LED professional Review

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LpR

The Global Information Hub for Lighting Technologies

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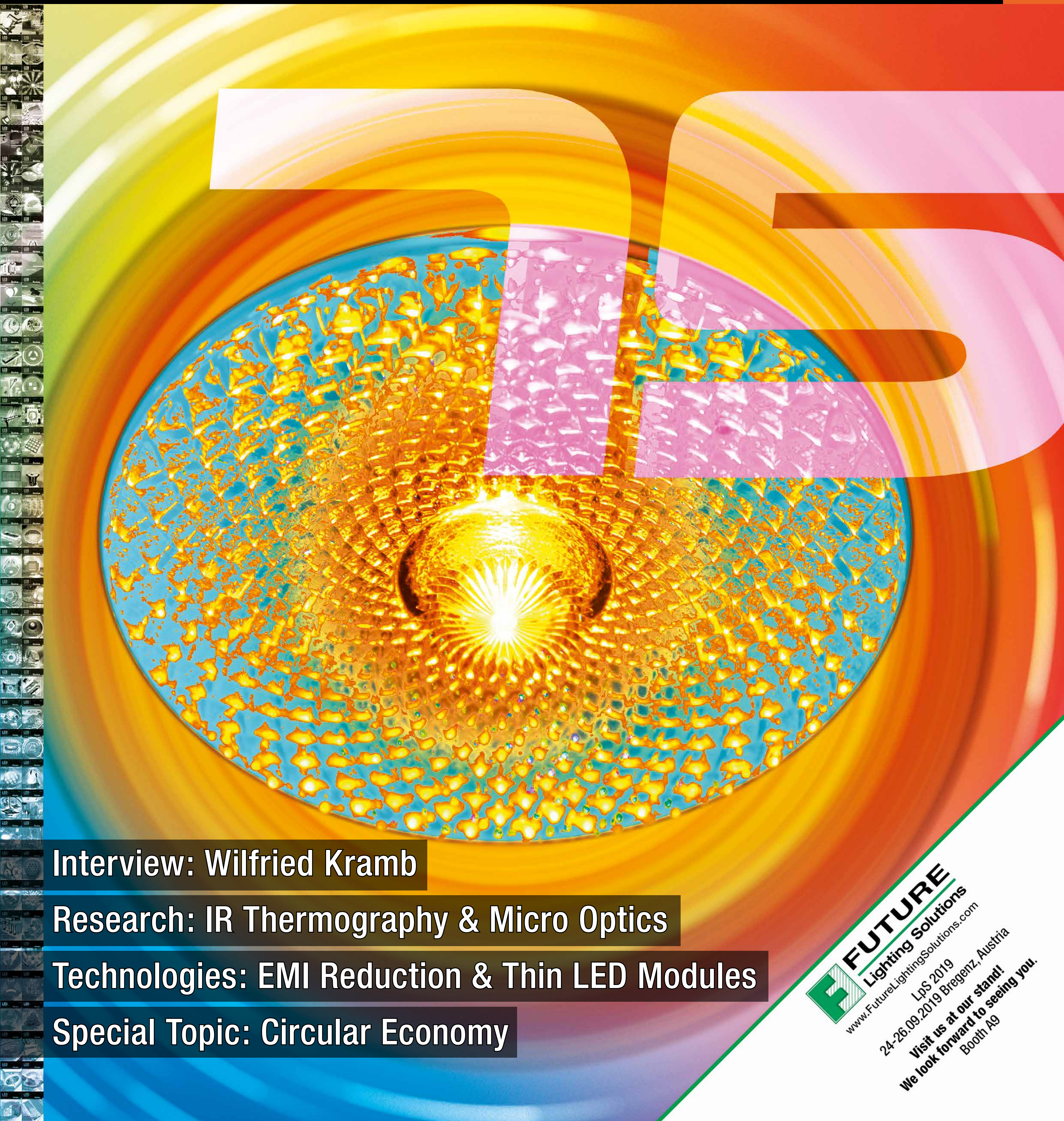
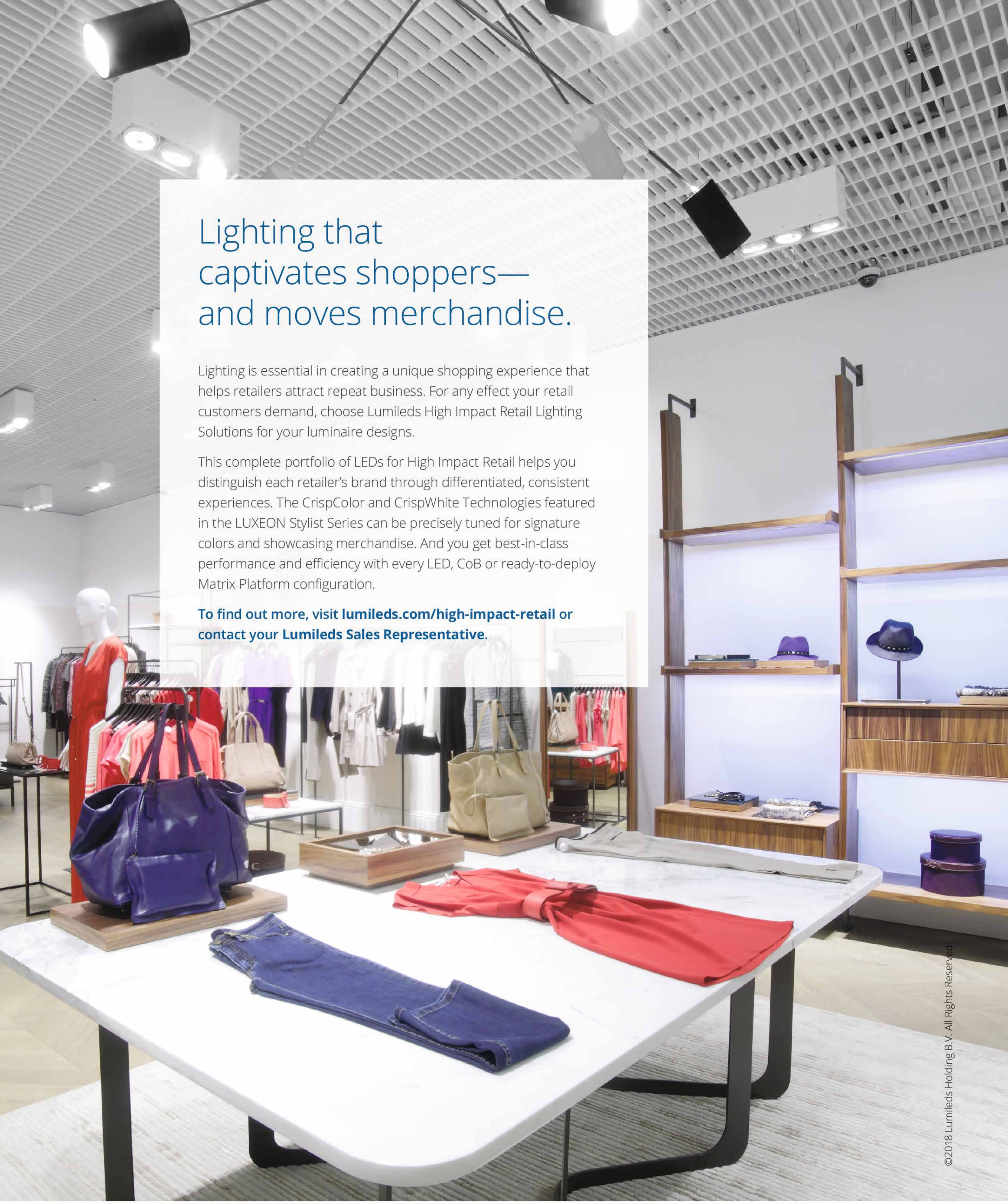


Interview: Wilfried Kramb

Research: IR Thermography & Micro Optics

Technologies: EMI Reduction & Thin LED Modules

Special Topic: Circular Economy



Lighting that captivates shoppers— and moves merchandise.

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This complete portfolio of LEDs for High Impact Retail helps you distinguish each retailer's brand through differentiated, consistent experiences. The CrispColor and CrispWhite Technologies featured in the LUXEON Stylist Series can be precisely tuned for signature colors and showcasing merchandise. And you get best-in-class performance and efficiency with every LED, CoB or ready-to-deploy Matrix Platform configuration.

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INVITATION TO

CIRCADIAN LIGHTING

A diploma course from DTU Fotonik
to strengthen your qualifications in how light impacts the human health

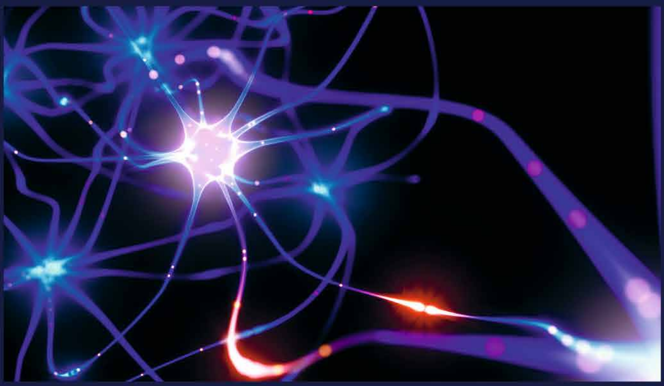
26 - 27 November 2019

2-day course on circadian lighting

The photonics department at the Technical University of Denmark, DTU Fotonik, is pleased to invite you to participate in a 2-day course on circadian lighting.

The course is a continuing education directed to companies and businesses in the lighting industry, and is held by Danish and international experts.

The course will be held at DTU Campus at Risø, north of Roskilde, Denmark, where the DOLL Quality lab, a state of the art lighting lab, is located.



After the course you will, among other, have competences in areas such as

- the basic aspects of circadian lighting
- lighting for workplaces, homes and light therapy
- How you verify the quality of circadian lighting
- Flicker and the impact of flicker on human health
- Light for humans with Alzheimer´s and dementia
- Lighting for delivery rooms and neonatal care lighting

The course will consist of both lectures and hands on practical exercises.

All participants will receive a diploma after finished course.

Course Fee

Before 28th September 2019: 5 900 DKK (790 EUR)
After 28th September 2019: 8 200 DKK (1100 EUR)
Prices are exclusive VAT.

For registration, please contact

Linda Christel: (linchr@fotonik.dtu.dk)
Mobile: +45 93511500

For more information and the program:
https://greenphotonicslab.com

Invited speakers:

Professor Troels W. Kjær, Zealand University Hospital (Denmark)
Dr. Klaus Martiny, Rigshospitalet (Denmark)
Dr. Marijke Gordijn, University of Groningen (Netherlands)
Professor Claude Gonfrier, INSERM (France)

Best regards,
The DOLL ACADEMY Team

DOLL
a Photonics GreenLab

DTU Fotonik
Department of Photonics Engineering

75th Issue Jubilee

In 2006 we came up with the idea to create a magazine that would cover LED and lighting technologies – and now, 12 years later, we are celebrating the 75th Jubilee!

For this reason we would like to take this opportunity to thank everyone who has contributed to our success over the past dozen years. On the one hand, there are our loyal readers, our advertising customers and our partners from science and industry. On the other hand there are all the authors, co-authors and initiators who have repeatedly drawn our attention to interesting and important topics.

Special thanks go to the editorial team, especially to LpR editor-in-chief Arno Grabher-Meyer and the entire team in the areas of editing, translation, design and graphics. We'd also like to thank our international network of representatives who have worked so hard to support us over the years.

The LED professional Review has contributed to the advancement of the use of LEDs throughout the world since the beginning. In recent years we have added important, new topics like HCL, digitization and networking. The commentary in this issue deals specifically with these changes. It follows our mission of EXPLORING LIGHT FOR A BETTER FUTURE.

This issue is not only the jubilee issue, but it is also the issue that will be distributed at the LpS/TiL/DALI Summit Events on September 24-26, 2019 in Bregenz, Austria - Europe's foremost lighting events.

We are very proud of the 75th issue and are happy to be celebrating this special edition in Bregenz!

We'd love it if you came to celebrate with us!

Siegfried Luger
Publisher, LED professional

"LEDs have revolutionized the lighting sector and linked it up with the advent of digitalization. We see further important innovative steps and research challenges in the years to come. It is valuable to have a trade magazine dedicated to these topics. I wish the team from LED professional Review (LpR) all the best for issue number 75!"

Prof. Dr. Shuij Nakamura,
University of California Santa Barbara USA,
Nobel Prize Winner Physics, 2014

COMMENTARY

TECH-TALKS BREGENZ

RESEARCH

TECHNOLOGIES

APPLICATIONS

SPECIAL TOPICS

REGULARS

HIGHLIGHTS

ADVERTISING INDEX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J. Norman Bardsley, PhD.
As President of Bardsley Consulting, Norman advises industry, government and academia on solid-state lighting, flat panel displays and energy efficiency, with special emphasis on diffuse lighting and organic electronics. He is a member of the Technical Advisory Team for the Solid-State Lighting Program of the US Department of Energy. Dr. Bardsley also acts as Chief Analyst for the International Solid-State Lighting Alliance (ISA) and is a member of the UNEP Expert Task Force on LED Lighting and Controls.

PROVIDING BETTER LIGHT SHOULD STILL BE THE FOCUS OF THE SSL INDUSTRY

Over the twelve years since the first Issue of LpR, SSL technology has been established as the best choice for almost all lighting applications. The market for LEDs in lighting has grown from around $300M to over $7B. Sales of LED packages now represent less than 15% of the total revenues from LED lighting, but further development is critical to the future of the industry. Although LEDs are available with efficacy over 200 lm/W, the dream of the early pioneers, these cover only a small portion of the gamut of color and power density. More efficient sources are needed at wavelengths greater than 480 nm and less than 360 nm to improve the quality of white light and provide the optimal spectrum for other applications. The efficiency of downlights and general service lamps needs to be brought closer to that of high-bay lamps.

Given the heightened concern about global warming, a renewed focus on energy savings is warranted. According to Strategies in Light, less than 40% of the installed global base of lamps and luminaires have been replaced by SSL and the savings already achieved have been partially offset by increased demand, especially in growing economies such as China and India. The adoption of high-quality solar lighting in off-grid communities has been particularly disappointing.

The reliability of SSL systems remains an issue for many customers. Perhaps the sole focus on lumen depreciation is no longer appropriate and more attention should be given to other factors, such as the probability of early failure. Visual comfort is also essential. Observable flicker needs to be eliminated. Glare is still a problem in many applications.

Although luminaire manufacturers have succeeded in the incorporation of LED sources, this has mostly been by fitting them into existing form factors. Very few luminaires seem to take optimal advantage of the properties of solid-state sources. We are still waiting for a replacement for the incandescent bulb that avoids the need for a shade to hide the lamp. The promise of efficient ultra-thin diffuse sources of light, with integrated drivers, that can be attached to any surface, flat or curved, has not yet been met, either by OLEDs or by waveguides lit by LEDs. Dynamic control of lighting is only in its infancy.

One sad aspect of the past twelve years has been the failure of US and European companies to adopt a long-term manufacturing strategy for both displays and lighting that recognized the opportunities for automation and encouraged the development and manufacture of the required robotic equipment. Ceding manufacturing to low-wage countries was perhaps short sighted, since there are now huge factories in China with no employees on the floor, even for some maintenance and simple repairs. However, the main profits in lighting now come from the assembly, marketing and installation of luminaires and lighting systems. Some large companies have withdrawn also from these parts of the business, whereas many others, small and large, have prospered.
One challenge that needs more attention is the training of a young work force that understands the opportunities and challenges of implementing the new lighting technologies and will work with architects, building and civic managers, and local regulators to bring the benefits to all users.

To end on a more positive note, SSL technology has given us a great opportunity to improve the quality of artificial light, which is essential to modern life. The lighting community must continue to work with health professionals, architects and others to deepen our understanding of the impact of light on physical and mental health and human productivity. ■

J.N.B.

Bridgelux Achieves 200 lm/W with 3rd Gen EB Series™ Products

Bridgelux announced an expansion of its EB Series™ LED product family to include increased efficacy of up to 200 lumens/watt (lm/W), new 2700 K standard CCT options, new 90 CRI options, and new slim linear and square form factors. As a customizable emitter-on-board platform using Bridgelux surface mount device (SMD) LEDs, EB Series offers customers choice in form factors, color points and CRI options tailored to their specific project.

Bridgelux's EB Series LED products now available with improved efficacy, expanded color point options and new form factors

Light is at the heart of life. In today's lighting market, customization and personalization are expectations, not trends. Customers demand manufacturers build comprehensive solution platforms that offer choice in efficacy, form factor, color point and light quality.

Bridgelux EB Series products now include third generation standard linear (280, 560 & 1120 mm) and slim linear (340, 590 & 1190 mm) lengths with typical efficacies of 200 lm/W and an expanded CCT range of 2700-5700 K. New 90 CRI options are also available for improved quality of light and enable luminaires compliant with California's Title 24 regulation. New custom products include eight- and twelve-inch square form factors with increased lumen output ideal for many commercial applications.

"Flexibility and customization are the foundation of today's lighting solutions," said Dr. Brian Cumpston, Vice President of Solutions at Bridgelux. "We are excited to offer customers new form factors with 200lm/W efficacy to meet their increasingly diverse needs, and to be able to do so in a cost-effective manner."

These EB Series products are now available for sampling and ordering as Gen 3, Slim Gen 3 and Square.

New High Output Lens LEDs for Vehicle Instrument Clusters

ROHM announces the availability of compact high output surface mount LEDs equipped with lens. This new lineup includes 18 devices, comprised of the CSL0901 series featuring standard brightness and the high brightness CSL0902 series.

ROHM 's new high output lens LEDs for vehicle instrument clusters are silver-free to prevent sulfuration

Recently, most vehicle instrument cluster designs have adopted shields to prevent light leakage from the LEDs to surrounding areas. However, light leakage remains a challenge due to a small amount of space that is required between the shield and the PCB to account for expansion caused by temperature changes. Additionally, some applications using LEDs, such as automotive and industrial systems where electrical components are exposed to severe conditions, require high reliability from these components, so they can better withstand the effects of aging caused by the extreme environments they are exposed to.

In response, ROHM has taken a step ahead in the industry to develop products targeting applications that require high reliability at the component level, such as developing the first high-brightness silver-free LEDs to prevent sulfuration, which is one of the leading causes of aging.

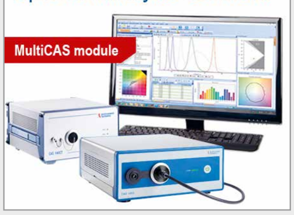
This newest series consists of automotive-grade products that ensure high reliability in vehicle instrument clusters which operate under harsh environments. Raising the light source position from 0.18 mm in standard products to 0.49 mm allowed ROHM to significantly reduce light leakage. Meanwhile, size was reduced by approx. 18x compared to conventional reflector-type LEDs.

In addition, all devices are designed to prevent light degradation even under high temperature environments (automotive). ROHM also developed a new type of resin for blue, green and white LEDs to achieve higher reliability. As a result, during high temperature testing with blue LEDs (85°C, I_F=20 mA, 1,000 hrs operation), ROHM succeeded in improving the residual luminosity rate by approx. 80% over conventional products, contributing to greater application reliability. Furthermore, achieving higher precision during the manufacturing process (i.e. die bonding, molding) while maintaining the compact 1608 size (1.6x0.8 mm) made it possible to increase core brightness by 5 to 7 times over conventional LEDs.

