fulfil the real needs of users, and there are many tools and techniques to do so, such as, surveys, focus groups or user testing.

As part of the REPRO-LIGHT project, both the technology acceptance and usability of the developed workplace lighting solution (Personal Table Light; PTL) should be evaluated. For this purpose, a specific longitudinal, uncontrolled usability and acceptance field study was carried out in two European countries (Spain and Austria).

After the field studies, different focus groups were carried out with field study participants. These specific focus groups aimed to measure the impact of the PTL in the work performance and wellbeing of the users and their acceptance of the technology, as well as get a better understanding of the field study results.

Personal Table Light

In 2018, 5 focus groups with specially selected participants and an end-user survey [5], which was answered by more than 1,000 people across Europe, were carried out to determine the requirements for future workplace lighting. As a result, there was a great demand for improved workplace lighting in the sectors of visual light quality, customization of lighting settings and non-visual effectiveness. Based on these results, the Personal Table Light was developed. The PTL's basic idea is to convert workplace lighting from general lighting (the same luminaire that is normally mounted on the ceiling for everyone in a room) to individual lighting on the user's desk. In this way, not only would individual workplace lighting be possible without social conflicts occurring among neighboring end users due to different lighting preferences, but due to the close proximity to the user, the high illuminance levels required to achieve non-visual effects would also be realized in an energetically efficient manner.

The PTL incorporates a highly controllable, intelligent LED light engine, which can be adjusted in color temperature (2200–5000 K), illuminance and light distribution separately for the desk and the included rear wall by using a single point control of 24 LED control points. It provides horizontal and vertical illuminances that greatly exceed the minimum requirements used in light planning (up to 1500 lx at the eye level and 6000 lx on the desk). Further, an automatic luminaire control system has been developed to provide the best light setting for varying visual tasks by estimating the user's gaze direction in real time using machine learning algorithms [6] and multiple sensors. Users are able to adjust the automatic settings to their individual preferences at any time by using a desktop app, which pursues the goals of both a deep user integration and full customizability of the workplace lighting.

Using free and highly standardized IT protocols and future-proof sensor technologies such as a depth camera, users are offered a wide range of functions and setting options for personalizing their workplace. This includes:

- *Automatic camera-based presence detection:* Using a depth camera, the presence at the workplace is automatically detected in the near field. By using a camera-based depth sensor system, an incorrect activation of the PTL caused by staying in the wider sensor area or by walking past the workplace is excluded.
- *Automatic adaptation to the current work task:* On the basis of the camera sensors and by means of neural networks, the current gaze direction is derived in real-time and classified with regard to the work task monitor and desk. Depending on the temporal characteristics of the current activity and the current lighting settings, the lighting is then adapted to the user's activity.
- *Manual scene switching:* Using the desktop app provided, users can manually switch scenes at any time and thereby deactivate the automatic system. The options here include activating the task scenes, activating a 15-minute light shower or switching off the light.
- *Customization of the lighting settings:* The predefined scene settings for the task-related lighting can be adapted by the user. When saved, the customized settings are also used as part of the automatic adjustment. The setting options included changing the illuminance, color temperature and light distribution separately for the rear wall and dask areas.

Field study

The field study was carried out as a longitudinal, uncontrolled usability and acceptance study at the premises of IREC (Barcelona, Spain) and Bartenbach (Aldrans, Austria) between June 8, 2020, and August 3, 2020. During the entire study period, the use of the PTLs was not subject to any specifications or restrictions. The lighting settings could be freely adjusted and changed at any time. Manual interventions (e.g. switching scenes or switching off the lights) were permitted at all times. The entire functionality of the devices was freely available for the entire duration of the study.

Figure 1: Personal Table Light (PTL)

The deployment and commissioning of the devices of the field study at the two study locations took place in two phases: a) an initial installation of the PTL at the workplaces with a subsequent four-week beta test phase of the control software and b) a phase of rectification of potential software and hardware problems. Usage data of the PTL and the workstation were automatically collected from all participants over the entire period of use. In addition, in order to get the acceptance rates for luminaire solutions, the users were asked about their

Figure 2: Left: A double workstation equipped with 2 PTLs with differently personalized settings. Right: Different lighting settings for the rear wall (2200 K) and the table (4000 K), © Bartenbach

acceptance and the usability of the device using an online questionnaire, which is based on the Technology Acceptance Model for Luminaires (TAMLIGHT).

A total of 8 people were included in the study. Of the five Austrian participants, three worked in an open-plan office. The remaining 2 subjects occupied a double office. The number of Spanish participants was fully located in an open-plan administrative office. All study periods were individually designed for each participant and based on external regulations.

All participants were fully instructed on the functions and operation of the PTLs before the start of the study. This also included the sensor technology (camera system) used and the associated data processing and storage. All participants signed a confirmation of their consent to participate in the study.

Field Study Fact Sheet For a qualitative evaluation of the system usability, the collected usage data was automatically aggregated to specific parameters and simplified graphics in a fact sheet personalized for each user. As the key figures were calculated in real time, a web app was used to visualize the fact sheets.

Each fact sheet includes distinctive information on key features related to the PTL's usability (**Figure 3**):

- User settings: For both task-related scenes, user-related preference settings were visualized, including the number of saved changes and the maximum length scene retainment. Additionally, the longest retained setting was displayed with regard to its color temperature, average intensity and light distribution separately for the rear wall and desk.
- Mode usage: The higher-level use of the PTL included information on the scene usage and daily on-off cycles. The user interaction behavior is based on the number of daily interactions, manual mode changes and switch-off processes. Additionally, information on the distribution of the scene usage and the scene deactivation behavior was provided.
- Light shower usage: The use of the light shower scene was characterized by the number of usage notifications and manual triggers as well as the total scene usage duration. In addition, information on how often a user activated the light shower after being notified by the system was provided.
- Gaze detection: The output of the AI components for estimating the gaze direction was provided on the basis of the tracking time per day and the percentage of successful gaze assessments in these time periods. In addition, the results of the AI components for each task were given in the context of a total task duration and a continuous task length.
- Occupancy profile: Since the PTL was used to automatically detect presence at the workplace, a complete presence profile could be created for each user,

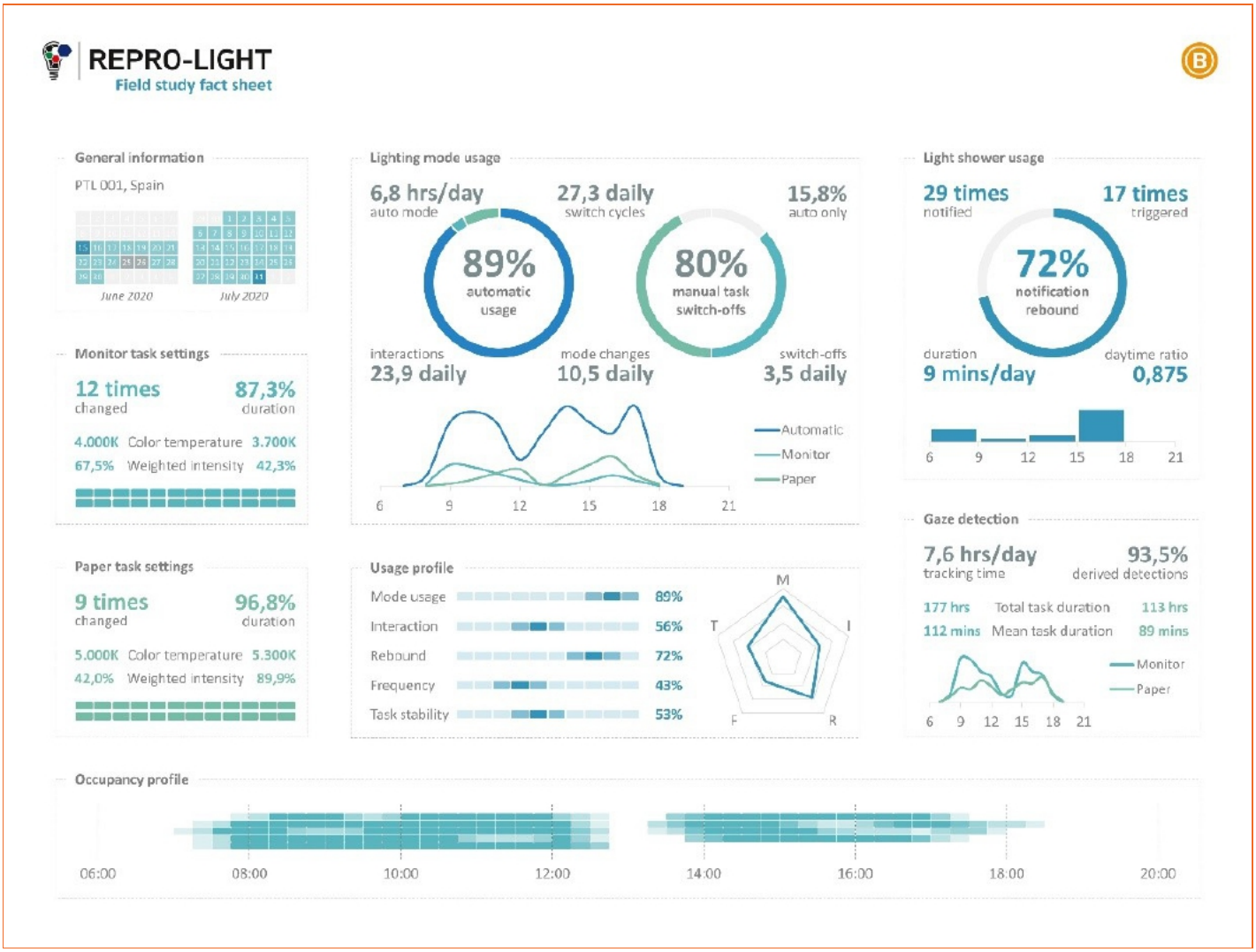


Figure 3: Exemplary representation of the personalized field study fact sheet, © Bartenbach

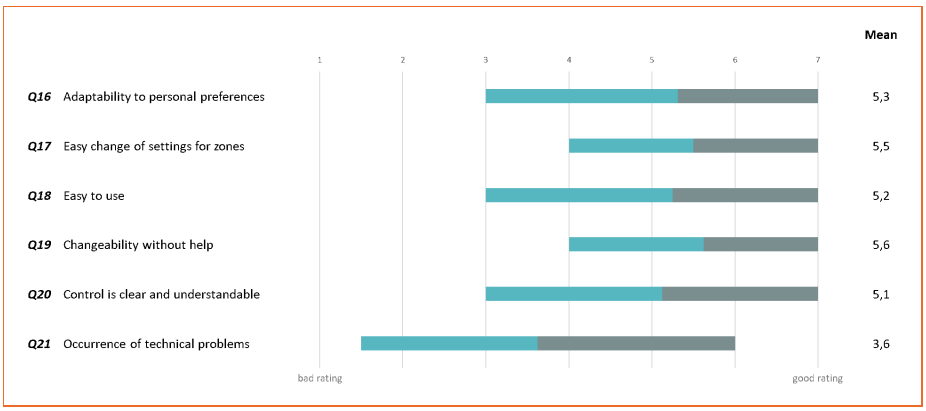


Figure 4: Results of the online survey regarding the PTL's system usability

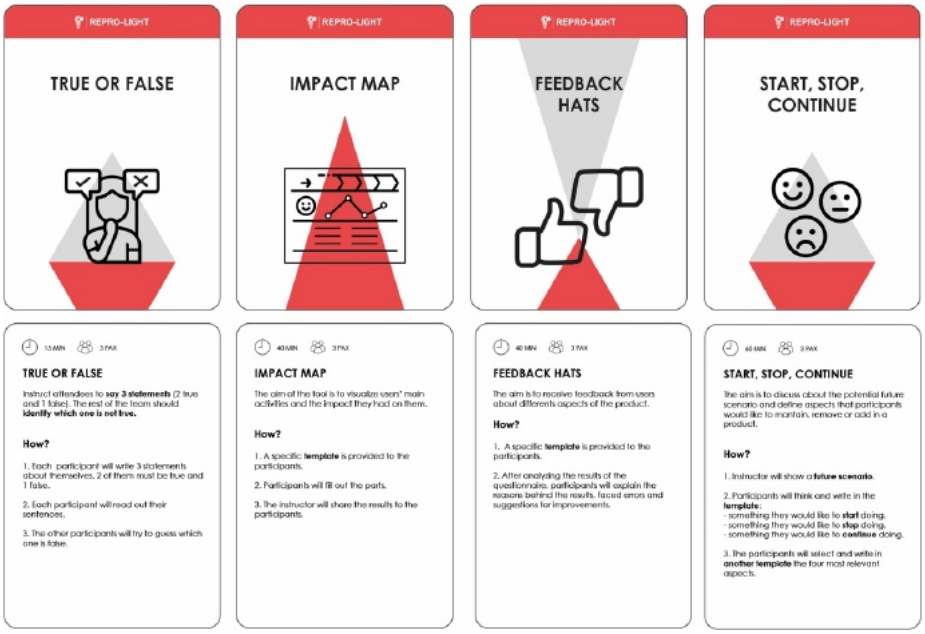


Figure 5: Visual cards of activities

which was used to put the other displays into perspective.

- Usage profile: Finally, to make it easier to compare the test persons, the individual was located within the entire group of test persons. For this purpose, five basic parameters were determined, which were transformed to ranges at group level. The individual was then located on the basis of the percentage of the individual value within the respective group range.

The information that could be obtained on the basis of the fact sheets was then made available as input for the focus groups.

Questionnaire

An online questionnaire with 34 questions in 5 different categories was sent to all participants at the end of the personalized study period, in which they were asked to assess their subjective experiences with the PTL. Besides, all test subjects with a participation of 4 weeks or longer (Austrian participants) were also presented with the questionnaire in the middle of their study period. The questionnaires were presented to all participants in their respective mother tongue.

The questionnaire contained questions in the following categories:

- Socio-demographical data: This part contained 9 questions to estimate the relevant characteristics of the test group. Questions about age, gender, use of visual aids and work and sleep times are included.
- Subjective impact assessment: This part contained 6 questions to estimate the subjective perception of the effectiveness of the lighting on lighting-relevant parameters (e.g. sleepiness, performance and mood). All questions in this group were mapped on a 7-point Likert scale.
- System usability: This part contained 6 questions to assess system usability. In particular, questions about the human-machine interface (desktop app) were in the foreground with questions about the easy understanding of the interface and the underlying control logic, as well as questions about the assessment of the problems that occurred during the study phase. All questions in this group were mapped on a 7-point Likert scale.
- System acceptance: This part contained 10 questions based on the TAMLIGHT model, to estimate the acceptance rates for different aspects of the control and system hardware. The focus here was on both the core aspects of the lighting solution developed (rear wall, shadows, reflective glare) and initial technological implementations (camera system and AI, lighting control using the Desktop app). Furthermore, the aspects of privacy and product design were addressed within this part. All questions in this group were mapped on a 7-point Likert scale.
- Overall rating: This part contained 2 questions to estimate the general rating of the development. Both the personal appraisal and the recommendation potential of the PTL were asked. Both questions were mapped on a 10-point Likert scale. In addition, at the end of the questionnaire, an open comment field was provided, in which the participants could freely share personal opinions with the study directors without any restriction.

All questionnaires were created using LimeSurvey (Version 2.05+) [7] and filled out by the participants within one day after submission.

Focus groups

From this UCD approach, two different focus groups with the participants of the field study were held in Austria and Spain. The purpose of the focus groups was to evaluate the customer's acceptance and satisfaction with the PTL. Therefore, several different aspects of the luminaire attributing to the user's acceptance towards the technology and the impact of the luminaire on wellbeing and performance were assessed.

For the structure of the focus group, the results of the field study have been used as a primary input, as the results of selected questions from the online survey and the data from the fact sheets was discussed in more detail. In particular, the focus group method should help to qualitatively find out

reasons for the results of the field study and gain detailed insights in the opinions of the users towards the acceptance, the impact of the PTL on performance and wellbeing and its exploitation.

The workshop was divided into four main phases: Introduction, Ice Breaking activity, Central phase and Closing. Visual aids and templates were created to work at each point (**Figure 5**).

Introduction: At the opening of the focus group, the moderators explained the REPRO-LIGHT project to the participants and explained the goal, activities, schedule and structure of the workshop. An agenda was handed out to the participants.

Ice-breaking activity: The focus group workshop was opened with an icebreaker activity, which has a positive effect on overall group interactivity **[8]**. With a quick 10-minute activity, the so-called true and false activity, the moderator intended to energize participants and to tackle the meeting with enthusiasm. To start this activity, the moderator simply asked each person to brainstorm three "facts" about themselves - two of the facts should be true, and one should be a lie. Co-workers could take turns guessing which is the lie. This short game could help the team learn facts about one another, so they could begin forming deeper bonds.

Central Phase: The central phase of the session, considered the key phase of the workshop, was subdivided into three subphases (acceptance, impact, exploitation) containing three activities: feedback hats **[9,10]**, impact map **[11,12]** and the start, stop, continue **[13]** activity.

Feedback hat activity: Feedback hats activity was the first technique proposed for the session, and participants had 90 minutes to develop this activity. The objective of this method is to get feedback from the users of the PTL about system usability and system acceptance. This task is divided into 4 sub-tasks. The participants received 4 templates and were asked to give feedback concerning:

- the system usability regarding the control.
- the system acceptance in terms of light quality.
- the system acceptance considering the design of the PTL System.
- the general/overall acceptance of the PTL System.

Participants were asked to answer 2-4 questions with keywords in each category, based on a provided template. Then the results were discussed on a group level, accompanied by the moderator, collected and written down by the assistant on a large template at the flipchart.

Impact map: After a break, the workshop continued with the impact map activity. This second activity aimed to investigate to investigate whether the PTL system had an impact on the work performance and well-being of the users compared to their previous lighting system. The steps to fulfil the activity were as follows: the participants filled in the templates individually; afterwards, they shared the results with the group, the moderator steered the discussion and asked for additional information. This session lasted 45 minutes.

Start, stop, continue: The third activity focused on potential future scenarios and participants were asked to define aspects that they would like to maintain, remove or add in the PTL. The participants collected aspects of these three categories in 10 minutes. Then the individual ideas were discussed in a 30-minute time slot within the group. In this part, the individual ideas were summarized and written to a large template pinned to the flipchart and ranked by the whole group.

Closing: At the end of the session, moderators conducted a dialogue with participants, discussing the obtained results and ideas. The participants made a final summary statement about the PTL system to close the session.

Results

The activities performed within the project and presented in this paper helped to identify the acceptance and impact level of new luminaire solutions. Referring to the key features of the PTL, the results show that confidence regarding the PTL is very high, the general disturbance by the real wall is low, but context-dependent, and users prefer the application for light control over classic control elements. Most of the users would continue using the PTL and even strongly recommend it to a friend or colleague for its use. Analyzing the main aspects that are linked to the acceptance rates, the PTL has reached better results in all aspects compared with current solutions that are installed in the workplace. The PTL users have a better perception of the impact of the light on both their overall wellbeing and their individual performance at work. Moreover, the PTL features enable users to adjust the light at their workplace to their personal preferences and change the settings of the luminaire more easily thanks to the desktop app. However, the characteristics that have been greatly highlighted by users are the features of personalization, individual adjustment, automatic presence detection and the light shower. In this line, the results of the focus groups have been a valuable addition to verify previously collected results of the PTL and have served to contrast and discuss these aspects, obtaining feedback and interesting ideas for improvement. Therefore, the results show the main aspects of the PTL having a positive or negative impact on the general technology acceptance and user's wellbeing.

Conclusions

The information and conclusions collected from the field study, questionnaire and focus groups, enabled us to identify and define the key aspects of the REPRO-LIGHT technologies regarding the usability, acceptance and impact perspective for further developments. Therefore, the authors can confirm that a human-centred lighting design approach helps to create more sustainable, user-friendly and competitive solutions, and increases the subjective perception of the developed products. Although the results presented in this paper mainly affect future implementations of the PTL, the use of the applied methods has proven to be advantageous with regard to any luminaire development. With the User-Centred Design (UCD) approach, stakeholders can be involved in the design process from the start of the project, leading to better and more sustainable solutions that effectively meet real-world requirements. ■

AUTHOR: Ganix LASA, Ph.D.[1]
Ganix Lasa is a lecturer and researcher in the Design Innovation Center (DBZ) of Mondragon University (Spain). He obtained his first degree in Industrial Design and Product Development Engineering at Mondragon University. He hold an MSc in Design Engineering from Polytechnic University of Valencia (UPV) and PhD degree in User Experience Evaluation at Mondragon University in 2015. Since then, Dr. Lasa is

carrying out several research projects with a User Centred Design approach, mainly related to interaction design and product development. He is author of several scientific articles referring technology of interaction design, user experience and product development.

CO-AUTHORS:
Itsaso GONZALEZ, Ph.D.[1],
Judith GROSS, DI[2],
Wilfried HUSS, Dr.[2],
Maitane MAZMELA, Ph.D.[1],
Chiara MESSINA, M.A.[2],
Wilfried POHL, Mag.rer.nat.[2]
Siegmund STAGGL[2],
Johannes WENINGER, DI[2]

[1] Design Innovation Center (DBZ), Mondragon University, Loramendi 4, 20500 Mondragon, Spain

[2] Research Department, Bartenbach GmbH, Rinner Straße 14, 6071 Aldrans, Austria

About Mondragon University
The Design Innovation Center (DBZ) is part of the Higher Polytechnic School of Mondragon University (MU). The DBZ holds all the research activities related to design knowledge generation and transfer and develops a collaborative strategy with companies, where mutual confidence and objectives multiply the efficiency of resources. In this sense, technological transfer and innovation continue to be a differential factor of Mondragon University.

About Bartenbach
Bartenbach GmbH (BB) is a leading international lighting consultant and R&D provider in day- and artificial lighting and well known for its functional and scientific based lighting design projects, for its studies on visual perception and on light & health, and for the development of new lighting solutions and technologies. This knowledge and the highly skilled technical and scientific employees allow the company to resolve highly complex lighting and building design tasks. Bartenbach was and is involved in several national or EU funded projects. In the last years, Bartenbach has used its extensive knowledge in optical design to develop its own series of components using freeform facetted technology. BB's scientific work results in a multitude of inventions and found its way into more than 100 patents.

Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No768780. The authors thank all members in the REPRO-LIGHT consortium, especially to Bartenbach members for the fruitful collaboration in producing the results presented in this manuscript.

References

[1] Mao, J. Y., Vredenburg, K., Smith, P. W., and Carey, T. (2005). The state of user-centered design practice. In: Communications of the ACM, 48(3), pp. 105-109.
[2] Mayhew, D. and Mantei, M. (1994). A basic framework for cost-justifying usability engineering. In: Bias, R. and Mayhew, D. (1994). Cost-Justifying Usability, pp. 9-43. Academic Press, New York.
[3] Kohno, I., Yasu, H., Sugawara, S., and Nishikawa, M. (2013). Pragmatic approach to cost benefit analysis of user centered design. In: International Conference of Design, User Experience, and Usability, pp. 525-534. Springer, Berlin, Heidelberg.
[4] Vredenburg, K., Mao, J. Y., Smith, P. W., and Carey, T. (2002). A survey of user-centered design practice. In: Proceedings of the SIGCHI conference on Human factors in computing systems, pp. 471-478.
[5] Tanzer, K. and Rudolph, H. (2018). Repro-light: Modularity,Sustainability and Personalization forthe Lighting Industry. In: Luger Research e.U. (Ed.): Proceedings of the 8th International LED professional Symposium + Expo (LpS), September 25-27, 2018, Bregenz, Austria, pp. 76-83
[6] Park, S., Spurr, A., and Hilliges, O. (2018). Deep pictorial gaze estimation. In: Proceedings of the European Conference on Computer Vision (ECCV), pp. 721-738.
[7] Schmitz, C. (2012). LimeSurvey: An open source survey tool. LimeSurvey Project Hamburg, Germany. http://www.limesurvey.org.
[8] Almethhib, M. M. (2009). The Impact of Ice Breaking Exercises on Trainees' Interactions and Skill Acquisition: An Experimental Study. In: Economics and Administration, 23(1).
[9] De Bono, E. (2017). Six thinking hats. Penguin UK.
[10] Gill-Simmen, L. (2020). Developing critical thinking skills: Using Edward de Bono's six thinking hats in formative peer assessment and feedback. In: Journal of Applied Learning and Teaching, 3(1).
[11] Hsu, S. H., Chuang, M. C., & Chang, C. C. (2000). A semantic differential study of designers' and users' product form perception. In: International journal of industrial ergonomics, 25(4), 375-391.
[12] Huang, Y., Chen, C. H., & Khoo, L. P. (2012). Products classification in emotional design using a basic-emotion based semantic differential method. In: International Journal of Industrial Ergonomics, 42(6), 569-580.
[13] Hoon, A., Oliver, E., Szpakowska, K., & Newton, P. (2015). Use of the 'Stop, Start, Continue' method is associated with the production of constructive qualitative feedback by students in higher education. In: Assessment & Evaluation in Higher Education, 40(5), 755-767.

REPRO-LIGHT

Initiating Transformation in the European Lighting Industry

Repro-light is a European research project that aims to support the European lighting industry in moving towards a more sustainable and competitive future.

www.repro-light.eu

Live Healthier With Light

Research has shown that poor lighting and unhealthy behaviors towards light can lead to desynchronized internal rhythms and sleep problems. This has been associated with a wide range of health problems, from obesity and compromised immunity to cardiovascular risks [4]. In the UK alone, sleep disruption costs the economy £38 billion every year due to lost productivity [5]. In contrast, healthy light can improve performance, alertness, mood and sleep quality [6,11]. With applications across research, corporate wellbeing, and personal health, LYS Technologies is on a mission to help people sleep better, and feel better using light. Paula Miseikyte, Scientific Lead at LYS, and Aliette POPLU, Product Specialist at LYS, explain how a tech start-up uses wearable technology, a mobile app and data science to enable healthier living with light.

Just as air, food, and water, light is a natural and vital source for health. To most people, the absorption of light is an unconscious choice in life. It's everywhere, always. But not necessarily in a healthy way. Most life on earth has adapted to the 24-hour light-dark cycle that underpins our physiology [1]. For thousands of years daily life was restricted to natural day-night periods. The introduction of electric lighting led to changes in our environment and the way we interact throughout the day. 55% of the world's population now inhabit the cities [2], and we, the urban dwellers, no longer rely on the natural light-dark periods for our sleep-wake cycles. More importantly, we spend more than 90% of our time indoors exposed to artificial lighting [3]. However, lighting in our environments is still not tailored to be optimal for our health and wellbeing. These factors have had a profound impact on our health considering that light is the strongest environmental cue regulating the body's internal clock and many functions and processes that are running in the background [1,2].

Raising Awareness with a Wearable Light Tracker that Puts People First

The LYS Button is pushing the frontier of research in circadian rhythms, light, and chronobiology. Designed to replicate the photosensitive cells in the eye [7] that control our sleep-wake cycles, the technology helps people understand how the light in their everyday surroundings affects their health and wellbeing. The button enables to accurately measure people's light exposure and translate it into value for the end-user. Integration with the LYS app allows users to gather data on their daily light intake and habits, which helps them understand their everyday environments and light's impact in real-time.

LYS Button – Technical Specifications:

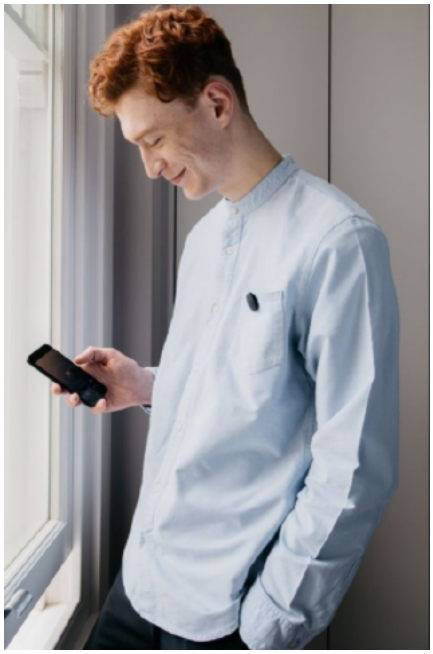
- Units of measurement and definition metrics: CCT, RGB Values, Movement, Lux, Mlux[1]
- RGB sensor with a spectral range from 350–750 nm; Counts $/\mu W/cm^2$
- Intensity range: 0–100 000 lux
- Movement (3-axis accelerometer): Proxy for activity. Counts the number of times acceleration exceeds 0.1875g (g = gravitational force) in any of the 3 axis over the logging time interval
- 15 seconds sampling rate
- 24 hours of internal memory, which means that it can be worn during a whole day without having to carry the phone
- With 7 days of battery life on a full charge (also tracking light while charging)

Figure 1: Smartphone app and wearable light tracker

[1] Melanopic Lux

Changing Behavior with a Personalized Health Program

The button works together with an in-app 2-week wellbeing program called the Light Diet®. With personalized in-app advice and detailed reports, users are nudged to make small changes in their daily light habits. Through a detailed analysis of the user's chronotype (a person's natural inclination to the times of day when they prefer to sleep or to be active - also known as being a night owl or morning lark [8]) the system identifies differences in light exposure required for each individual. Users learn about their peak times for exercise, cognitive performance, sleep, and whether they suffer from 'social jet lag' - the discrepancy between the individual's internal clock and social clock [9].



"I did see improvements in my energy levels after I made the changes based on the report, it was quite impressive."