Key Features

Optimized light source position prevents light leakage, achieving greater space savings

Reflector-type LEDs are typically used as light sources for instrument clusters.



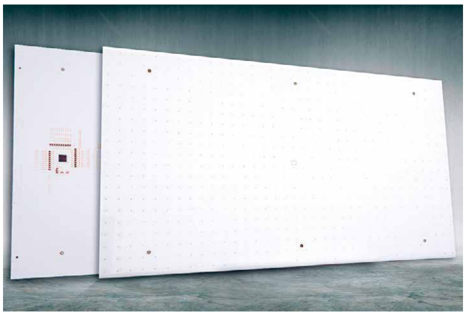
However, the increased need for space savings is causing many manufacturers to consider smaller LEDs. General compact molded LEDs are designed with light sources positioned as low as 0.18 mm, causing light to leak to adjacent areas. In response, ROHM raised the position of the light source to 0.49 mm, virtually eliminating light leakage. This makes it possible to use smaller LEDs (approximately 18x smaller in volume than conventional reflector-type LEDs), contributing to greater application space savings.

Contributes to longer application operation by reducing standby current consumption
Newly developed molded resin reduces degradation due to aging
ROHM developed a new molded resin that significantly reduces brightness degradation due to high temperature operation, even for short wavelength products such as blue. For example, during accelerated high temperature testing with blue LEDs, we succeeded in improving the residual luminosity rate by approx. 80% over conventional products.

Support for AEC-Q102 sulfuration testing
Until now, ROHM LEDs have been designed to comply with AEC-Q101, the international standard for high reliability in automotive applications used for discrete products, but more recently we have been working on obtaining certification under the AEC-Q102 standard for optical devices established in March 2017. This new regulation also includes sulfuration testing, which is expected to lead to even greater reliability in applications such as automotive and industrial systems exposed to severe environments.

Lextar to Releases New Mini LED Product Series

Lextar Electronics Corp. will release a new series of Mini LED ready for mass production, including I-Mini Blue, the smart backlight module integrating mini LED and driver IC, which can realize high contrast and slim design and is already introduced to applications such as gaming laptop panel. At the same time, Lextar will also launch pitch 0.7mm UFP I-Mini RGB display as well as micro LED technology. Applications of the whole series was presented in Touch Taiwan 2019 held in Nankang Exhibition Center during 28 to 30, August 2019.



Lextar extends their mini LED backlighting series suitable for a wide range of applications

The mini LED backlighting series released this time covers wide applications including TV, gaming monitor, laptop, automotive display and VR, demonstrating Lextar's speed in mini LED backlighting application deployment. Following the success of industry-leading mass production of mini LED backlighting, this year Lextar releases integrated I-Mini Blue backlight module, which integrates blue mini LED flip chip and driver IC to achieve high contrast, slim design and competitive cost in panel module assembly. Lextar's I-Mini Blue realizes new local dimming technology of over a thousand zones, which can precisely control the backlight and achieve dynamic contrast ratio of 1,000,000:1. This K-zone backlight solution is perfect for applications such as TVs, gaming monitors and laptops. Meanwhile, Lextar will also exhibit AM (active matrix) mini LED backlight module adopting COG (chip on glass) technology. By transferring the blue mini LED chips on TFT glass panels, it is possible to achieve a local dimming of over 2,300 zones on a 2.9" panel. Through this, a small-sized panel can realize a stereopsis with high contrast and is suitable for VR applications.

For mini RGB display, Lextar introduces a lineup of fine pitch RGB display modules. The UFP I-mini RGB module, with an ultra-fine pitch of P0.7, featuring high brightness, high contrast, sunlight readability and flexible in display size, is demonstrated in applications including signage, bus stop signs, chart plotters, automotive panels, HUD and tail lights. In addition, Lextar also launches mini RGB LED series, including 1313 & 2121 with a 4-in-1 fine-pitch design, as well as single package of 1010 & 1515. Customers can select the most appropriate package according to the viewing distance. The product series is expected to be mass produced by the end of this year.

In Touch Taiwan 2019, Lextar also presented the latest micro LED display technology, showing a 5.1" AM micro LED display. By assembling flip chip micro LED on the transparent glass, the brightness can reach up to 30,000 nits. This product not only shows micro LED's anti-strong light capability, but also proves Lextar's leading position in micro LED technology. Lextar's advanced opto-semiconductor components, including VCSEL for 3D sensing, IR LED, wearable application and UV package, are also one of the must-see points in Lextar's showcase. ■

EPtronics Expands UL Type HL Rated LED Drivers Portfolio

EPtronics has expanded its LED driver selection for hazardous location luminaires by offering a complete line of high-performance drivers from 25 W to 200 W output in constant current and constant voltage options. These LED optimized drivers are designed to operate inside HazLoc fixtures installed in dangerous or harsh locations. The LP, LD, LDAD, and LDHL Series EPtronics driver families are now UL Type HL rated, demonstrating product safety compliance when installed and operated in Class I, Division 2 Hazardous (Classified) Locations.

All EPtronics LP, LD, LDAD, and LDHL series driver families are now UL Type HL rated

EPtronics, a leading manufacturer of solid-state lighting power products, offers the broadest selection of UL listed and recognized off-the-shelf LED drivers. Our US-engineered products ensure exceptional performance and reliability to satisfy your technical requirements. All EPtronics products are protected by a standard 5-year limited product warranty. ■

EPtronics Simplifies Slimline LED Driver Selection with Wattages from 17-75 W

EPtronics has simplified its LED driver selection for linear luminaires by offering a complete line of high-performance drivers from 17W to 75W output in constant current and constant voltage options. These LED optimized drivers are designed to fit within the limited free space inside a light fixture such as a troffer or suspended linear.

Now available from EPtronics: A full line of slimline LED drivers in constant current and constant voltage options from 17-75 W

Slimline models include the LD17W, LD35W, LP55W, and LP75W Series families of drivers. In addition, the LP55W and LP75W Series in T5 format are programmable drivers, offering ease of configuration, adjustable versatility, and SKU reduction.

EPtronics, a leading manufacturer of solid-state lighting power products, offers the broadest selection of UL listed and recognized off-the-shelf LED drivers. Our US-engineered products ensure exceptional performance and reliability to satisfy your technical requirements. All EPtronics products are protected by a standard 5-year limited product warranty. ■

Infineon Launches Digital, Single-Stage Quasi-Resonant Flyback LED Driver Controller

Infineon Technologies AG releases a new LED driver IC to its XDP™ portfolio. It is a constant current flyback IC with a high-power factor and primary-side regulation. Key advantages of designing with XDPL8210 include outstanding functional performance for efficient designs as well as low bill-of-material (BOM) for small system cost and high flexibility. It enables excellent reliability for a long driver lifetime. For advanced products, the built-in features enable fast design cycles with little design efforts. The XDPL8210 is the best fit for innovative cost-effective, constant current, single-stage driver designs.

The excellent power factor of more than 0.9, and total harmonic distortion of less than 15% over a wide load and input range, reveal the outstanding performance of the XDPL8210

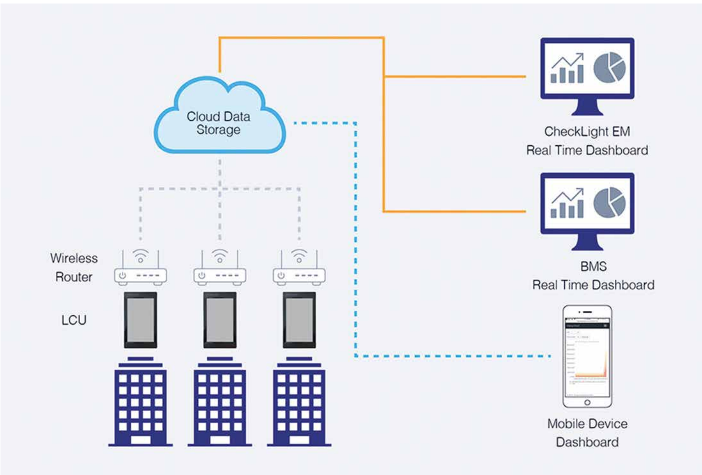
As a member of the XDPL family of LED driver ICs with a digital core, the XDPL8210 supports a great variety of LED driver products, based on the same hardware design. Therefore, it improves the supply chain efficiency by reducing efforts and cost for stock keeping. Infineon's new IC uses a PWM dimming input signal, and modulates the output current amplitude proportional to the duty cycle. A dim-to-off mode offers a standby power of less than 100 mW. The advanced feature set is complemented by an output voltage that can be varied by a factor of three.

The excellent power factor of more than 0.9, and total harmonic distortion of less than 15 percent over a wide load and input range, reveal the outstanding product performance. The XDPL8210 fully supports the IEC61000-3-2 class C standard. This makes the device well-suited for contemporary LED luminaires. The limited power mode improves functional safety. Sophisticated algorithms provide flicker-free dimming below one percent. With this excellent light quality can even at low dimming levels be achieved.

A set of comprehensive and configurable protection modes ensure advanced product quality as well as safe and robust operation. The XDPL8210 implements an adaptive temperature guard that prevents the driver hardware from thermal wear out. Additionally, the adaptive overvoltage protection enables lower safety margins to meet safety extra low voltage (SELV) specifications. ■

Douglas Lighting Controls CheckLight™ Energy Management Platform

Douglas Lighting Controls, a member of the Panasonic family of companies, recently announced the launch of its newest energy management platform, CheckLight™ The new cloud-based technology pairs seamlessly with Douglas centralized, distributed and wireless lighting control systems.



Structure and connections of Douglas Lighting Controls' new web based CheckLight™ energy management platform

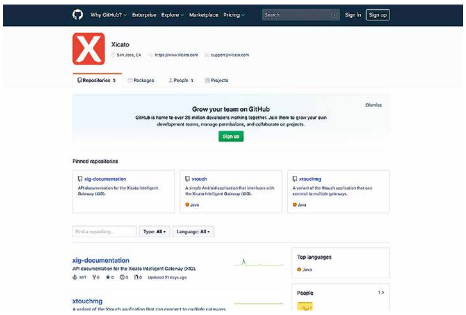
CheckLight has the ability to report through its own dashboard or share data through APIs compatible with Building Management Systems. The application allows secure global access to facility lighting allowing the user to adjust lights and lighting system settings from any location. This tool is essential in monitoring energy usage and optimizing cost based on consumption. CheckLight is OPEN ADR ready and can execute any automated demand response command.

"At Douglas, we are consistently focused on improvements that impact our clients' bottom line by enhancing and maximizing product efficiency," said Rob Mahaffey, General Manager of Douglas Lighting Controls. "CheckLight offers the most advanced technology designed to simplify monitoring and managing energy output from any location, at any time, allowing our clients to remain connected and able to control efficiency while on-the-go."

The new technology offered by CheckLight allows users to benchmark their portfolio of buildings, uncover energy conservation opportunities, create new energy conservation strategies, analyze growing inefficiencies in lighting loads and seamlessly share data with other building management software for in-depth comparative analysis. ■

Xicato Releases Open Source Software for Future of Smart Buildings

Xicato, the leading provider of highest quality light sources and smart building wireless controls, announced the official release of its XIG API (Xicato Intelligent Gateway application programming interface) to the software developer and system integration community under the standard MIT Free Open Source Software (FOSS) license. The XIG API enables configuration, control, monitoring, data reporting and data analytics of large networks of Bluetooth Mesh nodes installations that integrate lighting, sensors, switches, and audio-visual effects in any type of commercial or residential smart space.



Everything needed to program the controls environment for a user friendly, convenient, universal smart building solution, can be found on Xicato's GitHub site

"Today the wireless lighting industry is undergoing explosive growth. At this early stage I hope manufacturers embrace open control standards, cross platform compatibility, and most importantly, open-source control topologies as Xicato has done with their control API. The BLE handheld and peripheral consumers have clearly benefitted from this kind of philosophy and coordination among developers and manufacturers over the years;" stated Alexander Cooper, Head of Exhibit Technology at the Smithsonian.

The XIG provides translation between a Bluetooth Mesh network and any IP network or LAN, allowing centralized management of and remote access to large networks of Bluetooth nodes. With the availability of the open XIG API, customers can now use any lighting control, IoT, audio-visual, or building management system to control, monitor, and configure an unlimited number of Bluetooth nodes, potentially including HVAC systems, security systems, and many more, resulting in the development of customized experiences specific to an application, all using Xicato open and flexible software architecture.

"Xicato continues to reinforce its commitment to the advancement of smart building technologies and solutions that result in more productive, more efficient buildings and healthier living or working spaces.

We want our customers and partners to be able to join in our mission by leveraging our open software to create application-specific solutions that deliver the highest value to end users," said Xicato CEO, Amir Zoufonoun.

Several Xicato customers are already reaping the benefits of XIG API with installations in world-class museums, cathedrals, retail stores, warehouses, offices and residences. Examples include many acclaimed Heritage buildings such as the Van Gogh Museum, the Smithsonian, and Westminster Abbey. Control companies, system integrators and even end users have created customized environments through the XIG API from such systems as Medialon, ETC, Pharos, Extron, Crestron, LumiFi and Philips Dynalite.

Xicato's XIG API and source code for Xicato's XTouch and XTouch MG Android touchscreen interface, are available now on GitHub under a standard MIT FOSS license at https://github.com/orgs/xicato. ■

Casambi - Firmware Evolution Boosts Performance and Future-Proofs Networks

Casambi, the pioneer in wireless lighting controls based on Bluetooth Low Energy (BLE), has announced Evolution – a major firmware upgrade. Delivered over-the-air and free of charge, Evolution delivers enhanced performance with higher levels of security, and advanced feature capabilities that future-proof pre-installed Casambi Ready devices operating across existing networks.

Evolution can be applied to all luminaires, drivers and lighting control devices based on the Nordic Semiconductor nRF52 chip, across the Casambi ecosystem.
For Casambi products, the firmware is available for the CBM-002, CBU-PWM4, CBU-ASR, CBU-DCS, CBU-TED (manufactured from 3 January 2019 onwards), CBU-ASD (1 June 2018 onwards), and the Xpress (13 March 2019 onwards).

Casambi's firmware update concerns any product using the Nordic Semiconductor nRF52 chip: It improves levels of security and advances feature capabilities

When upgrading, all network settings are maintained. The optional Evolution firmware upgrade joins the company's existing Classic firmware which continues to be supported.

"This latest Evolution firmware upgrade underlines why the Casambi ecosystem is the de facto Bluetooth lighting control standard," said Timo Pakkala, co-founder of Casambi. "In addition to delivering advanced capabilities, Evolution demonstrates that Casambi is the leading end-to-end lighting control provider with the most seamless firmware upgrade path."

Supporting up to eight Pulse Width Modulation (PWM) channels, Evolution offers better operational performance to users, taking advantage of four times more RAM chip memory to store new configuration data, such as additional scenes and timers. The new firmware also delivers an enhanced security model.

With this firmware upgrade, information on the condition and priority level of a Casambi device is now transferred through the Bluetooth mesh network, enabling detailed information to be visible remotely. This can be used to communicate that it has overheated, for example, or if there is a configuration failure or a missing driver.

Evolution will run on any hardware platform that is based on the nRF52 and currently running Classic firmware version 25.0 or above. Backwards compatibility is maintained with previous versions of firmware, giving greater design flexibility to Casambi's ecosystem manufacturing partners and to lighting professionals who are using the multi-award-winning control solution in their products.

While Casambi can manage an unlimited number of luminaires across an unlimited number of networks, the firmware upgrade boosts the number of 'Casambi Ready' devices that can operate within each single mesh network from 127 (the number attained when using Casambi's Classic firmware) to 250 – an increase of more than 96%. ■

Gigahertz-Optik Updates MSC15 with Built-In Memory and Advanced Settings

As part of a product update, the range of functions of the compact MSC15 spectral light meter has been extended. The device is particularly suited to the measurement of LED based lighting in terms of illuminance, spectrum, color, CRI, PAR and human centric lighting metrics.

With this update the device gets internal memory for the local storage of up to 10 measurements which can be either managed directly by the MSC15 or by the supplied software.

With several added features and an integrated memory to store up to 10 measurements, Gigahertz-Optik's MSC15 spectral light meter is now more versatile than ever before

In addition, a menu for individually switching on and off the possible display screens has been added. This user customization no longer requires connection to a PC thereby simplifying the configuration of the device for individual measurement tasks.

The MSC15 offers simple and intuitive operation, fast display of measurement results and traceable calibration. It can be used to measure any light source, displaying spectral irradiance from 360 nm - 830 nm as well as photometric and colorimetric data including photopic, scotopic and melanopic illuminance, color rendering indices, color temperature and CIE chromaticity. For horticultural applications, the MSC15 also directly displays PAR PPFD in μmol/m²·s. ■

GlacialLight Announces New Natural Sunlight of GL-BL60-NL Series

GlacialLight announces the natural sunlight GL-BL60-NL series. With a CRI of 97, as well as the CQS (Color Quality Scale) is up to 97. The color fidelity index (TM-30-15 Rf) and color gamut score (TM-30-15 Rg) are close to natural light. The GL-BL60-NL can be mounted on ceiling or ground surfaces to project onto walls, as well as coming in suspension chain, pendant rod and outdoor stake options. It also features dimming.

For GlacialLight's GL-BL60-NL series, the bay light is now available in a neutral sunlight version

Features:

- High CRI is 97
- High CQS is 97
- TM-30-15 Rf is up to 96
- TM-30-15 Rg is up to 102
- IP66 rated
- The bracket can be adjusted 360 degrees horizontally or 180 degrees vertically
- Available surface mounted, suspension chain, pendant rod and outdoor stake
- Dimming function optional

The GL-BL60-NL is an adjustable bay light and rugged enough to be used both indoor and outdoor with IP66 rated. It can operate at ambient temperatures from -40°C ~ +50°C. The bracket can rotate 360 degrees horizontally, and 180 degrees vertically for complete lighting freedom. It can be angled downwards or upwards, adding even more options for lighting applications.

The natural sunlight GL-BL60-NL series can improve the light experience for human health benefits. It closely matches the spectrum of natural sunlight and harmonizes light output with natural circadian rhythms. The GL-BL60-NL is well suited for use in museums, art galleries, supermarkets and indoor plant walls. ■

LumenFocus FFL Surface Mount Kit

The Surface Mount Kit (SMK) is quickly and easily assembled in the field. The box has a steel frame with an aesthetically pleasing matte white finish. The SMK allows customers to have the same function and appearance as the rest of the FormFocus product line in a surface-mounted package.

LumenFocus' FFL series of lay-in LED luminaires is now available with an optional kit for surface mounting

All of the options available in the standard FormFocus lay-ins, such as the Philips EasySense occupancy/daylight sensor, are available with the surface mount kits.

LUXEON CSP HL1

Minimize your fixture size and create high intensity narrow beam spots

LUXEON CSP HL1 LEDs offer high flux density performance in a compact surface emitting footprint which makes it ideal for directional lighting applications. LUXEON CSP HL1 offers precise optical controls and superior color quality, enabling color-tunable lighting solutions.

Key Benefits

- Directional CSP leads to miniaturization of fixtures
- Ability to create narrow beam spotlights with high lumen output
- Quality of Light Improvement: Superior optical control and uniformity (COA <5 points)
- Perfect color mixing in CCT tunable applications (2700 to 6500K)
- Realize beam steering capability by leveraging the precise optical control

Key Applications

- Spotlights
- Downlights
- Tracklights
- Linear

To find out more on the LUXEON CSP HL1,
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LUMILEDS

The SMK is available for FFL 2x4, 2x2 and 1x4. On the FFL2R (dual-row lay-in), as well as the FFL2R HO ("High Output" version), the kit is available for the 2x2 and the 2x4.

LumenFocus now also offers a Frame-In kit for FormFocus products. This kit can be used to convert a concealed or drywall ceiling to be able to utilize the luminaire.

The FFL is available in a wide variety of lumen outputs for maximum versatility. The low profile and lightweight housing allow for easy installation. Specific models are DLC or DLC Premium listed. A matching retrofit kit, the FFR, is available to match the style and performance of the FFL. This kit can be installed within 3-5 minutes, depending on the model.

The FFL2R features the same function and versatility of the FFL but with a unique and modern dual-row design.

The FormFocus product line from LumenFocus combines the best in style and LED efficiency. Each luminaire and retrofit is engineered for the simplest installation possible to save customers time and money in the field. ■

Kinglumi® Launches Direct/Indirect Suspended LED Linear Lighting System

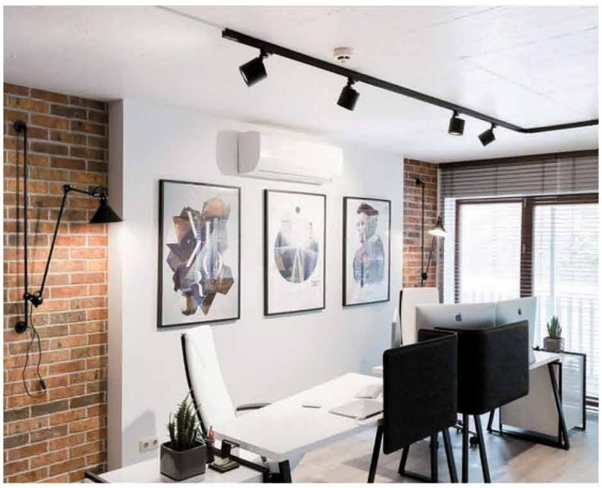
Kinglumi(K&L), one of the global LED lighting manufacturers, introduces its Xline™ Plus linear lighting system, a new category of high-performance portfolio to create a new trend for office and commercial task lighting with its sleek and energy-saving design.

Available in 1167 mm and 2330 mm of length, and includes DALI, 0-10 V or ON/OFF dimming control, various lighting distributions meet the requirement of general lighting for workplace, asymmetric lighting for shelves / wall washer, bi-symmetric distribution for aisle lighting. Energy-efficient LEDs with very good color rendering; binning initial ≤ 3 MacAdam; available in the light colors 3000 K, 4000 K and 5000 K; CRI ≥ 80; min. 70% of the luminous flux after 50,000 hours; degree of protection IP 20.

Xline™ Plus linear lighting system is a new category of high-performance portfolio for office and commercial task lighting

Aesthetic & Minimalistic

Distinctively rectangular aluminum luminaire housing from extruded aluminum profile for improved thermal management; No visible screws, super cleans and very compact design. Surface powder coated in white, or black (others on request, like white oak wood); no visible LEDs from the optics even when it turned off.



Seamless Continuous System
It's flexible and seamless continuous connection to build creative and innovative lighting system. The straight(l), L, T and X connectors perfectly fitted together which allows for a free assembly into light-line systems of different lengths, and different style/patterns seamless. Female and male plug & play connectors are provided.

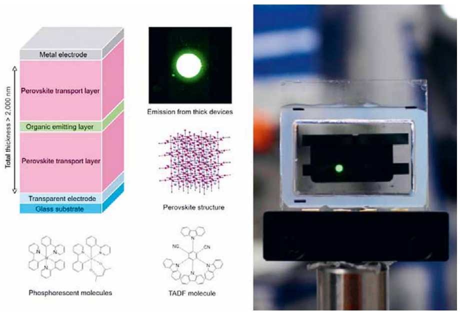
Diversified Light Distribution
The vacuum aluminum plating faceted louver with advanced optical lens design minimized the glare. Suitable for VDUs workplace light according to EN 12464-1 (UGR 19, UGR 22), ensuring high level of visual comfort. With general lighting, wall washer lighting and aisle lighting distributions, it simply configures multiple combinations to satisfy diversified lighting application schemes. Indirect light output reflected from the ceiling provides a softer and ambient illumination.

4 Different Installations
It can be mounted as recessed, surface, track and suspension lighting. The suspended Xline™ plus with 1500mm cable suspension integrated tool-less freely positionable and suspension height adjustable. What's more, all the other different installations are easily assembled by different installation sets, except the recessed mounted.

Application
Ideal for offices, lobbies, conference rooms, libraries, classrooms, shops, and many other applications. ■

High Performance from Extraordinarily Thick OLEDs with Perovskite

By combining thin organic layers with thick layers of hybrid perovskite, researchers at Kyushu University in Japan have developed micrometer-thick organic light-emitting diodes that could improve the affordability and viewing angles of high-performance displays and televisions in the near future.



Schematic depiction of the thick layers, molecules and perovskite structure (left) and the test OLED incorporating these thick layers of hybrid perovskite emitting green light (right)

Organic light-emitting diodes (OLEDs) use layers of organic molecules to efficiently convert electricity into light. The molecules, though great emitters, are generally poor electrical conductors, so the name of the game has been thin - as in 100 nm, or about 1/500 the thickness of a human hair. Only by using such thin layers can electricity easily reach where emission occurs in the middle of devices.

While extremely thin layers benefit from needing only a small amount of material, the use of such thin films complicates the reliable fabrication of millions of pixels since extremely small defects can cause device failure. Furthermore, light reflecting between the front and back of the thin layers often results in interactions - called cavity effects - that slightly distort the emission color at large viewing angles.

Thus, the challenge has been to make the devices thicker while avoiding the drawbacks of organics. To do this, researchers at Kyushu University turned to an alternative class of materials called perovskites, which are defined by their distinct crystal structure.

"Although perovskites have recently attracted a huge amount of attention as light-absorbing layers in solar cells, some perovskites are actually transparent while also being highly conductive," says Toshinori Matsushima, associate professor of the International Institute for Carbon-Neutral Energy Research at Kyushu University and lead researcher on the Nature paper announcing the new results.

"In addition, perovskites based on a blend of organic and inorganic components can be processed from low-cost starting materials using the same fabrication processes as for organics, making perovskites and organics a perfect match."

In their devices, the researchers sandwiched an emitting layer of molecules typically used in OLEDs between perovskite layers with a total thickness of 2,000 nm. The resulting devices have active layers that are 10-times thicker than typical OLEDs - though still a fraction of the width of a human hair.

The thick devices exhibited efficiencies that were similar to those in reference thin OLEDs while also having the same color from every viewing angle. On the other hand, OLEDs based on thick organic layers did not emit any light at similar operating voltages.

"These results overturn 30 years of thinking that OLEDs are limited to thin films and open new paths for low-cost, reliable, and uniform fabrication of OLED-based displays and lighting," says Prof. Chihaya Adachi, director of Kyushu University's Center for Organic Photonics and Electronics Research.

While researchers have also been attempting to use perovskites directly as light emitters, the lifetimes of the devices have been short so far. By keeping the emission process in the organic materials and using perovskites just for transporting electricity, the Kyushu team achieved similar lifetimes for both thick devices and reference OLEDs.

"Based on this work, perovskites will be seen in a new light as versatile, high-performance materials for supporting roles in not only OLEDs but also other organic electronic devices, such as lasers, memory devices, and sensors," predicts Adachi.

The organic emitting layer was composed of molecules that show efficient phosphorescence or thermally activated delayed fluorescence (TADF). Metal halide perovskite layers, which are transparent and easily carry electricity, were placed on both sides of the organic layer. The micrometer-thick OLEDs had very high external quantum efficiencies of up to 40%. Emission spectra were independent of viewing angles for OLEDs with appropriate perovskite thickness, contributing to OLED displays with no distortion of emission color at various viewing angles.

Researcher comments:
Over the 30 years since the first development of basic OLED architectures, researchers have thought that OLEDs are limited to thin organic films. Our idea of using thick perovskite transport layers for OLEDs overturns this traditional thinking. By further developing materials chemistry in parallel with device physics, we will pursue this new platform for fabricating next-generation devices with even higher performance and lower fabrication costs.

References:
High performance from extraordinarily thick organic light-emitting diodes, Toshinori Matsushima, Fatima Bencheikh, Takeshi Komino, Matthew Leyden, Atula S. D. Sandanayaka, Chuanjian Qin, and Chihaya Adachi, Nature (2019), https://doi.org/10.1038/s41586-019-1435-5

ALAN May Be Increasing West Nile Virus Spillover from Wild Birds

We're in the midst of summertime mosquito bite season and cities across the country are reporting a heightened number of West Nile Virus (WNV) cases. The house sparrow is one of the most common carriers of WNV in urban areas. Mosquitos feed off the infected birds and spread the virus to humans.
New research finds house sparrows exposed to artificial light at night, such as what's used in parking lots, maintain higher burdens of WNV for longer than those who spend their nights in the dark.

A new study on passerines suggest that ALAN may also have indirect negative consequences for human health because it can support the spread of zoonotic diseases

The study published in Proceedings of the Royal Society B concludes infected house sparrows living in light polluted conditions remain infectious for two days longer than those who do not, enhancing their host competence, or propensity to generate infection in other hosts or vectors. In turn, mathematical models show this likely increases the potential for a WNV outbreak by about 41 percent.

Original Abstract of the Publication in the Proceedings of the Royal Society B:
Among the many anthropogenic changes that impact humans and wildlife, one of the most pervasive but least understood is light pollution. Although detrimental physiological and behavioral effects resulting from exposure to light at night are widely appreciated, the impacts of light pollution on infectious disease risk have not been studied. Here, we demonstrate that artificial light at night (ALAN) extends the infectious-to-vector period of the house sparrow (Passer domesticus), an urban-dwelling avian reservoir host of West Nile virus (WNV). Sparrows exposed to ALAN maintained transmissible viral titers for 2 days longer than controls but did not experience greater WNV-induced mortality during this window. Transcriptionally, ALAN altered the expression of gene regulatory networks including key hubs (OASL, PLBD1 and TRAP1) and effector genes known to affect WNV dissemination (SOCS). Despite mounting anti-viral immune responses earlier, transcriptomic signatures indicated that ALAN-exposed individuals probably

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experienced pathogen-induced damage and immunopathology, potentially due to evasion of immune effectors. A simple mathematical modelling exercise indicated that ALAN-induced increases of host infectious-to-vector period could increase WNV outbreak potential by approximately 41%. ALAN probably affects other host and vector traits relevant to transmission, and additional research is needed to advise the management of zoonotic diseases in light-polluted areas.

"The findings may be the first indication that light pollution can affect the spread of zoonotic diseases," said lead author Meredith Kernbach, PhD student in the University of South Florida College of Public Health. "Many hosts and vectors use light cues to coordinate daily and seasonal rhythms, which is among the most reliable environmental cues, and disruption of these rhythms by light exposure at night could affect immune responses, generating the effects we see here."

Researchers studied 45 house sparrows, exposing half to artificial light at night. Following 7-25 days in captivity, the team exposed the birds to WNV and took blood samples 2, 4, 6, and 10 days post-exposure. Researchers found all birds were infected within 2-4 days, however after that, birds exposed to light at night maintained transmissible burdens of WNV.

Kernbach says they picked the little brown birds since they live in close proximity to humans in urban areas, play host to a number of parasites and diseases, and are frequent carriers of WNV. While birds exposed to light pollution remain infected for a longer period of time, this did not increase mortality rates.

These results follow a previous study led by the University of South Florida that found zebra finches that have the avian stress hormone corticosterone (CORT) are more susceptible to mosquito bites. Such stress is known to be caused by a number of factors such as road noise, pesticides and light pollution. Researchers suggest new lighting technologies be created that are detectable to humans, but not for wildlife. ■

References:

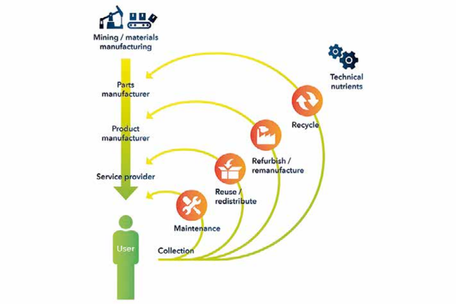
Meredith E. Kernbach et al, Light pollution increases West Nile virus competence of a ubiquitous passerine reservoir species, Proceedings of the Royal Society B: Biological Sciences (2019). Published: 24 July 2019. DOI: 10.1098/rspb.2019.1051

EU Policy Offers the Lighting Industry Risks and Opportunities

The European Union is pushing a number of policy initiatives in the coming months and years that will have a profound impact on the business models of firms competing in the European lighting industry.

LightingEurope (LE) is the industry's eyes and ears in Brussels and its foremost

representative in dialogue with policymakers. Like trade associations from all industry sectors it is monitoring potential policy threats to its members. But it also identifies growth opportunities that should be embraced by the lighting industry.



How circular economy works (Credits: Ellen MacArthur Foundation, drawing from Braungart & McDonough)

In order to minimize the risk and maximize the opportunities the lighting industry, led by LE, engages with policymakers to help them get the policy framework right. Without a clear voice in Brussels the industry risks being on the receiving end of ill-informed regulations. With the range of different policy initiatives currently underway or about to begin, the potential risk now is greater than ever.

As both the lighting industry and the EU agenda evolve there are more and more policy areas to monitor and help steer. Rules related to energy and the environment still are the most relevant and numerous. They include laws governing the use of hazardous substances, durability and reparability, rules designed to minimize waste and reduce the amount of it that ends up in landfill sites, rules on energy efficiency, energy labelling and eco-design.

Add to them internal market rules, and in particular, the complex legislative packages in the area of digitization and the data economy. These policy areas impact a wide range of industries that are all adapting to take advantage of the potential offered by the emergence of Big Data and the Internet of Things (IoT).

In such a complex legislative environment, the lighting industry can learn from other industries such as automotive, consumer electronics and home appliances, how they have been affected by, for example, CE-marking requirements or new data protection rules.

But in the area of environmental protection the lighting industry often leads the way. Hardly any other industry has done more to optimize the ecological footprint of the products it builds: LED technology has enabled further energy savings and coupled with lighting systems offers even more opportunities.

The same is possible with serviceability and the so-called "Circular Economy".

One of the four loops in the circle involves servicing products in use in order to extend their technical and economic lifespan. This isn't only good for the environment and the end user, it is also opening up lighting firms to new business models, and the move is very similar to what has been seen in other industries, such as the computer industry, where manufacturers like IBM and Microsoft are moving towards a business model based around service contracts rather than product supplier contracts.

In the lighting industry this trend is still at an early stage, and it is most evident in business-to-business markets. The Lighting-As-A-Service model has been piloted in airports and warehouses for example and is now also becoming common in some municipal areas such as street lighting.

The benefits to the lighting industry of moving towards serviceable luminaires are numerous. It creates new opportunities for professionals to offer customers added value through monitoring and maintenance services. Also, as service providers, manufacturers get much closer to their customers, allowing them to build stronger relationships with them.

The EU has a dedicated Circular Economy Action Plan and is looking to drive more circular products and business models in Europe. It's not all about serviceability, and it's not all good news. There are elements in the EU Circular Economy Action plan that pose serious challenges to many players in the industry. For example, some policymakers, especially in some EU countries and in the European Parliament, who are pushing for longer-life products that are easy to repair and recycle, are asking for modular products that can be opened up, and the components easily separated and replaced by the customer.

A proposal for mandatory removability of light sources and control gears was introduced into a draft text for the next set of energy efficiency rules for lighting products.

This poses problems for a wide range of manufacturers: from those that build heavy-duty, airtight luminaires designed for extreme conditions; to those that make the popular integrated household LED luminaires sold in retail outlets where the long-life light source inside the luminaire cannot be removed and replaced. The problem extends beyond the lighting industry – think of the manufacturers of furniture or home appliances that integrate light sources and control gears in their products (e.g. kitchen, bathroom cabinets).

It is vital for the lighting industry to explain to policymakers why mandating the removability of all light sources and control gears from all products and irrespective of the application for which they are intended, would be a serious mistake.

While LE members fully subscribe to the objectives of the Circular Economy, individual players must be allowed to choose the technology, design and business model for their products to deliver on the Circular Economy.

LE has been very active on this issue, making it clear that while some mandatory requirements are acceptable, EU policymakers must avoid pursuing a one-size-fits-all approach to removability and circular product design.

LE has had some success explaining why it would be undesirable to force all luminaires to have removable light sources, irrespective of where and how they are used. Some policy makers understand but others are less willing to consider the fact that in some circumstances forced removability would be against the interests of consumers. And in other cases – like an airtight, dust-resistant luminaire in a road tunnel - it could even be dangerous to insist that light sources are made removable.

LE calls for clear guidance from regulators, and it advocates an approach to the removability question that is fully in line with the position developed in the standardization body CEN CENELEC - JTC10 (Energy Related Products – Material Efficiency Aspects for Ecodesign) which requires removability only for the purposes of verification by market surveillance authorities and for recycling of light sources and the luminaire, all its containing components included, at the end of life.

LE has been talking regularly with the decision-makers in Brussels and, thanks to the support of the LE member national associations, to ministries in the EU countries. In addition to the removability question, it also urged policymakers to avoid setting rigid timeframes for the removal from the market of non-LED lighting technologies, such as some small halogen light sources or very common fluorescents lamps (e.g. T8, CFL, T5, HID), as well as lamps used in specific applications (a.k.a. special purpose lamps).

The phase out of conventional products and technologies is another aspect of the EU Circular Economy, looking to move away from the use of hazardous substances that risk harming people and the environment. Currently conventional lamps are being addressed by two separate EU processes.

Mercury containing lamps such as T8, CFL, T5, HID and Special Purpose lamps, already regulated by EU energy rules, are under threat in a parallel legislative initiative on the restriction of hazardous substances. The European Commission's Environment directorate is currently evaluating whether to renew RoHS exemptions for most conventional lamps on the market and may decide to ban many of these products from the market inconsistently and quicker that in the energy proposal (which foresee a phase out in September 2021), i.e. removing more products and even by 2020.

LE is asking policymakers to carry out a detailed impact assessment on removal of products and in particular on circular economy in time for the next review of eco-design rules expected to start around 2024. And it has urged the Commission not to introduce any other Circular Economy measures before the 2024 review.

There are two other potential regulatory challenges in the pipeline in Europe: the development of a scoring system to rate the ability to repair and – where relevant – to upgrade products. For the time being, this initiative excludes luminaires but there is every possibility that the reparability scoring system may become mandatory and may be extended to cover lighting.

The other potential challenge on the horizon is the EU Product Policy Framework. This broad initiative will examine options and potential action to adopt a more coherent policy from the different strands of work of EU product policy in their contribution to the circular economy. It will include among other things an analysis of the use of chemicals at all stages of manufacture and their impact on the recycling and reuse of materials. It will consider whether to use Green Public Procurement and Extended Producer Responsibility fees to boost circular products and incentivize consumers to choose them.