USER TESTIMONIAL

LYS Light Diet® represents a short-term, high-value program that allows for high engagement in the app. There is an average of 88% engagement with the app and users typically go through 4 Light Diet® a year, depending on the season or other changes to personal routines.

Measurable improvements can be seen in just two weeks according to the collected data. After two weeks of the Light Diet® program, users double their exposure to natural daylight showcasing the behavior change prompted by the program. With a 50% increase in exposure to natural daylight, positive impact can be observed on wellbeing outcomes, and users report an average of 17% improvement in sleep quality and a 20% improvement in energy levels.

Integrating with Light - Healthier Artificial Lighting

The system developers believe that personalized lighting is one of the key steps in making indoor living more human-centric. This has led to develop a lighting integration technology that connects the App with any smart light using Bluetooth. The app automatically detects smart lights and adjusts color temperature and brightness in real-time to the individual using machine learning algorithms to provide healthy light exposure by the means of personalized human-centric lighting (HCL) recipes. Fully personalized lighting matches the user's chronotype, age and preferences, which makes sure that users are receiving the right artificial light at the right time for optimal sleep and energy levels.

The integration enables healthier end-products and lighting solutions while justifying lighting decisions with evidence and data. It is also a data collection tool for partners including architects, lighting manufacturers or designers, and LED providers. Collecting aggregated and anonymized data for more informed design decisions.

Overall, the lighting industry is experiencing slow growth and new LEDs last up to 25 times as long as traditional light bulbs which challenge the traditional business model. Moreover, current smart lighting systems and apps are too complex for users. Finally, the human-centric lighting solutions currently on the market are still not human-centric but still rather a one-size-fits-all solution. The presented app offers a new way of adding value to traditional lighting products, which can drive new business models. It offers a simple and intuitive user experience, while machine learning algorithms offer a truly human-centric solution to adjust the light in real-time personalized to the user.

Wellbeing at Work

One of the reasons why we spent more than 90% of our time indoors, is because we are indoor workers. This new smart system also offers a data-driven approach to boosting productivity and wellbeing for employees who work indoors. With a combination of the LYS Button, the LYS app and the Light Diet®, employees can learn about their light habits, sleep-wake cycles and gain insights into how to improve sleep, energy levels, alertness and productivity.

The wellbeing platform enables employers to discover how the working environment affects their employees, identify easy changes that will increase wellbeing, productivity, engagement, and design teams and schedules following people's chronotypes to maximise their potential. It is also possible for clients to integrate directly with other data collection tools for example air quality and sound levels. A monthly subscription allows employees to go through a variety of focused wellbeing programs: Winter Blues, Sleep better, Working from home, etc.

The workplace wellbeing solution is fully digital and scalable and can be used in the office or a home working scenario. Due to lockdown, working from home is leaving people with disrupted routines and the responsibility to create their work-life balance. Similarly, employers are losing touch with their employees and there is a growing need for remote employee wellbeing solutions. The solution for work allows employers to care for their employees and gather data on wellbeing remotely.

In the past few months, the lockdown has negatively impacted employees' mental wellbeing: a recent study by the Nuffield Health [10] showed that 80% of employees

across the UK feel that the lockdown has negatively impacted their mental health. The loss of structure and disrupted routines have left employees with negative physical symptoms similar to jet lag: disturbed sleep, appetite, energy, and mood.

This new innovative system helps employees cope with the situation, and transform their "work from home" (WFH) experience:

- Employees can better structure their day for optimal performance. Through the detailed analysis of an individual's biological clock, the user can better organize their day and choose when to do physical activities, high cognitive tasks, and when to switch off for better sleep, and energy the next day.
- Employees can create healthier habits for better mental wellbeing. By prompting employees to go outside more often, to sit closer to windows, or get away from screens at night, employees will be more alert, sleep and feel better.
- Employees can choose the optimal working space in their homes for optimal productivity. Through the app's instant feedback on lighting environments' impact on energy levels, employees can better choose their home desk setting (place in the room and additional artificial lighting) to be more alert and productive.

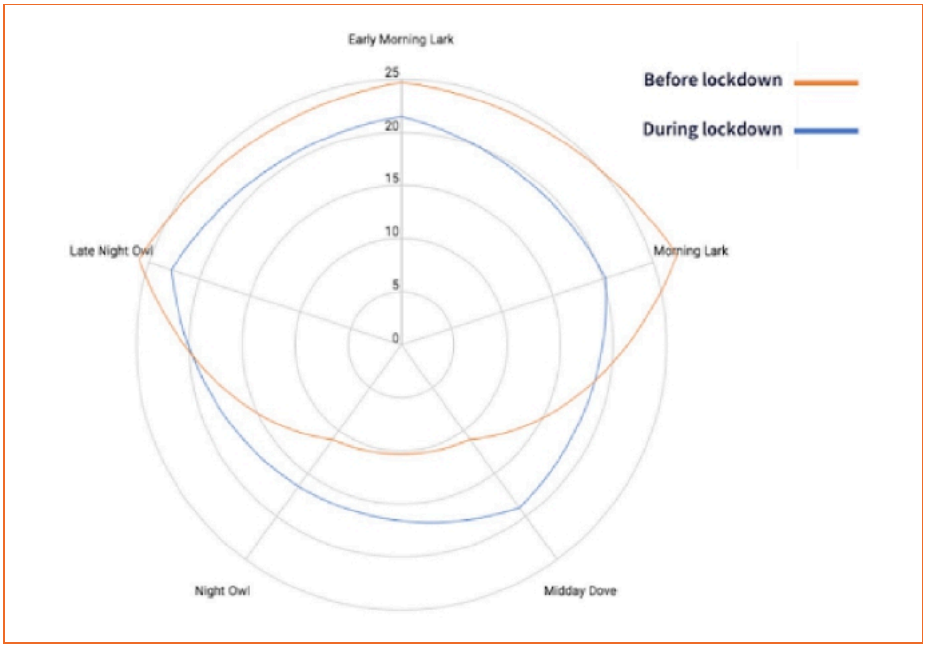


Figure 2: Sleep and circadian patterns changed during the lockdown (LYS data on chronotype distribution).

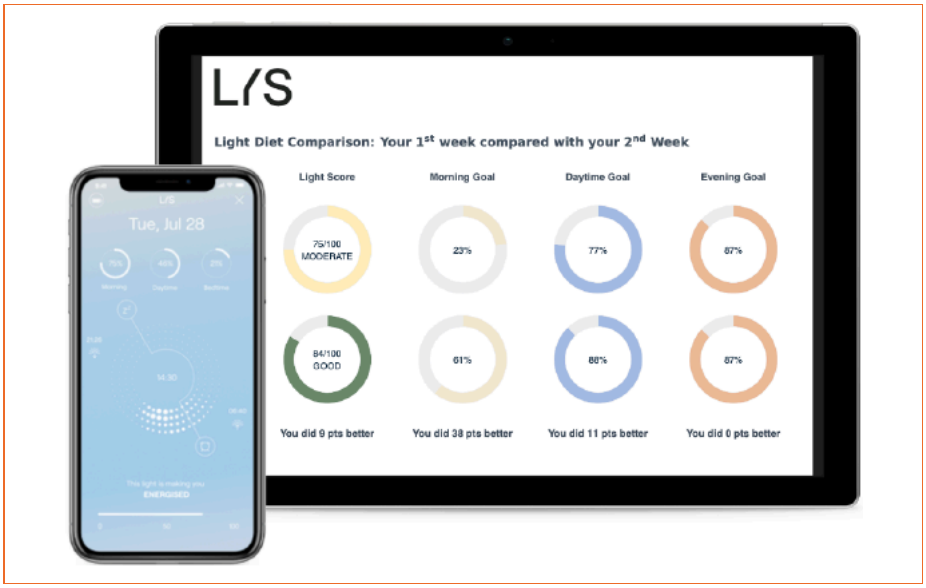


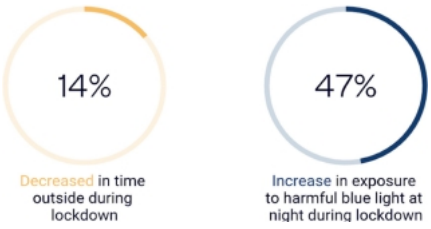
Figure 3: Light Diet comparison of two weeks

Database and Lockdown Case Study

With more than 1bn distinct sensor data items recorded, LYS holds the largest database on human light intake in the world. Data is gathered ethically and in a way that complies with the GDPR creating value for both people and the industry partners across lighting, architecture and research. LYS also publishes articles and studies to raise awareness about the connection between light and personal health.

Looking at the side effects of lockdown, they published a case study looking at the changes in users' habits before and during the initial lockdown in relation to sleep, energy levels and light intake. The case study gave fascinating insights into how – and why – the pandemic has changed people's daily routines and affected their wellbeing. During the lockdown, average sleep time increased by almost 35 minutes.

At first glance, this seemed like good news. Increased sleep time has a range of benefits: from better mood and concentration to a stronger immune system [4]. However, although sleep quantity increased, the data did not show a statistically significant improvement in perceived energy levels throughout the day.



According to the data, people spent more time indoors. Whilst this might seem straightforward, it could be easy to forget the knock-on effects. Indeed, data revealed diminished morning light exposure. Overall, people were not getting outdoors during the day and spent 14% less time outside during the lockdown. People seemed to be working more in front of screens in the evenings and on average receiving 47% more harmful blue light at night. The latter data point also showcases the difficulty in switching-off at the end of the day, revealing the loss of structure and routine induced by the lockdown.

Moreover, people's sleep-wake cycles became more evenly distributed. There was a trend away from early towards late chronotypes. In other words, more people acted like 'Night Owls' during lockdown. One explanation could be that remote-working means people settled into their natural rhythms. With no commute and more flexible schedules, people may have had more

freedom to live according to their true internal clock.

However, morning light and increased screen-time could have been the factors for the drift towards later chronotypes. Morning light is crucial for maintaining regular sleep patterns. Without good levels of light in the morning, people will tend to drift and wake up later in the day. Similarly, blue light before bed can increase the time it takes to fall asleep and disturbs sleep quality [6]. It's possible that this trend contributed to the overall shift towards later chronotypes.

Overall, this analysis gave useful insights into how light, sleep and circadian patterns changed because of the lockdown. The data revealed that changes to daily habits and lack of routine have made a big difference to people's light exposure. This also highlighted the need for better guidance and framework considering the ongoing pandemic situation. In general, the lockdown case study showed how data is essential for understanding light's impact on health and wellbeing.

Bridging the Gap Between Personal Health and Lighting

The key three steps of the LYS mission include creating awareness of light's impact on personal wellbeing in real-time, changing behavior for positive outcomes and integrating and improving indoor lighting. These key steps require collaboration within the lighting industry and highlight the need for data-driven solutions.

In recent years, the lighting industry has been looking at ways to innovate and to ensure the ongoing value of their products and services. It has also suffered a slow growth of less than 5% in the past 5 years. Human-centric solutions are perceived as the future of lighting and HCL market is estimated to grow by 35% every year, over the next 5 years. However, HCL is currently operating via tunable lighting solutions following a color pattern similar to the sun and is not fully personalized to individuals.

Hence, this smart system can be used by LED providers, lighting manufacturers, lighting designers and lighting controls providers to transform their business model and provide smart, truly personalized and user-friendly solutions to meet their client needs. With the help of a wearable light tracker, the app, wellbeing programs and light integration, the system can be used as an informative, commercial and innovative tool with a core mission to live healthier with light. The founders highly believe that to help people live healthier with light, there is a need for collaboration. Collaboration between lighting manufacturers, lighting designers, facility managers, architects and wellbeing experts to improve lighting and to educate people about the benefits of good light. ■

AUTHOR: Paula MISEIKYTE
Paula MISEIKYTE is Scientific Lead at LYS Technologies. Her background is in Sleep Medicine from the University of Oxford. By using the knowledge of circadian rhythms, sleep and light, her work includes constantly updating and improving LYS' technology, contributing to new initiatives and ensuring all advice is evidence-based.

CO-AUTHOR: Aliette POPLU, B.Sc.
Aliette Poplu is Product Specialist at LYS Technologies. She joined the company in 2019, after meeting the LYS team at the MIT innovators under 35 awards, where she was a part of the organising team of the competition. She has always been interested in sleep and circadian rhythms and is committed to helping people live healthier with light. She works on product development and data-driven approaches to customer experience and sales.

About LYS
Founded by two graduates of Imperial College London, LYS launched its first product as a Kickstarter campaign in 2017. After reaching its funding target in less than 48 hours, LYS has gone on to secure investment, win worldwide acknowledged awards, and work with clients across lighting, architecture and workplace wellbeing. With active users in more than 53 countries worldwide, the technology serves indoor dwellers in Nuiqsut, Alaska all the way to our southernmost user in Christchurch, New Zealand.

In 2019, LYS' Co-Founder, **Christina Friis BLACH PETERSEN**, was the winner of MIT's '35 Innovators under 35'. And later that year, LYS won AXA's prestigious 'Health Tech & You Award'. In 2020, LYS won Connected Lighting Innovation of Year at the LUX Awards. LYS' clients and corporate partners include Philips, Zumtobel Group, AXA PPP Healthcare, and Edge Technologies. LYS' technology is also being used in academic research with studies currently taking place at University College London, The Hong Kong Polytechnic, and the University of Surrey. What started as a Fitbit for light has now grown into data-driven applications across personal health, corporate wellbeing and human-centric lighting.

- Lecture of Christina Friis Blach Petersen on LpS Digital `http://www.LpS-Digital.global` and on LpS Digital Youtube Channel `https://youtu.be/ht8wsM8Q0lA`
- More about LYS: `www.lystechnologies.io`
- Follow LYS on LinkedIn, Twitter and Facebook: @lys technologies
- Email LYS to book a free demo: `info@lystechnologies.io`

References

[1] Duffy, J. F. and Czeisler, C. A. (2009). 'Effect of Light on Human Circadian Physiology', Sleep medicine clinics, 4 (2), 165–177.
[2] United Nations (2018). World Urbanization Prospects. Available at: https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.
[3] European Environment Agency (2013). Indoor air quality. Available at: https://www.eea.europa.eu/signals/signals-2013/articles/indoor-air-quality.
[4] Cappuccio, F., Miller, M. A. and Lockley, S. W. (2010). Sleep, health and society: from aetiology to public health. Oxford: Oxford University Press.
[5] Hafner, M., Stepanek, M., Taylor, J., Troxel, W. M. and Van Stolk, C. (2016). Why sleep matters- the economic costs of insufficient sleep: A cross-country comparative analysis. Santa Monica, CA: RAND Corporation.
[6] Blume, C., Garbazza, C. and Spitschan, M. (2019). 'Effects of light on human circadian rhythms, sleep and mood', Somnology: sleep research and sleep medicine, 23 (3), 147–156.
[7] Hattar, S., Liao, H. W., Takao, M., Berson, D. M. and Yau, K. W. (2002). 'Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity', Science (New York, N.Y.), 295 (5557), 1065
[8] Roenneberg, T., Wirz-Justice, A. and Merrow, M. (2003). 'Life between Clocks: Daily Temporal Patterns of Human Chronotypes', Journal of Biological Rhythms, 18 (1), 80–90.
[9] Rutters, F., Lemmens, S. G., Adam, T. C., Bremmer, M. A., Elders, P. J., Nijpels, G. and Dekker, J. M. (2014). 'Is Social Jetlag Associated with an Adverse Endocrine, Behavioral, and Cardiovascular Risk Profile?', Journal of Biological Rhythms, 29 (5), 377–383.
[10] Nuffield Health (2020). Working from home taking its toll on the mental health & relationships of the nation. Available at: https://www.nuffieldhealth.com/article/working-from-home-taking-its-toll-on-the-mental-health-relationships-of-the-nation#about.
[11] Souman, J. L., Tinga, A. M., Te Pas, S. F., van Ee, R. and Vlaskamp, B. N. S. (2018). 'Acute alerting effects of light: A systematic literature review', Behavioural Brain Research, 337 , 228–239.

Latest Lighting Design Trends for Top Grade Chinese Hotels

Carry YU's design philosophy, highly praised by customers, international architects, interior designers and other design colleagues, is, "Respect the architectural characteristics, tell the story of light". As General Manager & Design Director of CSLC International Lighting Design Co., Ltd. (located in China) [1], Carry thinks lighting design takes responsibility for the lighting environment, solving all the problems relevant to light such as aesthetic, energy saving, maintenance and environmental issues etc. He has been committed to creating and improving the lighting environment of human living space, giving life to specific architectural forms and artistic styles with new and vibrant light.

At present, many famous international hotel management companies have been stationed in China, and each one owns a series of brands with different styles, mainly divided into Business hotel, Resort and Luxury hotel, etc. Facing the huge challenges of the Chinese tourism market, more and more top grade hotels begin to focus on improving hotel quality to attract guests. This is why lighting design becomes so important now. The common goal of every quality hotel is to create a comfortable lighting environment. But how can we make that happen and what are the latest lighting design trends for top-grade Chinese hotels? Carry Yu shared his story with LED professional.

Beneficial But Not Harmful

2020 set a new stage for the development of the Chinese lighting industry. Design innovation, product precision and ingenuity have become the main axis of discussion in various forums. The final chapter of the Tao Te Ching mentioned that "the law of nature is beneficial but not harmful". This aims to remind everyone to follow the way of nature while pursuing benefits. For the design industry, only ingenuity can produce high-quality works and keep sustainable development. Chinese lighting design is entering a new era of "Artistic light environment", "Green light environment" and "Smart light environment".

Artistic Lighting

In a sense, lighting design is art design. A good art creation must be focused, layered, emotional, and distinctive. Just like laying out a painting, the light source is paint, and the lamps are paintbrushes; we need to study the structure of every single detail, and draw the best lighting that will set off the object perfectly.

Figure 1: Radisson Blu Hotel Hangzhou Xintiandi, proximity to the Jing–Hang Grand Canal, a premier Hangzhou hotel, Carry completed the lighting design of this hotel in 2019 [2]

As a senior lighting designer with more than 20 years work experience, Carry believes that aesthetic is the most important thing for design. Due to the late development of China's lighting design industry, lighting is often a field that can be easily misunderstood in China. Many non-professionals still keep a traditional view that it is not necessary to specifically design the lighting as long as the space is bright enough because they can't respond the aesthetics of lighting design. In order to help more people learn about this field, Chinese lighting designers have been working hard to create good works, but a good lighting design is really a rare piece of art, especially for hotel lighting design.

The lighting design of Chinese hotels is mainly based on the theme of the hotel. For business hotels in the city center, interior lighting design and architectural lighting design are usually the main requirements. The beauty of interior lighting stems from the expression of space, as the interior design consultants spend a lot of effort to lay it out. The space needs to show its greatest charm with the help of lighting. In addition to meeting the needs of the hotel management company, the lighting of the building's facade must also consider the lighting design plan of the local city.

Since most of the guests checking into business hotels are business travelers and their daily lives are relatively fast-paced, the hotel design is more functional, and the

overall lighting will be brighter than other hotels. For the purpose of enhancing the artistic effect, designers will look for every element that can be used in this space. After all, the style of each top grade hotel is specific; some may be based on the brand itself, and some may be based on local urban culture. Lighting design should make full use of the elements of the entire space. For example, the lobby of many top grade Chinese hotels normally has a very high ceiling so they prefer to design a background wall in different materials or with different patterns to emphasize the artistry and representativeness of the space. Therefore, the designer usually likes to use a few narrow-angle spotlights or wall washers to brighten the wall, which could be the first impression the guests have.

In recent years, many resort hotels have emerged in China, among which hot spring hotels and parent-child hotels are typical. Most of the resort hotels in China are built in mountainous countryside far from the city center. This kind of hotel normally covers a large area to construct building complex and landscape. The hotel's architectural structure is very distinctive, which is particularly critical to the test of light. For such a hotel, the designer will pay more attention to the details of the lighting. Light can affect people's emotions. The most intuitive perception of light by the human body is light and darkness. The key is to combine light with dark, rather than to illuminate the whole space.

"Where there is light, there is shadow, alternating light and dark, and light and shadow follow each other, this is the best effect that top grade resort hotels should pursue. And for the interior, light and shadow enrich the sense of hierarchy and art in the space."

CARRY YU

Where there is light, there is shadow, alternating light and dark, and light and shadow follow each other, this is the best effect that top grade resort hotels should pursue. And for the interior, light and shadow enrich the sense of hierarchy and art in the space.

Landscape architecture is no exception. The process of lighting design seems like a set of variations between light and shadow, using the light to create a fabulous shadow, that will be much more fun than usual. For most of the resorts, the garden landscape will not be particularly bright but rather, stay a little mysterious. This is the ingenious combination of nature and light. One only needs to hide one or two spotlights in a tree and the beautiful shadow of the branches and leaves will be projected onto the ground, swaying with the wind (**Figure 3**).

Linear lighting also plays a great role in enhancing the artistic sense of the space. With the introduction of LED light sources in recent years, linear lighting has been used for more diversified purposes, and has evolved from lighting sources into a completely independent lighting fixture. The characteristic of linear lighting lies in the application of various lighting methods, it provides the ideal solution for efficiently

Figure 2: Sheraton Zibo Hotel, Shandong: The lobby of many top grade Chinese hotels normally has a very high ceiling, so they prefer to design a background wall in different materials or with different patterns to emphasize the artistry and representativeness of the space, so the designer would like to use a few narrow-angle spotlights or wall washers to brighten this wall, which could be the first impression left to the guests. Carry completed the lighting design of this hotel in 2016 [3]

Figure 3: Crescent Hills, a large hot spring resort, located in Zhangzhou, Fujian. Carry Yu completed the lighting design of this hotel in 2015 [4]

illuminating cabinets, shelving, displays, and narrow spaces. With the introduction of OLED, flexible linear strips also increase the infinite possibilities of lighting design. They can exist as an independent design style, which allows different installation methods. Architects and lighting designers can "mix and match" parts and configurations or choose "linear and circular, surface mounted and recessed" installation methods. Indirect lighting is more closely related to the atmosphere; it can also be used to balance the sharp lines and general roughness of the room, just like a light-saber; very pure light.

Green Lighting

If Art lighting is life, then Green lighting is blood. Carry also pointed out that, "While paying attention to the lighting art atmosphere, we must also consider implementing energy saving." According to data, 60% to 70% of the energy consumption of hotels and restaurants is consumed by lighting, sockets, and air conditioners. It can be seen that lighting is a major consumer of hotel energy, and the energy-saving and high-efficiency lighting of lighting is naturally worthy of attention. This is also one of the important responsibilities for lighting designers. In order to reduce the seriousness of global energy waste, green lighting is also a policy that China has always encouraged and promoted. Green lighting does not mean to reduce the quantity of light fixtures, but to choose reasonably. Firstly, good lighting quality is one of the important parts of green lighting. It mainly includes a good color rendering index, appropriate color temperature, less glare, uniform illumination, and comfortable brightness. Secondly, select the light source scientifically, and the light distribution should adapt to space function requirements and have high light output efficiency.

As the core of green lighting, the light source is a device that converts energy

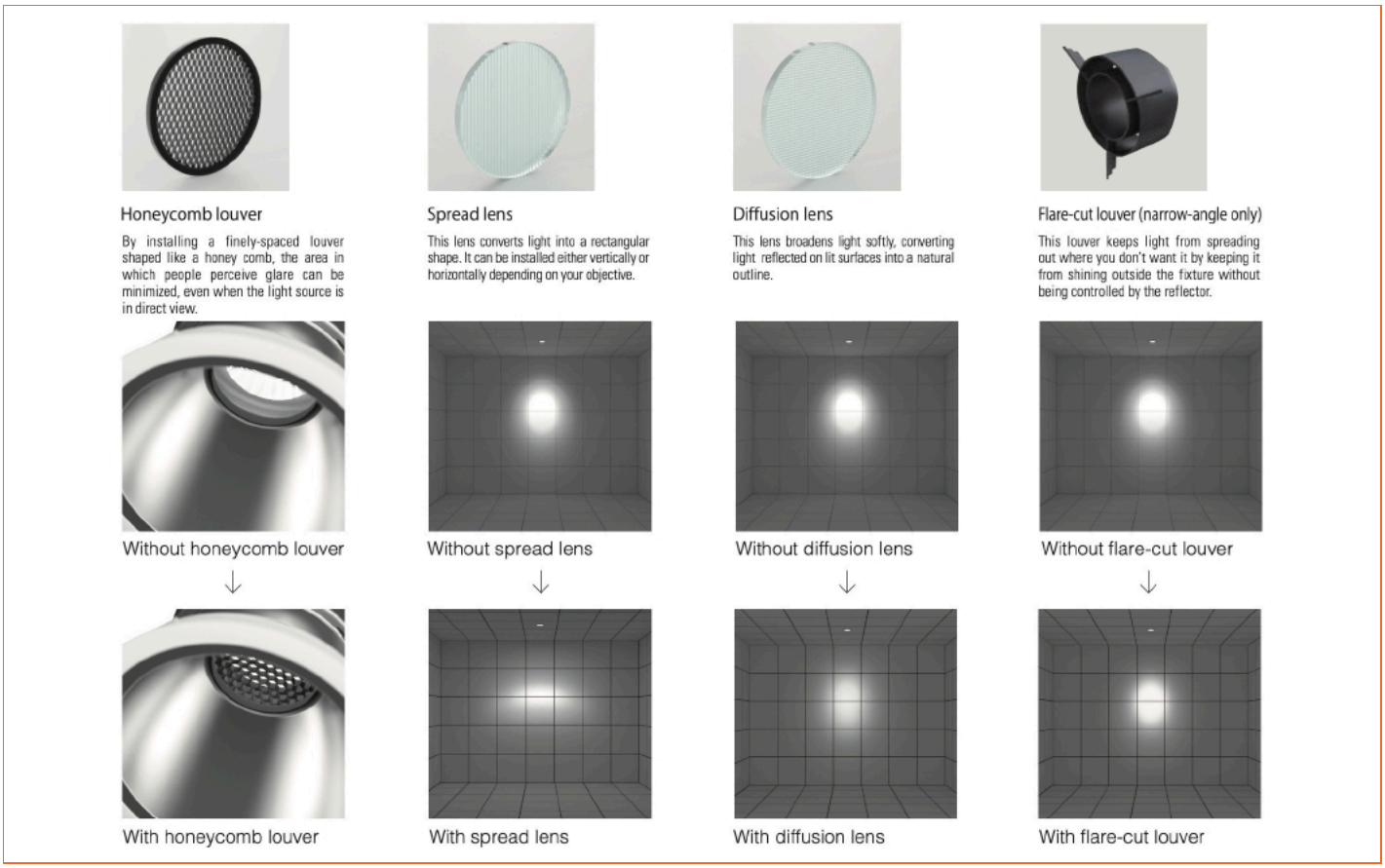


Figure 4: Japanese lighting brand : Endo, Glare-less series

into light. In the past century, electronic technology has developed rapidly and also created a new path in the manufacture of light sources and electrical fittings. For the past two decades, China has accelerated to catch up with the world trend of more and more high-frequency discharge lamps, DC fluorescent lamps, high-frequency induction lamps, microwave lamps and other light sources with longer life, better color rendering and higher luminaire efficacy. Light-emitting diodes (LEDs) have achieved breakthrough development, which has caused a huge change in the lighting field and had a significant impact on the implementation of green lighting. LED has many advantages, such as long lumen maintenance (almost 100,000 hrs), good color rendering (Ra 85-95), no flicker, short excitation response time (nanosecond level), vibration resistance, weather resistance, and safe use. The brightness of red and yellow LEDs has been improved, especially the break- through of third-generation semiconductor material manufacturing technology such as gallium nitride, and the development of blue and green LEDs, thereby solving white light. Because of its rich and diverse color lights, convenient color selection and color change advantages, it is particularly suitable for use in hotel banquet halls, special bars, garden landscapes or building façade lighting; any places that require multiple colors. Considering energy saving and environmental protection, almost all of top grade hotels will give priority to LED light sources. They only use a few decorative lighting pieces that need to use incandescent lamps. But not all LED products are suitable. The LED light fixtures used in top grade hotels should also meet some basic technical requirements: the color rendering index ≥90, the color temperature should generally be maintained at about 2700–3000 K, in addition to some special places may be designed into 4000 K cold white color temperature or RGB(W) mode (common in hotel banquet halls and outdoors), and some fixtures should be equipped with anti-glare covers or the cut-off angle is not less than 30°, etc.

On the other hand, these restrictions also protect the health of the human body. One piece of research shows that low color temperature light creates a smooth lowering of central nervous system activity, and that low color temperature illumination can be used effectively in a bedroom or other such environments where it is desirable to facilitate lowered physiological activity. This happens to be very suitable for the hotel industry. The level of Ra value is of great significance for the establishment of a good lighting environment in modern architectural places. It is not only the need to identify the color of the object, but it also has a great impact on the visual effect and viewing comfort. If the color rendering index of the light source is high, the image of the viewed object and the character will appear more real and vivid; otherwise, it will become unsightly and lose its original luxury and luster. Any dazzling light is glare, which can easily cause eye spasms. In some severe cases, it can damage the retina and cause blindness. High-quality lighting technology must be equipped with special technical measures to eliminate direct and reflected glare on the lamps, try to diffuse the light source as much as possible, and minimize the loss of light energy. As mentioned above, this is when people often say that ”soft” light enters our life.

At the same time, the hotel lighting design can also use natural resources to create green lighting, such as natural light. Skylights combined with artificial lighting can be designed for daytime lighting. The hotel public areas are designed with sub-period control: The brightness is highest when the customer flow is heavy during the day. As time goes on and it gets later, the brightness gradually decreases. After midnight, only a few functional areas reserve some necessary lights. It’s a good way to save energy and to control hotel operating costs. No one would refuse such a good thing.

After all, lighting design is the key factor in implementing green lighting, and the overall plan is determined in the design. As lighting design is closely related with electrical design, the requirements will be stricter than ever, so green lighting is a new trend as well as every lighting designer’s duty.

Smart Lighting

With the vigorous development of the hotel industry in China and the increasingly fierce competition, the traditional modular service of hotel lighting has gradually been unable to highlight the advantages of top grade hotels, in view of the fact that people are no longer satisfied with ordinary functions, but enjoy a higher quality of life. When challenges and opportunities coexist, lighting standardization is promoted as the current mainstream, a new service model is created. That’s the intelligent lighting control system. Actually, Smart lighting has become a global trend owing to the fact that it can establish a humanized and livable lighting environment. In recent years, this kind of technique has been widely used in hotel lighting design. This section aims to explain the technological development of lighting control systems in China.

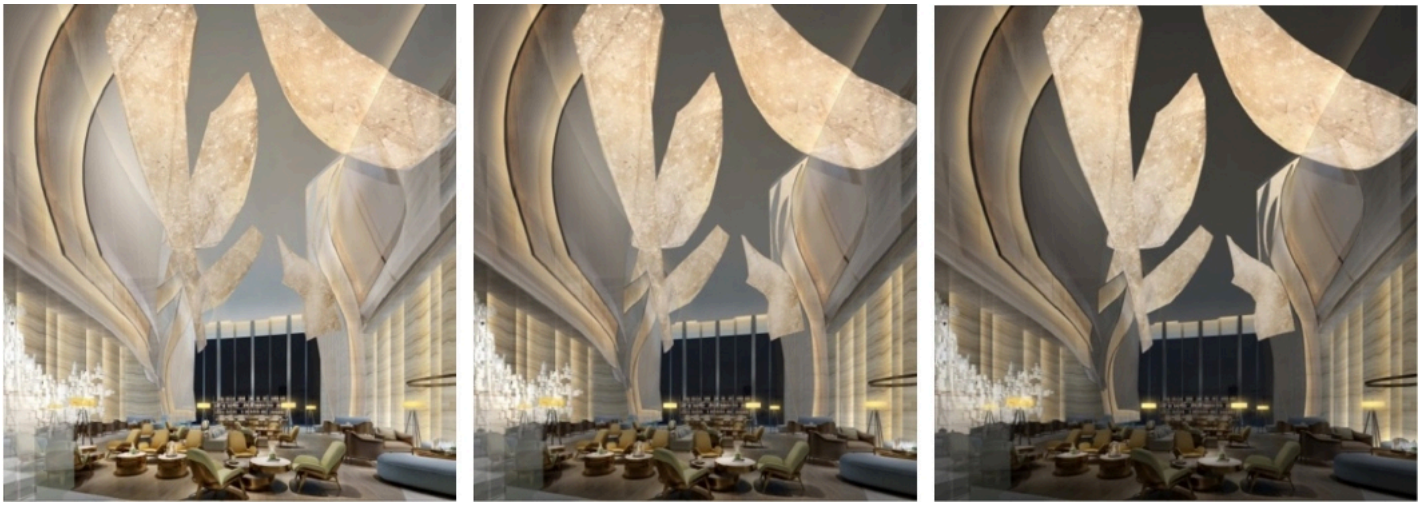


Figure 5: DoubleTree by Hilton Xiamen: Three different scene modes of the lobby bar set according to different time periods [5]

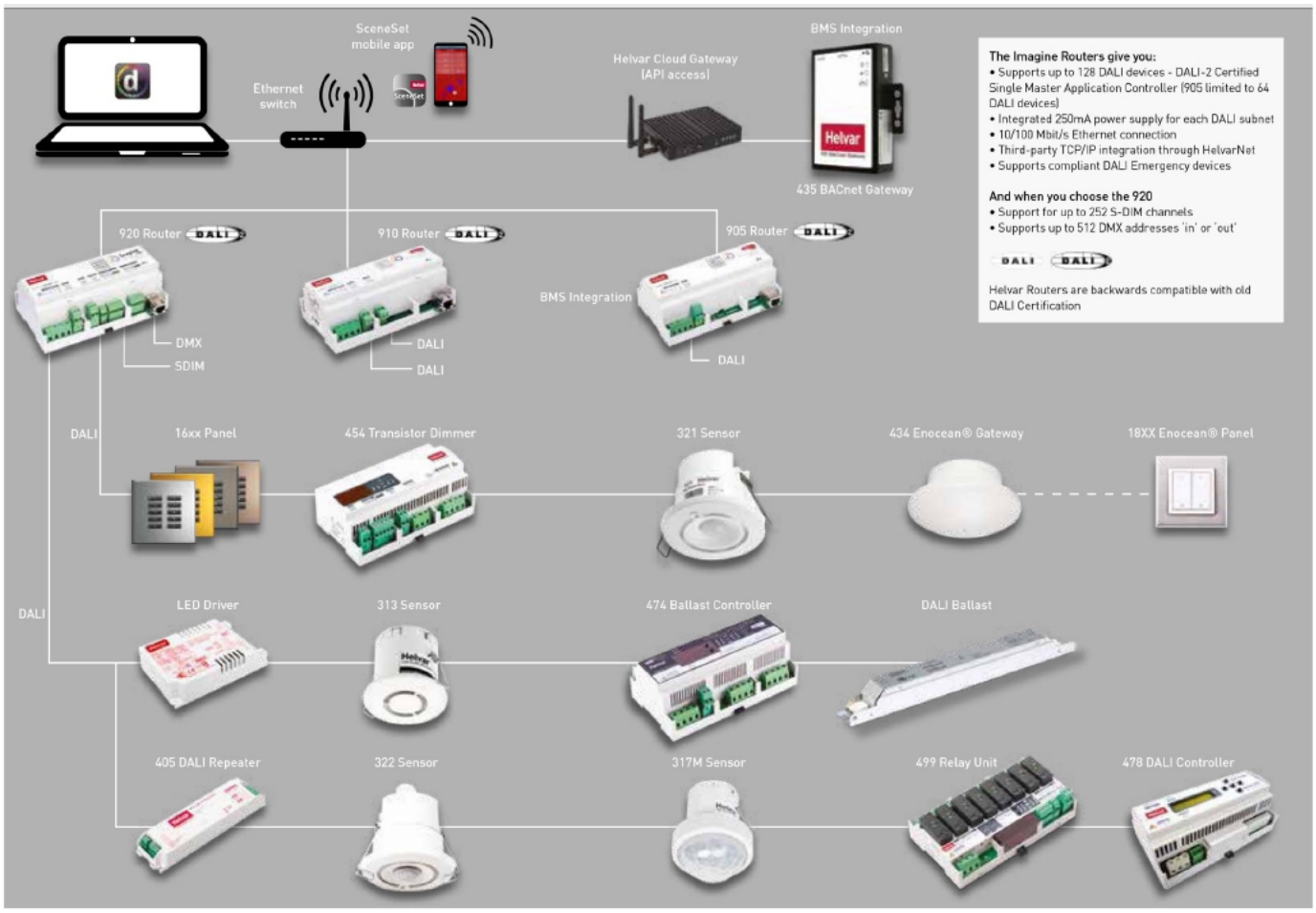


Figure 6: Working principle of the smart lighting control system (example). Note, the system is compatible with a wider selection of components

Figure 7: Chinese Five-star hotel's king room lighting layout rendering and lighting control panel

Carry YU

In general, the intelligent lighting system can evenly distribute the hotel's light and colors, leaving a good impression on the guests, and helping enhance the image of the hotel. In addition, it can automatically manage the lighting scenes according to the operation time of the hotel without manual intervention. This can help to extend the life of each light source in the hotel and save energy. Moreover, combined with local smart panels and tablet computers for controlling, this system improves hotel management efficiency by way of various scene modes. The hotel lobby can use a variety of adjustable light sources to maintain the softest and most elegant lighting environment through intelligent dimming. The lighting scene can be set according to different times of the day and for different purposes. When using it, you only need to call up the pre-set best lighting scene, so that guests can experience different visual effects. The management staff can control it through the smart panel on site or through the smart device touch screen in the lobby, and the light status can be displayed on the screen.

Active management is adopted to control the lobby lighting. To facilitate frequent entering and exiting of guests, all lights in the lobby are turned on. When guests enter and exit less, some lights are reserved. Different scene modes can be preset: business mode, day mode, night mode and security mode or cleaning mode, and so on. Restaurants and bars are public places with a high usage rate in hotels, so different scenes also need to be flexibly used at night to create different spaces and provide different dining experiences. And for large conferences, it's necessary to provide customers with a variety of functional options. With the intelligent lighting control system, the customized lighting scene and scene control can be realized with one click through the intelligent control panel, which greatly simplifies the complexity of meeting room equipment control and quickly meets the guests' needs for the interior lighting environment. Corridors and elevators are the most easily neglected public area. If the lighting control is planned properly, it can save considerable energy consumption and add a highlight for the entire building. The control method adopts microwave detectors and manual control, and it could have a function to delay turning off the lights.

As one of the most important areas of the hotel, the living habits of guests should be fully considered in the guest rooms and provide convenient and fast service. Dimming is the core of lighting design. Designers can use the system to set the brightness value of each dimming control loop to form different lighting scenes, usually including welcome mode, visitor mode, leisure mode, reading mode, sleep mode, and more. It is worth mentioning that the latest trend in top grade hotel is the control panel of the guest room. It is linked with a series of smart devices such as light, TV, curtains, music, etc. As soon as the door is opened, the magnetic switch will automatically activate the downlight of the entrance hall ceiling to light up and once the room card is inserted, the preset program will turn on the welcome mode lights in the room by default, the curtains will automatically close and soothing music will play on the TV. At this point, guests can start to enjoy their own private space without any extra operations. According to the needs of space function, the switch panel on both sides at the head of the bed is fully functional and clear. Switching lighting scene mode with one button, the bedside reading light is freely dimmable, and the table lamp or floor lamp power supply in the room will also require access to the Room Control Unit (RCU). In addition, there is a night light mode to ensure the safety of the guest should they get up during the night. With such an intelligent lighting control system, the different lighting effects presented by each mode can meet the individual needs of users. It is a pleasant plus point for both business travelers and vacation tourists. Who can refuse this new change?

Meanwhile, the flood lighting and landscape lighting of the hotel can be automatically controlled by the coordinated method of illuminance sensor and timing. When the collected natural light turns dark, most of the outdoor lighting is automatically turned on, and when the natural light turns bright, the outdoor lighting is turned off. It can also locate the specific longitude and latitude of the city based on the perpetual calendar and realize the monitoring and management of sunrise and sunset times.

In fact, the ultimate goal of design is to serve people, and the results come from the bits and pieces in our lives. Every work is a process of telling a story, and every story is different. This all stems from the creative inspiration generated by the deep exploration of the hotel's corporate culture and local civilization, as well as the realization of the design concept. Therefore, the story is finally implemented through the two keywords: "inspiration" and "reality". The designer should not only propose smart and unique ideas based on the requirements of customers and the extension of local civilization, but also analyze the interests of all aspects to realize the plans. This is the lighting design trend in China. ■

AUTHOR: Carry YU
Carry YU attended Tsinghua University in 2006 where he studied Interior Design, Lighting Design and Art. Following his studies he worked as a designer in the Design Department at Light-source in Hong Kong from 2006 to 2010. In 2010, he founded CSLC Lighting Design in Chongiqng, China, which has achieved outstanding results in China's lighting design field to date and where Carry YU serves as General Manager & Design Director. He has worked on many representative projects for the Radisson Hotel Group, Hilton Hotels Corporation, Starwood Hotels & Resorts Worldwide and Hyatt Hotels Corporation as well as many others. Among his many awards are First Prize of Entertainment Club Space – Zhu Rong Award in 2019, First Prize of Hotel Space – Zhu Rong Award in 2020 and Best Designer Award – Golden Palace in 2020.

Awards

- 2014 Outstanding Designer of World Lighting Industry
- 2015 Second Prize of Interior Decoration Design – Lingnan Cup
- 2016 Elite Award – Chinese Lighting Design Association
- 2016 Nomination Award – I-Ding International Design Award
- 2016 Second Prize of Catering Space – Zhu Rong Award
- 2017 Outstanding Designer of Guangdong Province
- 2017 Top Ten Engineering Awards – Aladdin Magic Lamp Award
- 2017 Best Lighting Design Award – Golden Bund
- 2018 Top Ten Lighting Designers – Asia-Pacific Space Design
- 2018 First Prize of Hotel Space – Zhu Rong Award
- 2018 Gold Award of Designer's Works Contest – CIDF
- 2019 First Prize of Entertainment Club Space – Zhurong Award
- 2020 First Prize of Hotel Space – Zhu Rong Award
- 2020 Best Designer Award – Golden Palace

References

[1] 2F Unit 1, Green Space, No.19 Longyue Road, Yubei District, Chongqing, China +86 13983020993 | cqcslc@163.com
[2] Radisson Blu Hotel Hangzhou Xintiandi, proximity to the Jing–Hang Grand Canal, a premier Hangzhou hotel
[3] Sheraton Zibo Hotel, Shandong, 0.9 miles from Zibo Railway Station
[4] Crescent Hills located in Zhangzhou, Fujian
[5] Hilton Xiamen

Showcase Your Lighting Excellence in 2021

www.led-professional.com

Human-Centric Lighting Will Usher in Another Once-in-a-Century Golden Era for General Lighting

Biologists have known for a long time that light is not only essential for vision, but also for life. Invisible parts of the spectrum must not be forgotten for humans. For a long time it wasn't a serious oversight to ignore these facts because humans were outside in natural sunlight long enough to get the required doses of all spectra. But this isn't the case anymore. Many of us spend approximately 90% of our time indoors. Therefore, HCL needs to be considered seriously and the non-visual effects must be a part of it. HCL must not only become affordable but also the "lighting standard" and not be considered a fancy trend for the luxury segment. James TU, Chairman and CEO, Chris JOHNSTON, Director of Total Sustainability, and John Davenport, Chief Scientist at Energy Focus explain what HCL means to them, propose how it could be implemented and why including disinfection in HCL concepts could be a good idea.

Light's influence far surpasses its role in vision. Sunlight aids the synthesis of vitamin D and acts as a mood enhancer through the production of beta-endorphins [1]. Research is continually finding that advanced artificial lighting systems are capable of providing similar benefits in the form of more amicable and productive environments, which is particularly relevant as people spend approximately 90% of their time indoors, according to the Environmental Protection Agency (EPA) [2]. A study published in the American Journal of Psychiatry [3] found that bright light and dawn simulation treatments can be effective in reducing depression symptom severity in people with non-seasonal depression as well as seasonal affective disorder. The term that has arisen to account for these advanced capabilities is human-centric lighting (HCL). HCL is used to describe lighting that considers both visual and non-visual effects of light. By taking advantage of both biological rhythms and sensitivity to particular wavelengths, HCL enhances the biological and emotional health and wellbeing of people.

Circadian Rhythm and Lighting

Biological rhythms are cyclic changes in biological parameters, manifested at both the multicellular and unicellular levels; biological rhythms with a periodicity of approximately 24 hours are called circadian rhythms. These circadian rhythms in humans include or influence sleep-wake, hunger-satiety, body temperature fluctuation, energy level, the autonomic nervous system, cortisol levels, and melatonin levels. One of the most prominent circadian rhythms is the sleep-wake cycle. During the day, the suprachiasmatic nucleus (SCN), the body's master clock [4], sends signals to the rest of the body to induce alertness. In the evening, it directs the production of melatonin [5] to promote sleep. The SCN ensures that our behaviors, psychological reactions, and metabolism perform at the appropriate time. Light is the most powerful time cue [6], or zeitgeber, for setting this biological clock, and while these rhythms persist in the absence of external stimuli, the result is a free-running cycle. According to Progress in Molecular Biology and Translational Science [7], "Mounting evidence indicates that disruption of circadian regulation is associated with a wide variety of adverse health consequences, including increased risk for premature death, cancer, metabolic syndrome, cardiovascular dysfunction, immune dysregulation, reproductive problems, mood disorders, and learning deficits." As the primary zeitgeber, light can reset or phase shift [8] (phase advance or phase delay) the internal clock/circadian rhythm to counteract such circadian desynchronization. A relatively recent advancement in LED technology is enabling the development of lighting that helps synchronize the body's circadian rhythm.

Circadian lighting alters the wavelength and intensity to that which our bodies naturally respond. The photoreceptors responsible for vision– the rods and cones– are each maximally sensitive to particular wavelengths [9]. However, as it turns out, sight is dual functional. It helps us see AND detect light for a range of behavioral and physiological responses separate from sight, called 'non-visual' responses. These effects of light are mediated by non-rod, non-cone photoreceptors located in the ganglion cell layer of the eye called intrinsically photosensitive retinal ganglion cells

(ipRGCs) [10]. IpRGCs are the primary conduit from the retina to the SCN, but they receive input from the rods and cones, meaning that all of the photoreceptors play a role in circadian regulation.

Manipulating an LED's output wavelength can increase alertness, performance, mood, and sleep. Exposure to "bluer" light, particularly around 473 nm [11], has been demonstrated to increase activity in brain areas associated with alertness, performance and mood during the day. It is possible to achieve similar alerting effects without stimulating the circadian system using red light. Both blue and red light have been shown to effectively increase alertness [12], indicating that alertness induced by lighting is not solely directed by the circadian system. According to Dr. Andrew Elliot [13], a professor of Psychology at the University of Rochester, "Red enhances our physical reactions because it is seen as a danger cue." When your body thinks there is a threat it immediately, automatically, mobilizes energy to flee or fight. The reverse effect, promoting a relaxing or calming environment, can also be accomplished through warm (low) correlated color temperature (CCT) [14]. Warm color temperatures are particularly useful to help promote calm to help go to sleep.

Carefully adjusting the CCT and brightness of lighting throughout the day should also prove useful in facilities such as assisted living facilities and nursing homes. Studies using light therapy have demonstrated significant promise in alleviating some of the symptoms of Alzheimer's disease and related dementias [15], such as improving nighttime sleep efficiency, reducing nocturnal wandering, and alleviating evening agitation.

Constant electric light is the first factor that affects how well we sleep. Evening blue LED light has twice the harmful impact on nighttime melatonin suppression than warm yellower light, even at the same light intensity [16]. For this reason, exposure to blue light (or high CCT) should be limited in the evening and particularly immediately prior to going to bed. Altering the spectral distribution of lighting to de-saturate wavelengths below 500 nm that will be used in the evening, can also reduce the suppression of melatonin, thus minimizing the disruptive effect on sleep and circadian rhythms [17]. However, lighting designers and manufacturers must consider the influence of sub-additivity for circadian stimulation when altering spectral distributions. Sub-additivity is the effect when, for example, exposure to combined wavelengths of blue and green light results in less melatonin suppression than exposure to monochromatic green or blue light [18]. This means that the pathway between the photoreceptors and the brain to predict the circadian response is not just a single photopigment.

It is for this reason that we must consider the entire photic pathway to determine how best to stimulate the circadian system. Circadian Stimulus (CS) is a metric devised by the Lighting Research Center, which has been formally adopted for use in UL 22480 (Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People). It considers light level, spectrum, and duration to reflect an expected level of melatonin suppression to correlate circadian regulation. The Lighting Research Center has designed a circadian absolute sensitivity chart to simplify this otherwise complicated equation (keep in mind that the lux measurement is vertical illuminance and not horizontal illuminance).

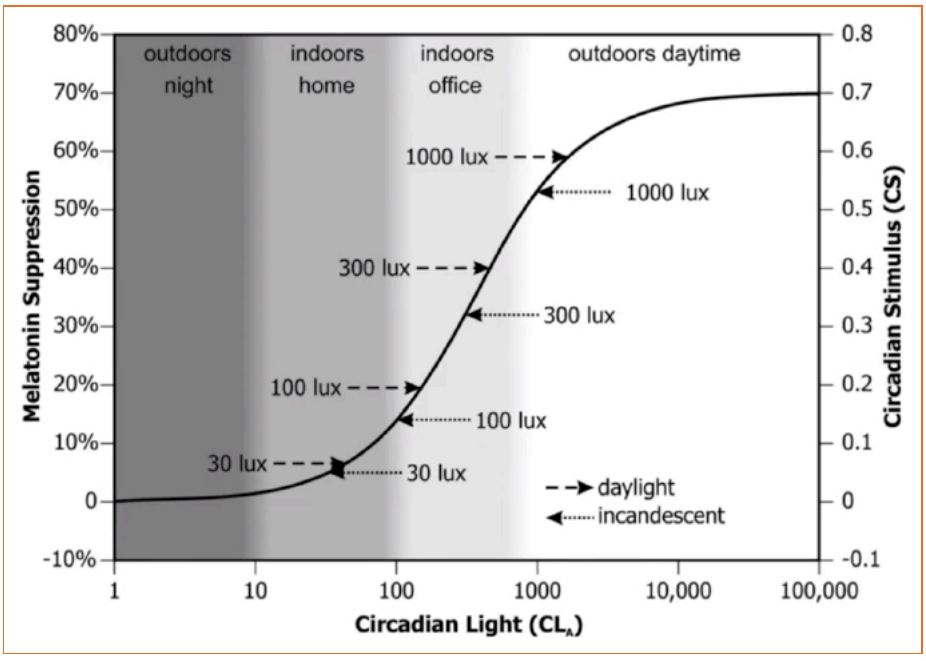


Figure 1: Circadian absolute sensitivity [19]

Quite simply, the goal is exposure to a CS of 0.3 or greater at the eye for at least one hour, preferably in the morning as that is when the antidepressant effect of light is most pronounced [20]. A simple three-step guideline for maintaining a well-entrained circadian rhythm is as follows: 1) Timing: avoid bright and blue light in the evening and spend at least 30 minutes outside in the morning; 2) Brightness: keep artificial lighting brightest in the morning and early afternoon and dim the lights in the evening; 3) Correlated Color Temperature: where possible, maintain exposure to high (cooler) CCT in the morning and early afternoon, and low (warmer) CCT in the evening [21]. When designing a circadian lighting system, keep in mind that a higher CCT may not always provide a higher CS. It is entirely possible that a 4500 K light source may produce a higher CS than a 5000 K source depending on the spectral distribution (SPD). It is best to check the CS using the Lighting Research Center's CS calculator by entering the SPD file for the particular light source [22].

To further reinforce the importance of a properly entrained circadian rhythm here are several disorders associated with a disrupted rhythm:

- Impaired cellular immunity and overactive inflammatory responses [23]
- Increased anxiety and depression [24]
- Increased tobacco dependence [25]
- Increased risk of cardiovascular disorders [26]
- Increased risk of type 2 diabetes [27]
- Increased risk of breast cancer [28]

Flicker Induced by AC Powerlines

An often-overlooked, yet extremely important feature of human centric lighting is AC power-line induced flicker. Power-line induced flicker (changes in light output) occur at 120 cycles per second as a result of the AC power line passing through zero 120 times a second. While electronic ballast-driven fluorescents made dramatic reductions in flicker from their magnetic ballast-driven predecessors, when lower quality LED products came to market, they reintroduced high flicker rates. Unfortu-

nately, everyone is sensitive to flicker to some degree. For many people, high flicker rates may contribute to headaches, eye strain and fatigue; acute symptoms that may vary from mildly distracting to severely uncomfortable. In a study published in Current Pain and Headache Reports, visual triggers such as flicker account for 38% of reported migraines [29].

Implementing Human-Centric Technology

While there are a plethora of connected lighting or lighting control companies serving the commercial and industrial (C&I) sector, the vast majority focus on the new build and renovation markets because communication capacities are limited in existing C&I buildings. Numerous lighting control approaches have been developed to take us beyond the simple on/off control afforded by the more than 100-year-old wall switch (US 1,233,597). These include wireless (e.g., Bluetooth and Zigbee), added low voltage wiring (e.g., 0-10 V and DALI), and conventional power line control ("PLC" e.g., phase control dimming, x-10 and universal powerline bus) approaches.

Implementing complex control systems can have major drawbacks, including the commissioning and additional hardware costs as well as the potential security issues associated with wireless; the installation and additional hardware and installation costs associated with adding low voltage control wires; and the power line distortion impact of phase control or the commissioning, cost and potential noise issues associated with modulating the power line.

Energy Focus' new – and utterly simple – powerline control approach avoids all of the above issues. Instead of modulating the power line, a specially designed control switch [34] briefly interrupts it. This signals the TLEDs to, for example, change brightness or color without disrupting the light output. Since the interruptions are inherently digital, a wide range of lamp control commands can be accommodated [34]. In addition, unlike more complex PLC systems, only those lamps on the switched line receive signals which automatically associates the lamps with the control. No commissioning is required. Thus, retrofitting an existing lighting system is simply a matter of retrofitting the bulbs and light switch.

Given the substantial energy savings and sustainability impacts provided by LED lighting today, one might wonder why the

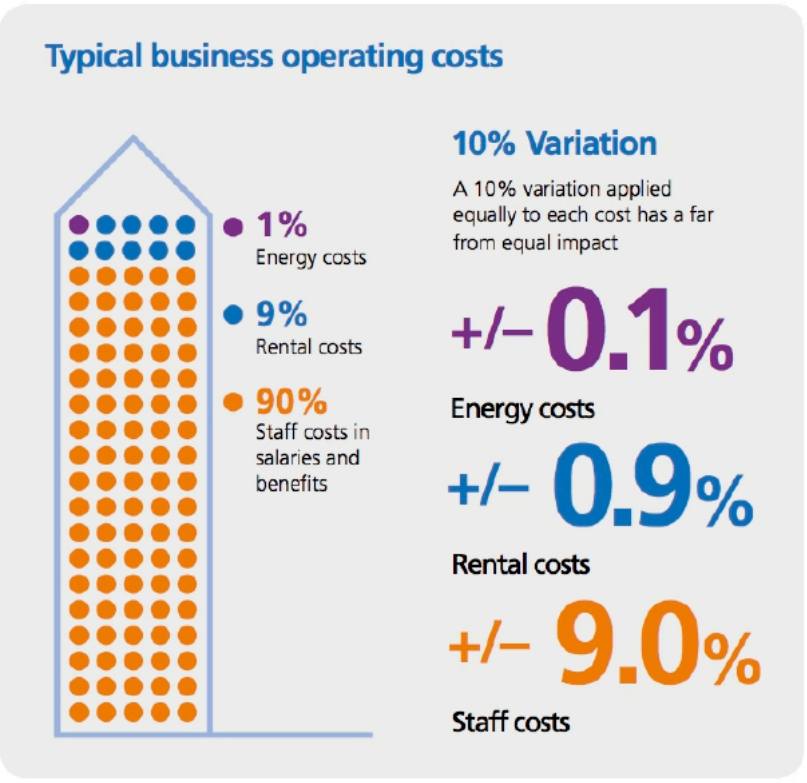


Figure 2: Typical Business Operating Costs

penetration rate of LEDs in linear fixtures—the primary form factor in the C&I sector—still hovers around just 20% after more than 10 years of commercialization based on the latest DOE LED adoption report [30]. And the penetration of connected LED lighting, which has been available for years as well, is still near non-existent with penetration rate below 1% based on the DOE report.

An LED lighting retrofit is a capital project that takes advanced planning, funding, coordination and execution not required by traditional lighting products that are sold via fulfillment processes. Most facility managers need to be educated about and extremely comfortable with the ROIs from LED's energy savings, in addition to quality and reliability of the LED products, to commit to such retrofit projects. In addition, facility managers, already quite occupied on a daily basis tending to maintenance, fixes and problem solving, simply don't have enough time, motivation and resources to conduct the due diligence of the rapidly evolving landscape of LED lighting products and initiate such projects. Reduced configuration complexity increases the likelihood that deployed connected lighting systems will be correctly and consistently operating, increasing the persistence of energy savings. EnFocus lighting systems offer extremely simple installation and intuitive operation without cumbersome configuration protocols and zero risk of cyberattacks, and therefore have the potential to significantly broaden and accelerate deployment of connected lighting systems.

Energy savings had been touted as the primary benefit of LED lighting—DOE estimated that in 2018 LEDs were saving over 1.3 trillion BTUs of electricity in the US alone, and an additional 5 trillion BTUs are potentially achievable through additional LED adoptions. LED adoption clearly has not been broad and fast based simply on energy savings. The catalyst for much more rapid and massive LED adoptions likely lies in the potential of non-energy benefits (NEBs), which are driven chiefly by connected LED lighting.

According to World Green Building Council's report, "Health, Wellbeing & Productivity in Offices", typical business operating expenses and staff costs account for 90% of the total, with rent and energy accounting for 9% and 1% respectively (a similar rule from Jones Lang Lasalle's called "3-30- 300TM" [31] states that in real estate, on average, annually, it costs a building USD 3 per square foot in utilities, USD 30 per square foot in rent and USD 300 per square foot in payroll). Such expense breakdowns show that health, wellbeing and productivity related investments impact companies' bottom lines far more significantly than simple energy savings and

could provide stronger incentives for organizations to upgrade to connected LED and human-centric lighting.