Both upcoming initiatives fall under the Circular Economy plan. The current Commission is unlikely to pursue any concrete steps in either case, beyond the consultations it has launched, leaving it for the next Commission to pick it up in the following year as of 2020.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These policy initiatives are not going away. The lighting industry must engage with policymakers to transform current policy initiatives into business opportunities and to avoid the risk of serious mistakes that could undermine firms competing in Europe's lighting market. LE is doing just that. It has established a good working relationship with a wide range of policymakers in all the Commission departments involved in these initiatives, in the European Parliament and in the EU countries.

The lighting industry has its work cut out for it in the months and years ahead. LE is the voice of over 1,000 lighting companies competing in Europe. It is a strong voice in Brussels, and it always welcomes others to help it shape the debate and the future.

Some first examples of DALI-2 certified input devices and sensors

DALI-2 Certification of Sensors and Input Devices Is Now Underway

The Digital Illumination Interface Alliance (DiiA), the global industry organization for DALI lighting control, has introduced DALI-2 certification for a range of products including light sensors, occupancy sensors, push-buttons, switches and sliders. These products, known as DALI-2 input devices, provide user-derived and environmental information to the lighting-control system.

"This is a significant milestone for DALI-2," said Paul Drosihn, DiiA General Manager. "Now, all the main components of a lighting-control system can be DALI-2 certified."

In addition to input devices, DALI-2 already includes application controllers (devices that make decisions and send commands); bus power supplies; and control gear such as LED drivers.

The DALI-2 test specifications for input devices were written by DiiA, based on Parts 301, 302, 303 and 304 of IEC 62386, the global DALI standard. Part 301 covers push-button devices, Part 302 specifies absolute input devices e.g. switches, sliders, Part 303 covers occupancy sensors, including presence and movement sensors, and Part 304 defines light sensors. A DALI-2 input device will implement Parts 101 and 103, as well as one or more of the new Parts (301-304).

The first input device to achieve DALI-2 certification was the zc-switch, a push-button device from DiiA member zencontrol, which implements Part 301 of the DALI-2 specification. The first certified input device to implement more than one of the new DALI-2 Parts was the LDALI-BM2 from LOYTEC electronics, which implements both Parts 301 and 302.

Also, the first DALI-2 sensor has achieved DALI-2 certification. The zc-pir from zencontrol is a combined occupancy (PIR) and light (lux) sensor, which implements Parts 303 and 304 of DALI-2.

"Our member companies have worked together to create robust DALI-2 test specifications that will further build market confidence in product interoperability," said Paul Drosihn. "We expect to see many more certified DALI-2 products in the near future, supporting the acceleration in market demand."

For all product types, DALI-2 certification is granted only after DiiA verifies that testing is complete and successful. Certified DALI-2 products can be identified by the DALI-2 logo, and are all listed in the Product Database on the DiiA website.

LpR 75 Jubilee

Patrick Durand

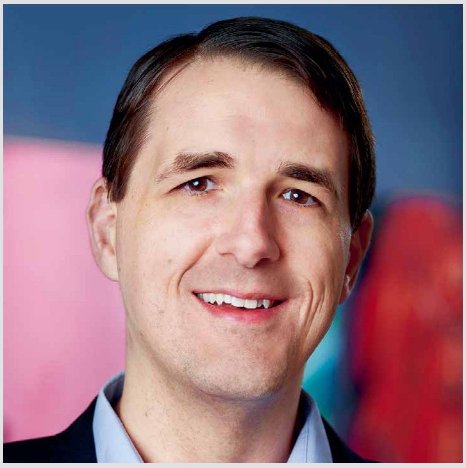
Worldwide Technical Director,
Future Lighting Solution

"LpR has been for 75 issues, and continues to be, a leading trusted source for the latest advancements in the LED industry. It's an essential resource to obtain fact-based assessments of potential technology trends for making strategic decisions."

What has changed most in the lighting business?
The commoditization of the LED lighting industry, which was enabled by standard packages (i.e. 3535, 3030, 2835), standard board-level form factors (i.e. Zhaga), and industry standards (i.e. LM-80, TM-21). As a result, the competitive landscape became much fiercer for LED vendors and lighting manufacturers.

What's coming next in lighting?
In the short-term (2020), the emergence of Bluetooth mesh as a dominant interoperable lighting control protocol where it will be adopted by several leading lighting OEMs. In the medium-term (2021), the technology and cost of UV LEDs will reach a turning point that will enable wide market adoption.

What are you still missing or what still needs to be improved/researched in lighting?
A technical definition of human-centric lighting with clear parameters and industry-recognized quantifiable thresholds that determine whether a light source is human-centric vs. one that is not. Without this, human-centric lighting will not be able to play a significant role in the lighting industry.



Paul Scheidt

Leader of Product Marketing, LEDs,
Cree Inc.

"LpR's focus on core technology makes it a unique and valuable resource to the LED industry. Congratulations on 75!"

What has, in general, changed most in lighting application or technology since 2007?
Many people doubted that LED could replace the many different lighting technologies still in use back in 2007 – the warmth of incandescent, the punch of halogen, the efficacy of fluorescent. The fact that LED is now the default technology in most cases just 12 years later is astounding.

What do you like most about LED/OLED lighting?
I love how LEDs have so much more design flexibility than previous light sources. This flexibility opens new areas of creativity and has enabled new forms of luminaires. Options abound with LEDs in terms of CCT, color rendering, size and lumen density.

What are you still missing or what still needs to be improved/researched in lighting?
At Cree, we've always envisioned that LEDs would close the gap between efficient lighting and good lighting, so that they weren't at odds with each other. The right LED technology can help designers achieve high quality lighting that is also exceptionally efficient. Some applications are improving (e.g., street lights) but there's still room for improvement in others.

Anna Liza Bernaldez Müller

Business Development Manager,
Nichia Chemical Europe GmbH

"Congratulations to LpR 75. This is my go-to magazine for lighting technologies, applications and industry news. Through their valuable contributions LpR has gained the respect of the lighting community. I wish you all the best and many more issues to come!"

What has, in general, changed most in lighting application/technology since 2007?
In the last 10 years, LED in lighting showed rapid technology shifts. The focus of LED changed from lm/W, CCTs and CRIs towards visual and non-visual effects of light. Today LED is no longer just a light source but an experience that affects us emotionally and biologically. It has become human centric as it offers suitable solutions that promote human wellbeing.

What has changed most in the lighting business?
The evolution in lighting business encompasses a broader range. It includes developments in products, technologies, market trends and solutions. The industry's value chain, although not easily seen in the big picture, also went through a significant change. Several industry players moved up or went down the value chain, some totally left the industry and changed their business direction (strategy).

What's coming next in lighting?
It will be exciting. More customers will be interested in buying quality solutions rather than just buying a product. The shift from products to human centric solutions will be more obvious. Tunable, personalized, human centric and smart lighting will become prevalent. LED manufacturers will continue to explore and innovate to answer the demands for lighting solutions in diverse application.

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Energy Efficiency	Streetlighting Products	SASO 2927:2019	KSA	In its meeting No. 170 Saudi Arabian Standards, Metrology and Quality Organization adopted Standard 2927:2019 on 28 March 2019 regarding lighting products within the part 3 for street lighting products. The standards covers energy efficiency functionality and labeling requirements for several street and road lighting applications. It will come into force mandatorily from 19 January 2020 onwards.
Energy Efficiency	LED Products for Indoor Lighting	GB 30255-2019	China	On 4 April 2019 China published standard GB 30255-2019 which applies to indoor LED-lighting products. In this standard calculation methods as well as testing methods for non-directional self-ballasted LED lamps are defined. Also technical requirements and minimum allowable values regarding energy efficiency are fixed. The standard will enter into force on 1 May 2020.
Technical Standards in General	LED Lamps	Resolution No. 008-2019-INACAL/DN	Peru	In Peru INCAL published a list of technical standards regarding conductors, LED lamps, water heaters, air conditioners, washing machines and other electrical products. This list of standards was approved through resolution number 008-2019-INCAL/DN in force since 10 July 2019.
Performance Standards	Analogue Dimming Interface	EN IEC 63128:2019	Europe	Lighting control interface for dimming - Analogue voltage dimming interface for electronic current sourcing controlgear. This standard specifies the analogue control interface of controlgear which has the function of controlling the output of the controlgear by use of a resistor.
Performance Standards	LED Packages	EN IEC 63146:2019	Europe	LED packages for general lighting - Specification sheet This standard establishes requirements for specification sheets relating to light emitting diode (LED) packages designed for the emission of white light for general lighting applications. This document does not contain compliance criteria.
Safety Standards	Self Ballasted Lamps and Control Gears	IEC TR 63037:2019	World	Edition 2.0 (2019-07-10): Electrical interface specifications for self ballasted lamps and controlgear in phase-cut dimmed lighting systems This technical report specifies the electrical interface between phase-cut dimming equipment and lighting equipment, such as LED integrated lamps and light sources with external controlgear, with the intention of helping designers of both types of equipment to develop products that will work together properly. This document describes both the dimming phase and the off phase. In addition to the specification of the interface, test procedures are given for testing the proper operation. It may be expected that controlgear fulfilling the requirements of this document are also suited to be used with electronic switches that use a circuitry comparable with that of a phase-cut dimmer, but do not contain means for the adjustability of the phase-cut angle. Safety requirements are not covered by this document, but by respective product standards.
Safety Standards	Lighting Products - Explanation	IEC TR 63139:2018	World	Edition 1.0 (2018-10-19): Explanation of the mathematical addition of working voltages, insulation between circuits and use of PELV in TC 34 standards This report is related to the insulation coordination in TC 34 standards and provides explanations on mathematical addition of working voltages, insulation between circuits, use of protective extra low voltage (PELV) and insulation between LV supply and control line conductors in order to cover new technologies associated with the use of LED light sources and controllable products.

A free training can be arranged for a clear understanding of the upper stated standards.

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Environmental Aspects of Obtrusive Light from Outdoor Lighting Installations

One of the trending topics in lighting technology is research into the effects of exterior lighting at night, known in some circles as Artificial Light At Night (ALAN), colloquially referred to as "light pollution" and more accurately known as "obtrusive light". – CIE and its workgroup members take this issue very serious, provide already several reports on that topic, and installed several new work groups to work on it.

Obtrusive light is spill light produced mainly from outdoor lighting installations such as road lighting, flood lighting and landscape functional lighting which falls outside the boundaries of the intended design area, giving rise to annoyance, discomfort, distraction, or a reduction in ability to see essential information. These are not new uses, and problems related to obtrusive light did not start with the introduction of LED technology, as many people think. Increased urbanization has placed more obtrusive light into formerly undeveloped areas, and the introduction of energy-efficient, long-life LED luminaires has introduced new spectra, often with more lighting points and at higher average illuminances than formerly.

Obtrusive light, due to its complexity and novelty, is still separately addressed within different disciplines, e.g. ecology, astronomy, and illuminating engineering. Furthermore, the lighting research community and industry use different methods for the assessment of lighting installations. Therefore, knowledge is highly fragmented, and it is difficult to compare and translate outcomes from and between different fields.

Obtrusive Light Interferes with Astronomers, Fauna and Flora

Obtrusive light can cause significant interference with professional and amateur astronomic observations and the loss of the night sky in cities.

The International Astronomical Union (IAU) and International Dark Sky Association (IDA) work to protect observatory sites from light pollution. In some places, legislation limits obtrusive light in defined areas to create "dark-sky reserves", often around observatories or in areas where there is a strong desire to preserve biodiversity, such as the Natura 2000 network in Europe.

Starry sky above Zselic Park along with the obtrusive artificial nightlight of the city of Kaposvar (Credits: Dr. Constantinos Bourissis - Commons Attribution 4.0 International: https://creativecommons.org/licenses/by/4.0/)

Life on Earth has evolved around cycles of light and dark, so the fundamental biological problem of ALAN is that there is light in locations where and in times when there ought not to be. Researchers focus on the effects of light at night on humans, organisms from microbes to mammals and entire ecosystems covering terrestrial, freshwater and marine environments. Nocturnal organisms, both vertebrates and invertebrates, developed their senses in order to be active during low-light conditions. Signalling thresholds in flora and fauna at night are close to moonlight intensity, far below outdoor lighting levels; furthermore the light distribution is not consistent with nature. Animals including insects, as well as birds and mammals, experience disrupted orientation from this additional illumination; they can be either attracted to or repulsed by high luminance, which affects foraging, reproduction, communication, and other critical behaviours. Sky glow produced by cities can also disrupt distant ecosystems.

Although one often reads about the hazards of "blue light", there is no strict rule on which light spectrum, intensity, distribution, or timing of light at night has a greater effect on the environment. Each species reacts differently to various light sources, and to patterns of light that are not consistent with their evolutionary niche.

For example, the photoperiod affects reproduction in fish, whose physiology depends on there being a pattern of light and dark each day; without a dark night, the normal rhythms are disrupted and spawning might not occur. Animals that live at different water depths may detect light throughout almost the entire spectral range of available light. The degree to which there is disruption will depend on the interplay of the spectrum and intensity of the light and the depth at which the species lives, as well as the timing and distribution of the obtrusive light.

Lunar light polarization is a signal to some nocturnal animals' navigation systems. Thus, migrating birds and fish can be disturbed by unnaturally unpolarised light, which is typical of electric lighting systems.

Urgent Research Questions and Problems

There is still limited knowledge on how electric light is detected by various species and what biological and behavioural effects result. It will be valuable to understand both the natural and electric components of light at night in atmosphere, land, and water in a broad range of species and ecosystems, under various weather conditions, using common methods and research approaches. Work in this field demands the co-operation between scientists from many disciplines including ecologists, astronomers, physiologists, horticulturalists, engineers and lighting designers.

The CIE knows of several urgent research and application needs concerning obtrusive light:

- A cross-disciplinary investigation of the effects of obtrusive light on humans, fauna and flora based on spectrum, intensity, directionality, proximity, and timing and taking an ecological systems approach.
- A unified metrology system for the measurement and monitoring of obtrusive light is missing. Quantities that are appropriate for human visual performance are not correct for predicting effects on other species. Consensus on what to measure is critical to collecting long-term monitoring data.
- Holistic approaches to lighting design guidelines and legislation would address many goals at once. As obtrusive light has different effects to different species, there is no magic recipe for lighting levels or spectrum or directionality of the light sources. Optimized lighting design and lighting control techniques should be developed in conjunction with the appropriate light sources and illumination levels in respect of each area under illumination. Contemporary living patterns mean that it is unlikely that light at night can be totally extinguished, but a better balance between environment and humans should be achieved.
- Manufacturers of lighting equipment are recommended to work with environmentalists in order to produce optimized products for each application. Intelligent lighting control systems will also play a significant role on the mitigation of obtrusive light and its effects on the environment.

Current CIE Activities in the Field

The CIE has considered obtrusive light for over 30 years.

Currently available Technical Reports are as follows:

- CIE 150:2017 Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations, 2nd Edition
- CIE 206:2014 The Effect of Spectral Power Distribution on Lighting for Urban and Pedestrian Areas
- CIE 126-1997 Guidelines for minimizing sky glow
- CIE 001-1980 Guidelines for minimizing urban sky glow near astronomical observatories (Joint publication IAU/CIE)

Three Technical Committees listed below are currently active, and others are under consideration:

- TC 4-58 Obtrusive Light from Colourful and Dynamic Lighting and its Limitation
- TC 4-51 Optimization of Road Lighting
- TC 4-56 Masterplanning Urban Lighting

A new reportership was established in 2019 to begin the work of integrating perspectives and to gather best practices:

- DR 4-53: Environmental Aspects of Obtrusive Light from Outdoor Lighting Installations

The aim of this reportership, is to investigate the status of current CIE publications, and other relevant publications, regulations in different countries, practical experience and all other available knowledge. The outcome of this reportership will be to recommend revisions of currently published CIE Technical Reports, along with recommendations for the new work items in CIE, both guidelines and International standards. ■

Remark:
To contribute to any CIE technical work, please contact the CIE at ciecb@cie.co.at

Tech-Talks BREGENZ - Wilfried Kramb, Interior & Lighting Designer, a·g Licht

Wilfried Kramb

Wilfried Kramb founded the ag Licht office in Cologne in 1996 together with his partner, Klaus Adolph. Today it is run together with Daniel Walden. Prior to this, he studied interior architecture at the University of Applied Sciences in Wiesbaden, Germany after which he worked at the Electric and Lighting Design Office, SIWO in Taunusstein. The next four years were spent working in Sydney Australia for the interior architecture office, Frank Grill & Associates, where he stayed until 1991. In 1992 he managed and helped to establish the department of Light Application for the German Institute of Applied Lighting Technology (DIAL) in Luedenscheid, Germany. While working as an independent Interior Architect he also took advantage of an apprenticeship offered by the University of Applied Sciences in Wiesbaden on the subject of Light Planning. From 1994 to 1996 he was the project manager for the Light Planning Office "Lichtdesign" in Cologne. Wilfried Kramb is the recipient of a number of national and international awards for projects and products that he managed and gives lectures for the master study program of architecture at the msa Muenster.

The value of lighting design and light planning has always been underestimated, despite it becoming more important with the rise of Solid-State-Lighting. This is a fact that the public doesn't realize, even though the industry does. Digitalization, compared with the special properties of LED lighting and the aim of the lighting industry to establish their IoT hubs, is a new challenge. This is even more apparent when trying to integrate light sources directly in building structures. Responsibilities and tasks are no longer clearly separated between the different disciplines of architect, lighting designer, IT planner and electro planner. Guenther Sejkora and Arno Grabher-Meyer talked with Wilfried Kramb, owner and CEO of a·g Licht, about these tendencies and topic.

LED professional: Thank you, Mr. Kramb for coming to this interview! To start us off, would you tell us a little about your company?

Wilfried Kramb: Thank you very much for inviting me. I'd be quite happy to give you some background information on the company! First of all, a·g Licht was founded in 1996 and is a lighting designer company with about 8 employees that is specialized in architectural lighting. In the beginning, my founding partner, Klaus Adolph, and I worked in a large office and we decided that we wanted to have something smaller so that we could do the work we love - designing - and not managing a company. He was an architect and I am an interior designer and all of our people have backgrounds in design, product design, architecture or interior design. That's why we see ourselves as a mediator between architects and technology people, engineers and the builders. Basically, we have the architectural design language as common ground to start creating the projects.

LED professional: You said that you work in the field of architectural lighting design - Most architectural lighting designers have a special idea about light that they want to bring into the building. There are thoughts, or a philosophy behind the idea. Can you tell us about a·g Licht's philosophy and maybe give us some examples of projects?

Wilfried Kramb: I don't know if I'd call it a philosophy. Me and myMy current partner, Daniel Walden, and I are always trying to find the best solution for the building itself, as well as for the people that work in the building, by looking at each project individually. That means that we always try to understand the architecture first. That is one of the bigger tasks that we have because we work with so many different architects on projects. The idea is to create a solution that works for the architecture - because that's our language. In addition, we have to find solutions for the task that the building has to perform, light-wise. It can be atmospheric or there may be a certain function that it has to perform. So I guess if I were to boil all that down into a philosophy, I would say it's to work architecturally integrated and to try to find a specific lighting solution for each particular building.

LED professional: You don't only work on lighting installations in buildings; you have done some special designs for luminaire manufacturers, as well. You have also won several design awards. What is the idea behind that? Do you want to utilize a design that you made or is it that you want to share your experience with the industry?