Some of these new systems also grant facilities the ability to introduce UV disinfection capabilities into ceiling mounted lighting fixtures to further improve occupant wellness particularly in the post-COVID-19 era. The effectiveness of UV-C radiation to destroy airborne "superbugs" has been demonstrated since the late-1930s, when it was used to prevent the spread of measles in some Philadelphia schools [32]. Unfortunately, that same capability to destroy viruses also poses risks to human skin and eyes. Self-contained units for UV air disinfection – as well as automated systems to sterilize surfaces when humans aren't present – enable facilities to regularly disinfect spaces without endangering occupants. Lighting troffer-based air disinfection systems [33] provide disinfection at the source, closest to the occupants where viruses and bacteria are spread, and risk of human exposure is highest. Fans pull contaminated air directly into a UV-C chamber and emit the clean air directly back down. This reduces the travel of pathogens and continuously improves air quality. Simultaneously, an appropriate UV technology [33] and control platform [34] provides flicker-free, dimmable (10-stage) and color tunable (2700–6500 K) circadian-ready lighting [34]. Quite simply for facilities with 2x4 or 2x2 troffers, which account for the majority of lighting sources in commercial and industrial spaces, the replacement of these troffers offers an effective long-term solution for safer, healthier and more productive environments.

Conclusion

After staying relatively uninspiring in technological breakthroughs for over 100 years since the Thomas Edison days, thanks to a wide range of LED, electronics, software and connectivity technologies, lighting now has unprecedented and rapidly advancing capacity to further enrich lives and improve health. For the immediate future, connected lighting that provides circadian capabilities will bring significant human comfort, productivity and health benefits while UV-related innovations will provide a safer environment that is crucial for bringing people together and back to work. Most importantly, it's never been so simple and cost-effective to deploy HCL technologies to make them massively impactful for modern lives. ■

AUTHOR: James TU

James Tu is Chairman & Chief Executive Officer of Energy Focus, Inc., an industry-leading innovator of sustainable LED lighting technologies and solutions. James is an advocate for LED and human-centric lighting technologies that provide environmental, health and business ("triple-bottom-line") benefits.

References

[1] Holick MF. Biological Effects of Sunlight, Ultraviolet Radiation, Visible Light, Infrared Radiation and Vitamin D for Health. Anticancer Res. 2016 Mar;36(3):1345-56. PMID: 26977036.

[2] https://www.epa.gov/report-environment/indoor-air-quality

[3] Golden RN, Gaynes BN, Ekstrom RD, Hamer RM, Jacobsen FM, Suppes T, Wisner KL, Nemeroff CB. The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence. Am J Psychiatry. 2005 Apr;162(4):656-62. doi: 10.1176/appi.ajp.162.4.656. PMID: 15800134.

[4] https://www.nigms.nih.gov/education/fact-sheets/Pages/circadian-rhythms.aspx

[5] Doghramji, Karl. "Melatonin and its receptors: a new class of sleep-promoting agents." Journal of clinical sleep medicine: JCSM : official publication of the American Academy of Sleep Medicine vol. 3,5 Suppl (2007): S17-23.

[6] Münch, Mirjam, and Vivien Bromundt. "Light and chronobiology: implications for health and disease." Dialogues in clinical neuroscience vol. 14,4 (2012): 448-53. doi:10.31887/DCNS.2012.14.4/mmuench

[7] Evans, Jennifer A., and Alec J. Davidson. "Health Consequences of Circadian Disruption in Humans and Animal Models." Progress in Molecular Biology and Translational Science Chronobiology: Biological Timing in Health and Disease, 2013, pp. 283–323., doi:10.1016/b978-0-12-396971-2.00010-5.

[8] Lall, Gurprit S., et al. "Distinct Contributions of Rod, Cone, and Melanopsin Photoreceptors to Encoding Irradiance." Neuron, vol. 66, no. 3, 2010, pp. 417–428., doi:10.1016/j.neuron.2010.04.037.

[9] Pickard G.E., Sollars P.J. (2011) Intrinsically Photosensitive Retinal Ganglion Cells. In: Nilius B. et al. (eds) Reviews of Physiology, Biochemistry and Pharmacology. Reviews of Physiology, Biochemistry and Pharmacology, vol 162. Springer, Berlin, Heidelberg. https://doi.org/10.1007/112_2011_4

[10] Vandewalle, Gilles et al. "Brain responses to violet, blue, and green monochromatic light exposures in humans: prominent role of blue light and the brainstem." PloS one vol. 2,11 e1247. 28 Nov. 2007, doi:10.1371/journal.pone.0001247

[11] Plitnick, B., et al. "The Effects of Red and Blue Light on Alertness and Mood at Night." Lighting Research & Technology, vol. 42, no. 4, Dec. 2010, pp. 449–458, doi:10.1177/1477153509360887.

[12] https://www.sciencedaily.com/releases/2011/06/110602122349.htm

[13] Hussein S. El-Ghoroury, Yoshitake Nakajima, Milton Yeh, Evan Liang, Chih-Li Chuang, and J. C. Chen, "Color temperature tunable white light based on monolithic color-tunable light emitting diodes," Opt. Express 28, 1206-1215 (2020)

[14] Figueiro, Mariana G et al. "Tailored lighting intervention improves measures of sleep, depression, and agitation in persons with Alzheimer's disease and related dementia living in long-term care facilities." Clinical interventions in aging vol. 9 1527-37. 12 Sep. 2014, doi:10.2147/CIA.S68557

[15] "The Dark Side of Modern Light." Why We Sleep: Unlocking the Power of Sleep and Dreams, by Matthew P. Walker, Scribner, an Imprint of Simon & Schuster, Inc., 2018, pp. 265-270.

[16] Santhi N, Thorne HC, van der Veen DR, Johnsen S, Mills SL, Hommes V, Schlangen LJ, Archer SN, Dijk DJ. The spectral composition of evening light and individual differences in the suppression of melatonin and delay of sleep in humans. J Pineal Res. 2012 Aug;53(1):47-59. doi: 10.1111/j.1600-079X.2011.00970.x. Epub 2011 Oct 24. PMID: 22017511.

[17] Lee, S., Uchiyama, Y., Shimomura, Y. et al. Subadditive responses to extremely short blue and green pulsed light on visual evoked potentials, pupillary constriction and electroretinograms. J Physiol Anthropol 36, 39 (2017). https://doi.org/10.1186/s40101-017-0156-4

[18] https://www.lrc.rpi.edu/programs/lighthealth/pdf/LookUpTable_Indirect.pdf

[19] Blume, Christine et al. "Effects of light on human circadian rhythms, sleep and mood." Somnologie : Schlafforschung und Schlafmedizin = Somnology : sleep research and sleep medicinevol. 23,3 (2019): 147-156. doi:10.1007/s11818-019-00215-x

[20] https://www.lrc.rpi.edu/resources/newsroom/LDA_CircadianStimulus_Oct2016.pdf

[21] https://www.lrc.rpi.edu/cscalculator/

[22] Eismann, Emily A., et al. "Circadian Effects in Cancer-Relevant Psychoneuroendocrine and Immune Pathways." Psychoneuroendocrinology, vol. 35, no. 7, 2010, pp. 963–976., doi:10.1016/j.psyneuen.2009.12.011.

[23] Du□Quiton, J., Wood, P.A., Burch, J.B., Grutsch, J.F., Gupta, D., Tyer, K., Lis, C.G., Levin, R.D., Quiton, D.F.T., Reynolds, J.L. and Hrushesky, W.J.M. (2010), Actigraphic assessment of daily sleep–activity pattern abnormalities reflects self□assessed depression and anxiety in outpatients with advanced non□small cell lung cancer. Psycho□Oncology, 19: 180-189. https://doi.org/10.1002/pon.1539

[24] Kageyama, Takayuki, et al. "Associations of Sleep Problems and Recent Life Events with Smoking Behaviors among Female Staff Nurses in Japanese Hospitals." Industrial Health, vol. 43, no. 1, 2005, pp. 133–141., doi:10.2486/indhealth.43.133.

[25] Takeda, Norihiko, and Koji Maemura. "Circadian Clock and Cardiovascular Disease." Journal of Cardiology, vol. 57, no. 3, 2011, pp. 249–256., doi:10.1016/j.jjcc.2011.02.006.

[26] Kreier, Felix, et al. "'Diabetes of the Elderly' and Type 2 Diabetes in Younger Patients: Possible Role of the Biological Clock." Experimental Gerontology, vol. 42, no. 1-2, 2007, pp. 22–27., doi:10.1016/j.exger.2006.07.004.

[27] Hansen, J. Risk of Breast Cancer After Night- and Shift Work: Current Evidence and Ongoing Studies in Denmark. Cancer Causes Control 17, 531–537 (2006). https://doi.org/10.1007/s10552-005-9006-5

[28] https://migraine.com/blog/top-10-triggers-according-new-research/

[29] https://www.energy.gov/sites/prod/files/2020/09/f78/ssl-led-adoption-aug2020.pdf

[30] https://www.worldgbc.org/news-media/health-wellbeing-and-productivity-offices-next-chapter-green-building

[31] http://www.us.jll.com/united-states/en-us/Documents/Workplace/green-productive-workplace-perspective.pdf

[32] Wells, W. F., et al. "The Environmental Control Of Epidemic Contagion." American Journal of Epidemiology, vol. 35, no. 1, 1942, pp. 97–121., doi:10.1093/oxfordjournals.aje.a118789.

[33] Energy Focus' abUV™ : https://uvcd.energyfocus.com

[34] Energy Focus' EnFocus™ control platform: https://www.energyfocus.com/enfocus/

Dynamic Lighting Complementing the Dynamics of the Sky and Sunlight

The design of dynamic lighting should be grounded in an understanding of human connection to the natural variations of daylight and how humans have evolved in response to these variations. Daylight dynamics are based on endless variations of diffuse light from the sky and direct light from the sun and their respective changes in warm, neutral and cool colors. What if we design dynamic lighting complementing these dynamics of the sky and sunlight? This was the question asked when, in 2017, Aalborg University teamed up in a unique collaboration with the four industrial partners Fagerhult, iGuzzini, Tridonic and Zumtobel on the research project "Double Dynamic Lighting (DDL), bringing the qualities of daylight into the office".

The DDL project was targeted to develop strategies and lighting design concepts of dynamic indoor lighting for office environments. The research group aimed to investigate how advanced responsive lighting technology can create lighting scenarios referring to the perceived qualities of natural light, and thereby improve the visual appearance, perceived atmosphere and work engagement in an office.

The Perceived Qualities of Daylight

The potentials of dynamic lighting have been recognized by the industry, architects, and lighting designers aiming to deliver positive effects of light to support non-visual responses and thereby stimulate the circadian rhythm of human lives. In this approach dynamic lighting is often adjusted in intensity and spectral distribution over time, referring to even horizontal light distribution. Drawing from an architectural background Professor HANSEN found a need to bridge this natural scientific approach to a basic understanding of the interplay of how daylight dynamics and dynamic lighting as one light component is perceived by the occupants in a space. In the research group and the master's degree course in lighting design she leads, it is essential therefore to study how different light settings in a space can complement the perceived qualities of daylight dynamics. In a pre-study these perceived qualities of light were investigated. Starting with a reference to the two main components of daylight; direct sunlight and diffuse skylight. The concepts of flow of light, light modeling and light zones were identified to describe the perceived spatial qualities of daylight intake in a space [1]. The ratios of direct and indirect lighting components have been studied in lighting research, stating that a combination of direct and diffuse lighting is preferred over only using direct or indirect, which is often the situation in office spaces today [2,3,4]. The novelty in this project is that the direct light has a tilt angle creating a directionality referring to the inflow of daylight from the side windows in the space. Hereby, we aimed to create an integrated daylight and lighting approach, where the two complement each other in respective variations in direct/diffuse ratio, intensities and color temperatures.

Illustration 1: Signe has chosen this specific space for reading, in the light zone created by the inflow of daylight

Testing the Ratio of Direct and Diffuse Light

First, we wanted to find out if it was possible to create the desired perceived qualities of the directionality of flow of light in a space. We focused on the visual qualities of creating shadow patterns and light modeling of objects on the work plane, as well as a light zone around the workspace without creating glare and discomfort from the direct light source. A full-scale experiment was set up in an office space at Aalborg University in Copenhagen **[4]**. Traditional 60 cm × 60 cm diffuse ceiling panels (Fagerhult Multilume Flat Delta tunable white, 2700–6500 K) were distributed evenly in the ceiling referring to how lighting today is often used in offices.

Secondly, and the new approach was that we added the "flow of light component", four ceiling mounted spotlights (Zumtobel, Arcos 3, 2700–6500 K) with a beam angle of 36° and tilt angle of 32°. Then 30 test participants were asked to evaluate the perceived qualities of the different lighting scenarios by answering a questionnaire for each of the four scenarios with different ratio of direct and diffuse lighting, all of them meeting 500 lx on the table and minimum 300 lx in the space.

Nine questions with semantic opposites on an analogue scale were grouped in two categories covering aspects within visual appearance, including perceived brightness, evenness, shadow distinction, light modeling, visual comfort and glare. The other aspect was the perceived atmosphere, addressed within three questions asking about naturalness, coziness and dullness. Finally, 30 words were defined, half of them relating to visual appearance and the other half to perceived atmosphere. The analysis of the data from the questionnaires show that an increase in the direct lighting also increases the distinction of coziness and shadow patterns, contributing to form modeling and perceived atmosphere. However, the increase in direct lighting also increases glare, which could have a negative impact on visual comfort. The reaction cards seemed to complement this. The analysis of the data told us that an increased ratio of direct lighting decreased the perceived brightness and evenness of the lighting.

The atmosphere in the scenario with only diffuse lighting was perceived as unnatural and clinical by 43% of the participants, this was correlated with the words chosen, such as bright, formal and task focused. Based on the analysis of the data from this modest test group it can be concluded that adding directional lighting to the traditional diffuse ceiling panels in an office, it is possible to enhance the visual appearance, form modeling of objects as well as the perceived atmosphere in the space. The direct light must, however, be balanced to avoid glare.

This study helped to define the recommendations for the directional lighting to be more than 15% of the total light to create light zones at work planes and contribute to the flow of light, the light modeling of objects. The answers also showed that less than 45% of direct lighting is recommended to avoid discomfort from glare for visual tasks. The data from this modest test group showed the directional light to be more than 15% and less than 45% **[4]** (**Figure 1**).

Testing Combinations of Correlated Color Temperatures (CCTs)

Based on these findings we designed an experiment, testing how different combinations of respective high, neutral and low CCT were perceived in the space, and if there was a difference when the scenarios were tested in two different sky situations, clear sky and overcast referring to CIE3 and CIE13 sky types. The ratio of the DIRECT : DIFFUSE lighting was here fixed $40 : 60$, meeting 500 lx on the task area and a minimum of 300 lx in the space. The five combinations of DIRECT : DIFFUSE CCT's can be seen in **Figure 2**. The photo registrations of the visual appearance of the objects on the work plane and the perceived atmosphere in the space can be seen in **Figure 3**. 15 participants conducted one test under clear skies and the same test under overcast conditions. For each scenario the participants were asked to select up to three of the 30 reaction cards describing the appearance of the light and space. Finally, the participants were interviewed.

The analysis revealed that the **C:C** (2.1)[2] setting with cool task lighting and cool ambient lighting had the most negative validation in both the interview and the choice of reaction cards. The light was characterized as unpleasant, uncomfortable and the perceived atmosphere as clinical. The **W:W** (2.5) setting on the other side was ranked as the most relaxed, but in the interviews, it was evident that it was not identified with proper lighting in an office.

[2]Light color temperature relations between task-light (first letter) and ambient-light (second letter); C = cold white light, W = warm white light, N = neutral white light. The numbers in brackets are the scenario numbers.

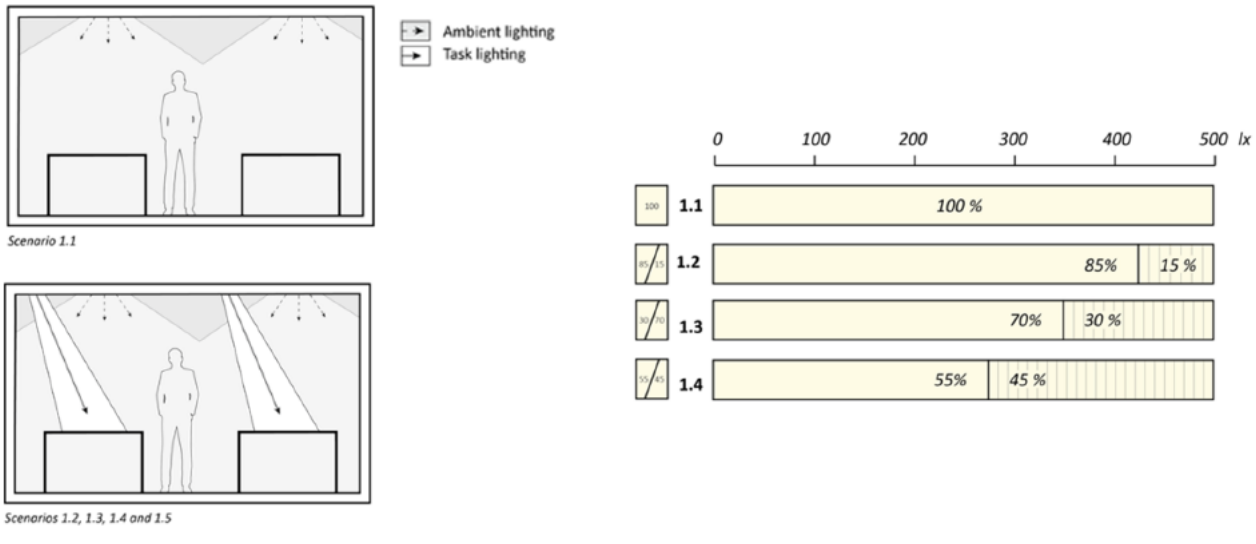


Figure 1: Four scenario testing ratios of direct and diffuse lighting [4]

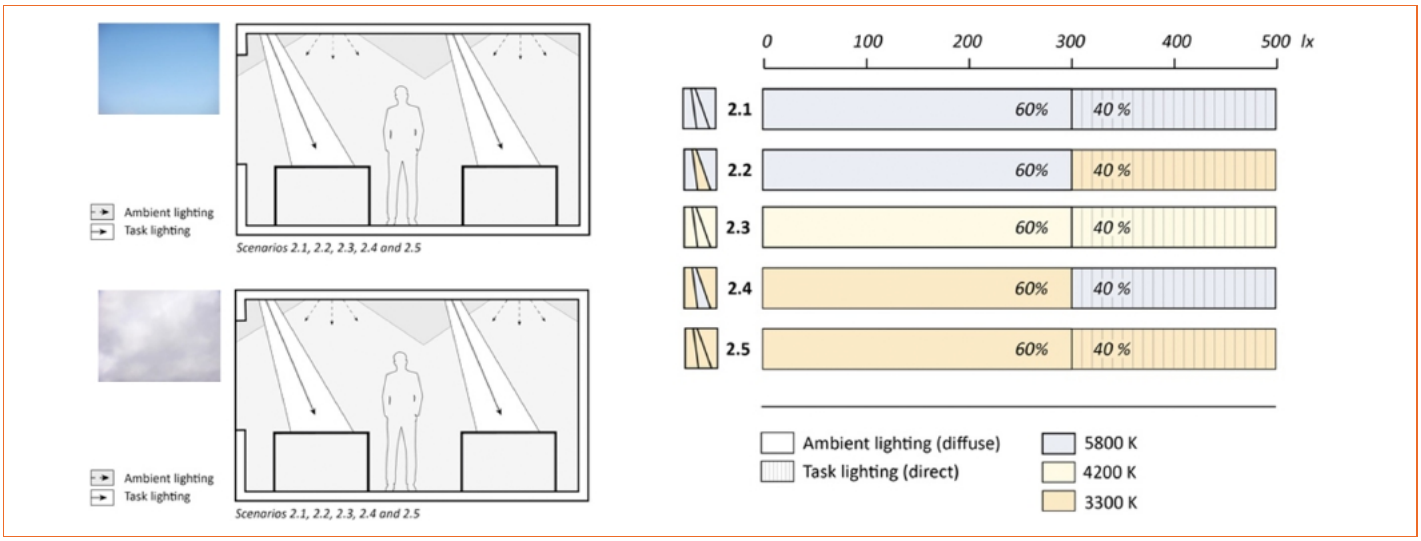


Figure 2: Five scenario testing combinations of cool, neutral and warm direct and diffuse lighting [4]

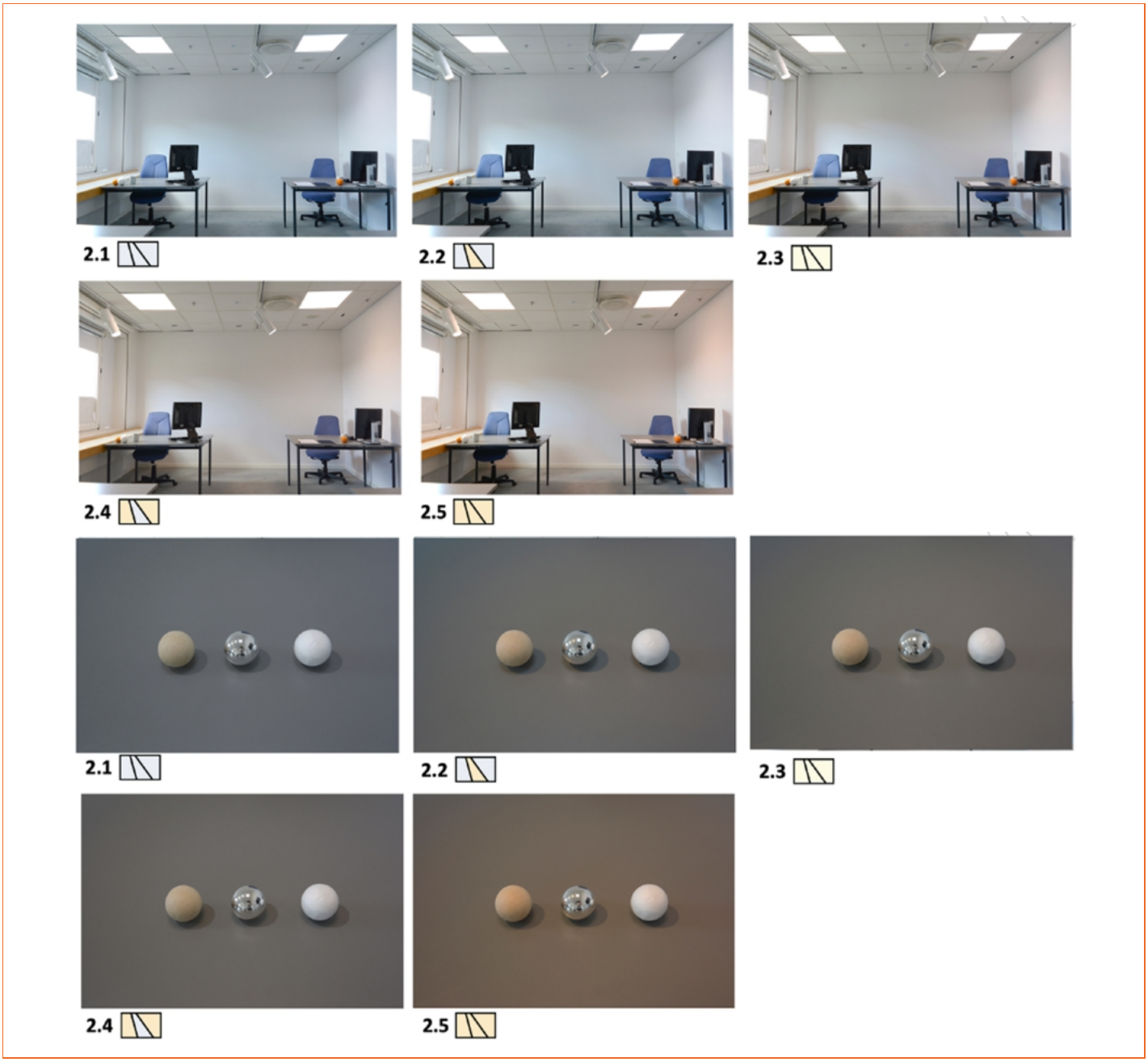


Figure 3: Photos of the five scenario testing combinations of cool, neutral and warm direct and diffuse lighting [4]

When the CCT's were combined in the ambient and task lighting, interesting feedback occurred in relation to the design possibilities of combining colors and directionality using a natural flow of light. The findings regarding the different preference of the two sky types are indications, and they need to be confirmed in future research. In the clear sky condition, the **W:C** (2.2) setting, combining the warm task light and cool ambient light, mimicking the clear sky, 40% of respondents indicated *natural*. This is further supported by the analysis of the interviews where the **W:C** (2.2) scenario was ranked highest. The opposite scenario with the warm ambient lighting and cool task light **C:W** (2.4) was perceived as *unnatural*. In the overcast condition the card *natural* was the most chosen for the **N:N** (2.3) setting, where a more neutral ambient light mimicked the overcast sky, this outcome was supported by reaction cards such as *comfortable*, *pleasant* and *bright*. In addition, the analysis of the interviews suggested the **N:N** (2.3) setting was ranked highest in overcast sky. The results regarding the sky types are proposed to be confirmed in future research. However, the results indicate the potentials of combining CCT's using the warm directional light and cool diffuse ambient lighting for clear sky conditions and a more neutral setting in overcast sky conditions. These studies are described in further depth in a paper published in December 2020 in LEUKOS [4].

Testing DDL Scenario and Sky Variations

Seven lighting criteria were defined for an experimental study based on the recommendations concerning DIRECT : DIFFUSE ratio, CCT's in relation to sky conditions. The criteria were defined to respond to daylight from the side lit windows and the sky condition. A luxmeter on one of the worktables measured the daylight level and a sky sensor on the roof detected if the sky was clear or overcast. From September to December, covering the fall and a winter seasons, four test participants worked in the office. The lighting was set to change every two weeks between the dynamic lighting scenarios and a baseline lighting, with only diffuse ceiling panels. Additionally, a control group was established, working in a similar space at the university, with the same baseline lighting provided by ceiling panels. Online questionnaires were collected every two weeks and the test persons were interviewed individually. The data was collected and analyzed within the criteria perceived atmosphere, referring to how the office space was experienced and the visual qualities with reference to the task lighting, and from modeling of objects on the work plane. Finally, the data was evaluated in relation to work engagement. More details on the test set up, methodologies, data, analysis and findings from this field experiment will soon be available in Indoor & Built environments [5].

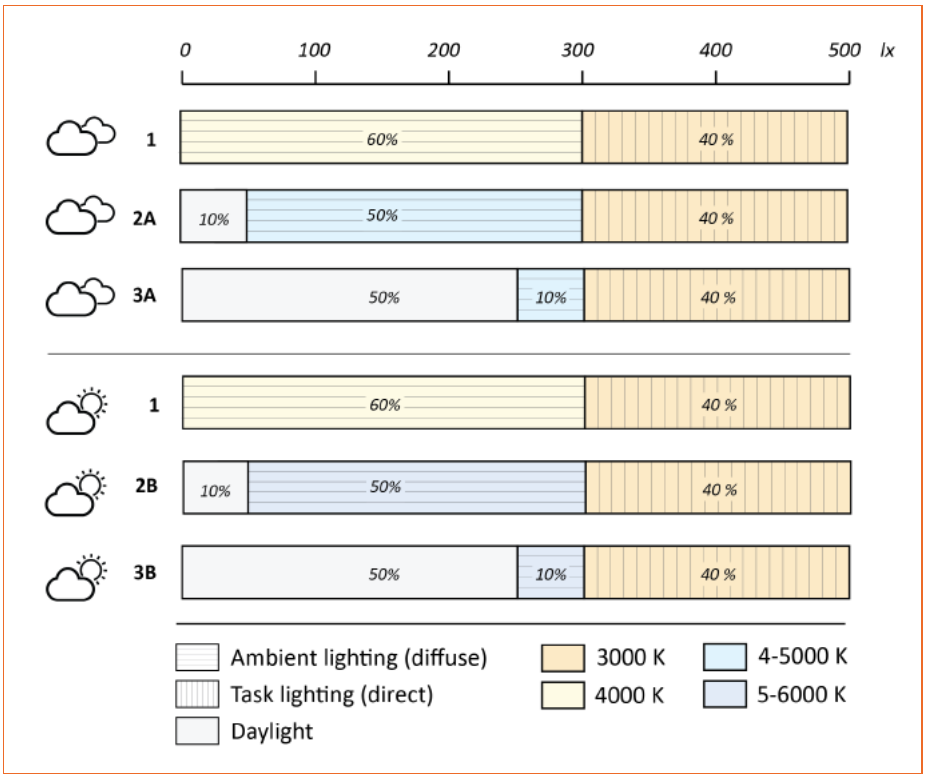


Figure 4: Illustration of the Double-Dynamic Lighting (DDL) recommendations [6]

The findings based on this small amount of test persons did indicate that the dynamic lighting was preferred over the static lighting both in regard to the perceived atmosphere, the visual comfort and the work engagement. To demonstrate further evidence, a larger field study must be set up. Despite the small number of test subjects the findings have been used to develop generic design recommendations for general inspiration for future lighting design and design experiments, these can be seen in the White Paper we edited as a short summary of the project [6].

Dynamics

Use of intelligent sky and light sensors to respond to daylight inflow and sky variations. Detection of two main sky variations:

1. Overcast
2. Clear sky

Three daylight levels on the task area:

1. < 50 lx during dark and transition hours
2. 50–250 lx primary for morning and evening hours
3. 250–550 lx general daytime hours (> 550 lx, the electrical lighting switches off, daylight is sufficient)

Direct / Diffuse Lighting Components

Directional lighting with approximately 30° tilt angle referring to daylight inflow from side windows, to create a flow of light and enhance the naturalness of a luminous environment. Combination of direct and diffuse light sources, with a ratio of 20-40% from directional lighting, to create the light modeling effect and personalized light zones.

Correlated Color Temperatures (CCT)

Direct light source with 3000 K (warm) , referring to the warm sunlight as a standard (**Figure 3**, **Figure 4**).

Diffuse light source, representing the ambient lighting with different color temperatures; for overcast, 4000–5000 K (neutral), and for clear sky 5000–6000 K (cool), to contribute to perceived atmosphere (**Figure 3**, **Figure 4**).

Light Levels

Light levels of min. 500 lx on the task area and 300 lx in the space, meeting EN 12464 standard. However, the direct light source is proposed to be personalized to meet the users' needs best with adjustable intensity and CCT, due to the variation in meeting visual comfort or perceived atmosphere.

DDL Guideline Notes

The aim of these generalized guidelines is to act as an inspiration for future designs and developments of the dynamic lighting potentials and thereby support the indoor environment to meet human needs for natural variations. The guidelines are based on the specific context and can be adjusted to different spatial, functional and geographic context. Act as inspiration for future designs and experiments ***[6]****.*

Illustration 2: Ellen Kathrine HANSEN, Ph.D., Assoc. Prof. | Aalborg University, Copenhagen

Discussion

Recently the four "stars" within lighting research Boyce, Cuttle, Kelly and Raynham published an article "The ambient lighting manifesto" stating that there is a need for a paradigm where we stop designing lighting following illuminance standards for a uniform illumination on a horizontal work plane **[7]**. They suggest that we give the priority to the lighting of the space rather than solely focusing on the visual tasks. Their reason for this is that today, we mainly use screens for reading and working and the printed material is of high quality. Their recognition of light generating both visual and nonvisual responses for both health and well-being creates a focus on the light meeting the eye, not a horizontal plane but also a focus on the need for understanding the effect of balancing the ambient light in the space with the task lighting. Finally, they stress that the high level of uniform illumination can use more energy and money and therefore it is not environmentally friendly. Following the current standard, light is delivered where it is not needed and, in an intensity, not necessary and a waste of energy. They suggest that the current standards for minimum uniform illumination at a horizontal space to a minimum ambient illumination and thereby include considerations of light distribution throughout the space and thereby consider the perception of the space **[7]**.

This is exactly the approach with the Double Dynamic Lighting concept. We need the lighting community to understand that the lighting should be designed as one integrated component, whereby the dynamics of daylight and the dynamics of electrical lighting are distributed in a space with an understanding of creating space for people. People, who have a natural need for being inspired, engaged and stimulated to encourage creativity and collaboration in a dynamic environment. ■

AUTHOR: Ellen Kathrine HANSEN, Ph.D., Associate Professor
Head of MSc program and Lighting Design Research Group, Ph.D., Associate Professor Aalborg University, Copenhagen. Ellen Kathrine Hansen holds a Master in Architecture from the Royal Academy of Fine Arts in Copenhagen and a Ph.D. in transdisciplinary Lighting Design processes from Aalborg University.

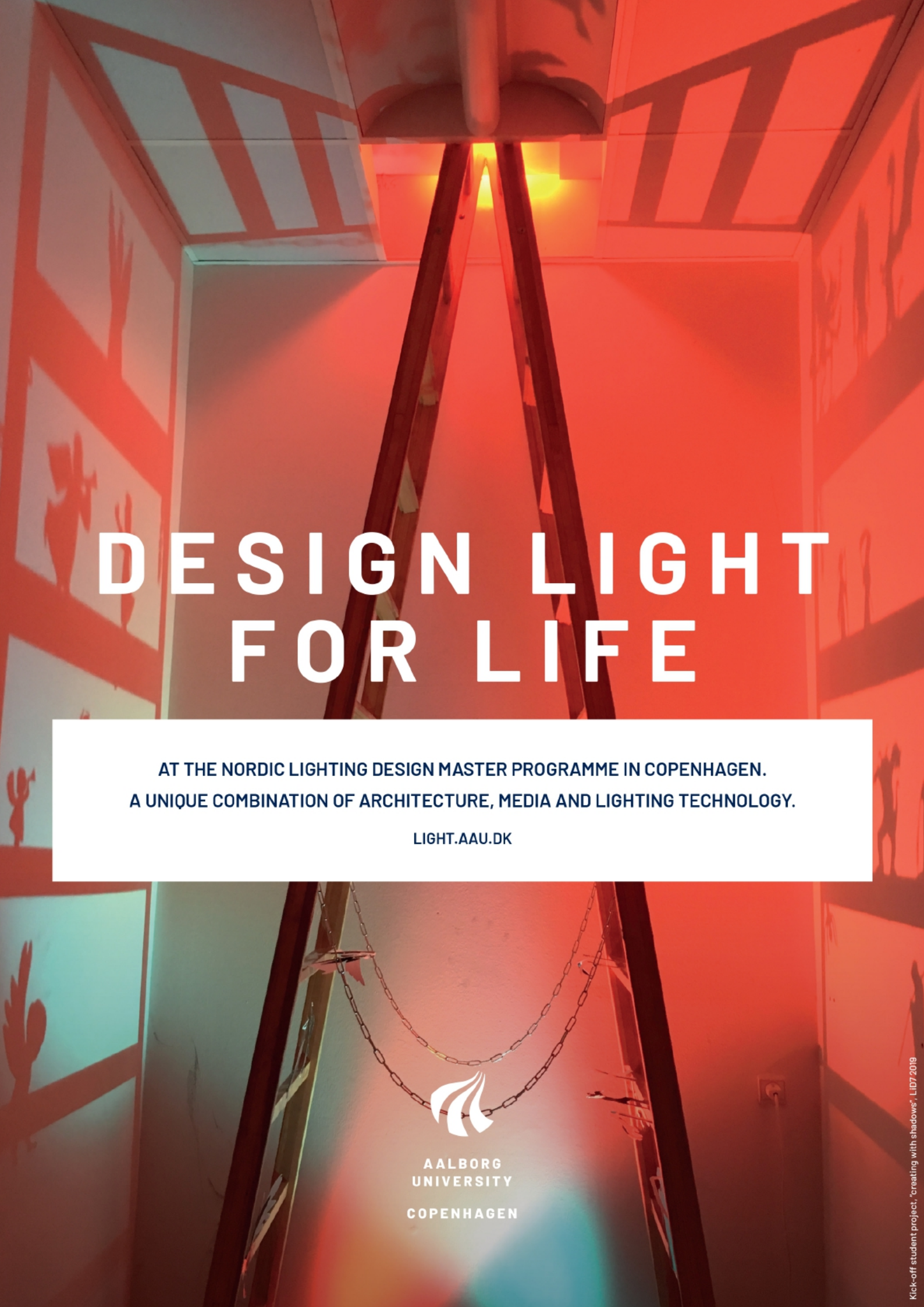
Hansen is a prominent person in the field of transdisciplinary design research and teaching within light and sustainable architecture. She has more than 25 years of experience driving projects within the field of developing new sustainable and architectural potentials through integration of daylight, technology and materials. Her projects are based on combining knowledge and skills from technical, humanistic and industrial environments.

In 2012 Hansen left the window industry to start up a new Master of Science program and research platform at AAU, designing with light in a transdisciplinary context combining lighting technology, architecture and media technology. In this context the Double Dynamic Lighting (DDL) approach was founded by Hansen and integrated in the research and teaching. Hansen has been leading this research project "Double dynamic lighting, bringing the qualities of daylight into the office" co-financed by the industrial partners Tridonic, Fagerhult, iGuzzini and Zumtobel.

Acknowledgement
This ambitious approach has made such progress because of valuable contributions from our Lighting Design Research Group at AAU. Thanks to Sofie Linnebjerg, Nanet Mathiasen, Mette Hvass, Kathrine Schimmermann, Michael Mullins, Michael Clary, Georgios Triantafyllidis, George Palamas, Nicklas Andersen, Mihkel Pajuste, Manos Xylakis, Thomas Bjørner and Sophie Stoffer. I would also like to thank our industrial partners for believing in our approach and supporting us financially and with equipment. A special thanks to Saurabh Madan and Jan Schottenholzer from Tridonic, Henrik Clausen from Fagerhult, Peter Roos and Laura Cinquarla from iGuzzini and Daniel Lechner from Zumtobel.

References

[1] Hansen EK, Mathiasen N. 2019. Dynamic lighting balancing diffuse and direct light. Presented at Arch19 Conference, Building for Better Health, Reserach & Innovation in Architecture & Urban Design for Care & Health", June 12th-14th 2019, Trondheim, Norway.
[2] Cuttle C. Lighting design: a perception-based approach. New York NY, Routledge, 2015.
[3] Boyce PR, Veitch JA, Newsham GR, Jones CC, Heerwagen J, Myer M, Hunter CM. 2006. Lighting quality and office work: two field simulation experiments. Lighting Res Technol. 38(3):191–223.
[4] Hansen EK, Pajuste M, Xylakis E. Flow of light: balancing directionality and CCT in the office environment. Leukos. The Journal of the Illuminating Engineering Society 2020. DOI: 10.1080/15502724.2020.1808014
[5] Hansen EK, Bjørner T, Xylakis E, Pajuste M. An experiment of double dynamic lighting in an office responding to sky and daylight: Perceived effects on comfort, atmosphere, and work engagement. Indoor and Built Environment, 2021 in press.
[6] Hansen, EK, Pajuste M. Double Dynamic Lighting — Bringing Qualities of Natural Light into the Office. White Paper, 2020. https://www.light.aau.dk/digitalAssets/853/853595_ddl_whitepaper_13.08.20.pdf. 17.12.20
[7] Boyce P, Cuttle K, Kelly K, Raynham, P. The ambient lighting manifesto, SSL Light Lines, September/October 2020. https://issuu.com/matrixprint/docs/3043_sll_light_lines_september_october_2020_issuu/s/10939717. 27.11.20



DESIGN LIGHT FOR LIFE

AT THE NORDIC LIGHTING DESIGN MASTER PROGRAMME IN COPENHAGEN.
A UNIQUE COMBINATION OF ARCHITECTURE, MEDIA AND LIGHTING TECHNOLOGY.

LIGHT.AAU.DK

AALBORG
UNIVERSITY

COPENHAGEN

Kick-off student project, "creating with shadows", LiD7 2019

III-Nitride Nanowire microLEDs on Si Substrate for Next Display Technology

The microLED display is an interesting and emerging technology which utilizes inorganic self-emissive micro light-emitting diodes (μLEDs) as built-in components. Each pixel basically includes three self-emissive red, green, and blue (RGB) LEDs. The precisely controlled emission of subpixel RGB LEDs results in full colors in the visible wavelength for the display applications. Ha Quoc Thang Bui, a Ph.D. candidate under the supervision of Prof. Hieu Nguyen in the ECE department at New Jersey Institute of Technology has successfully grown indium gallium nitride (InGaN) nanowires on a silicon substrate by molecular beam epitaxy (MBE) for red, blue, green, and phosphor-free white LEDs. The colors of the μLEDs are defined by the adjusted indium composition in InGaN/AlGaN core-shell nanowire heterostructures. They also demonstrated white-color μLEDs without a phosphor converter emitting high color quality with the rendering index of $\approx$ 94. The μLEDs show stable emissions, superior color gamut, and a high efficiency, thereby being considered an extremely suitable candidate for the monolithic next generation of high-resolution microLED displays.

Introduction

The MicroLED display is considered an ultimate generation of display technologies. A microLED display is made up of millions of individual inorganic μLEDs. Promising numerous advantages of microLED displays consist of ultra resolution, low power consumption, high fidelity and longevity, and especially superior color quality and environmentally friendly. Both the academia and industry have found MicroLED display technologies an exciting topic. In that, microLED displays are enormously potential for screens like smart watches, smartphones, televisions, billboards, and virtual reality and augmented reality devices. MicroLED display technologies have been booming since recent years [1], and still require many breakthroughs to become prevalent. Considerable research has introduced different approaches to bring MicroLED displays to the market [1,2,3,4,5].

High standard MicroLED displays, first begin with the right type of RGB μLEDs on a substrate from which the emissions of individual tiny LEDs can be controlled precisely for a display purpose.

Among approaches for achieving a micropixel with a full-color gamut [6,7,8,9], III-nitride μLEDs based on heterostructure nanowires grown on silicon substrates exhibit a promise since emission colors of a pixel could be directly controlled by constituent μLEDs. The authors have published their research of μLEDs built on silicon substrates with a long longevity, superior brightness, and high efficiency. It is easy to control color emission of each pixel when the LEDs are grown on silicon substrates because transistors later could be integated on that Si substrate. The emission of nanowire LEDs is defined by indium composition in the InGaN quantum wells. Controlling the growth temperature and/or In/Ga flux ratios during the MBE epitaxial growth process is the method to achieve a wanted In composition [10,11,12,13]. Technically, the InGaN's energy band gaps can be tuned from 0.65 eV (InN) through 3.4 eV (GaN) [4] for full colors to microLED display applications. Therefore, InGaN nanowire μLEDs are an ideal candidate for developing monolithic micro-LED displays [4].

Existing LEDs widely present in household lightings and automotive headlights are based on InGaN thin film LEDs. But, lack of InGaN LEDs in green to red wavelengths has limited their advanced applications. Conventional GaN planar LEDs for long wavelengths have a poor performance due to high level of defects which lead to unexpected polarization fields [15,16], Auger recombination [17,18], poor hole transport [19], defects/dislocations [20,21], and electron leakage [22,23,24]. Unlike thin-

films, nanowires are capable of reducing polarization fields and dislocation densities thanks to their highly lateral stress relaxation. For that reason, InGaN nanowire heterostructures have long been considered an alternative for developing full-color LEDs for displays. Nanowire structures are also very sufficient in heat dissipation and spreading resistance, thereby leading to an advanced performance under high levels of injection currents [25,26,27] in the LED devices. The color quality, reliability, energy efficiency of the nanowire LEDs are foreseen to be far superior to organic and inorganic thin-film emitters [28]. As such, the authors have demonstrated InGaN nanowire μLEDs in three primary RGB μLEDs and white-color μLEDs, targeting for the microLED displays. The characterization shows that the nanowire μLEDs have strong and stable emissions in entire visible colors from red through green to blue wavelengths.

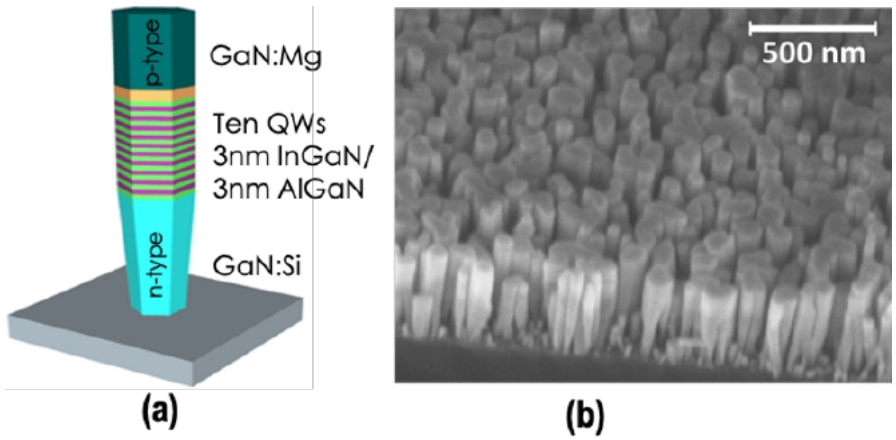


Figure 1: Schematic nanowire structure (a), and the 45° tilted SEM image of nanowires on Si substrate (b)

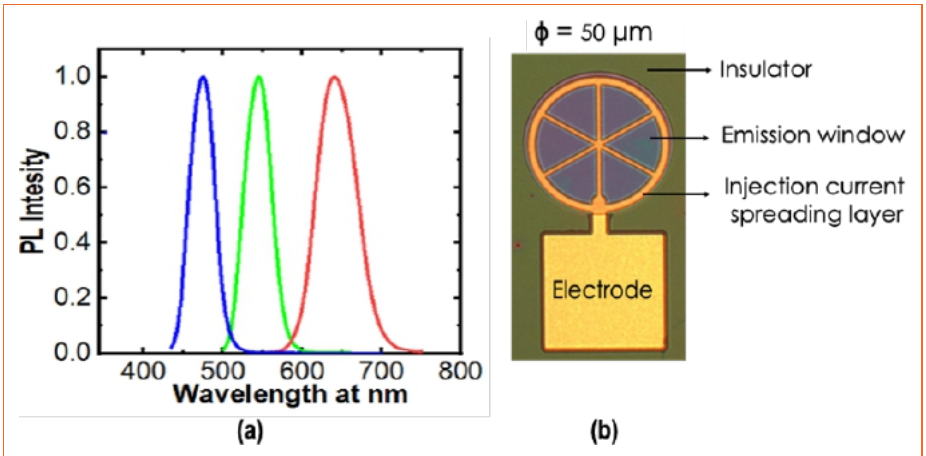


Figure 2: Room temperature photoluminescence spectra of the RGB nanowire μLEDs (a) and optical image of μLEDs and the electrode pads (b)

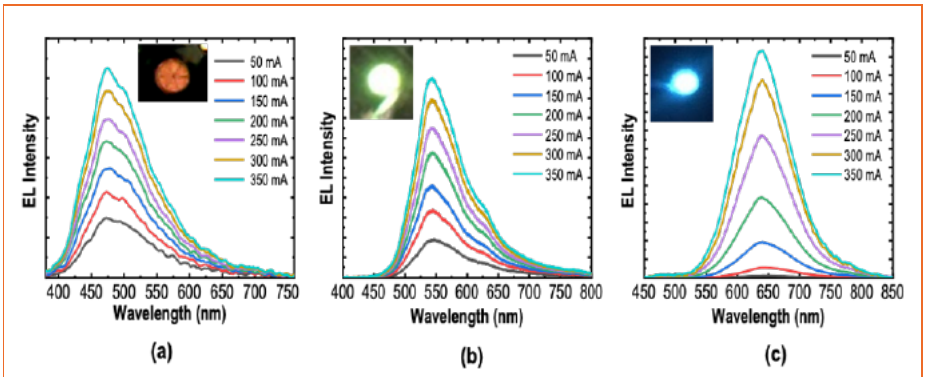


Figure 3: The electroluminescence of blue μLED (a), green μLED (b), red μLED (c) with insets of their corresponding optical images

LED Nanowire MBE Epitaxial Growth and Device Fabrication

The authors have grown InGaN/AlGaN core-shell nanowire μLEDs using a Veeco Gen II MBE (PAMBE) system. The n-GaN and p-GaN segments were formed with silicon and magnesium dopants, respectively. The schematic structure of a single InGaN/AlGaN nanowire on a Si substrate is illustrated in **Figure 1**a. The nanowires consist of ten quantum wells in the active region. Each quantum well has a 3 nm InGaN dot sandwiched between two 3 nm AlGaN barriers. The bottom GaN:Si segment was first grown on a silicon substrate while the GaN:Mg portion was grown latest on the top. The nitrogen flow and plasma power were fixed at 1 sccm and 350 W during the epitaxial growth, respectively. To enhance the indium composition, InGaN quantum wells were grown at 580–650 °C while the GaN layers were grown at 750 °C.

When growing AlGaN barriers, due to the laterally favorable diffusion, the Al-rich AlGaN spontaneously accumulates outside of the nanowire, forming the core-shell structure [29,30]. The μLEDs' color emissions were defined by controlling the Ga/In flux ratios and the substrate temperature. For example, to shift from red to blue colors, the growth temperature of LED nanowires was ramped up from 580–650 °C by 10 °C/min. The μLEDs were fabricated with standard micro/-nanofabrication techniques [3,33,35,36,37].

Results and Discussion

The SEM image in **Figure 1**b. shows uniform InGaN/AlGaN LED nanowires on the silicon substrate. The nanowires are as high as 500-600 nm. The normalized photoluminescence (PL) spectra of the InGaN/AlGaN core-shell nanowires were measured at room temperature, presented in **Figure 2**a. The real image of the fabricated μLEDs under an optical microscope can be seen in **Figure 2**b. The circular μLED has an emissive area of 50 μm in diameter, connected with the square electrode pad. The strong PL central wavelengths of red, green, and blue spectra are at 645 nm, 555 nm, and 475 nm, respectively.

The electroluminescence (EL) spectra of the RGB μLEDs are illustrated in **Figure 3**. The measurements were conducted with pulse biasing conditions from 50 mA to 350 mA. The red, green, and blue emissive LEDs were recorded at 645 nm, 550 nm,

and 475 nm at their center wavelengths, respectively. The blue EL spectra remain highly stable in different injection currents from 50 mA to 350 mA. An emission shift into shorter wavelengths is usually found from thin-film LEDs under high driving currents due to QCSE [39]. However, in this work, the shift in peak wavelengths is negligible, chiefly attributed to the reduced quantum-confined Stark effect (QCSE) in the nanowire structure. The calculated blue-shifts as small as 1.5–3.0 nm for the nanowire μLEDs in this report. These values are significantly smaller than those recorded from planar quantum well LEDs. The advantage of nanowire μLEDs is also due to the reduced crystal strain and thus efficiency droop free [40].

The authors also demonstrated phosphor-free white μLEDs with strong emission by engineering quantum wells in the core-shell nanowire structures. **Figure 4**a shows the white light μLEDs' emission, which covers from 450 nm to 750 nm and obtains a spectral stability with a blue-shift as small as ≈ 4 nm under injected currents from 50 mA to 350 mA. The emission characteristics of the phosphor-free white μLEDs are further illustrated in the 1931 Commission International l'Eclairage chromaticity diagram in **Figure 4**b. The x and y values are derived to be in the ranges of ≈ 0.351-0.362 and 0.391-0.398, respectively, meaning nearly a neutral white light emission with correlated color temperature of ≈ 4850 K. Additionally, a relatively high color rendering index (CRI) of ≈ 94 was measured for this phosphor-free white-color μLED. Such high CRI is extremely difficult to achieve with planar LED structures, which usually have CRI values in the range of 80–86 [41,42,43,44]. Although some special designs of phosphor converters, the CRI of planar white LEDs can be reached to 90–97 [45,46,47,48,49], the fabrication process is complex and the device reliability is a major concern. According to the author's mention, up to this moment, the CRI value for white-color μLEDs have not yet been reported, possibly due to the complexity of the device fabrication for such μLED devices. In this scenario, their RGB μLEDs and white-color μLEDs are highly desirable for the next generation μLED display technology.

Conclusions

The authors demonstrated full color μLEDs based on nanowire InGaN/AlGaN core-shell heterostructures grown on silicon substrates. The precisely controlled nanowire MBE growth resulted in the RGB μLEDs with the color stability under different operations, promising for monolithic μLED displays. Also, phosphor-free nanowire white light LEDs have been achieved with an unprecedentedly high CRI of ≈ 94. Monolithic display technologies built in from RGB subpixel μLEDs grown on silicon substrates are able to reduce complex procedures like pick-and-place process. Now that the high demand for the display manufacturing production, high efficiency, high color rendering properties, and low power consumption μLEDs using GaN nanowire heterostructures are perfectly suitable as an alternative replacement of current display technologies. This work is expected to offer lucrative growth opportunities for the micro-display market. ■

Author

Ha Quoc Thang BUI, Ph.D.(c)[1]

Ha Quoc Thang Bui is currently a senior Ph.D. candidate in the ECE department at New Jersey Institute of Technology (NJIT), NJ, USA, and a permanent biophysics lecturer from Pham Ngoc Thach University of Medicine, Vietnam. He was born in Dak-Lak province, Vietnam. Then he moved to Ho Chi Minh City to earn his B.S degree in physics from the Vietnam National University Ho Chi Minh City - University of Science (VNUHCMC-US). He also earned a master's degree in Nanomaterials and Nanodevices from VNU University of Engineering and Technology before coming to the U.S. for his Ph.D. program in electrical engineering at NJIT. His research focuses on solid-state light-emitting diodes and their applications as well as other semiconductor devices like high-electron-mobility transistors (HEMTs) using III-nitride nanostructures. So far, Mr. Bui has been an author and co-author of over 20 peer-reviewed publications.

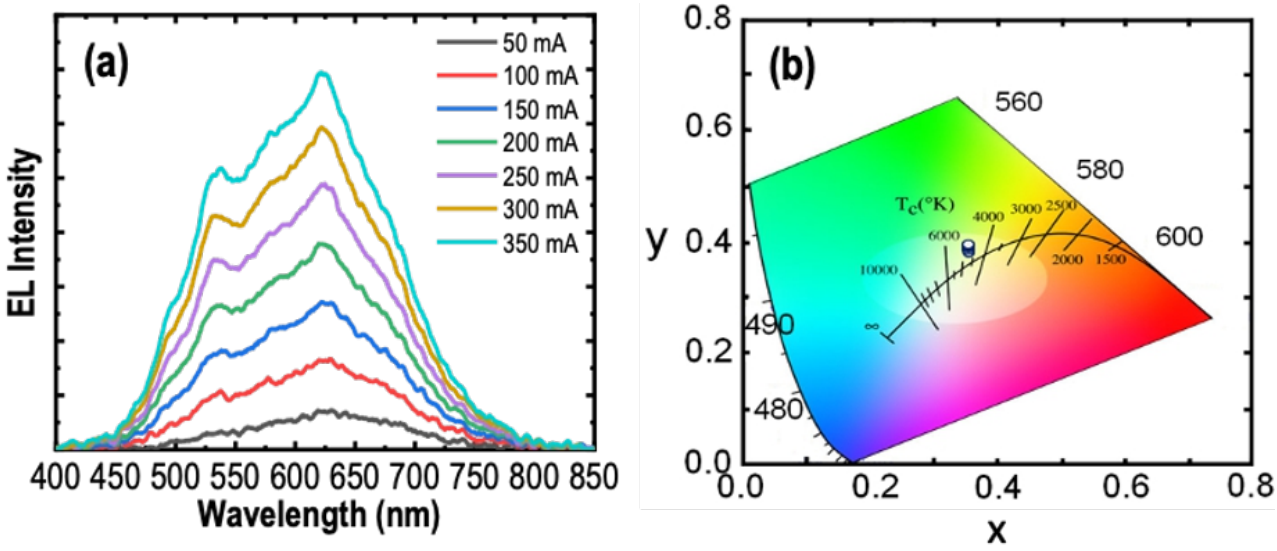


Figure 4: The 1931 Commission International l'Eclairage chromaticity diagram presents stable white emission characteristics of the phosphor-free white InGaN/AlGaN nanowire μLED

Co-Authors

Ravi Teja Velpula[1], Barsha Jain[1], and Hieu Pham Trung Nguyen[1]

[1] Department of Electrical and Computer Engineering, New Jersey Institute of Technology, Newark, NJ 07102, USA.

References

[1] Virey, E. Are microLEDs really the next display revolution? SID 2018, 3, 22–27.

[2] Choi, M.K.; Yang, J.; Hyeon, T.; Kim, D.H. Flexible quantum dot light-emitting diodes for next-generation displays. NPJ Flex. Electron. 2018, 2, 1-10.

[3] Sun, Y.; Jiang, Y.; Sun, X.W.; Zhang, S.; Chen, S. Beyond OLED: Efficient Quantum Dot Light-Emitting Diodes for Display and Lighting Application. Chem. Rec. 2019, 19, 1–25.

[4] Zhang, X.; Li, P.; Zou, X.; Jiang, J.; Yuen, S.H.; Tang, C.W.; Lau, K.M. Active Matrix Monolithic LED Micro-Display Using GaN-on-Si Epilayers. IEEE Photonics Technol. Lett. 2019, 31, 865–868.

[5] Zhao Jun, L.; Wing Cheung, C.; Ka Ming, W.; Kei May, L. 360 PPI Flip-Chip Mounted Active Matrix Addressable Light Emitting Diode on Silicon (LEDoS) Micro-Displays. J. Disp. Technol. 2013, 9, 678–682.

[6] Chen, K. J.; Chen, H.C.; Tsai, K.A.; Lin, C.C.; Tsai, H.H.; Chien, S.H.; Cheng, B.S.; Hsu, Y.J.; Shih, M.H.; Tsai, C.H. Resonant-Enhanced Full-Color Emission of Quantum-Dot-Based Display Technology Using a Pulsed Spray Method. Adv. Funct. Mater. 2012, 22, 5138–5143.

[7] Chen, S.W.H; Shen, C.C.; Wu, T.; Liao, Z.Y.; Chen, L.F.; Zhou, J.R.; Lee, C.F.; Lin, C.H.; Lin, C.C.; Sher, C.W. Full-color monolithic hybrid quantum dot nanoring micro light-emitting diodes with improved efficiency using atomic layer deposition and nonradiative resonant energy transfer. Photonics Res. 2019, 7, 416–422.

[8] Teng, C.H.; Zhang, L.; Deng,H.; Ku, P.C. Strain-induced red-green-blue wavelength tuning in InGaN quantum wells. Appl. Phys. Lett. 2016, 108, 071104-4.

[9] Chung, K.; Sui, J.; Demory, B.; Ku, P.C. Color mixing from monolithically integrated InGaN-based light-emitting diodes by local strain engineering. Appl. Phys. Lett. 2017, 111, 041101-4.