Wilfried Kramb: I think it's both. In the beginning we couldn't find solutions for projects that we liked. Sometimes we thought they weren't adequate or that they didn't work with the architecture. Therefore we started to design fixtures that we thought were better for the environment and much better for the task they had to perform. Thinking about our own designs for certain buildings we found manufacturers that wanted to go into a product design process with us. These manufacturers invested in the creation of fixtures and then went on to standardize them. So in the end, we had a standard product. Nowadays there are two additional ways: Manufacturers might approach us because they possibly like the design language we use or they see other designs that we made are successful and fit into the market. The second way is when we come up with an idea about how to work with a new technology. We see that it's not available on the market yet and we think it would be

The "BMW-Welt" is just one of many prestigious projects that Mr. Kramb was an integral part of something interesting. We would then approach a manufacturing company that might be interested.

LED professional: I worked together with your office around twenty years ago and at that time designs were very clean and very pure. With the arrival of LED lighting, have these types of designs changed?

Wilfried Kramb: At the time we were very surprised to find that there was only one design language. We felt that it didn't fit the architecture any more, and so the working title of our first fixture was "Non-Design" because we wanted to minimize it as much as possible and reduce it to the technology. This is still what we think when we start designing fixtures; we try to wrap the current technology in a most minimal way. LED helps to minimize the size of fixtures. On the other hand, I think that in the design field the wish for a bit more decoration in certain areas, certain spaces, has become bigger compared to 15 years ago. I'm not sure if that is driven by manufacturers that actually offer good decorative design or if the designers and planners themselves want more decoration and try to find highlights in the building.

For example, in Siemens headquarters in Munich, it was quite important to us that the main entrance hall should have a big focus. So we designed a very decorative installation. In the building itself, we stayed reduced, and tried to work into the architecture but compared to 15 years ago that has also changed. There is a little more desire for decoration, but mainly in a low-key way, so that it has an importance as well as a creative focus for people.

LED professional: You said that you like to focus on minimizing the luminaire. During the past few years we have seen trends come up that ask for the LED to be completely integrated in the structure - for example, in the tiles, or the wall or directly in the ceiling. What are your thoughts on this approach?

Wilfried Kramb: We talked about philosophy a bit and I mentioned architecture integrated - those trends fit quite well into that philosophy. We often think that the light itself is more important than the fixture that produces the light. We're working on a project at the moment where, for office use we more or less have no visible fixture. We hide it. So there is a trend with LED as a technology that is very minimal. We can do that - we have enough optical tools to get the properties the light should have into small spaces. So I think it fits quite well into our philosophy of trying not to put too much emphasis on the fixture itself, but rather the light it produces in the space.

LED professional: Besides the design and optical aspects, there are also technical aspects of completely integrating a building. Do we have the technology to do it without having problems?

Wilfried Kramb: I would say that we aren't in that position yet. One could think of other visions. For example, if you take an OLED - you could have the vision of having wallpaper that glows at night. That would be full integration but you still have the problem of size for the OLEDs. You always have to find space for a transformer; you need something to reduce the voltage. It's still a special effort to integrate it in that way. So you have to find new solutions for each particular project. We have a lot of tools, but we're not quite at the end, yet.

LED professional: You just said that light is more important than the shape of the luminaire. I think LED lighting opened up quite a number of new opportunities. Colored light, for example, or dynamic light. Rapidly changing light situations that weren't possible with fluorescent or high-pressure lamps. What kind of new opportunities have opened up by using LED and how has LED lighting influenced lighting design?

Wilfried Kramb: I wouldn't say that it wasn't possible before - it just took a little more effort. So when we talk about fluorescents - they were dimmable and controllable. In those days you even had tunable white situations with fluorescents. You had two or three colors. So it was possible, but it wasn't really accepted. Nowadays, people expect it to be possible.

I think there are two big changes. LED as a point light source gives us the opportunity to work smaller. We have to find a space for the transformers, but there might be other ways in the future. So that is one of the major things: you can go flat and you can go very small.

The second thing is that control is a lot easier than they used to be. Now that we have ready-made modules with tunable white or

Mr. Kramb gave thoughtful and detailed answers to all of the questions demonstrating his sound knowledge of the subjects

RGB, we do have a lot of opportunities. I think that was a dramatic change for us in the office. We think much more about controls and dynamics now and we think about smaller, integrated ways. So in the end, that certainly changed the approach to lighting design as well.

LED professional: A few years ago you gave an interview and at that time you said, "LEDs are mainly used as a new light source in old bodies." And in regards to controls you said that when you are using different scenes, your company prefers it to be subtle - not bold. Is that still valid?

Wilfried Kramb: The first quote was a reaction to the lack of understanding in the industry. When LEDs started to enter the market, I always had the feeling that the industry was delaying even thinking about that particular light source. What most of them did for the first two to five years was say, "Oh, we have LEDs, so we'll put them in the old body," without even thinking about the possibilities that LEDs had. That, of course, has changed: We saw at fairs like Light & Building that after two or three fairs, suddenly everyone understood that LED was a different light source and needed to be treated differently. We suddenly had optical entities, filtering possibilities, small volumes, and you had cooling systems. Particular fixtures were starting to be designed for LEDs. So fortunately, that has changed. And of course it is market driven.

Regarding controls, experience shows that either it is automatic and not influenced very much by people - or if people can influence it, it has to be as simple as possible because people are overwhelmed by technical situations. Everyone knows that when you start your new smart phone, a camera or your laptop, people only use a small capacity of their device. We now have many more projects where control is the subject.
I believe that this is a field that people should be thinking about more. And the industry should be supplying panels and surfaces that are easier to handle and, like a smart phone, easy to use.

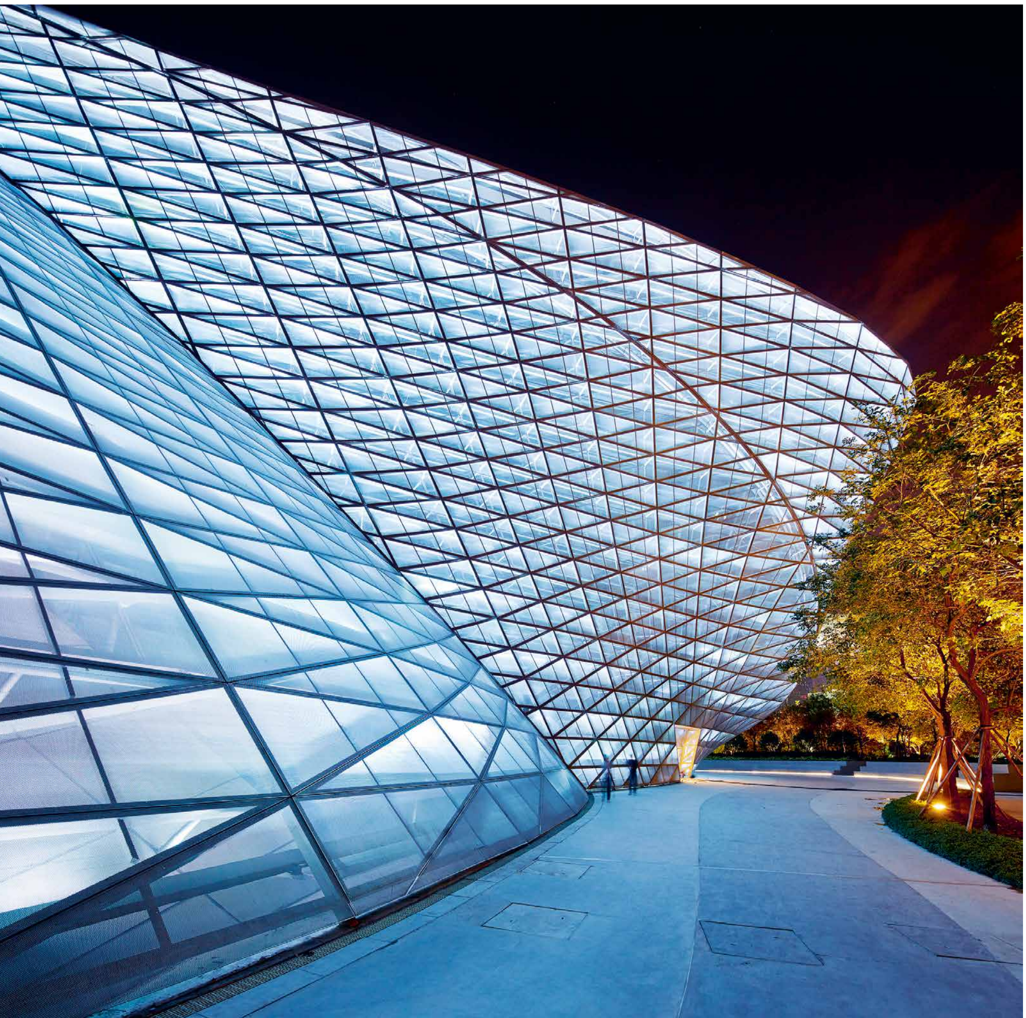
LED professional: Another topic that came up around the same time as the LED is Human Centric Lighting. In the early 2000's we became aware of the fact that light doesn't only influence our visual system, but that it also has a direct biological influence. In the early years of the new millennium we had already installed the first Human Centric Lighting systems, but it took a tremendous amount of effort to do it with fluorescent lamps. And now, together with LEDs and the possibilities brought about by color change, and the easier controllability of the LED, things should have gotten a lot easier, but in fact, not much has happened. What do you think about Human Centric Lighting? Is it just a story that people tell?

Wilfried Kramb: The short answer is - Yes. It's a story. I believe that there is a lot of information on the market that is wrong. Let's put it this way: The knowledge that we have about light being received in our bodies by light sensors in our eyes was only discovered at the beginning of the millennium, when they found the first cells. Some studies have been made during that time and what I see now is that the amount of light that we use in certain spaces does not trigger any biological processes.
We need much higher lux levels and much different lighting than what we are thinking of now. To trigger it, you need a bigger surface, like a blue sky, you need colder colors for the eyes and you need a high lux level.

There are a lot of stories being told about it, but there are also a lot of studies and investigations that show a physiological benefit when people are sitting in a room where there is dynamic lighting and they can feel the dynamics in color changing - meaning maybe tunable white - or in the dynamics themselves, in changing light scenes. So, of course this has a positive effect on people sitting in a conference room for three hours. They concentrate better when they are working in a room with dynamic light rather than static light. This is something that is very important and something that we would propose to clients in a sense of well-being. It's actually good economically because people are more concentrated and much more motivated.

So it's something that we would always try to suggest in our designs. A lot of times you see that the client has an open ear for that, up to a point when you talk about money, which is still a topic. And then, a lot of ideas, a lot of concepts are not realized because of the money.

I believe that with the further development within the industry with tunable white options



Today, many big projects are located in soaring Chinese cities, like the Museum of Contemporary Art & Planning Exhibition in the city of Shenzhen

and dimming, it becomes more affordable and people might be inspired to lay a little more money down. And it will, in the end, spread further, even in normal office lighting, than it has before.

But people don't only have to rely on LED technology. People have to think about their space concept, in general. Daylight harvesting is still the best lighting source for me. This provides people with a good space, and interesting working environments will have the same effect on people. So we shouldn't always rely and put the pressure on LED development. It helps, and it will definitely be used, but there are a lot of other components and aspects that make a person feel comfortable in a space.

LED professional: Daylight usage has a lot to do with the architecture of the building itself. How can you, as a lighting designer, influence that?

Wilfried Kramb: We often work on daylight concepts as well. If we are early enough we can influence the situation - with skylights, for example, and often protection against glare. But glare control doesn't mean that in the summertime you have the blinds drawn and artificial light on in that space. We talk a lot about the transmission of glass, the quality of glass, the color rendition of glass. We always have to fight the technical engineers because they don't want any heat transfer from the inside out and vice versa. But that is usually related to the lack of transmission of light. So we can influence architecture and for us it's always interesting when we have a project with both disciplines.

So here we come back to controls: How do we use daylight in a sensible way, and if we think about the future in prestigious projects, how can we change the color inside - how can we adapt it to the color outside? That situation is the most fruitful combination a lighting designer can have, it doesn't matter if you see light as daylight or artificial light.

LED professional: On the topic of connected lighting: As you just told us, it's not enough to connect light - you have to connect other things, too, like the blinds or heating or air conditioning. A couple of years ago, what is now called connected lighting was called light control. Is there a qualitative difference between the two?

Wilfried Kramb: As I understand it, there is no difference. As other people understand it, there is a difference. For me, lighting control means that I control the lighting. So if it's a daylight situation, I would like to control it so it's most useful and beneficial in the space. And the same goes for artificial lighting. A combination of both is, of course, the optimal. I mentioned before that sometimes controls should be automatic, which could be connected light or lighting control with parameters in the lighting control that give you an optimal situation.

I think that the term "connected light" - is more about future possibilities of not only connected light, but a lot of different things connected to light and vice versa up to a point where you might have total control of things without a person being a part of it. Maybe it's because of my age, but I don't think that it's always a good thing - it can just as easily be the opposite. If you suddenly start doing things only because it's possible to do them - without thinking about whether or not you need or want it - the responsibility is taken away from me and the question is whether I'm a victim of my own parameters. In my opinion, that would be bad quality and bad development. So, in the future, people should give a lot of thought to what they need and what they want and then work on connectivity in the sense of an optimal

The Raffles City, Hangzhou, is a typical example of China's prospering cities that require thorough lighting design support for the futuristic architecture

situation and not just doing things because it's possible.

LED professional: I think that connected lighting opens up a couple of new opportunities for lighting design because we can think about, not only static or dimmable situations but also something like "network solutions" where everything influences everything. This would be a new chance as well as a new challenge for lighting design. How do you approach the topic of - let's say - more degrees of freedom in lighting?

Wilfried Kramb: It's more or less what I said before: One has opportunities, but one needs to guide the client and make suggestions about what parts of those opportunities are good for or beneficial to him or her.

LED professional: Does that mean that you don't just design one light situation?

Wilfried Kramb: Yes, as a lighting designer, before we start our work we have a briefing. We figure out what exactly our task is that has to be performed in that particular building. And that is something that we always talk to the client about, as well. We find out what the client's needs are for the building and for the people that work in it. And then we try to solve that problem. So not everything is beneficial for every project and nowadays you have to be even more careful about what you suggest. You have to ask yourself if it's too complicated, if it's necessary or if it's possible. And as I mentioned earlier, we think a lot more about controls now and we have more opportunity to think about the atmosphere and the light situation than we did before. So this is very beneficial to us, in a sense.

LED professional: Another term that is similar to connected lighting is smart lighting. What do you understand by "smart"?

Wilfried Kramb: I don't think lighting itself is smart - but I believe it can be used in a smart way. Smart is a term that is strongly connected to human beings, so you have to have smart planners to have smart lighting. It's another term that I think we have to be very careful with.

LED professional: Another thing we wanted to ask you about is the future of lighting. Today, a very important topic is energy usage. We have improved the use of energy just by changing from conventional lamps to LED. As we mentioned before, though, some of the savings may get lost because the installations get brighter and brighter. In lighting design, I assume that you also have to think about how much energy will be used for a given installation. How do you approach this topic?

Wilfried Kramb: We don't do it any differently than we did twenty years ago. We have always thought of projects in an economical and ecological way. The only advantage we have nowadays is, what we mentioned before, the controls are better and easier to handle. And I think this is the best way to control energy consumption. Even today we see a lot of spaces being lit to full capacity at times when nobody is interested. Fabrication halls or public spaces are two examples. If you have a control system that is used smartly, the energy consumption can be reduced even with current installations. For us, nothing has changed in our thinking about economical and ecological topics when creating our designs. But now I think we have more possibilities by changing the controls - not the design.

LED professional: Around fifteen years ago, because of the use of LEDs, lighting became very colorful. Most of the installations used color effects in each corner with dynamically changing light. The truth is, it was annoying. But maybe technologies, or connected lighting, or LED technologies will change lighting again in the near future. Do you see a trend coming?

Wilfried Kramb: I think the discussion about Human Centric Lighting has gotten people thinking that light might be beneficial for mankind and that might be something to talk about. So I think you'll hear a lot about that in the future. In addition to that I think that in the future you'll hear about more tunable white solutions - even as a standard in our future offices. We have already talked to manufacturers that are at least thinking about providing standard fixtures automatically with tunable white capabilities. I would be very happy if I really knew what the future of lighting held, but I don't think there will be a big dramatic change like the one we saw when LED first appeared on the market.

LED professional: With all the discussions going on, new sciences and fields came on the scene and this influenced the situation on the market - like who will do what and who will provide this service or task, and so on. Do you think your profession will have to change and/or adapt? Or do you think there will be cooperations between other players like network technicians or medical practitioners?

Wilfried Kramb: I think as a lighting designer we have to combine more disciplines and to be the mediator, not only between design and technology but also for installers or work biologists or to medical people. We also will need to do more consulting than we have been doing up until now. I think we're prepared for that - we are growing into that market with all the research that is on hand and we can provide good advice to our clients who are now forced to think more about their employees than they were ten or fifteen years ago. For example, we have found, while working on the central headquarters for Bookings that everything is focused on making that young person that works for them, happy and feeling as comfortable as possible, in order to keep them. The workforce is suddenly a valid issue now and providing a happy, comfortable workplace for employees means that the designers have to consider a wider range than we have been used to.

LED professional: I think that is a good thought to finish on! Thank you very much for your time.

Wilfried Kramb: My pleasure. ■

Temperature Profiling of Secondary LED Optics by Infrared Thermography

Over the last few years, the power density of white LEDs has increased dramatically. Whilst there are large efforts to optimize the thermal management and thus the temperature stability of the LEDs, less attention is paid to the temperature of the secondary optic. Peter W. Nolte, Franziska Steudel, Bernd Ahrens, Nils J. Ziegeler, Frank Drees, Horst Rudolph, and Stefan Schweizer from the Fraunhofer Application Center for Inorganic Phosphors, the South Westphalia University of Applied Sciences, and the Innovations- and Technologycenter GmbH, TRILUX Group respectively, have approached this issue. They investigated the temperature profiles of polymethyl methacrylate (PMMA) and polycarbonate (PC) secondary optics and they discuss the results.

If the secondary (polymer-) optic is permanently operated at high temperatures, its optical properties or even its geometry might change. Therefore, it is important to have an exact knowledge on the temperature profile within the secondary optic. Here, the temperature profile of a secondary polymer optic is analyzed in combination with a high-power LED module by infrared thermography.
Two different materials for the secondary optic are investigated: polymethyl methacrylate (PMMA) and polycarbonate (PC).

In the experiments, the temperature of the LED module is set to 85°C with an external temperature controller.
To examine the temperature profile within the optic, a cross-sectional cut is prepared and the surface is polished to optical quality.
The investigation yields the exact temperature profile within the optic. In particular, the temperature at the inner surface is determined precisely.

Introduction

As power dissipation and thermal robustness of LEDs rise, their power density and temperature, in particular the phosphor temperature, increases as well. While modern LEDs are designed to withstand high temperatures, it has to be made sure that their application environment also keeps up with this trend. A higher temperature stability of the LED and the primary optic might result in conditions, where the temperature of the secondary optic exceeds its specified working temperature range. This is of particular interest if the secondary optic is made out of a polymer. The heat distortion temperature (HDT) of the commonly-used materials for secondary optics, such as polymethyl methacrylate (PMMA) and polycarbonate (PC) is at 95°C [1] and 122°C [2], respectively (both values according to ISO 75 at 1.8 MPa). If the secondary optic is permanently operated above these temperatures, its optical properties might degrade [3]. In a worst-case scenario, even a deformation is possible. While glass optics are certainly an alternative, polymer optics are preferred by lighting manufacturers due to their lower cost and weight. An exact knowledge on the temperature profile within the secondary optic is thus crucial for high-power LED applications.