[10] Wang, R.; Nguyen, H.P.; Connie, A.T.; Lee, J.; Shih, I.; Mi, Z. Color-tunable, phosphor-free InGaN nanowire light-emitting diode arrays monolithically integrated on silicon. Opt. Express 2014, 22, A1768–A1775.

[11] Sekiguchi, H.; Kishino, K.; Kikuchi, A. Emission color control from blue to red with nanocolumn diameter of InGaN/GaN nanocolumn arrays grown on same substrate. Appl. Phys. Lett. 2010, 96, 231104-3.

[12] Ra, Y.H.; Wang, R.; Woo, S.Y.; Djavid, M.; Sadaf, S.M.; Lee, J.; Botton, G.A.; Mi, Z. Full-Color Single Nanowire Pixels for Projection Displays. Nano Lett. 2016, 16, 4608–4615.

[13] Philip, M.R.; Choudhary, D.D.; Djavid, M.; Bhuyian, M.N.; Piao, J.; Pham, T.T.; Misra, D.; Nguyen, H.P.T. Controlling color emission of InGaN/AlGaN nanowire light-emitting diodes grown by molecular beam epitaxy. J. Vac. Sci. Technol. B 2017, 35, 02B108-5.

[14] Arnaudov, B.; Paskova, T.; Paskov, P.P.; Magnusson, B.; Valcheva, E.; Monemar, B.; Lu, H.; Schaff, W.J.; Amano, H.; Akasaki, I. Energy position of near-band-edge emission spectra of InN epitaxial layers with different doping levels. Phys. Rev. B 2004, 69, 115216-5.

[15] Kim, M.H.; Schubert, M.F.; Dai, Q.; Kim, J.K.; Schubert, E.F.; Piprek, J.; Park, Y. Origin of efficiency droop in GaN-based light-emitting diodes. Appl. Phys. Lett. 2007, 91, 183507-3.

[16] Schubert, M.F.; Xu, J.; Kim, J.K.; Schubert, E.F.; Kim, M.H.; Yoon, S.; Lee, S.M.; Sone, C.; Sakong, T.; Park, Y. Polarization-matched GaInN/AlGaInN multi-quantum-well light-emitting diodes with reduced efficiency droop. Appl. Phys. Lett. 2008, 93, 041102-3.

[17] Shen, Y.C.; Mueller, G.O.; Watanabe, S.; Gardner, N.F.; Munkholm, A.; Krames, M.R. Auger recombination in InGaN measured by photoluminescence. Appl. Phys. Lett. 2007, 91, 141101-3.

[18] Zhang, M.; Bhattacharya, P.; Singh, J.; Hinckley, J. Direct measurement of auger recombination in In0.1Ga0.9N/GaN quantum wells and its impact on the efficiency of In0.1Ga0.9N/GaN multiple quantum well light emitting diodes. Appl. Phys. Lett. 2009, 95, 201108-3.

[19] Xie, J.Q.; Ni, X.F.; Fan, Q.; Shimada, R.; Ozgur, U.; Morkoc, H. On the efficiency droop in InGaN multiple quantum well blue light emitting diodes and its reduction with p-doped quantum well barriers. Appl. Phys. Lett. 2008, 93, 121107-3.

[20] Monemar, B.; Sernelius, B.E. Defect related issues in the "current roll-off" in InGaN based light emitting diodes. Appl. Phys. Lett. 2007, 91, 181103-3.

[21] Yang, Y.; Cao, X.A.; Yan, C.H. Investigation of the nonthermal mechanism of efficiency rolloff in InGaN light-emitting diodes. IEEE Trans. Electron Devices 2008, 55, 1771–1775.

[22] Ozgur, U.; Ni, X.; Li, X.; Lee, J.; Liu, S.; Okur, S.; Avrutin, V.; Matulionis, A.; Morkoc, H. Ballistic transport in InGaN-based LEDs: Impact on efficiency. Semicond. Sci. Tech. 2011, 26, 014022-12.

[23] Ni, X.; Li, X.; Lee, J.; Liu, S.; Avrutin, V.; Ozgur, U.; Morkoc, H.; Matulionis, A.; Paskova, T.; Mulholland, G. InGaN staircase electron injector for reduction of electron overflow in InGaN light emitting diodes. Appl. Phys. Lett. 2010, 97, 031110-3.

[24] Vampola, K.J.; Iza, M.; Keller, S.; DenBaars, S.P.; Nakamura, S. Measurement of electron overflow in 450 nm InGaN light-emitting diode structures. Appl. Phys. Lett. 2009, 94, 061116-3.

[25] Gong, Z.; Jin, S.; Chen, Y.; McKendry, J.; Massoubre, D.; Watson, I.M.; Gu, E.; Dawson, M.D. Size-dependent light output, spectral shift, and self-heating of 400 nm InGaN light-emitting diodes. J. Appl. Phys. 2010, 107, 013103-6.

[26] Kim, T.; Jung, Y.H.; Song, J.; Kim, D.; Li, Y.; Kim, H.S.; Song, I.S.; Wierer, J.J.; Pao, H.A.; Huang, Y. High-Efficiency, Microscale GaN Light-Emitting Diodes and Their Thermal Properties on Unusual Substrates. Small 2012, 8, 1643–1649.

[27] Meyaard, D.S.; Shan, Q.; Cho, J.; Schubert, E.F.; Han, S.H.; Kim, M.H.; Sone, C.; Oh, S.J.; Kim, J. K. Temperature dependent efficiency droop in GaInN light-emitting diodes with different current densities. Appl. Phys. Lett. 2012, 100, 081106-3.

[28] Zhao, C.; Ng, T.K.; ElAfandy, R.T.; Prabaswara, A.; Consiglio, G.B.; Ajia, I.A.; Roqan, I.S.; Janjua, B.; Shen, C.; Eid, J.; Droop-Free, Reliable, and High-Power InGaN/GaN Nanowire Light-Emitting Diodes for Monolithic Metal-Optoelectronics Nano Lett. 2016, 16, 4616–4623.

[29] Nguyen, H.P.T.; Djavid, M.; Woo, S.Y.; Liu, X.; Connie, A.T.; Sadaf, S.; Wang, Q.; Botton, G.A.; Shih, I.; Mi, Z. Engineering the Carrier Dynamics of InGaN Nanowire White Light-Emitting Diodes by Distributed p-AlGaN Electron Blocking Layers. Sci. Rep. 2015, 5, 7744-7.

[30] Tchernycheva, M.; Neplokh, V.; Zhang, H.; Lavenus, P.; Rigutti, L.; Bayle, F.; Julien, F.H.; Babichev, A.; Jacopin, G.; Largeau, L. Core-shell InGaN/GaN nanowire light emitting diodes analyzed by electron beam induced current microscopy and cathodoluminescence mapping. Nanoscale 2015, 7, 11692–11701.

[31] Nguyen, H.P.T.; Djavid, M.; Woo, S.Y.; Liu, X.; Wang, Q.; Botton, G.A.; Mi, Z. High-power phosphor-free InGaN/AlGaN dot-in-a-wire core-shell white light-emitting diodes. In Proceedings of the SPIE Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XIX, San Francisco, CA, USA, 9 March 2015.

[32] Mi, Z.; Nguyen, H.; Djavid, M.; Zhang, S.; Connie, A.; Sadaf, S.; Wang, Q.; Zhao, S.; Shih, I. High Power phosphor-free InGaN/GaN/AlGaN core-shell nanowire white light emitting diodes on Si substrates. ECS Trans. 2014, 61, 9–15.

[33] Philip, M.R.; Choudhary, D.D.; Djavid, M.; Le, K.Q.; Piao, J.; Nguyen, H.P.T. High efficiency green/yellow and red InGaN/AlGaN nanowire light-emitting diodes grown by molecular beam epitaxy. J. Sci. Adv. Mater. Devices 2017, 2, 150–155.

[34] Philip, M.R.; Bui, T.H.Q.; Djavid, D.D.C.M.; Phuoc, V.; Pham, T.T.; Nguyen, H.P.T. Molecular Beam Epitaxial Growth and Device Characterization of AlGaN UV-B Nanowire Light-Emitting Diodes. J. Adv. Opt. Photonics 2018, 1, 3–11.

[35] Nguyen, H.P.T.; Cui, K.; Zhang, S.; Djavid, M.; Korinek, A.; Botton, G.A.; Mi, Z. Controlling Electron Overflow in Phosphor-Free InGaN/GaN Nanowire White Light-Emitting Diodes. Nano Lett. 2012, 12, 1317–1323.

[36] Nguyen, H.P.T.; Djavid, M.; Mi, Z. Nonradiative Recombination Mechanism in Phosphor-Free GaN-Based Nanowire White Light Emitting Diodes and the effect of Ammonium Sulfide Surface Passivation. ECS Trans. 2013, 53, 93–100.

[37] Nguyen, H.P.T.; Zhang, S.; Connie, A.T.; Kibria, M.G.; Wang, Q.; Shih, I.; Mi, Z. Breaking the Carrier Injection Bottleneck of Phosphor-Free Nanowire White Light-Emitting Diodes. Nano Lett. 2013, 13, 5437–5442.

[38] Schubert, E.F. Light-Emitting Diodes, 2nd ed.; Cambridge University Press: New York, NY, USA, 2006; 61–63.

[39] Hwang, J.I.; Hashimoto, R.; Saito, S.; Nunoue, S. Development of InGaN-based red LED grown on (0001) polar surface. Appl. Phys. Express 2014, 7, 071003-4.

[40] Piprek, J. Efficiency droop in nitride-based light-emitting diodes. Phys. Status Solidi 2010, 207, 2217–2225.

[41] Wang, X.F.; Yang, Q.; Wang, G.G.; Wang, X.Z.; Han, J.C. A new single-component KCaY(PO4)2: Dy3+, Eu3+ nanosized phosphor with high color-rendering index and excellent thermal resistance for warm-white NUV-LED. RSC Adv. 2016, 6, 96263–96274.

[42] Kuo, T.W.; Liu, W.R.; Chen, T.M. High color rendering white light-emitting-diode illuminator using the red-emitting Eu2+-activated CaZnOS phosphors excited by blue LED. Opt. Express 2010, 18, 8187–8192.

[43] Quoc Anh, N.D.; Lee, H.Y.; Thanh Phuong, T.; Khanh Nhan, N.H.; Quang Minh, T.H.; Huu Ly, T. Y2O3:Eu3+ phosphor: A novel solution for an increase in color rendering index of multi-chip white LED packages. J. Chin. Inst. Eng. 2017, 40, 228–234.

[44] Nizamoglu, Z.; Demir, G. Color-converting combinations of nanocrystal emitters for warm-white light generation with high color rendering index. Appl. Phys. Lett. 2008, 92, 031102-3.

[45] Chen, L.Y.; Chang, J.K.; Cheng, W.C.; Huang, J.C.; Huang, Y.C.; Cheng, W.H. Chromaticity tailorable glass-based phosphor-converted white light-emitting diodes with high color rendering index. Opt. Express 2015, 23, A1024–A1029.

[46] Huang, C.H.; Chen, T.M. Novel yellow-emitting Sr8MgLn(PO4)7: Eu2+ (Ln = Y, La) phosphors for applications in white LEDs with excellent color rendering index. Inorg. Chem. 2011, 50, 5725–5730.

[47] Alvi, N.H.; Ali, S.U.; Hussain, S.; Nur, O.; Willander, M. Fabrication and comparative optical characterization of n-ZnO nanostructures (nanowalls, nanorods, nanoflowers and nanotubes)/p-GaN white-light-emitting diodes. Scr. Mater. 2011, 64, 697–700.

[48] Fang, M.H.; Ni, C.; Zhang, X.; Tsai, Y.T.; Mahlik, S.; Lazarowska, A.; Grinberg, M.; Sheu, H.S.; Lee, J.F.; Cheng, B.M.; et al. Enhance Color Rendering Index via Full Spectrum Employing the Important Key of Cyan Phosphor. ACS Appl. Mater. Interfaces 2016, 8, 30677–30682.

[49] Wang, Z.; Yuan, F.; Li, X.; Li, Y.; Zhong, H.; Fan, L.; Yang, S. 53% Efficient Red Emissive Carbon Quantum Dots for High Color Rendering and Stable Warm White-Light-Emitting Diodes. Adv. Mater. 2017, 29, 1702910-7.

Disclaimer: This report is based on the authors' article published on Micromachines 2019, 10(8), 492; https://doi.org/10.3390/mi10080492

Early Stage Computational Fluid Dynamics (CFD) Design Simulation

Advertorial SimScale

A lighting product has many components. If you consider even a simple LED lamp, the number of individual components working together to ensure the product is fit-for-purpose can be surprising. Each part, its material and the way it is positioned is crucial for overall performance. An LED lamp must have a predictable lifetime under given operating conditions such as temperature or power input quality. The optical, thermal, physical and electronic characteristics of the LED lamp are decided at an early stage of the product development process. An ability to simulate and effectively optimize these parameters lends a significant advantage to the manufacturer.

How to Get Started with CFD

Designers can get started with a free version of SimScale CFD [2]. SimScale has thousands of public projects with templates for simulating lighting and electronic products. A new user can search for and duplicate public projects or, easily begin a new project. Free tutorials and user guides are available to help a user get started.

Early Stage Design

The physics inside an LED lamp can be complicated. Multiple instances of the primary heat transfer mechanisms; conduction, convection and radiation, are present simultaneously. Thermal effects are dominant drivers of overall performance. An LED lamp will have various types of components and materials used for different purposes.

For example:

- Optical diffusers - the principal covering of the LED, used to transmit and diffuse light output. These also heat up as energy is emitted from the LED.
- Heat sinks and thermal transfer pads - a primary driver of overall thermal performance, the heat sink is coupled directly to the LEDs (LED module) to dissipate heat and keep the overall temperature within a safe range.
- LED module - a component for placing the LEDs. The LEDs sit in between the optical diffuser and heat sink and are connected to the driver.
- Drivers - the printed circuit board containing a driver used to control the LEDs, power and controls. A driver must also be operated within a temperature range.
- Base and socket - for connecting the LED lamp to a luminaire.

Simulation

Each of the above components will have their own set of parameters and variables that need considering when designing the product.

Computational Fluid Dynamics (CFD) is a branch of computer-aided engineering (CAE) that models the behavior of fluids (liquids and gases). CFD is used in most types of engineering design to evaluate the impact of heat transfer, fluid and material properties and the operating environment of whatever is designed. It is useful especially for thermal management of electronics products such as phones, laptops, healthcare devices, lamps and microprocessors.

A typical workflow is to import a 3D cad model into the CFD software, apply boundary conditions (E.g. the speed and temperature of an incoming flow), simulate and analyze the results (Post-processing). In the case of designing an LED lamp, early-stage design simulation can assist in converging on a narrow set of design options without ever spending money on developing prototypes. Each component can be modelled in a 3D model, imported into the CFD tool and then simulated under typical environmental conditions. The material and physical properties of each element are defined in the CFD software, and multiple operating scenarios are simulated to understand how the LED lamp might behave in practice. It is easy to swap materials and components, meaning a designer can evaluate multiple variants quickly and accurately. Simulating on the cloud (The CFD software is accessible via a web-browser) also means that cloud computing power can be utilized to deliver fast results in a collaboration enabled environment. Designers, engineers and manufacturers can work on the same project remotely.

Figure 1 shows an LED spotlight encasing. The LED module, driver and heat-sink are integrated as one unit and simulated for temperature and airflow. The temperature distribution is visualized to show the high-temperature areas and what impact air flowing over the device has in cooling. The heat-sink geometry and material properties are just some examples of components in the overall product that can be simulated. Being able to simulate and evaluate these options at the early design stage is critical for avoiding costly design changes later on.

In this example, a user can easily simulate the following parameters with varying input values:

- Heat-sink material properties
- Heat-sink fin thickness and spacing
- The properties of the LED/SMD itself and how much heat it generates.
- The materials used in the optical diffuser, drivers and thermal pads
- Whether natural convection and conduction alone are enough to dissipate heat or, is some kind of active cooling required.

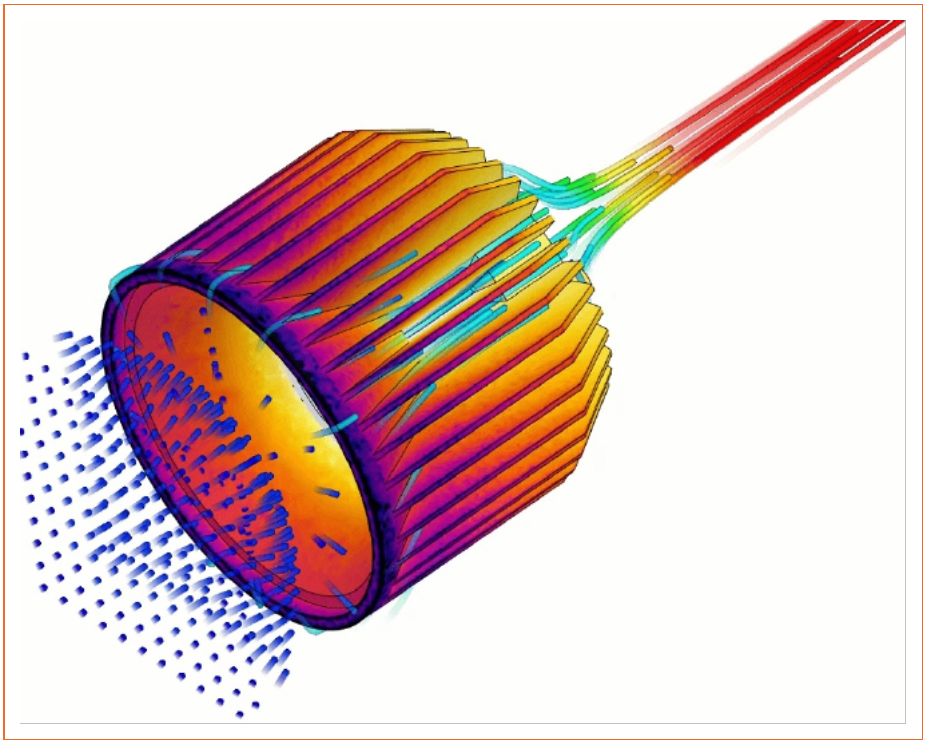


Figure 1: LED spotlight device, colored by temperature and streamlines comets colored by velocity (Source: SimScale [1])

Summary

Simulation is essential for designers and engineers to be able to assess component options and configurations critically. A user can compare several options for a particular component, orders of magnitude faster than physical prototyping. Critical design decisions are made at the earliest of stages and, having a robust and accessible tool like CFD is now cost-effective and indispensable. ■

AUTHOR: Naghman KHAN, Dr.
Dr. Khan is a simulation expert working at SimScale. He has a Ph.D. in simulation and modelling from the University of Nottingham and a Master's Degree from the Imperial College in London, UK.

References

[1] https://www.simscale.com
[2] https://www.simscale.com/product/cfd/

Component	Properties to capture	What can be simulated in CFD	Useful outputs that influence design
Optical diffuser	Light transmittance and diffusivity (Spectral)*, radiation, conduction, convection, size and shape.	Heat transfer through the material due to conduction and radiation using material properties such as emissivity, thermal conductivity, specific heat capacity and density—also internal condensation risk.	Rate of heat transfer through the material, Surface temperatures, peak temperatures and therefor optical diffuser material of choice and cost.
LED module	Spectral light output, heat generated due to radiation and conduction.	Heat generation due to power flow and light output, rate of heat transfer, peak temperature.	Rate of heat transfer through the material, Surface temperatures, peak temperatures.
Heat sinks	Radiation, convection and conduction due to size, shape and layout of heat sink.	CFD can simulate the rate and flow of heat and air in the heat-sink.	Is heat-dissipating effectively? What is the temperature in the lamp because of this heat sink design? Evaluate multiple heat sink layouts.
Drivers	Spacing and enclosure for the driver, material properties.	Temperature and airflow distribution in and around the driver.	Does the PCB have enough space for air to flow around it, is it overheating? Are the electronic components within specified temperature ranges?
Base and socket	Material properties, spacing and thermal bridging.	Do these components allow enough temperature and air distribution? What are they connected to? How is heat escaping the bulb assembly?	If the base and socket are heating up too much this may damage connecting parts like wires, socket housings etc.

Table 1: Components in an LED lamp and how CFD can benefit the design process. *Varies by wavelength

UV-LED Curing Process and Applications

Curing is a very important process in many industrial applications and UV-curing has meanwhile become the standard process in many applications. For a long time, this was the domain of mercury arc lamps but more and more UV-LEDs are replacing the older technology. Stacy Hoge, Marketing Communications Manager at Phoseon Technology, has accompanied many technical developments in this field since she joined the company. She describes the curing process, why this change to UV-LEDs is an important step forward, gives an overview of the most important applications, and she explains what is crucial to being considered when choosing a UV-LED curing system.

UV curing is a photopolymerization process that uses UV energy to change a formulation of non-crosslinked solids into a crosslinked solid. Upon absorption of the UV energy, photoinitiators produce free radicals that initiate crosslinking with monomers and oligomers. This creates a reaction that cures or solidifies the ink, coating or adhesive. UV formulations incorporate various additives such as stabilizers, wetting agents, adhesion promoters, defoamers, and pigments. This provides the needed formulation characteristics to successfully apply the material and produce the desired color. UV-LED improves on the conventional processes by enabling the technology to be used with thinner, heat- sensitive substrates and constructions as well as sensitive electronics and assemblies. It simultaneously reduces byproducts such as ozone and improving workplace safety through the elimination of UV-B and UV-C wavelengths.

UV-LED Curing vs. Mercury Arc Lamps

Conventional UV curing systems emit ultraviolet (UV), visible, and infrared output when mercury is vaporized into a plasma gas inside a sealed quartz tube. Both mercury arc and microwave UV lamps are considered broad spectrum. In contrast, UV light-emitting diodes (LEDs) have a narrow spectral output in the ultraviolet band with some visible output and no infrared.

UV-LED curing systems produce light by generating a voltage to join positive holes with negative electrons emitting energy in the form of photons. If engineered correctly, these semiconductor devices last beyond 40,000 hours of operating time unlike traditional UV lamps. Traditional lamps produce light by generating an electric arc inside an ionized gas (typically mercury) chamber to excite atoms, which then decay, emitting photons. Commercially, UV-LED technology has significant market adoption with longer UVA wavelengths (365 nm, 385 nm, 395 nm, and 405 nm), and there is also ongoing development work in shorter UVB and UVC bands. UV-LED wavelengths are able to penetrate deeper into the chemistry and produce better through cure particularly with opaque and pigmented formulations. For clear coatings, achieving a hard, scratch resistant surface cure without yellowing has been the primary challenge for UV LEDs. This is because many coatings formulations rely on the shorter wavelengths emitted by broadband lamps for sufficient cross-linking at the surface, and current UVB and UVC LEDs do not yet satisfy curing requirements in these shorter wavelengths. Nevertheless, higher irradiances and adjustments to the formulations have often been found to resolve these issues in many cases.

The benefits of UV-LED as compared to traditional mercury arc UV lamps are numerous and significant. UV LEDs are more environmentally friendly because they do not generate ozone and contain no mercury as arc lamps do. They are a cool source compared to arc lamps, largely due to no output in the infrared range. This reduced heat eliminates complicated cooling mechanisms such as chill rolls and external shutters, and enables applications on heat-sensitive substrates. The electrical-to-optical conversion efficiency of UV LEDs is much better and the ability to instantly turn the unit off and on enables saving up to 50-75% on electricity.

Compared to an arc lamp's 500 hours - 2,000 hours life, most UV LEDs are specified for 10,000 hours, but can last more than 40,000 hours. It's also important to note that over this lifetime UV-LED output only drops about 5%, compared to arc lamps that can lose about 50% of their original output by the end of their life. In a production environment, UV LEDs require

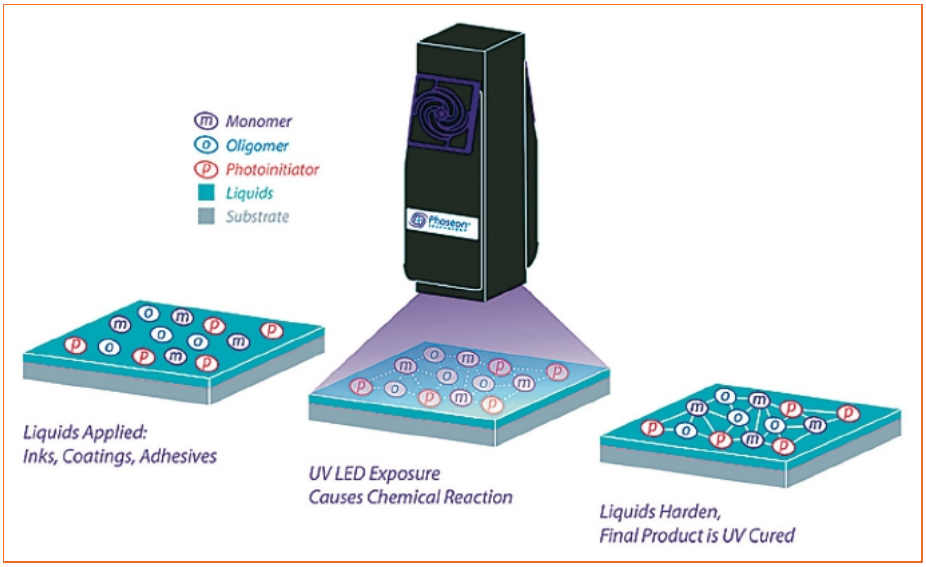


Figure 1: The basic steps and phases of the UV curing process are the application of the coatings or adhesives, followed by the exposure to UV light causing the polymerization to crosslinked solids

significantly less space, monitoring, maintenance and down time. That translates into higher productivity rates, less scrap and higher quality end products. Paybacks for retrofitting onto existing machines or replacing existing UV arc lamps can be as low as 12 months.

Ultraviolet Wavelengths

The Sun is a source of the full spectrum of ultraviolet radiation, which is commonly subdivided into UV-A, UV-B, and UV-C (**Figure 2**). Wavelength, a fundamental descriptor of electromagnetic energy, is the distance between corresponding points of a propagated wave. Typical UV light source emission wavelengths range from ultraviolet (UV-C 100–280 nm, UV-B: 280–315 nm, UV-A 315–400 nm) to visible light (400–700 nm) and infrared (700–3000 nm).

UV wavelengths typically are measured in nanometers (nm). Nanometer, a unit of length, is equal to one billionth of a meter. UV light-emitting diodes (LEDs) have a narrow spectral output centered on a specific wavelength, +/- 15 nm, with typical commercial UV-LED lamps emitting at 365 nm, 385 nm, 395 nm, or 405 nm wavelengths.

The irradiance (W/cm^2) produced by UV-LED light sources has increased consistently year over year because of advancements in both diode and lamp technology, and now is available at effective outputs higher than those offered by traditional UV curing lamp technologies. UV-LED lamp systems have enough power to conquer a wide range of applications and today are being used commercially to cure inks, coatings and adhesives.

Technical Requirements for UV-LED Curing

There are several technical requirements needed for successful UV-LED curing. UV-LED technology performs well when UV output is correctly matched to the needs of the application and paired with a suitably formulated ink, coating or adhesive. Unfortunately, there is not a one size fits all curing applications. With the abundance of UV-LED curing systems and vendors out there, many claim very similar product features and operational benefits but not all are the same.

When evaluating features for UV-LED curing systems, it's often unclear which of the many metrics and benchmarks are the most important selection criteria. Which are the most critical for ensuring optimal UV curing of inks, coatings and adhesives?

Peak Irradiance and Energy Density

There are two key parameters of an LED lamp that should be understood for the purposes of optimizing cure and establishing a process window. Identifying this process window will result in the most durable and desirable finish, as well as acceptable

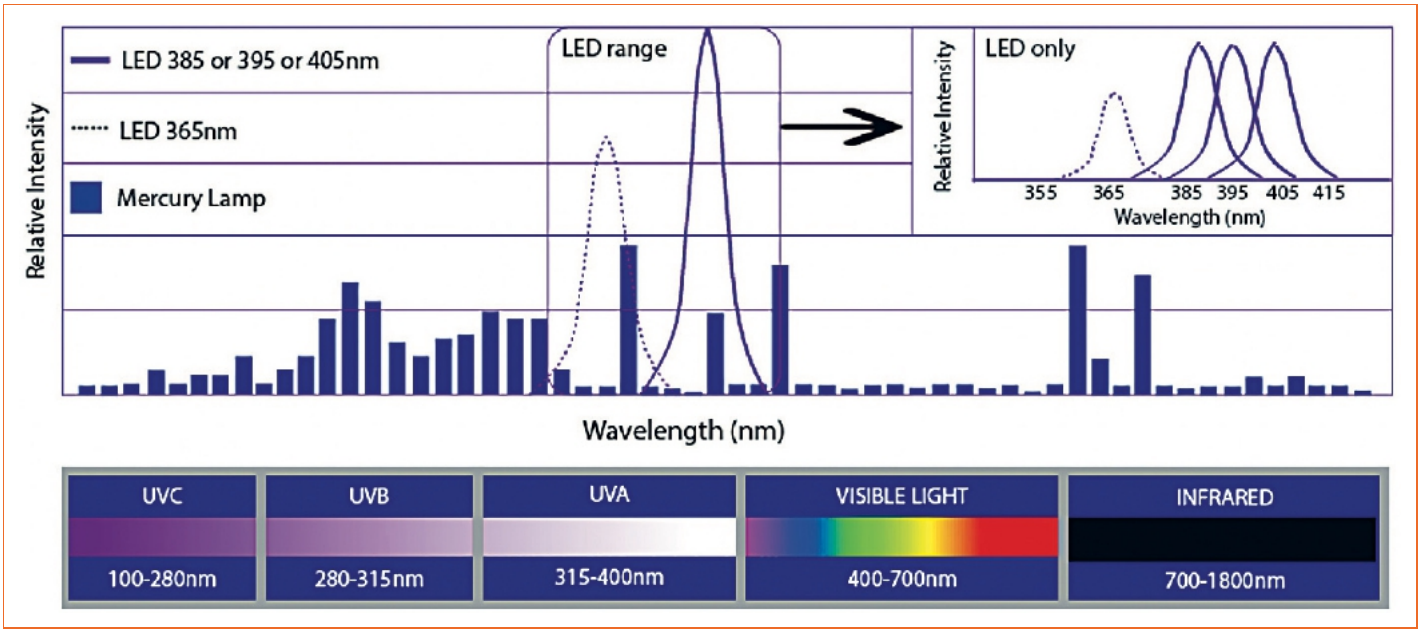


Figure 2: The comparison between UV-LED and mercury lamps shows a very broad spectral distribution of mercury lamps, while UV-LEDs have a narrow and well-defined spectral range that can be exactly matched for the curing process

adhesion and surface cure: peak irradiance and energy density.

Peak irradiance, also called intensity, is the radiant power arriving at a surface per-unit area. With UV curing, the surface is the cure surface of the substrate or part, and a square centimeter is the unit area. Irradiance is expressed in units of watts or milliwatts per square centimeter (W/cm^2 or mW/cm^2). Peak irradiance is instrumental in penetration and aiding surface cure. Peak irradiance is affected by the output of the engineered light source, the use of reflectors or optics to concentrate or contain the rays in a tighter surface impact area, and the distance of the source from the cure surface. The irradiance for UV LEDs at the cure surface decreases quickly as the distance between the source and the cure surface increases.

Energy density, radiant energy density, or dose is the energy arriving at a surface per-unit-area during a defined period of time (dwell or exposure). A square centimeter is again the unit area and radiant energy density is expressed in units of joules or millijoules per square centimeter (J/cm^2 or mJ/cm^2). Energy density is the integral of irradiance over time. A sufficient amount of energy density is necessary for full cure.

Requirements to Integrate UV-LED Into an Application

There are three key components that contribute to a UV-LED curing system. When these components are optimized correctly, they can provide an economically advantageous high throughput solution to a wide range of industries.

These elements together provide a long-term sustainable UV-LED curing solution.

- UV curable materials (inks, coatings, adhesives) that can absorb energy in the UV region to undergo polymerization process
- UV-LED curing lamp, which provides energy in the UV region of the spectrum
- A machine or system where the UV-LED lamp is integrated to cure material underneath it

Today, a large number of suppliers have developed inks, coatings and adhesives that work well with LED technology. As LED technology has become more powerful and more compatible materials are available, this has resulted in substantial advanced capabilities for UV curing. Material suppliers have formulated raw materials that absorb energy corresponding to the wavelength of LED light sources. One of the key ingredients in the chemical formulation is a photoinitiator that serves as a catalyst to initiate the polymerization process when exposed to narrow spectrum UV-LED energy. With the continued wide-spread acceptance of LED systems, availability of suitable base materials continues to grow. The driving factors in advancement of chemistry of raw materials is increased capability and cost effectiveness of commercially available LED light sources.

Product Selection

Even though LED technology is reliable, it is important to keep in mind that LED light sources are not created equally. Suppliers of LED light sources have significant architectural and implementation decisions that significantly impact their product's performance. If a product is built correctly, the end result will be a LED curing system with optimized LEDs, arrays, optics, and cooling for a specific application. Knowing how to characterize the performance allows the user to identify the best overall system to meet their specific needs.

If maintained properly, LEDs have a long lifetime. Traditional mercury lamps may last up to 3,000 hours requiring frequent lamp replacements, but properly managed LEDs will last over 40,000 hours. With impressive efficiency and longevity LED technology is poised to be an energy efficient technology.

Applications

UV-curing is meanwhile a standard process in many applications. The following examples are the most important applications while UV-curing is not limited to these applications.

Fiber and wire

UV-LED fiber curing systems offer many benefits for curing fiber and wire applications, including optical fiber, electrical and structural wire, and threads for smart fabrics. Only few companies, for instance Phoseon, offer complete UV-LED systems that bring many advantages and benefits such as fast and more consistent results around the full diameter of the fiber and wire, reduced operation costs, higher yield, and energy savings up to 70% over the more traditional UV or arc light curing.

Wood furniture

UV-LED curing technology is utilized in the wood coatings industry for applications such as edge coating, roller coating and digital printing. UV-LED technology drastically reduces energy consumption and significantly reduces work-piece surface temperature.

Electronics

UV-LED curing technology is ideally suited for electronic assembly applications. Many electronics manufacturers utilize UV-LED curing in the production of products such as touchscreens, mobile phones, micro-speakers, and hard disk drives (**Figure 3**).

Medical devices

Adhesives used in medical applications such as syringes, catheters, IV delivery systems, endoscopes, and hearing aids often benefit from UV curing technology because it offers better uniformity, low heat, instant on/off capability, and long lifetime.

Ammunitions

UV-LED curing solutions are also suited to ammunitions production for water-proofing, adhesive bonding, sealing, and coating. The UV-LED curing of external ammunition sealants can make bullet pull strength more consistent, thereby improving performance and accuracy. Example ammunitions-related applications include:

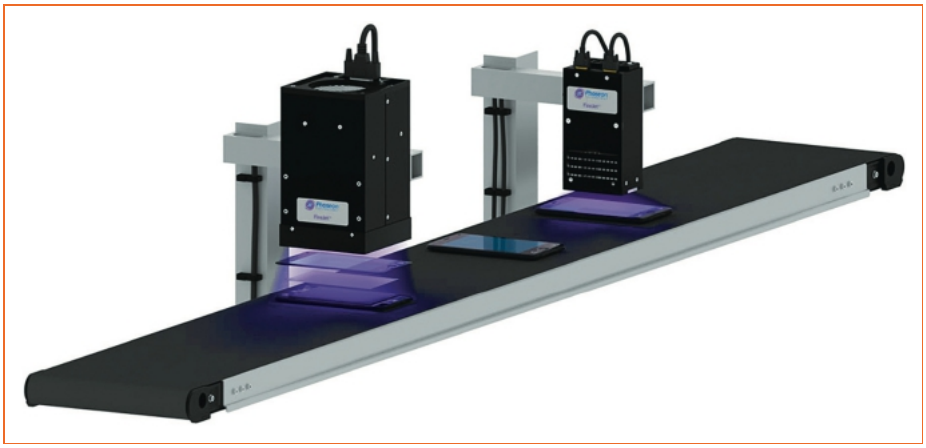


Figure 3: 3D graphics of an LED-curing line for touch-panel manufacturing

external ammunition sealing (i.e., waterproofing); igniter, fuse, and detonator UV sealing; specialty UV coatings and primers; blank ammunition sealing; shot shell crimp sealing; and tip color coding.

Automotive

UV-LED is also a curing solution for automotive coating applications because it provides near-instant curing of functional and decorative coatings. The lightweight materials used in today's automobiles benefit from the low temperatures enabled by UV-LED technology. The automotive industry utilizes UV-LED curing solutions for forward lighting, tail lenses, interior and exterior trim components, and body panels.

Labels

UV-LED curing technology is ideal for a variety of label printing applications, enabling end users to print high-quality material at maximum speeds. Flexo label printing can be used for beverage, household, medical, personal, promotional, and many other industrial markets. UV-LED curing shows measurable advantages in higher productivity, lower energy usage, while utilizing thinner substrates with improved adhesion along with clear environmental benefits.

Packaging

UV-LED curing technology is ideal for a variety of flexo packaging applications, enabling end users to print on a variety of packaging materials at high speeds. UV-LED curing can be utilized for printing on flexible films, boxes, cartons, corrugated containers, and a wide variety of other packaging materials.

Decorative printing

Decorative printing applications enhanced by UV-LED technology create product differentiation and increased visual impact, all while providing a return on investment unparalleled in today's decorative printing market. Decorative printing processes allow for ultra-high gloss, matte and holographic effects. "Cast and Cure" is a fast growing technology that creates a holographic style decorative finish on a variety of substrates for sheet-fed and web applications. "Cold Foil" allows the decorative printing application of metallic foil, in line, at press speed in an infinite spectrum of colors.

Posters, signage and 3D objects

UV-LED can also be used for full cure of digital inks in bi-directional, single pass, and 3D printers to create products such as posters, signage, and 3D objects.

Bottle and tube decoration

The combination of low heat and high energy makes UV-LED a good fit for screen printing, which allows a wider variety of materials to be used including plastics, metals, ceramics, glass, wood, posters and other items. UV-LED for screen printing is most commonly used for direct bottle and tube decoration, which eliminates the need for a label.

Conclusions

Ultraviolet (UV) LED technology for curing has gained worldwide acceptance and continues to grow. Initial challenges have been overcome and UV LED- based curing is now an accepted, user- friendly tool in printing, coatings and adhesive markets. UV-LED system characteristics enable a number of applications that are impractical or limited by physical constraints of conventional mercury-based UV sources. UV-LED curing units have become more efficient in delivering UV energy to the substrate, thus driving not only environmentally clean, energy-efficient and compact-size units but also enabling increased throughput and process flexibility. The future is very bright for UV-LED curing technology. ■

AUTHOR: Stacy HOGE

Stacy Hoge joined Phoseon Technology [1] in 2009 as marketing communications manager. Prior to Phoseon, Hoge was marketing communications manager at Ambric and at MathStar before that. Both companies focused on programmable integrated circuits. At Phoseon, Hoge is responsible for all Marketing Communication efforts.

References

[1] https://phoseon.com

Planar Steerable Luminaires on the Way to Replacing Rotating Projectors

Dynamic lighting is already used in several applications and has become an increasingly important part in lighting. Insolight, a start-up based at the Swiss Institute of Technology in Lausanne (EPFL), has developed an innovative dynamic luminaire technology that aims to replicate the beam of a rotating projector within a compact encapsulation, achieved by a patented planar optical micro-tracking technology. Noé Bory, Sven Menge, Ross Stanley and David Schuppisser explain the technology and the latest progress in its development. The authors demonstrate the advantages over conventional technologies in respect to costs, compactness, high power output, homogeneous luminance, and continuous displacement of the light.

The new technology was inspired by the sun: it all began in 2015 when Insolight developed a compact photovoltaic solar tracking technology that eliminated the need for rotating optics – but what if the module could emit light instead of capturing it, and become a luminaire? Applied to lighting, the same patented technology allows a displacement of a narrow beam from normal incidence to as far as 45° whilst maintaining good photometric behavior, thus replicating the effect of a rotating projector. In addition to Insolight's success in its solar business, the opto-mechanical technology lighting platform is reaching commercial maturity with seven development partnerships and two technology licensing deals signed. Based on this experience, the article will discuss the technical principle and review selected potential applications.

Design and Functionalities

The novel technology enables manual or remote control of the beam direction (e.g., wirelessly or cabled DALI/DMX).

Figure 1 shows the basic principle: A LED is displaced by a mechanical system which ensures purely planar motion with respect to a lense. Initially, with the LED centered on the luminaire, a tight beam is produced by the lens, and on scanning the LED in the plane perpendicular to the optical axis of the lens the beam scans in the opposite direction. Good efficiencies can be achieved up to scanning angles of 45°. The technology developed by Insolight allows not only for excellent scanning and efficiency but also good beam profile.

From an optical design viewpoint, the motion of the LED breaks the axial symmetry of the system. The standard design rules and tricks for designing optics in luminaires no longer function. **Figure 1** shows the result of an optimization in Zemax™ modelled with lenses using a high index commercial polymer (Zeonex®) and a 4.5 mm diameter LES, chip-on-board LED from Luminus inc. (CMX-4).

An interesting property of the design is the capacity of the beam to reach high efficiencies (e.g., 3700 lumen/steradian at 45° for a 567 lumen LED). Moreover, by using small and light actuators, the beam can be steered at high displacement speeds. This specific functionality is achievable thanks to the overall light weight of the moving components and therefore to its low inertia. It is also possible to use the beam steering feature in a static fashion to produce versions of the same luminaire with differing photometrics on a single assembly line. Finally, the system is scalable and can be easily implemented in the encapsulation of existing luminaires with a low bill of material, meaning significant time and cost-savings for the manufacturer.

The technology can be benchmarked to multiLED and the motorized rotational projectors.

The multiLED is a single luminaire composed of photometrically distinct, modular and static "sub-luminaires" that benefits from various photometric configurations when selectively switching on the "sub-luminaires". Specifically, it is possible to vary the breadth of the beam. Despite this photometric advantage, the multi-LED technology presents certain limitations: its intensity range at a specific beam position is limited by the combination of "sub-luminaires" that are switched on for one specific photometric configuration. Consequently, the solution to increase the beam intensity at a specific photometry is

to multiply the system, thus losing the advantage of a compact design. In addition, multiLED luminaires are in essence modular, requiring different configurations of the sub-luminaires for every new use-case. The output beam is also characterized by a discontinuous displacement because of the defined discrete configuration of each distinct static LEDs. The motorized rotational projector solves this inhomogeneous and limited output issue through a continuous and powerful moving beam, but at the cost of a bulky and heavy encapsulation.

The planar steerable luminaire concept presents clear advantages over these two competing technologies by respectively overcoming their limitations with a compact design, a high power output, a homogeneous luminance and a continuous displacement of the light at low-cost.

System and Concept Description

The technology is the combination of three respective in-house designed components. A micro-tracking system guides an LED PCB in a planar way respective to an optical layer designed for a good photometry at large LED PCB-optical layer displacement.

LED PCB

The source of emitted light is a single or set of standard LEDs positioned over a PCB. LED choice depends on the target applications, e.g., for applications with high light quality requirements, CSP LED packages are chosen, as they ensure a better diffusion of the light.

Optical Layer

The lens redirects the emitted light of the LED PCB to a chosen angle. The optical surfaces of the lens have been specifically designed for the photometry to imitate the rotation of a projector when the LED PCB is displaced in a plan parallel to the optical layer. To guarantee various optimized optical shapes for a wide set of targeted photometric curves, an optimization process was developed and implemented in ZEMAX™ using a mixed sequential and non-sequential design strategy. The design is inspired by optical layers developed for the initial approach in solar application and are produced with a simple and standardized injection process.

The technology is essentially planar meaning that the system can be arranged as a single LED-lens for small encapsulation or as customized suites of LED-lenses for higher light output without losing functionality, opening up various domains of application.

Micro-tracking System

The guiding element ensures a movement of the optical layer compared to the LED PCB without rotation or misalignment. It is a mechanical system that operates without friction and in the elastic realm of the material ensuring a lifespan beyond 1 million cycles (i.e., controlled with a finite element analysis, solver and mechanical simulation software). The actuators are integrated into the mechanism to move the optical layer compared to the LED PCB by either one or two actuators when remotely controlled, or none when the system is handled manually (screw, etc.).

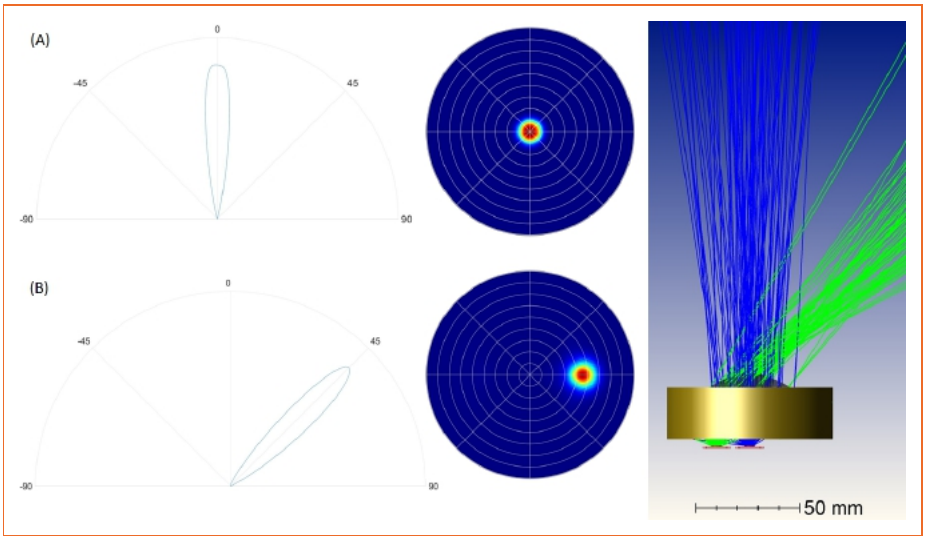


Figure 1: a) Photometric curves at 0 degrees b) photometric curves at 45 degrees c) Light rays at 0 degrees and 45 degrees

The unique advantages of the system are the easy and low-cost manufacturing process, while maintaining an excellent mechanical resistance for a high degree of displacement on the x and y planar directions. Considering the heat emission from the LED PCB, the micro-tracking system is specifically designed to behave as a heat-sink through a precise choice of material and geometry.

Off-the-shelf Components

The goal is to have a simple and innovative solution that can be rapidly implemented in the market at a low cost. In accordance, the planar steerable luminaire technology is composed of affordable off-the-shelf components (e.g. same actuators used as reflexes cameras or automotive) and standardized manufacturing processes.

Bill of Materials

From the experience in solar cells costs for adding motion control, the added costs over an existing luminaire can be as little as EUR 0.50 depending on the implementation version and are driven by:

- Actuators (if any): off-the-shelf and mass-produced for other industries
- Electronics: standardized components once in large-scale production
- Lenses: material costs and injection time
- Other mechanical parts: very simple to manufacture in large-scale production

Range of Applications

The high versatility (**Figure 2**) of the design and the ability to be encapsulated in a wide range of existing luminaires, poise the technology for incorporation into the product lines of incumbent players across lighting segments.

Beyond the existing use cases, which are currently confidential, a wide range of applications are foreseen where the design demonstrates disruptive features from an ergonomic and economic point of view. The most promising use cases to date have been brought forward by the incumbent companies who have deep market expertise and a drive for innovating.

Automotive Interior Lighting

Cost, compactness and usability being the key requirements of automotive lighting, the technology presents interesting

opportunities. With the optical layer, a single LED and a manual haptic mechanism to control the micro-tracking system, it is the leanest and simplest implementation of the technology. By manually moving a small joystick integrated in the encapsulation and controlling the guiding system, the user can intuitively steer the beam up to 45° from normal incidence in all directions. The smart design results in very low added bill of materials.

Stage Lighting

Motorized directional projectors across stage lighting from small venues to production stages offer steerable beams at wide angles from normal incidence, but at a high weight and cost. Bulky and expensive motors are required to counter the inertia for a fast-moving projector. In comparison, planar steerable technology solves this issue by only using light moving components with small momentums, requiring only small actuators. The approach offers a more discreet light design that is attractive to use-cases such as small venue stages, where dynamic directional lighting would be a benefit but the supporting structures, size and cost of a projector are not worthwhile. The flexibility of the directional beam can also be integrated in the illumination of conference rooms. With a wide variety of lighting configurations and without refurbishment costs, the user can, for example, remotely choose to light a part of the meeting table before orienting the beam to the dashboard for a presentation by changing its intensity. Self-tracking systems could also be integrated to follow the movement of a subject.

Smart Home

At home, the versatility of the beam offers an infinite adaptation to the ambiance of the room. From a warm illumination of the walls in the morning of a cold winter to another directed and brighter illumination of the room in the evening, the scenes can be freely rearranged depending on the mood of the user. In addition, the luminaires are discreetly incorporated in the ceiling thanks to a small and unobtrusive design.

Street Lighting

When incorporated in the encapsulation of a street light, the technology offers a highly adaptive illumination frame with only a small adjustment on the manufacturing line. With a manual and low-cost implementation on one hand, a worker can easily handle a simple mechanism (e.g., a screw,) controlling the displacement of the LED PCB over the optical layer to freely redirect the beam. On the other hand, in an actuated implementation the beam of each street light could be adjusted to the situation, both in direction and illumination frame. Whether as a function of the time of the day, the amount of people in the street or the weather, this adaptive dynamic lighting holds the potential for more welcoming, engaging and safer for public areas.

Industrial Lighting

The large number of assembly lines inf manufacturing industry requires many specific lighting systems. For applications such as in assembly lines, inspection lines or production facilities, the recessed and compact design of the planar steerable technology enables for the end-user to (remotely) adapt the direction, shape and intensity of the beam, or follow moving parts. This feature could represent significant time and cost-savings, and potentially increase security.

Figure 2: Example prototypes: a) A downlight in two different beam positions; (b) Industrial light prototype composed of an array of LED-lens pairs; (c) Implementation in a reading lamp designed for automotive

Conclusion

Our patented planar optical micro-tracking technology has given rise to a new generation of steerable luminaires. These new systems are interesting due to their opto-mechanical features while remaining low cost to the end-customer. Within a compact and static encapsulation, it allows for a remotely controllable directional beam up to 45° from normal incidence with good beam profiles and additional functionalities, such as: a wide range of intensities, various fixed shapes of the beam and a wide choice of temperatures. Beyond the existing use cases, which are currently confidential, a wide range of applications are foreseen where the technology demonstrates disruptive features from an ergonomic and economic point of view. Accordingly, each of the components are affordable and either off-the-shelf or produced with standardized manufacturing processes. From a concept initially designed to increase the efficiency of solar panels to its implementation in various lighting applications, this technology platform has already been successfully implemented in both industries. Yet, a wide range of promising lighting applications is still to be explored with a bright horizon already in sight. ■

AUTHOR: Noé BORY, MSc.
Noé is the lead lighting R&D engineer at Insolight [1], with a deep experience in micro-systems design. Together with Insolight's opticians and electronic engineers, he brought the planar steerable luminaire concept from ideation to prototypes that are being implemented in luminaires across different industries.

FURTHER AUTHORS:
Sven Menge [1], Ross Stanley [2] and David Schuppisser [1]

References

[1] Chemin de la Dent d'Oche 1A, 1024 Ecublens, Switzerland https://www.insolight-lighting.com
[2] Route du Village 35, 1066 Epalinges, Switzerland https://www.optiross.com

Short-Pulse Testing Eliminates Self-Heating Errors to Produce True L-I Graphs

Since the rise of LEDs as the preferred light source, accurate determination of their parameters has become crucial. One of these parameters - and a standard measure - is measuring LED light output vs current (L-I). Unfortunately, the result is not independent of other parameters. The environment, the package type and many other factors may distort the result. Some of these impacts can be minimized by reducing the measurement time by using ultra-short pulses in the domain of microseconds. Vektrex has designed such a measurement system. Jeff HULETT from Vektrex, and Markus SCHNEIDER from from OSRAM Optosemiconductors explain in detail, the basic problem, why short-pulse testing is relevant, what such a system-setup looks like and how such measurement results differ from standard measurements.

LED Professionals are finding that measuring LED light output vs current (L-I) for next-generation LEDs is increasingly difficult using widely established test methods. These methods use DC current steps or ≈ 20 ms current pulses to power the LED during measurements and they assume that the LED continues to operate close to the ambient temperature throughout the measurement. As this article will show using example data from LEDs manufactured by three different companies, this assumption is increasingly invalid due to advancements in LED technology. To combat this problem, this article presents a method that will accurately measure these next-generation parts using short (< 40 µs) current pulses instead of the longer ≈ 20 ms pulses that are the foundation of existing test methods.

Advanced LED Package Designs Tax Existing Testing Methods

To reduce cost, recently introduced LEDs often incorporate package designs that eliminate the internal heat spreading elements that were present in previous-generation LEDs. In those older LEDs, these heat-spreaders acted like heat reservoirs during testing, slowing the LED's junction-temperature rise during measurements. The newer LEDs, on the other hand, heat quickly during a single long-pulse measurement and, when an L-I sweep is made, the cumulative heating from multiple measurements can result in a heating-induced droop that masks the LED's true L-I characteristic.

Figure 1 and **Figure 2** show thermal simulations of two LEDs from Manufacturer 1 driven by a long (30 ms) current pulse. The two parts employ different state-of-the-art LED packaging principles. One features a heat-spreading element. The other does not.

Figure 3 shows the simulated junction temperature over time, for the two package types, per 1 W dissipated heating power. The simulation is done without heat transfer to the ambient environment. This is the typical measurement condition for an LED during production binning. The simulation covers a 20 ms time span – a typical long-pulse testing time.

The simulation begins with the LED at a junction temperature of 25 °C, and within the first millisecond, the temperature rises to 27 °C. One millisecond is about the time constant for the internal heat flow of a typical vertical chip design; during this time the heat flow is still concentrated within the chip itself. After about 1ms, the heat flow reaches the interface between the chip and the package, and the two graphs fork due to the different heat-flow characteristics of the two package designs. The temperature increases further to approximately 30 °C

(per 1 W heating power) after 10 ms, and to 33 °C after 20 ms.

One can conclude first that measurement results are independent of the package design if the measurements are ended within 1ms. Second, a junction temperature increase cannot be avoided. It can be minimized however, not only by ending the measurement within the first millisecond, but also by reducing the measurement time as much as possible.

Existing Testing Methods Did Not Anticipate High-Luminance LED Applications

Next-generation LEDs also increasingly target high-luminance applications such as machine vision, video projection, specialty lighting and automobile lighting. For these applications, a point-source-like surface emitter is favored to simplify optics design, and overall efficiency is traded off for increased light output. Thus, instead of large-area LEDs operated very efficiently at low current density (<1 A/mm^2), high-luminance LEDs feature small light-emitting-area LEDs operated at current densities well above the traditional 1 A/mm^2 limit. At these high current densities, electrical conversion efficiency is significantly lower. This, along with the small light emitting area, results in a high power dissipated per unit area. Like the optimized parts above, high luminance LEDs experience rapid junction heating during testing, and when these high-luminance LEDs are tested with long-pulse techniques, the LED's junction temperature can shift by forty degrees or more, greatly distorting the resulting L-I curves.

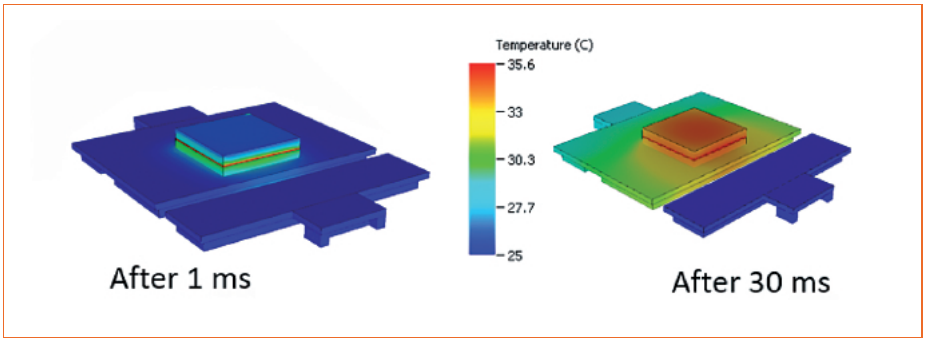


Figure 1: Manufacturer 1, Package Type A – uses a heat-spreading element

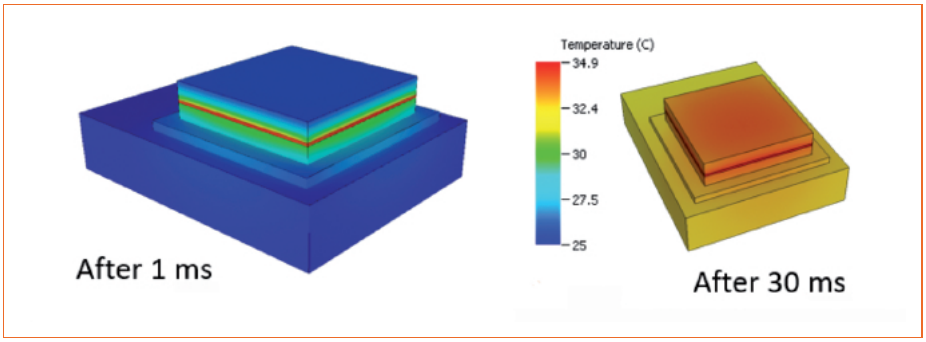


Figure 2: Manufacturer 1, Package Type B – no heat-spreading element is used

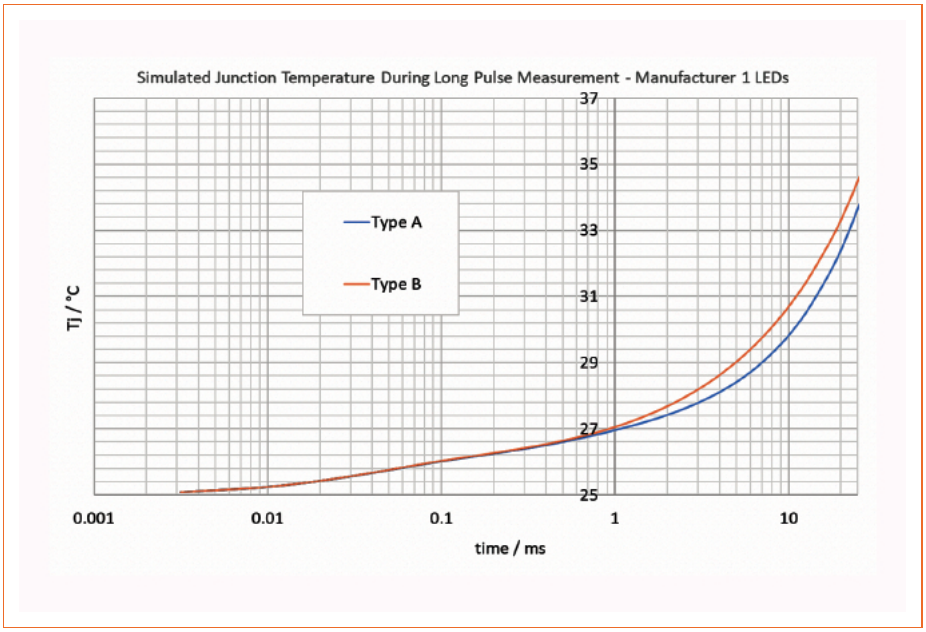


Figure 3: Manufacturer 1's LED junction temperatures diverge after 1ms during a long-pulse measurement

Correct L-I Curves Allow Designers to Produce More Cost-Effective Products

An LED's light-vs-current (L-I) curve quantifies its primary functional characteristic: how well the device converts current to light. Lighting designers use L-I curves to predict how much current will be needed to produce the light required for an application. They also use related current-vs-voltage (I-V) curves to determine the voltage needed to drive the current.