Experimental Details

The temperature profile of two secondary optics made of PMMA and PC in combination with a high-power LED module are investigated. Both optics have identical geometry and differ only in material. Figure 1 shows a scheme of the used LED module and the geometry of the optic. The LED module consists of four high-power LEDs on a printed circuit board (PCB) with an aluminum core (Figure 1, top part). The LEDs are connected in series and arranged in a square 2x2 array.

In Figure 1, the secondary optic is shaded in blue. For some experiments, a cross-sectional cut is performed along the symmetry axis of the optic. This allows to measure the temperature profile within the optic (Figure 1, bottom). In this case, two of the LEDs are fully covered, while the other two are only half covered by the optic. The whole setup is mounted on a sample holder, which is equipped with a heater and a temperature controller. To control the operation current of the LEDs and to measure the electrical power consumption a source measure unit (Tektronix Keithley 2600) is used.

Transmittance measurements in the visible spectral range are carried out using a UV-Vis-NIR spectrophotometer (Agilent Technologies Cary 5000). The LED emission spectrum is recorded with an absolute photoluminescence quantum yield measurement system (Hamamatsu C9920-02G).

Measurements of the temperature distributions in operation are performed with an infrared (IR) thermography camera (InfraTec ImageIR 8380S), which uses an indium antimonide (InSb) focal plane array (FPA) snapshot detector with a geometric resolution of 640x512 px. The spectral range for detection is between 2.0 μm and 5.7 μm.

In principle, infrared thermography allows a precise measurement of the radiation intensity only. However, if the emissivity value for the surface of the investigated material is known, the exact temperature can be deduced. Parts of the LED module are thus painted in black. This ensures for the painted areas in very good approximation a homogeneous black-body emissivity of ε = 1.0.

It is obvious that the approach of a painted reference point is not reasonable to determine the temperature of the polymer optic. The painted part of the optic would lead to an additional temperature increase, since the visible part of the LED emission would be absorbed by the black paint resulting in false temperature values. Thus, the emissivity values of both polymers are estimated as follows: First, the transmission and reflection spectra are recorded in the near infrared spectral range with a Fourier transform infrared spectrometer (Bruker Vertex 70 with a combined transmission and specular reflection unit A510/Q-T). On the basis of these data, the spectral absorbance is calculated, weighted with the black body spectrum, and then integrated for the sensitivity range of the thermography camera, i.e., in the spectral range from 2.0 μm to 5.7 μm. Finally, the integrated absorbance is compared to the integrated emission intensity of a black body in the same spectral range; the ratio of these values approximates the emissivity of the sample. For PMMA as well as PC an emissivity value of ε = 0.95 is found.

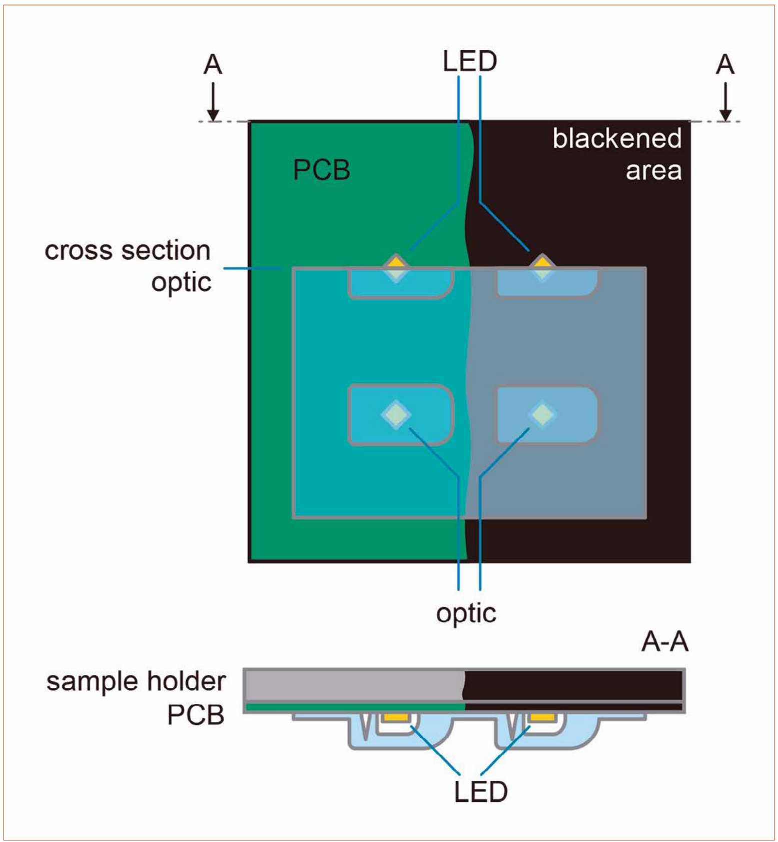


Figure 1: Schematic drawing of the setup. The LED module and the secondary optic are mounted on a sample holder with external heating. One half of the PCB is painted in black to enhance the emissivity. For some experiments, the optic is cut open to reveal the cross section (top). For temperature profilng of the secondary optic, the module is operated upside down (bottom)

The thermographic images shown in this work are all corrected for the emissivity of the material. To mimic the operation in a warm environment, the sample holder is kept at a constant temperature of 85°C. This is the maximum reference temperature for the LED system. The current of the LED module is set to 1050 mA, the voltage amounts to 12.5 V. This leads to an electrical power consumption of about 13 W for the total LED array. Prior to the thermographic measurements, the module is run for two hours to reach thermal equilibrium.

Experimental Results

Thermographic imaging of the LED module

Figure 2 shows a thermographic image of the LED module without secondary optic. In this image, the blackened part of the PCB (Figure 1) is seemingly warmer than the other. This is due to the larger emissivity (ε = 1.0) of this area compared to the unpainted one. In fact, the entire PCB is at the same temperature of 85°C. As proven in preceding investigations, the LED itself has an emissivity of ε = 1.0. In this experiment, the surface temperature of the LEDs reaches an average value of 125°C.

Optical properties of PMMA and PC

Figure 3 shows the transmission spectra of PMMA (black) and PC (blue) in the visible (left) and the

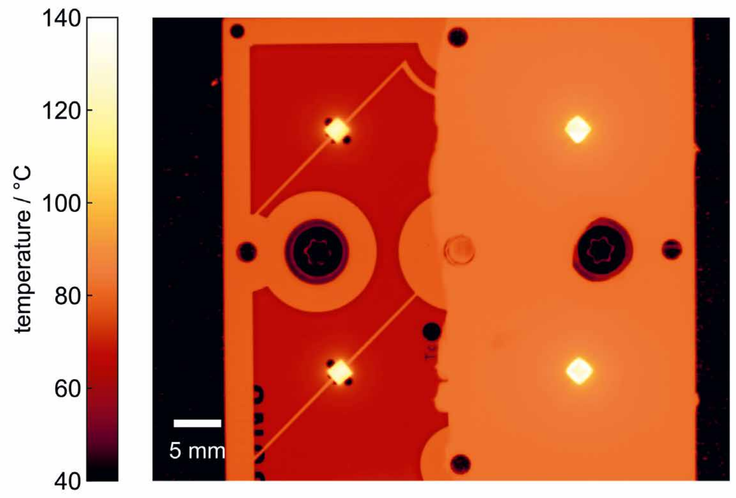


Figure 2: Thermographic image of the LED module without secondary optic. The right half of the board is painted in black

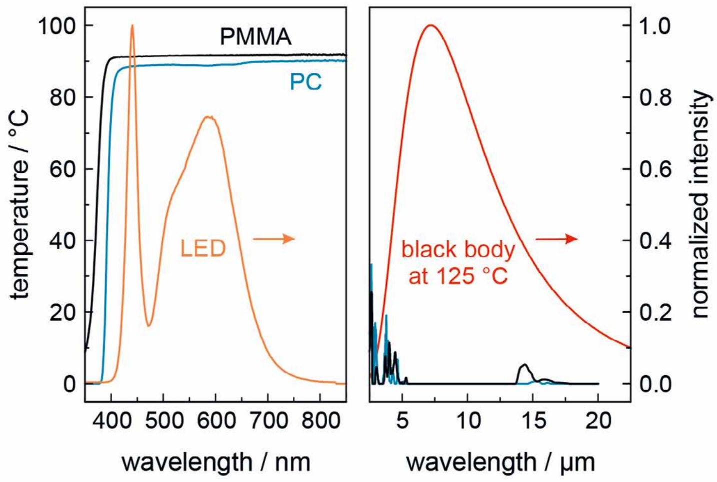


Figure 3: Transmittance of PMMA and PC (black and blue) as well as the LED emission spectrum (orange) and the black-body curve for a temperature of 125°C (dark red). The left panel shows the spectra in the visible range, whereas the right panel shows the near-infrared part. The LED emission spectrum and the black-body curve are each normalized to the maximum intensity and thus not to scale

near-infrared (right) spectral range. In addition, reflection and scattering spectra are recorded (not shown), so that the absorbance can be estimated. The emission spectrum of the white LED in the visible spectral range is shown on the left in orange color. The spectrum comprises the relatively narrow blue emission at 439 nm from the LED itself and the broad yellow emission from 470 nm to 750 nm from the phosphor. On the right, the emission spectrum for a black body at a temperature of 125°C (dark red) is shown for comparison. This represents the infrared radiation from a LED at this temperature.

Both polymer optics show excellent optical properties in the visible spectral range. The transmittance is almost constant over the entire visible spectral range. At a wavelength of 500 nm, it amounts to 92% and 90% for PMMA and PC, respectively. Since the reflectance is 8% and 10% for PMMA and PC, respectively, the absorbance is estimated to be in the order of the measurement accuracy of 1%. However, a more precise knowledge of the absorbance is necessary to allow an accurate estimate of the power absorbed by the polymer. This is of particular importance for high-power LED applications as it is the case here.

The slightly better transmission property of PMMA is due to its lower refractive index, n. At a wavelength of 500 nm, a typical refractive index of PMMA and PC is $n_{PMMA} = 1.496$ [4] and $n_{PC} = 1.597$ [4], respectively.

For perpendicular incidence and considering multiple reflections, the resultant transmittance, T, of two polymer interfaces in air ($n_{air} = 1$) is given by

$$T = \frac{2n}{(n^2 + 1)} \quad (1)$$

This leads to a theoretical transmittance of 92.4% and 90.0% for PMMA and PC, respectively. The ultraviolet absorption band of PC is at 394 nm, whereas that of PMMA is deeper in the ultraviolet, i.e., at 373 nm. This might be an issue if the LED emission spectrum has a significant part also in the ultraviolet spectral range.

However, in the near-infrared spectral range the transmittance vanishes for a large part of the spectrum. For both polymers, noticeable transmittance is only found for wavelengths shorter than 4 µm. The spectral reflectance (not shown here) is mostly constant in the spectral range investigated and amounts to approximately 7%. Thus, the blackbody radiation, originating from the PCB and the LEDs, is almost completely absorbed for wavelengths longer than 4 µm.

Thermographic imaging of a cross-sectional cut through the polymer optic

To measure the temperature profile inside the optic, a cross-sectional cut is fabricated with the surface polished to optical quality.

Figure 4 shows the temperature distribution of a cross-sectional cut of one of the investigated optics. The LED module is operated with the optic (indicated by a white frame) facing downwards.

Figure 5 enlarges the area of interest. Characteristic positions within the cross-sectional cut are labelled. Position 1 lies within the PCB. Having passed the white-yellowish hotspot from the LED, position 2 indicates a location within the cavity of the optic, while position 3 marks the inner surface of the optic. Position 4 indicates the outer surface of the optic, i.e., the polymer-to-air interface.

The vertical white line through the center of the LED serves as reference for the temperature profile inside the optic, as shown in figure 6.

Analysis of the temperature profile within the polymer optic

For both polymers (PMMA and PC), the temperature profile through the optic can be seen in Figure 6. At the bottom of the cavity (z = 1.8 mm), both polymers are at the same temperature of 82°C. This value is very close to the set board temperature of 85°C. Within the cavity, the temperature falls linearly down to 67.7°C and 66.5°C for PMMA and PC, respectively, at the boundary to the bulk (z = 5.5 mm). Within the bulk, it becomes more obvious that the temperatures diverge due to the different thermal conductivities of λ_{PMMA} = 0.19 W/m·K [5] and λ_{PC} = 0.20 W/m·K [6]. At the cavity-to-bulk interface, the temperature shows a slight increase, followed by a significant drop by approximately 7°C. From there on, the temperature again decreases linearly to 52.6°C and 49.4°C for PMMA and PC, respectively, at the outer surface of the optic (z = 10.5 mm).

Three mechanisms are contributing to the heating of the optic:

- A significant contribution is given by thermal conduction since the secondary optic is in direct contact with the PCB. The PCB itself is kept at a constant temperature of 85°C by an external heater
- A further contribution is due to convection. The air within the cavity is heated by the LED and the PCB, and there is convective heat transfer to the cavity-to-bulk interface
- The contribution of radiative heat transfer is negligible. Thermal radiation is typically only important for very hot objects, or for objects with a large temperature difference, which both is not the case here

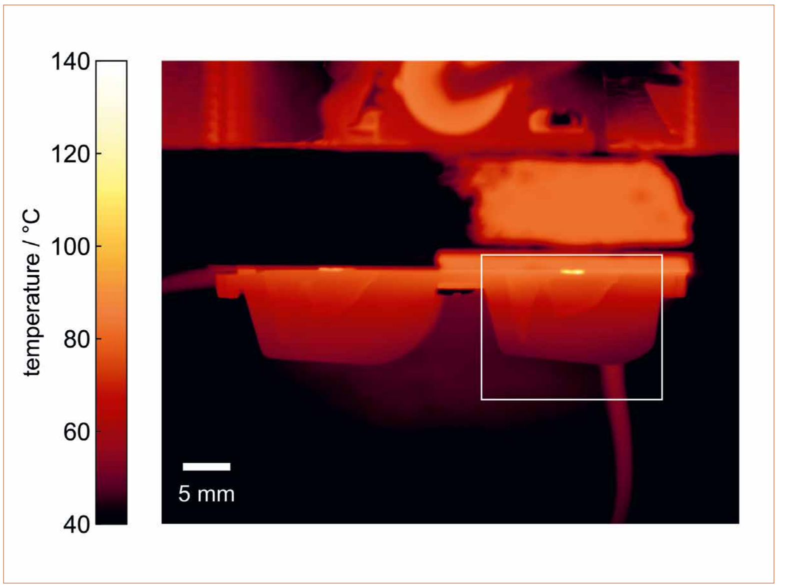


Figure 4: Thermographic image of a cross-sectional cut through the polymer optic (PC). The marked area is shown enlarged in Figure 5. The module is analyzed upside down as depicted in Figure 1, bottom part

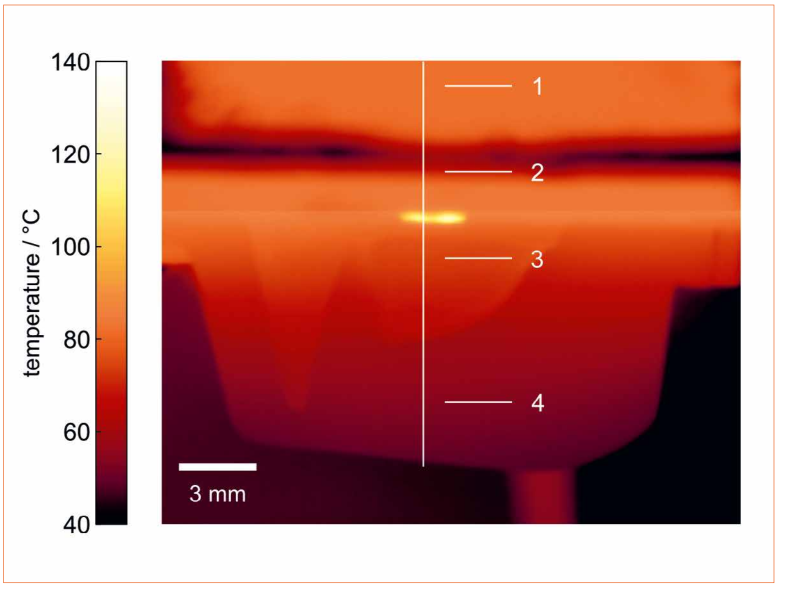


Figure 5: Magnified cross-sectional cut through the secondary optic (PC) as indicated in figure 4. The temperature profile along the white line is shown in figure 6

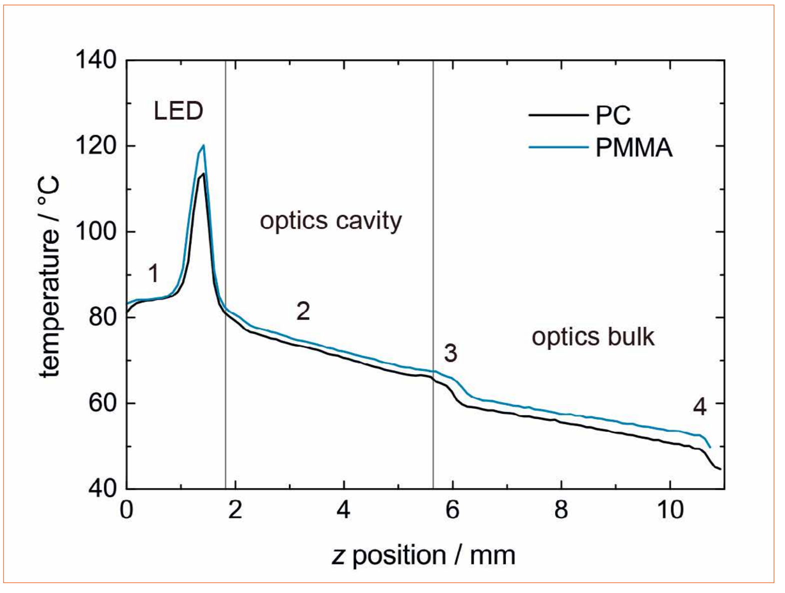


Figure 6: Temperature profile of the investigated PMMA and PC optics. The positions 1 to 4 are consistent to the positions indicated in Figure 5

Apart from the above-described mechanisms for heat transfer (conduction, convection, and radiation), a significant contribution might be due to absorption of the LED emission

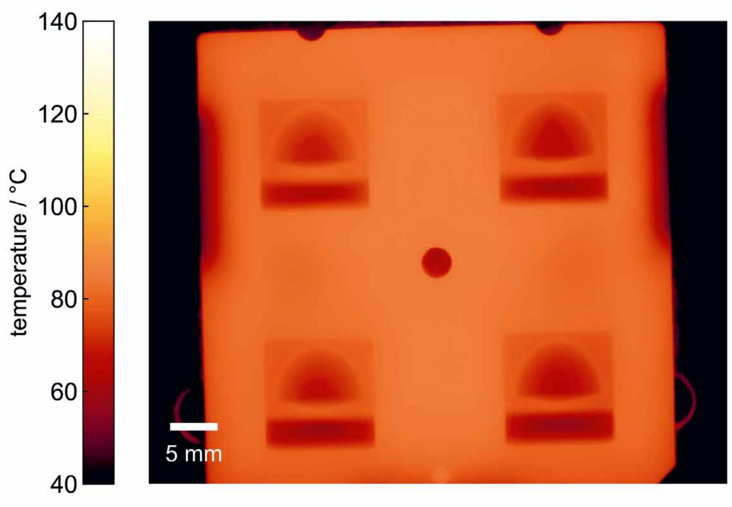


Figure 7:
Thermographic image of the inner surface of the polymer optic (PC) after operation facing downwards. The cooler areas on the left and right side of the image are caused by the mounting of the optic

in the visible spectral range. Though both polymer optics provide an excellent transmittance in the spectral range of the LED emission, a small, but not negligible part might be absorbed by the optic due to marginal absorption within the optic. Partial absorption of the visible emission is probably the most critical part since the optical output power in the visible spectral range is in the order of several watts, i.e., an absorbance in the order of a few tenths of a percent already results in a heating power of a few milliwatts.

Comparison between cross-sectional cut and complete optic

To prove the suitability of cross-sectional cuts for the temperature profile analysis, a similar experiment is carried out for a complete optic. Again, the LED module is operated with the optic facing downwards. Once the temperature has reached a steady state, the LED module is removed from the optic. During this process, thermographic images are taken every 50 ms. The time scale to remove the LED module is in the order of a few hundreds of milliseconds. For such a short period of time, the temperature of the optic shows only a negligible decrease and is in the order of 0.1°C. Figure 7 shows the temperature distribution of the inner surface of a complete optic having removed the LED module. At the position of the optics cavity, the temperature at the cavity-to-bulk interface amounts to approximately 66°C, which is in good agreement to the measurements at the cross-sectional cuts. The use of cross-sectional cuts is thus a suitable method to investigate the temperature profile within a (polymer) optic.

Conclusions

For the investigated combination of a high-power LED module and a polymer optic, the maximum temperature of the optic lies below the heat distortion temperature of the polymer. However, for smaller distances between LED and optic unwanted effects are expected. The results indicate that even a very low absorbance in the visible spectral range might be detrimental, in particular as LED power densities increase. In addition, the transmission properties of the optic need to be carefully matched with the LED emission spectrum.

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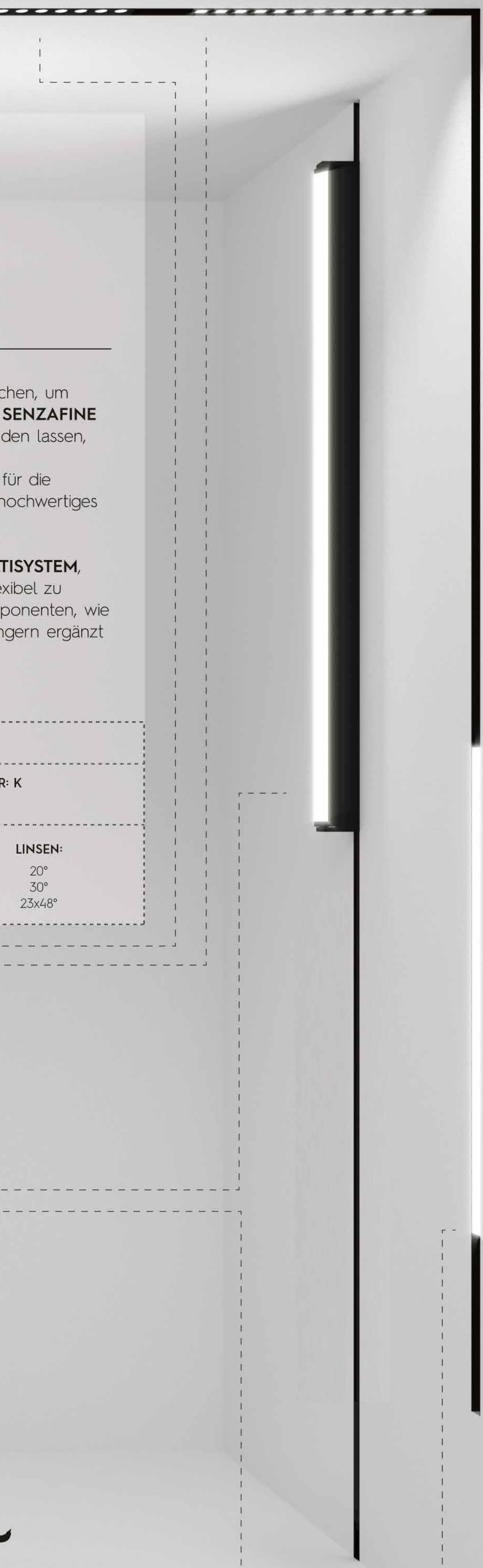
References:
[1] A. Siegmann, M. Narkis, and N. Rosenzweig, Polymer Engineering and Science 19, 223-225 (1979), doi: https://www.doi.org/ 10.1002/pen.76019031010.1002/pen.760190310
[2] A. Brydson, Plastics Materials, 7th Edition, Elsevier LTD, Oxford, 1999
[3] W. D. van Driel and X. J. Fan (Eds.), Solid State Lighting Reliability, Springer-Verlag New York, 2013, doi: https://www.doi.org/10.1007/978-1-4614-3067-410.1007/978-1-4614-3067-4
[4] N. Sultanova, S. Kasarova and I. Nikolov, Acta Physica Polonica A 116, 585-587 (2009), doi: https://www.doi.org/10.12693/APhysPolA.116.58510.12693/APhysPolA.116.585
[5] M. J. Assael, S. Botsios, K. Gialou, I. N. Metaxa, International Journal of Thermophysics 26, 1595-1609 (2005), doi: https://www. doi.org/10.1007/s10765-005-8106-510.1007/s10765- 005-8106-5
[6] J. Blumm and A. Lindemann, High Temperatures - High Pressures, 2003/2007, volume 35/36, pages 627-632



MULTISYSTEM

SAME CORE : MULTIPLE SHAPES

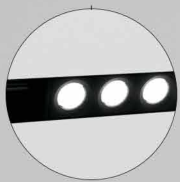
SENZAFINE

THE ENDLESS LIGHTLINE INSIDE MULTISYSTEM TRACKS

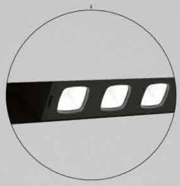
SENZAFINE ist die neue A.A.G. Stucchi-Produktlinie mit allem, was Sie brauchen, um mit MULTISYSTEM-Tracks eine **„endlose Lichtlinie“** zu kreieren. Die linearen **SENZAFINE** Lichtmodule sind in verschiedenen Längen erhältlich, die sich nahtlos verbinden lassen, um Linien ohne sichtbare Verbindungsstelle zu erzeugen.
Die grosse Auswahl an verfügbaren CRIs sowie Optiken und Linsen sorgen für die perfekte Abstimmung für sämtliche Anwendungen. SENZAFINE ermöglicht hochwertiges lineares Licht an beliebigen Stellen einer installierten Schiene.

Die gesamte Produktpalette bietet unseren Kunden ein "ready to use" **MULTISYSTEM**, kombiniert mit direkten und indirekten Lichtmodulen, welche einfach und flexibel zu installieren sind wie die Schienen selbst. **MULTISYSTEM READY** Systemkomponenten, wie die lineare Lichtmodule können jederzeit mit kompatiblen Spots oder Anhängern ergänzt oder ausgetauscht werden.

SENZAFINE			
VERFUEGBARE LÄNGEN: mm 300 / 600 / 900 / 1200 / 1500		FARBETEMPERATUR: K 3000	
CRI: ≥90 ≥95	TATSÄCHLICHER FLUSS: 338 - 2692	OPTIK: Opaler UGR<19 Mikroprismatische	LINSEN: 20° 30° 23x48°



SENZAFINE LENS



SENZAFINE UGR

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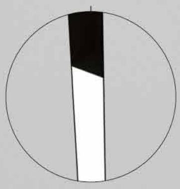

SENZAFINE OPAL

A.A.G.
STUCCHI
Follow your illumination

On Life Cycle Assessment to Quantify the Environmental Impact of Lighting Products

The lighting industry has made great efforts to increase energy efficiency around the world with a strong participation from governmental organizations, multilateral organizations and agencies. However, energy consumption is not the only aspect that needs to be considered for transforming the lighting industry. Víctor Ferreira, Deidre Wolff, and Cristina Corchero from Catalonia Institute for Energy Research (IREC) will explore relevant environmental metrics to help inform the reader about circular economy and Industry 4.0 strategies to achieve a sustainable lighting product.

In the last decade, the introduction of LEDs and other energy efficient lighting technologies have contributed to these efforts saving around 480TWh and 200 million tons of CO_2 emissions per year for European consumers. Furthermore, LEDs have radically changed the lighting industry with their ability to reach efficacies of more than four times higher than fluorescent lamps. New designs, like that being developed in the Repro-light project (funded by the European Union), aim to initiate a further transformation in the European lighting industry through the creation of customizable and sustainable products with high functional value. The Repro-light design is being developed considering the circular economy principles, which are to design out waste and pollution, to keep products and materials in use, and to regenerate natural systems. As energy consumption is not the only aspect that needs to be considered, the impact categories that have been addressed in previous environmental life cycle assessments of lighting products are identified. The impact categories and their importance in measuring the impact of lighting product designs that aim to meet the circular economy principles and improve the sustainability of the product will be explained.

Introduction

The lighting industry accounts for the consumption of approximately 16 to 20% of worldwide electricity production, the majority of which originates from residential and commercial use. For this reason, the development of new lighting technologies has focused on improvements in energy efficiency, which resulted in the deployment of LEDs and other efficient lighting systems. This technology advancement has contributed to savings of around 480 TWh of electricity and 200 million tons CO_2 emissions per year for European consumers in the last decade [1]. Furthermore, LEDs have the potential to reach higher efficacies through technological advancements, meaning that even more energy savings are obtainable. However, besides improvements in energy efficiency as a means to achieve a more sustainable product, technological innovations should also focus on designing products that consider the circular economy principles, which are to design out waste and pollution, to keep products and materials in use, and to regenerate natural systems.

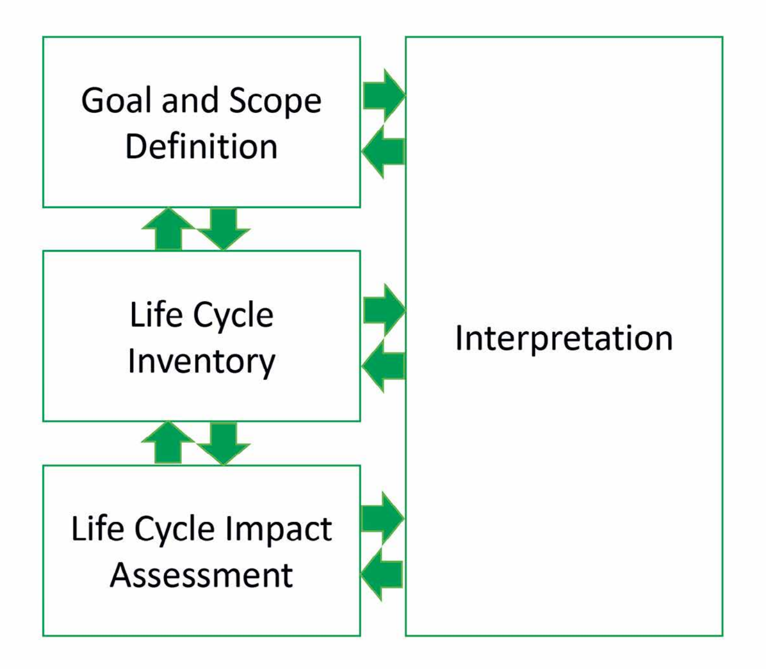

Figure 1:
Phases of an LCA study, ISO 14044:2006 [3]

The European project, Repro-light (Re-usable and re-configurable parts for sustainable LED-based lighting systems) is one research project that aims to include the circular economy principles in the production of LED luminaires. The Repro-light luminaire is designed to be reconfigurable, dimmable, exchangeable and customizable. It not only demonstrates improvements in energy efficiency through smart technologies such as daylight control, but also reveals possible economic and social benefits, including the creation of job opportunities and new sustainable business models based on serviceability of the luminaires. The project aims to demonstrate the ability to design a more sustainable lighting product and most importantly, to initiate a transformation towards circularity in the European lighting industry by the year 2020.

In order to quantify improvements in sustainability, Life Cycle Assessment (LCA) is one methodology that can be used. LCA is a holistic tool that considers the life cycle of a product or system from raw material extraction through to final end-of-life disposal. This methodology follows guidelines presented in the international standards, ISO 14040:2006 [2] and ISO 14044:2006 [3]. Other guidelines have also been developed from these standards for specific products or systems in order to harmonize the methodology used to assess their impact. For example, Product Category Rules (PCRs) have been developed to guide LCA studies of specific products. These rules must be followed for developing Environmental Product Declarations (EPDs) [2,3], which are independently verified and aim to allow for comparison of LCAs of specific products. All of these guidelines use the four iterative steps of an LCA (Figure 1).

All of these guidelines use the four iterative steps of an LCA:

- Goal and scope definition
- Life cycle inventory (LCI)
- Life cycle impact assessment (LCIA) and (iv) interpretation

In the goal and scope definition, the objective of the study is defined as well as the functional unit, the system boundary, and all other methodological considerations. The functional unit describes the function of the product. In the case of lighting sources, the functional unit may be a specific amount of lumen-hours [4,5,6,7], or the illuminance of a surface or room. The system boundary defines the inputs and outputs included in the LCA. The data for these inputs and outputs is collected during the LCI step and related to the functional unit. The LCIA step is where the environmental impacts are calculated using the results of the LCI. And lastly, the interpretation states the conclusions and recommendation of the study and checks that the goal and scope definition has been met.

This paper identifies the impact categories used in the LCIA stage that have been addressed in previous environmental life cycle assessments of lighting products and gives a description of their environmental significance. As stated above, energy consumption is an important impact to assess for lighting, however, LED luminaires also contain electronic components and LED spots which consist of non-renewable raw materials that should also be considered.

Environmental Impact Categories in the LCA of Lighting Products

Several LCA studies have been conducted in the past three decades for comparing the incandescent lamp, CFL and LED lighting sources. Across these LCA studies, various impact categories have been considered in the LCIA (Table 1). Impact categories represent environmental issues of concern. Characterization factors relate the impact of a specific emission or output in the LCI data to the impact of a reference emission as defined by the characterization model for the specific impact category [3]. Each characterization factor (CF_i) is multiplied by the LCI result (LCI_i) to yield the LCIA result. This is repeated for all outputs of the LCI (n) that are categorized in the same impact category. The sum is then taken to yield the total result for the impact category (IC). Taking m to be the LCI result associated with the IC, the total impact can be calculated using equation 1 for each impact category.

Table 1: **Summary of impacts categories considered in LCA studies of lighting**

Impact category	Ref.	Year
Global warming, Acidification, Carcinogenics, Non-carcinogenics, Respiratory effects, Eutrophication, Ozone depletion, Ecotoxicity, Smog and Cumulative energy demand	[15]	2017
GWP (excluding biogenic carbon), HTP and TET	[16]	2016
AP, Climate change, EP, Freshwater aquatic eco-toxicity, Freshwater sediment eco-toxicity human toxicity, Marine aquatic eco-toxicity, Marine sediment eco-toxicity, Terrestrial eco-toxicity, Ionizing radiation, Land use, Maladours air, Abiotic depletion, Photochemical and Stratospheric Ozone depletion.	[17]	2014
PED, Renewable energy, Non-renewable energy, ADP, Water consumption, Hazardous waste, Inert waste, GWP, AP, Air pollution, Water pollution, ODP, POCP, EP.	[18]	2013
ADP, AP, EP, GWP, ODP, POCP	[19]	2012
GWP; AP; POCP, ODP; HTP; freshwater aquatic, marine aquatic, and terrestrial ecotoxicities; EP; ecosystem damage; ADP; land use; hazardous, non-hazardous, and radioactive wastes	[20]	2012
PED, GWP, EcoIndicator'99	[21]	2011
PED, GWP	[22]	2009
GWP, AP, EP, POCP, ADP, HTP, Primary Energy Demand (CED)	[5]	2009
ADP; GWP; ODP; HTP; AP; EP; POCP; freshwater aquatic, marine aquatic, and terrestrial ecotoxicities; carcinogens; respiratory effects; minerals; fossil fuels	[23]	2006
PED, Hg emissions, radioactive materials	[24]	1996
GWP, SO2, NOx, CH4, ashes, Hg, solid waste	[25]	1991

Global warming

Gobal warming is an increase in global temperature over time, which is enhanced by human activities that impact radiative forcing. Radiative forcing results when greenhouse gases in the atmosphere absorb infrared radiation reflected from the earth's surface and re-emit it in all directions, thus redirecting it from passing through the earth´s atmosphere and into space. In other words, radiative forcing is a measure of how the energy balance of the earth-atmosphere system is influenced when factors that affect climate are altered [30]. Carbon dioxide (CO_2) emissions have caused the largest radiative forcing over the period of industrial era started from 1750. In fact, CO_2 has accounted for about 82% of the increase in radiative forcing over the past decade [31]. Apart from CO_2, other greenhouse gases, such as CH_4, N_2O and CFCs and SF_6, can also cause this. Changes in global temperature can lead to climatic disturbance, desertification, rising sea levels and the spread of disease.

Equation (1) to calculate impact:

$$IC\ Result = \sum_{i=m}^{n} LCI_i \cdot CF_i \qquad (1)$$

Various characterization models can be used to derive the characterization factors, such as CML (base line and no-baseline) [8], Eco-indicator 99 [9], ReCiPe [10], TRACI [11], USEtox™ [12,13] and Cumulative Energy Demand [14].

From Table 1, seven impact categories were chosen for more detailed discussion of their impact models and environmental significance, including global warming, acidification, eutrophication, abiotic depletion, photochemical ozone creation, ozone depletion, and primary energy demand. These categories have also been used in the preparation of Environmental Product Declarations (EDPs) by Philips [26] and David Trubrige [27], and can be derived using the recognized CML method, which was developed by the Institute of Environmental Sciences at Leiden University in The Netherlands [28].

The descriptions that follow intend to educate the reader on the various impact categories that can be assessed in LCA studies. It should be noted that while some impact categories are considered robust, others are still immature and require significant development to ensure that their use does not lead to incorrect decisions being made [29]. The scientific debate around LCIA methodologies has increased with the increase in projects [29], such as Repro-light, however, conclusions and recommendations can still be made through comparative LCA studies.