LED manufacturers specify L-I and I-V curves at a nominal temperature, for example 85 °C. But in many LED application situations, operating conditions deviate from this temperature. In these situations, lighting designers must calculate predictions of electrical and optical parameters using the nominal curves along with LED-manufacturer-supplied thermal coefficients or temperature dependence curves.

If the sample LEDs that the manufacturer used when creating the product datasheet experienced self-heating effects when the nominal I-V and L-I curves were measured, the graphed curves will deviate from true, constant-temperature curves. The magnitude of the deviation depends on the applied current (**Figure 11**). When the distorted curves are used by designers, this deviation results in a prediction error that is virtually impossible to account for. The prediction error is greatest at high current values.

Predictions based upon these distorted I-V curves can lead designers to design larger power and cooling systems than would be necessary if correct data was available, thus increasing product size and costs. Using both L-I and I-V curves the LED's efficiency can also be calculated. For most

LEDs the primary efficiency metric is known as the *Wall Plug Efficiency* (WPE or radiant efficiency ηe).

WPE includes three components:

1. Internal quantum conversion efficiency – how well electrons are converted to photons,
2. Light extraction efficiency – how much of that light escapes the package, and
3. Electrical efficiency – how much power is dissipated in resistive losses. LED WPE is low at very low current density, it quickly rises to a maximum, and then it falls as current density increases. **Figure 4** shows the WPE for a phosphor-converted white LED.

This characteristic of decreasing WPE with increased current density is known as *"droop"*. Droop is mainly caused by a decline in the internal quantum-conversion efficiency subcomponent. Instead of holes and electrons combining to produce photons, at high current densities they instead combine non-radiatively, in what is known as *Shockley-Read-Hall recombination* and *auger recombination*. LED designers strive to improve WPE overall, and to delay the onset of these non-radiative recombination processes to higher current densities, especially in high-luminance applications.

While WPE depends primarily on the LED chip's construction (including the material system used), temperature also greatly influences WPE. Increased temperature reduces both quantum-conversion efficiency and electrical efficiency. In addition, for phosphor-converted LEDs, phosphor down-conversion efficiency decreases with increased temperature through a process called *phosphor quenching*.

Traditional L-I and I-V Sweep Measurements Have Timing and Heat-Induced Distortions

Historically the L-I and I-V curves that form the basis of WPE graphs have been drawn using a *sweep measurement* – that is a series of single measurements made at increasing currents. The sweep can utilize pulsed current, or it may use contiguous current steps – what is known as a staircase sweep (**Figure 5**).

Staircase sweeps have two primary issues. First, because the LED is driven continuously, heat accumulates from the beginning of the sweep until the end. Thus, early measurements occur at a

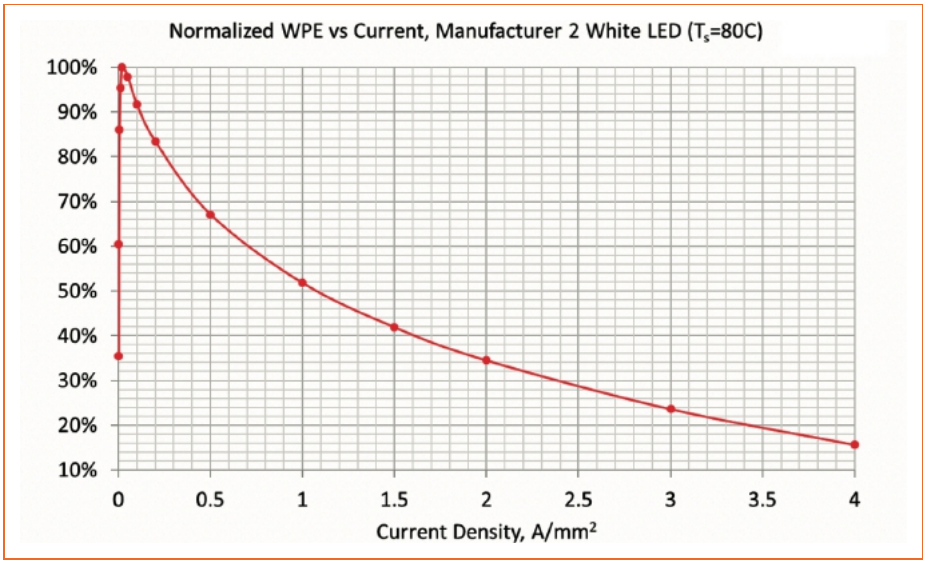


Figure 4: Manufacturer 2 Warm white LED wall plug efficiency (WPE), measured with long-pulse technique, normalized to the peak WPE, declines to 16% at 4 A/mm^2

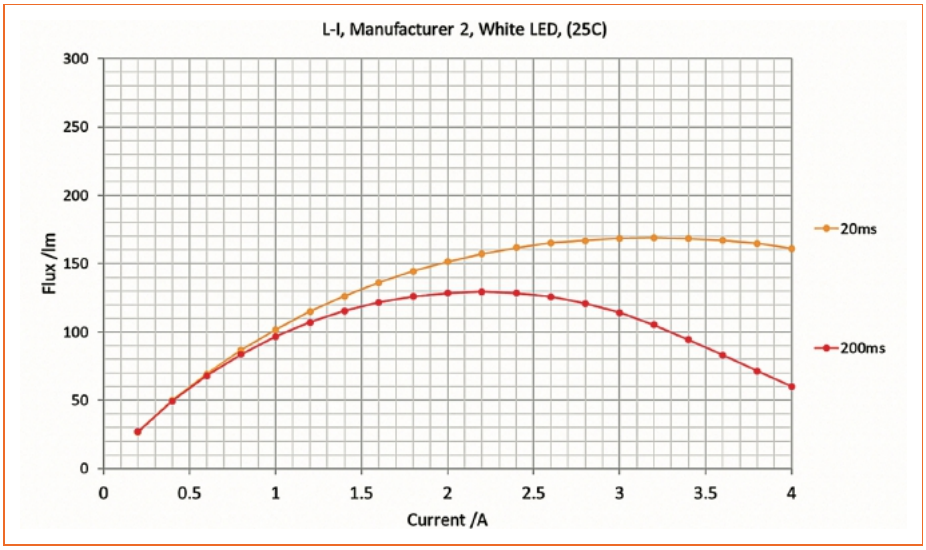


Figure 6: Manufacturer 2, White LED I-V sweep exhibits thermal rollover if the LED is operated at or above the maximum allowed forward current

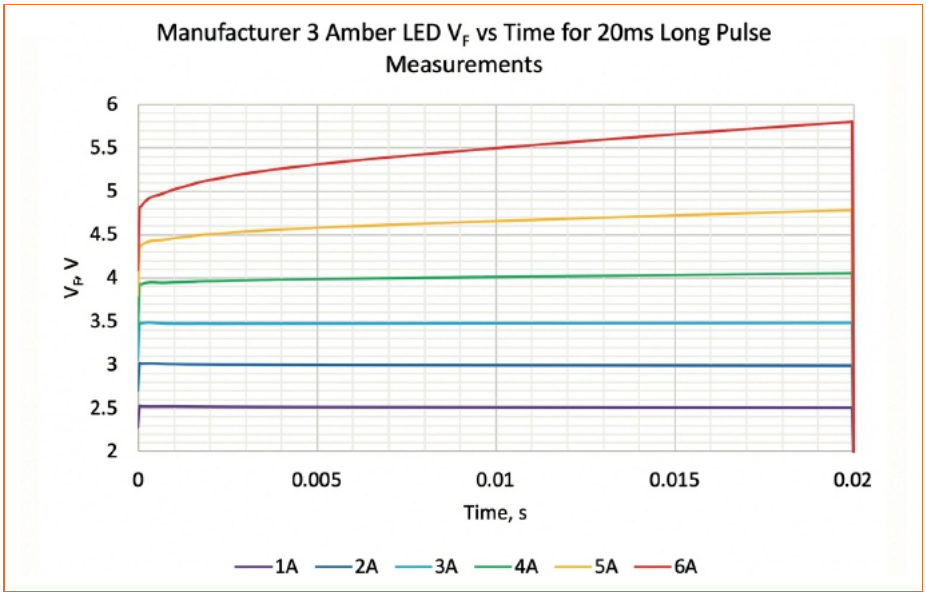


Figure 7: Manufacturer 3 Amber LED V_F vs time for 20 ms measurements reveals distortion caused by interconnect heating

temperature close to the LED's ambient condition, but later measurements are at a higher temperature. Second, step timing is often controlled via software algorithms that have indeterminate timing delays. This variability ultimately results in additional distortions in the resulting L-I or I-V curve.

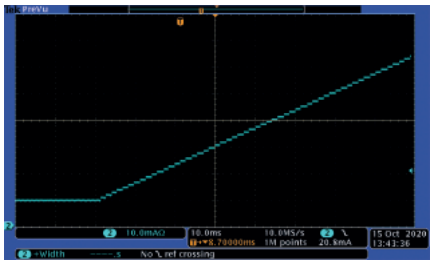


Figure 5: Oscilloscope capture of "Staircase" current sweep shows timing variations caused by software delays

The LED Industry Turned to Pulsed Current to Reduce Heating

To reduce heating, the industry switched from staircase steps to a pulsed-current measurement technique called Single Pulse, documented in the IES LM-85 standard and CIE Technical Reports CIE TR 225/ TR 226. Single Pulse sweeps reduce heating by powering the LED only briefly during a measurement and then driving the current off for the time between measurements. If the off time is long enough (several tens or hundreds of milliseconds), and the DUT is also mounted to a thermal platform, junction heat has time to escape to the outside environment, and cumulative heating is eliminated. However, these pulsed measurements can still result in significant junction heating during the duration of the pulse – especially at the higher current points.

The LM-85 standard and CIE Technical Reports CIE TR 225/ TR 226 specify that optical and electrical measurements should begin once the DUT has reached a *"quasi-stable"* condition, that is when the rate of temperature rise slows, purportedly at approximately 5 ms. Optical and electrical measurements are then made within the next 20 ms. Single Pulse measurements like these have been used by LED manufacturers for at least two decades. They were satisfactory because the first commercially-available LEDs operated at low current density and their package thermal elements provided significant heat reservoirs. Thus, heating-induced errors were usually insignificant, and they could be ignored. Much of the industry standardized on Single Pulse measurements, for internal R&D testing, datasheet development, and production binning.

As LEDs evolved to higher currents and current densities exceeding 350 mA/mm^2 in the last decade, Single Pulse remained the widely-used method even though the underlying assumption – that heating-induced errors were insignificant – became increasingly invalid.

An Example: L-I Plot for 1 A Phosphor-Converted White LED

Figure 6 shows an L-I sweep for a 1 A high-power white LED. Two curves are shown. One used 200 ms current pulses with minimal time between measurements (approximating the staircase sweep). The other used 20 ms pulses with an off time for cooling. The tested LED has a die area of 1 mm^2, so the maximum current density tested was 4 A/mm^2. As the curves show, the 200 ms and 20 ms curves are similar up to the nominal operating current. But above the nominal level the output is degraded by heating. At 2 A the 200 ms curve starts to decline with increasing current, a phenomenon called *"roll-over."*

High current-density testing also generates heating in LED internal electrical interconnect structures like bond wires. The resistance changes caused by this heating can significantly increase forward voltage (V_F) values if it is not mitigated with appropriate interconnect structures and materials. The resistance changes further if the package power dissipation increases. At high currents the resulting heating spiral can destroy interconnect structures and even melt bond wires.

Figure 7 shows an amber AlGaInP LED driven with a 20 ms single pulse. At currents above 4 A V_F increases dramatically during the pulse.

Figure 8: Precision pulsed source/measure instrument used for article's fast-pulse and long-pulse testing

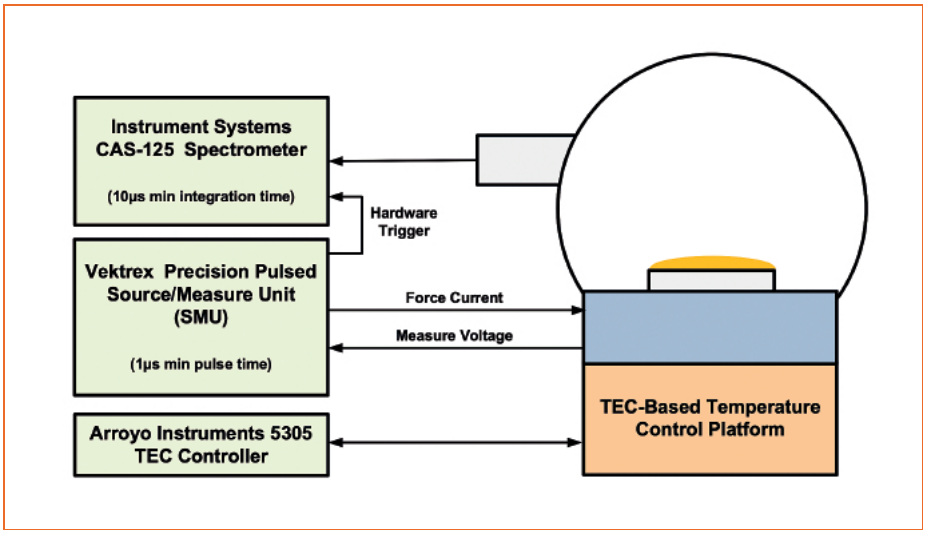


Figure 9: This fast-pulse testing setup was used for this article's measurements

Much Shorter Pulses Are Needed

To reduce heating during characterization of high current-density LEDs with smaller heat reservoirs, tests must use much shorter pulses. As the example simulation showed, pulses should be shorter than 1 ms to avoid being influenced by the outside environment, and the best results are obtained if the pulse width is well below 40 µs.

Such pulses are possible using *precision pulsed current sources* that feature fast (<3 µs) current rise and fall (**Figure 8**). These instruments also have hardware-based timing to ensure that the spectrometer measurement is always made at the same place within the pulse. For Single Pulse short-pulse testing, spectrometers that can accurately trigger and integrate in the sub-millisecond range are also required. When using short pulses are used, a delay for the quasi-stable time is not required, measurements may be made as soon as the current is stable.

Figure 9 shows the fast-pulse testing setup used to make the measurements in this article. In addition to the precision pulsed current source, a Thermoelectric Cooler (TEC)-based temperature platform was used to control the LED case temperature, and a spectrometer that supports microsecond integration times performed the optical measurements.

Tips for Successful Short-Pulse Testing

Successful short-pulse measurements depend on flat current pulses with fast rise and fall times. To accommodate cable inductance and device capacitance, most fast sources include response-tuning settings. Adjust these settings for best waveshape with actual cable and load conditions. If the current waveform is within compliance and flat during the measurement window, the setpoint current may be taken as the stimulus current. If it is not, the current must be measured with an external instrument and the average current during the measurement window should be used. A high-frequency shunt and a fast digitizer may be used for this average current correction/measurement.

With fast rise times, cable inductance has a significant effect on pulse shape. Minimize inductance by shortening cables and twisting wires. Since $dI/dt = V/L$, the current source's maximum compliance setting can also be increased to improve pulse shape.

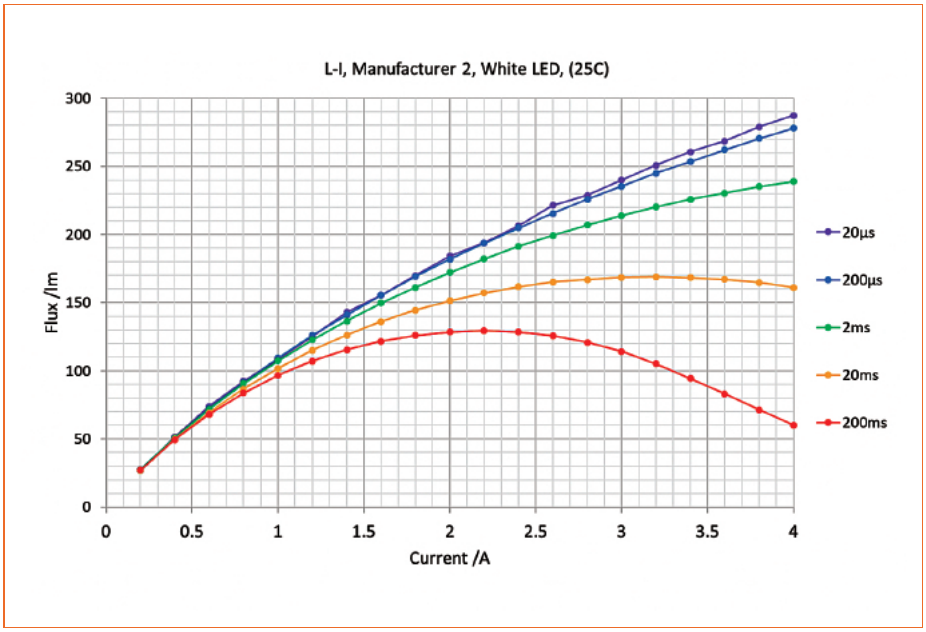


Figure 10: Short-pulse testing reveals Manufacturer 2's White LED true L-I characteristics

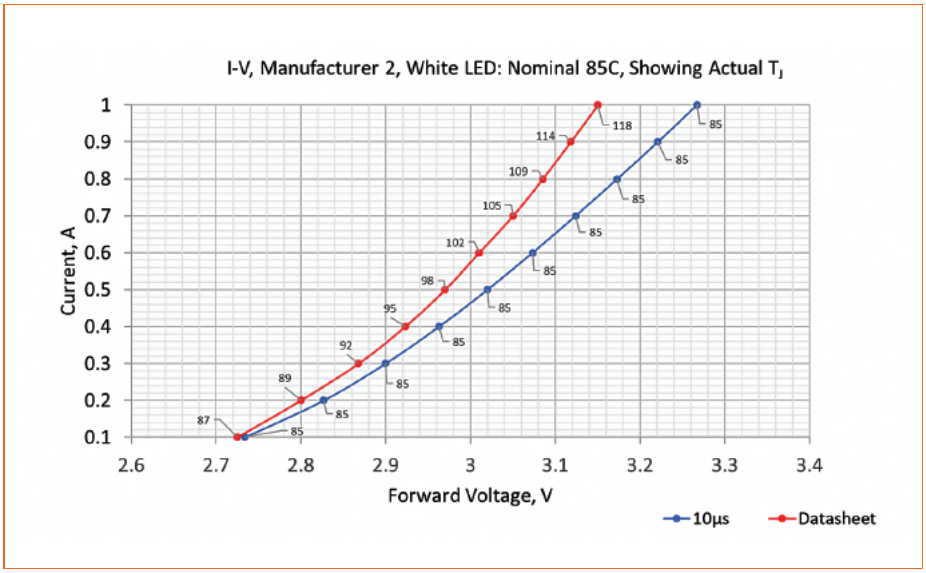


Figure 11: Manufacturer 2's white LED long pulse and short pulse I-V curves illustrate distortion caused by T_J error

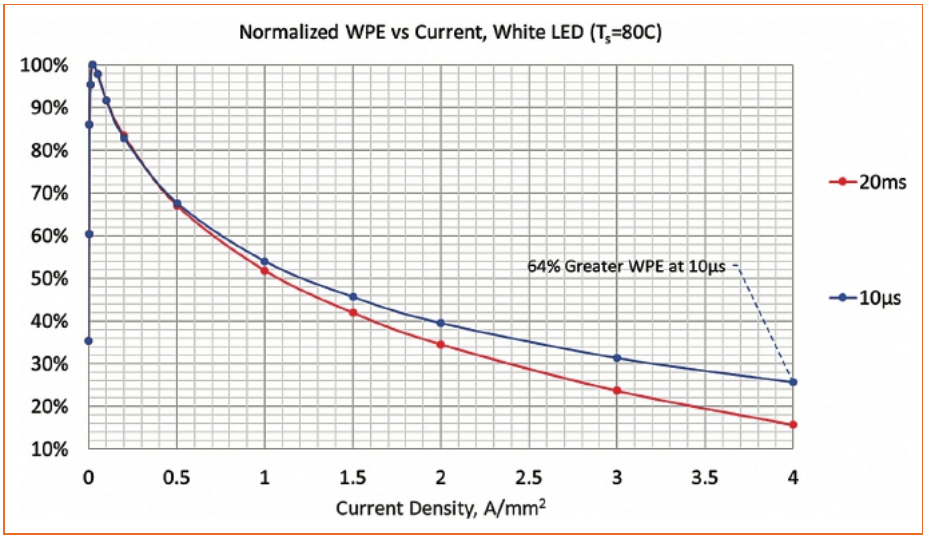


Figure 12: Short-pulse testing shows WPE at 4 A/mm^2 is actually 26%, 64% better than long-pulse testing indicated

When sweep testing over a current range of more than 10:1 or 20:1, break the sweep up into multiple sweeps, to take advantage of the current source's multiple current ranges. Low-current sweeps may also be performed with longer pulses as the energy delivered per pulse at lower currents is much less. Longer pulses at low currents are easier for the current source to produce, and they provide additional light for the spectrometer measurement.

Short Pulses Eliminate Heating-Induced Droop

When Manufacturer 2's white LED is retested using short pulses, heating-induced droop is greatly reduced and the roll-over is eliminated, revealing the device's true characteristics. **Figure 10** shows the part's L-I characteristic tested with pulse widths from approximately 200 ms to 20 µs. For the shortest pulse, a spectrometer integration time of 20 µs was used.

Shorter Pulses Improve I-V Curves

Short pulse testing also improves I-V curves. **Figure 11** compares Manufacturer 2's white LED datasheet I-V curve (published as an 85 °C junction temperature curve and measured with long pulses) against an 85 °C L-I curve measured with 10 µs short pulses. The shifted long-pulse curve underrepresents the maximum current compliance voltage by 117 mV. Actual T_J values for the measurement points are also shown. These were obtained by duplicating the pulsed sweeps with sweeps that included a small DC bias current. The T_J values were then calculated using the JESD 51-51 Electrical Test Method.

Short Pulse Testing Reveals True WPE

When correct L-I curves are combined with correct I-V curves, the LED's true WPE at the designated junction temperature is revealed. **Figure 12** shows the Manufacturer 2 white LED WPE vs current curve up to 4 A/mm^2, 4× the normal current density. 20 ms long-pulse and 20 µs short-pulse curves are shown; both were performed at a TEC temperature of 85 °C. The plots show that the 4 A/mm^2 WPE is 64% better than long-pulse testing indicates. Such a difference can have profound implications for LED chip designers and for lighting engineers, especially those working on high-luminance applications.

Conclusions

Long-pulse testing has served the LED industry well over the last two decades, but the heating-induced errors that accompany this method can no longer be ignored, especially for upcoming LED designs and high-luminance applications. Fortunately, recent advances in instrumentation enable a shift to short-pulse testing that greatly reduces heating. The resulting improved curves will enable lighting designers to create more efficient lamps and luminaires. They will also allow chip developers to more quickly discern a device's actual characteristics and make comparisons with design simulations. The time is right to switch to short-pulse testing. ■

AUTHOR: Jeff HULETT
HULETT is the founder and CTO of Vektrex Electronic Systems, Inc., a manufacturer and supplier of precision pulsed current sources, and systems used world-wide for reliability test, burn-in, and photometric measurement. He is the chief designer for Vektrex's SpikeSafe SMU source/measure product. Hulett holds a BSEE from the Illinois Institute of Technology, and he has been awarded several US and international patents. Hulett is an active member of the Illumination Engineering Society of North America (IESNA) where he chairs the LM-80 working group. He also participates in the IES LM-85 committee and the CIE TC2-63 committees, where he is focused on improving measurement accuracy and repeatability.

About Vektrex:
Vektrex designs, develops, manufactures and markets advanced precision current source instruments and systems for specialized needs of LED manufacturers and the SSL marketplace. Our products include current sources, thermal control chambers, light measurement systems, LM 80 systems, LM 85 systems, software, and accessories. https://www.vektrex.com

CO-AUTHOR: Markus SCHNEIDER, Dr.
Markus Schneider is employed at OSRAM Opto Semiconductors GmbH, Regensburg, Germany, a global leader in the field of optical semiconductors and high-quality products in the fields of illumination, visualization and sensor technology. He takes the responsibility for the characterization of LED products and development of advanced optical measurement procedures and has been awarded several international patents. SCHNEIDER holds a diploma in physics and a doctoral degree in natural sciences. He is a member of the Illumination Engineering Society (IES) of North America, CEN/TC 169 WG7 (light and lighting), DIN - the German Institute for Standardization, and chairs the CIE Technical Committee 2-91 that is focused on optical measurement methods of LED packages.

About OSRAM:
OSRAM, based in Munich, is a leading global high-tech company with a history dating back more than 110 years. Primarily focused on semiconductor-based technologies, our products are used in highly diverse applications ranging from virtual reality to autonomous driving and from smartphones to smart and connected lighting solutions in buildings and cities. OSRAM uses the endless possibilities of light to improve the quality of life for individuals and communities. OSRAM's innovations enable people all over the world not only to see better, but also to communicate, travel, work and live better. OSRAM had approximately 21,000 employees worldwide as of end of fiscal 2020 (September 30) and generated revenue of around three billion euros from continuing activities. The company is listed on the stock exchanges in Frankfurt and Munich (ISIN: DE000LED4000; WKN: LED 400; trading symbol: OSR).
https://www.osram.com

Cover Mar/Apr 2021 | LpR 84

Annual Subscriptions

LpR Digital Magazine
- eMagazine (PDF download)
- 6 Issues per Year (Bi-monthly)
- Full Archive Access (all previous eMagazine issues)
- EUR 78.80

LpR Printed & Digital Magazine
- Print Magazine including shipping
- eMagazine (PDF download)
- 6 Issues per Year (Bi-monthly)
- Full Archive Access (all previous eMagazine issues)
- Shipping costs included
- EUR 97.80

Subscribe

https://www.led-professional.com/subscription

Advertise

https://www.led-professional.com/advertise

Mar/Apr 2021 | LpR 84 PREVIEW

Mar/Apr 2021 | LpR 84 DEADLINES

AD CLOSE
FEBRUARY 28, 2021

MATERIAL DUE
FEBRUARY 28, 2021

DIGITAL PUBLICATION
MARCH 15, 2021

PRINT PUBLICATION
MARCH 31, 2021

Mar/Apr 2021 | LpR 84 ENQUIRIES

mailto:info@lugerresearch.com

Imprint

LED professional Review (LpR)
ISSN 1993-890X

Publishing Company

Luger Research e.U. | © 2001-2021
Institute for Innovation & Technology
Moosmahdstrasse 30, A-6850 Dornbirn,
Austria, Europe
info@lugerresearch.com | www.lugerresearch.com
P +43 5572 39 44 89
F +43 5572 39 44 89 90

Publisher
Siegfried Luger +43 699 1133 5570 s.luger@lugerresearch.com

Editors
Arno Grabher-Meyer +43 699 1133 5518 a.g-m@led-professional.com

Dr. Günther Sejkora +43 699 1133 4343 g.sejkora@lugerresearch.com

Sarah Toward +43 699 1133 5521 sarah.toward@lugerresearch.com

Theresa König +43 699 1133 5520 theresa.koenig@led-professional.com

Account Manager
Christine Luger +43 699 1133 5520 c.luger@lugerresearch.com

China, Hong-Kong
Lolo Young +852 9792 2081 lolo@castintl.com

Germany
Armin Wezel +49 30526 891 92 armin@eurokom-media.de

India
Priyanka Rai +91 124 4787331 priyanka.rai@binarysemantics.com

South Korea
Jung-Won Suh +82 2 78 58222 sinsegi@sinsegimedia.info

Taiwan
Leon Chen +886 2 256 81 786-10 Jeon@jkmedia.com.tw

Benelux, France, Ireland, Scandinavia, UK
Zena Coupé +44 1923 85 25 37 zena@expomedia.biz

USA & Canada
Lesley Harmoning +1 218 686 6438 lesley@lhmediainc.com

Copyrights – Luger Research e.U.

LpS DIGITAL

THE FIRST DIGITAL LIGHTING CONFERENCE AND EXHIBITION

EXPERIENCE THE
FUTURE OF LIGHT

CALL FOR PAPERS

SUBMIT YOUR LECTURE

www.LpS-Digital.global