The characterization factors measuring the global warming effect of each greenhouse gas are called Global Warming Potentials (GWPs). Each factor is an estimate of a chemical atmospheric lifetime and radiative forcing that may contribute to global climate change compared to the reference value CO_2. Thus, global warming potential is calculated in kilograms of carbon dioxide equivalents (kg CO_2-eq). In detail, each greenhouse gas is assigned a GWP index expressing the ratio between the increased infrared absorption due to the instantaneous emission of 1 kg of the substance and that due to an equal emission of CO_2. In other words, it describes the increase of the concentration of greenhouse gas and radiative forcing with respect to CO_2 considering the time after the release. In this sense, the GWP can be calculated applying

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PROGRAM

Time	Seestudio	Seefoyer	Propter Homines	Time	Saal Bodensee	Parkstudio
	LpS 2019 LED professional SYMPOSIUM +EXPO				**TiL 2019**	
	Sept. 24th, 2019	**Lighting Industry**			**Sept. 24th, 2019**	**Lighting Design**
08.30	**REGISTRATION**					
	Standards Driving Business	**Potentials of Digital Disruption**	**Human Centric Lighting I**		**How Smart and Intelligent Can Lighting Be?**	**New Lighting Design Approaches Applications**
10.00	**When Circular Economy Meets the Lighting Industry (LCA)** *Deidre WOLFF, MSc* *IREC, Spain*	**Supply Chain Based Disruptive Business Revolution** *Stefan KREIDLER, Dr.* *onlog, Switzerland*		10.00	**Innovative PC-App with Camera for Adjusting the Perfect Light Colour Fully Automatic** Peter HAUMER Lumitech, Austria	**Hospitality Lighting Design** Theodore D. KONTORIGAS, Kontorigas LD, Greece
10.30	**Ecodesign Directive and Energy Label-ling Regulation** *Elena SCARONI* *LightingEurope, Belgium*	**LiFi Technology** *Tomasz ZAREBA, Dr.* *Zumtobel, Austria*	**Critical Opinion on the Current Devel-opment Status of HCL Solutions** *Wilfried POHL, Mag* *Bartenbach, Austria*	10.30	**Smart Lights with Machine Learning for Truly Smart Living** Harry EDELMAN, Dr. Arch. Prof. Tampere University, Finland	**Ambient Lighting Design for Persuasive Environments Using Social Media Data** Yasaman MAVVAJ, MSc Körner Design, The Netherlands
11.00	**Latest Zhaga Updates - Interoperability, Smart Lighting** *Dee DENTENEER, PhD* *The Zhaga Consortium, The Netherlands*	**Collective Intelligence in Lighting Control** *Szymon SLUPIK, MSc* *Silvair, Poland*	**Lighting Beyond Light** *Alexander WILM, DI* *OSRAM Opto Semiconductors, Germany*	11.00	**The Rise of Pixel Art: The Lasting Effects of Affordable Addressable LEDs** Stefan Yazzie HERBERT The Paranormal Unicorn, Austria	**Inside the Pyramids - Light Where There Should be Darkness** Ruairi O'BRIEN, Professor Ruairi O'Brien Lighting Design, Egypt
11.30	**LUNCH**					
	User Centric Lighting Studies & Surveys	**Innovation in Lighting Process & Realization**	**Human Centric Lighting II**		**The Light The New Awareness**	**Women in Light - The Digital Era**
13.00	**A European Workplace Lighting Survey** *Ganix LASA, PhD* *Mondragon University, Spain*	**Virtual Prototyping in the Lighting Prod-uct Development** *Ervand KANDELAKI, Dr.* *CADFEM, Germany*	**Energy and Quality Metrics in Melanop-ic Stimulus Evaluation for HCL** *Octavio Luis PEREZ, PhD* *Mount Sinai Hospital NYC, USA*	13.00	**Light as Essential Part of the Concept** Sergei Tchoban, Arch. Tchoban Voss Architekten, Germany	*PANEL* **Women in Lighting: The Digital Era, a Step Back a Step Forward** Mahdis ALIASGARI & Barbara RODRIGUEZ, MA Arch, LD, Lighting Design Collective, Spain
13.30	**An Interactive Approach to the Optimization of Public Space Lighting with Resident's Participation** *Boris A. PORTNOV, PhD* *University of Haifa, Israel*	**Mass Personalization - User-centered Development of Lighting Solutions and Services** *Daniel N. PIMENTA, DI* *Fraunhofer, Germany*	**Current State of Knowledge and the Levels of Various Non-visual Lighting Effects** *Lisa POHL, Dr. med.* *Bartenbach, Austria*	13.30	**Langsames Licht / Slow Light - From Theory Into Practice and From Art Into Function** Siegrun APPELT Siegrun Appelt, Austria	*PANEL* **Women in Lighting: The Digital Era, a Step Back a Step Forward**
14.00	**Dynamic LED Public Lighting Solutions: Citizen Perceptions and Evaluations** *Nicolas HOUEL, PhD Student* *AAU Laboratory, France*	**Complete Luminaire Development Workflow and Practical Results for Tunnel Lighting** *Lorenzo TREVISANELLO, PhD* *Arianna, Italy*		14.00	**Daylight and Light Design Intertwining** Isabel VILLAR, Maha SHALABY, MSc White Arkitekter, Sweden	
14.30	**BREAK**					
	KEYNOTES - Room: Großer Saal					
15.30		**Designing with Light - Day and Night** *Keith BRADSHAW* *Principal, Speirs + Major, UK*	**Ledification and Connectivity is Chang-ing the Lighting Industry** *Dietmar ZEMBROT* *CTO, Trilux, Germany*	**Lighting an Idea** **Mark RIDLER** *Head of Lighting* *BDP, UK*		
17.00	**Expo Opening, Press Conference, Come Together - Room: Showfloor Stage, Exhibition Area**					

Sept. 25th, 2019	Lighting Industry			Sept. 25th, 2019	Lighting Design		DALI Summit 2019	
Time	**Seestudio**	**Seefoyer**	**Propter Homines**	**Time**	**Saal Bodensee**	**Parkstudio**	**Time**	**Seestudio**
	Light Sources I	**Internet of Things - IoT**	**Optics I**		**The Smartness of Buildings & Cities**	**Visual Perception and Health Demonstration - Experience Yourself**		**DALI Session 1: DALI-2 Certification and Specification**
08.30	**SALON, a New High Performance Red Phosphor** *Hubert HUPPERTZ, Prof.* *Leopold-Franzens-University, Austria*	**Monetizing the Cloud for Lighting Control** *Patrick DURAND* *Future Electronics, Canada*	**Micro-optics for Efficient LED Spotlights with Arbitrary Farfield Distributions** *Peter SCHREIBER, Dr.* *Fraunhofer IOF, Germany*	08.30	*WORKSHOP* **LED Lighting Concepts: Visual Perception and Health – Demonstrations** Wilfried POHL, Mag. Bartenbach, Austria	**Sensor Ready and MasterConnect: Simple, Scalable, Standardized** Peter DUINE Signify, The Netherlands	08.30	**DALI-2: The Global Standard for Smart, Digital Lighting Control** *Scott Wade* *DiiA*
09.00	**Value and Opportunities from Integrated LED Matrix Solutions** *Ingolf SISCHKA* *Lumileds, Germany*	**IoT System Architecture Testing as Part of Continuous Integration** *Jürgen WÖLFLE* *Tridonic, Austria*	**Ultrathin Freeform Micro-optical Elements – The Potential of Tailor-made Light-directing Structures on Foil** *Claude LEINER, Dr.* *Joanneum Research, Austria*	09.00	*WORKSHOP* **LED Lighting Concepts: Visual Perception and Health – Demonstrations**	**Intelligent Lighting for Smart Buildings and Smart Cities Enabled by Integrated Sensing Solutions** Richard FIX, Dr. Bosch, Germany	09.00	**Expanding DALI-2 Certification for Complete System Coverage** *Ronald Tol* *DiiA/Signify*
09.30	**LED Innovations for the Improvement of HCL Luminaires** *Menno SCHAKEL* *Nichia, Japan*	**The Transformation from a Luminaire Manufacturer to a Smart Building Enabler** *Fabian GERSCHWILER* *Regent, Switzerland*	**Freeform Optical Structures: From Macro to Micro Scale** *Tamara ADERNEUER, MSc* *CSEM, Switzerland*	09.30	*WORKSHOP* **LED Lighting Concepts: Visual Perception and Health – Demonstrations**	**Good Night = Good Light. New Ways to Reduce the Use of Artificial Lighting - Especially During Night** Ofer KEREN Keren Energy, Israel	09.30	**New DiiA Specifications and Collaborations** *Scott Wade* *DiiA*
10.00	**BREAK**							
	Light Sources II	**Controls I**	**Optics II**		**Innovations in Lighting Design Thinking Out of the Box**	**Nutritional Light (Human Centric Lighting)**		**DALI Session 2: DALI in Action**
11.00	**GaN-Substrate LEDs: Introduction to nPola** *Chae Hon KIM* *Seoul Semiconductor, Germany*	**80-20 Vision HCL: How to Conduct an Orchestra of Tunable White Lights to Deliver Affordable HCL** *Patrick V. KELLY, PhD* *ROBUS, Ireland*	**Rapid Optics Design and Manufacture for Future Proof Illumination Systems and Customized Project Lighting** *Marco de VISSER* *Luximprint, The Netherlands*	11.00	**Dynamic Light and Urban Spatial Artworks** Ruairi O'BRIEN, Professor Ruairi O'Brien Lighting Design, Egypt	**Light and Health: What are the Mechanisms?** **Claude GRONFIER, PhD** Professor Inserm, France	11.00	**Energy Efficiency, Safety and Comfort with DALI Lighting Management** *Dirk Dronia* *WAGO*
11.30	**Towards New Generations of Lighting and Display: Micro-LEDs** *Hani KANAAN, Dr.* *Cea Leti, France*	**Luminaires and the Internet of Things – A Feasible Approach for Retail Applications** *Meike BARFUSS, Prof.* *FH Südwestfalen, Germany*	**Freeform Optics for Precise Non-uniform Illumination Patterns** *Oscar FERNANDEZ, PhD* *CSEM, Switzerland*	11.30	**When Lighting Design Meets Design Thinking: Putting People First** Sabine DE SCHUTTER, MA Architectural LD Studio De Schutter, Germany	**From Nobel Prize to Daily Practice - Offices, Home and Therapy** Marijke GORDIJN, PhD, Founder/Owner Chrono@Work, The Netherlands	11.30	**New Opportunities for DALI with D4i in Outdoor Lighting Applications** *Jan Fitters* *Signify*
12.00	**Degradation of Green High-Power LEDs - Influence on Color Stability of Multi-Channel Luminaires** *Alexander HERZOG, MSc* *TU Darmstadt, Germany*	**Sensing Outside the Box – The Lighting and Building Automation Convergence** *Tom GRIFFITHS* *ams, USA*	**Application of Diffraction-based Optical Components in Advanced Lighting Systems** *Marek SKEREN, Dr.* *IQ Structures, Czech Republic*	12.00	**Evolution of Lighting Design Processes in Digital Times** Bert JUNGHANS, DI Zumtobel, Austria	**Rethinking Lighting: Nutritional Light Indoors** Jan DENNEMAN, MSc, Chairman Foundation Good Light Group, The Netherlands	12.00	**Case Study: A Cloud-monitored, Fully Integrated, Large-scale DALI System** *Fabian Mayer* *Trilux*
12.30	**LUNCH**						12:30	**Implementation of a DALI Lighting System at Manchester Airport (UK)** *Volker Barth* *LOYTEC*
13:30	**CEO Panel - Zumtobel, Nichia, etc.**							
	Light Sources III	**Controls II**	**Human Centric Lighting III**		**Light and Lighting Design Under The Focus**	**Digital Times Changes the Process of Lighting Design**		**DALI Session 3: DALI Developments and Next Steps**
14.30	**LED Spectrum Optimization for Improvement of Human Performances and Psychophysiological Responses** *Makoto OGAWARA* *Nichia, Japan*	**Data Analytics in Connected Lighting Systems – A Case Study** *Sebastian KNOCHE, Dr.* *Trilux, Germany*	**Critical Evaluation of Adverse Effects of LED Light Sources** *Markus CANAZEI, PhD* *Bartenbach, Austria*	14.30	**Development of Neurotechnology in Lighting Design** Olga TUZOVA, MA Politecnico di Milano, Italy	*WORKSHOP* **Evolution of Lighting Design Processes in Digital Times** Holger LEIBMANN, DI Architect Zumtobel, Austria	14.30	**Get WELL with DALI** *Alan Jackson* *Helvar*
15.00	**Wafer Integrated Chip on PCB** *Marc JUAREZ* *Seoul Semiconductor, Germany*	**IP to the Node - An Upcoming Disruption in Lighting Controls** *Walter WERNER, Dr.* *Werner Mgt. Services, Austria*	**Photobiomodulation: A New Dimension to Human Centric Lighting** *Martijn DEKKER, Dr.* *Seaborough, The Netherlands*	15.00	**Illuminance, Apparent Brightness and Circadian Rhythms. A New Era in Lighting Design?** Alexandra KALIMERI, MA ME Engineers, UK	*WORKSHOP* **Evolution of Lighting Design Processes in Digital Times**	15.00	**Standardizing Luminaire Technology with D4i** *Jens Herter* *Tridonic*
15.30	**Synergy Between Display and Lighting Technologies** *James Norman BARDSLEY, Dr.* *Bardsley Consulting, USA*	**NFC Current Configuration and Constant Lumen Output Functions in LED Power Supplies** *Qi ZHU, Dr.* *Infineon, Germany*	**Human Centric Lighting for Top Performance – Learnings from Light Stimulation of World Class Athletes** *Andreas WOJTYSIAK, Dr.* *OSRAM, Germany*	15.30	**Safeguarding Your Investments into Connectivity** Mathias BURGER SAMSUNG, Germany	*WORKSHOP* **Evolution of Lighting Design Processes in Digital Times**	15.30	**Where does DALI Fit in a Wireless World?** *Arnulf Rupp* *DiiA / OSRAM*
16.00	**BREAK**							
	Light Sources IV	**Controls III**	**Future Luminary Design PANEL**		**The Process of Modern Lighting Design**	**Walk-In Light Experience @ Booth N3-N5 NICHIA**		**DALI Session 4: PANEL - What is the Future of DALI?**
17.00	**Case Studies of Lighting Applications Implementing High Luminance Laser Light Sources** *Julian A. CAREY* *SLD Laser, USA*	**New 48V LED-Tape Technology with Optimized Efficiency** *Roland MICHAL, Dr.* *Bilton, Austria*	**Moderation by** *Ourania Georgoutsakou* *Secretary General from LightingEurope* **Panelists:** *Arnulf Rupp, Osram* *Wilfried Pohl, Repro-Light* *Horst Rudolph, Trilux* *Ruari O'Brien*	17.00	**Stakeholders: How Can They be Organized in Order to Achieve the Desired Quality of Public Lighting in 2030?** Iris DIJKSTRA, MSc, Atelier LEK, The Netherlands	*WORKSHOP* **Experience The Latest Innovative LED Technologies That Truly Addresses Human Centric Lighting.** **Let us walk you through newest HCL solutions.** *WORKSHOP* **Experience The Latest Innovative LED Technologies That Truly Addresses HCL.** By Giovanni Vecchio and NICHIA team.	17.00	**PANEL: Panellists from major lighting companies will give their company's perspective on the critical question.** **"What is the future of DALI?"** **Speakers from:** *Helvar, Lutron, Osram, Signify and Tridonic*
17.30	**A New Method of Spectral Tuning LED With High Color Quality** *Daniel HAN* *Beijing Yuji International, China*	**Miniaturization of LED Drivers and Integration of Connectivity** *Laurent JENCK, MBA* *ERP Power, USA*		17.30	**Light Designer's Role in Complex Projects** Diana GALIC, Master LD NOVA-LUX, Hungary			
18.30	**GET TOGETHER / AWARD CEREMONY (Eil.Gut.Halle - Harbour Lindau - 18.30-23.30)**							

PROGRAM

Time	Sept. 26th, 2019 Lighting Industry			Time	Sept. 26th, 2018 Lighting Design	
Time	Seestudio	Seefoyer	Propter Homines	Time	Saal Bodensee	Parkstudio
	Quality and Testing I	**Quality Engineering I**	**Light in Applications I**		**Digitalization in Lighting What We Should Know?**	**Lighting Installation Commissioning & Troubleshooting**
09.00	**Software for Detection of Color Defects in Light Beam** *Saitgalina A. KAMILOVNA* *LLC Lighting Technologies, Russia*	**Analysis of Improved SAC+ Solders for CSP LEDs on Al-IMS** *Gordon ELGER, Prof.* *TU Ingolstadt, Germany*	**Aspects of Different LED Spectra for Street Lighting** *Markus HOFMANN, DI* *OSRAM Opto Semiconductors, Germany*	09.00	**Light Connects – The Symbiosis of Light and Digital Content Creates New Levels of Customer Experience** Andreas HENRICH, DI fh+p	*WORKSHOP* **Setting up a Robust Lighting Control System with Bluetooth Mesh - From Commissioning Basics to Troubleshooting** Silvair, Poland
09.30	**Challenges for Measuring Multichip LED Light Engines for Interior Lighting Applications** *Mete MUSLU, BSc* *Ozyegin University, Turkey*	**Transient Infrared Thermography for Thermal Conduction Path Analysis of LED Modules** *Peter W. NOLTE, Dr.* *Fraunhofer, Germany*	**Real Environment Research Laboratory with Light Pollution Optimized Street Light Luminaires** *Ferenc SZABÓ, PhD* *LightingLab Calibration Laboratory, Hungary*	09.30	**Lighting Control - Truly Wireless** **Matthias KASSNER, DI** EnOcean, Germany	*WORKSHOP* **Setting up a Robust Lighting Control System with Bluetooth Mesh - From Commissioning Basics to Troubleshooting**
10.00	**Automatized Lighting Audit: Development of a Robotic Illuminance Meter** *Péter CSUTI, PhD* *University of Pannonia, Hungary*	**Plasma-metalized Flexible PCBs for LEDs Applications** *Yaser HAJ-HMEIDI, MSc* *Lumitronix, Germany*	**Are UV LEDs a Credible Alternative for Disinfection?** *François MIRAND* *Future Electronics, France*	10.00	**Best Practice in Wireless Lighting Controls** **Antonio ARTECHE** Casambi, Finland	**Improving the Performance of Daylight Harvesting Systems** Robert LUBAS, PhD Silvair, Poland
10.30			**BREAK**			
	Quality and Testing II	**Quality Engineering II**	**Light in Applications II**		**Trends in LED Lighting Solutions**	**From OLEDs to Light-Guides**
				10:30		*WORKSHOP* **Next Generation Lightguides, OLED and R2R Manufacturing** Jose POZO, Dr. EPIC
11.00	**Increase Product Quality with Reduced Effort: Best Practice in Photometric Measurement of LED Luminaires** *Simon RANKEL, Dr.* *Ophir Spiricon, Israel*	**Cooperation with China in the Real World of Lighting** *Fabien BUBENDORFF, MSc* *Origin Services, Austria*	**How to Reduce Jetlag by Innovative Cabin Lighting** *Achim LEDER, Dr.* *jetlite, Germany*	11.00	**Tunable Lighting Systems for Optimal Health in Humans and Plants** Tom JORY, MBA Luminus Devices, USA	
11.30	**An Evaluation Guide for Blue Light Hazard** *Denan KONJHODZIC, Dr.* *Instrument Systems, Germany*	**Enhanced LED Lighting Modules Protection with New Silicone Encapsulant** *Thierry COOREMANS, MSc* *Dow Silicones, Belgium*	**UL 8800 Update and New Performance Label for Horticultural Lighting** *Hans LASCHEFSKI, Dr.* *UL, Germany*	11.30	**Spectrum Engineering for HCL** Aleksandar NASTOV SAMSUNG, Germany	*WORKSHOP* **Next Generation Lightguides, OLED and R2R Manufacturing**
12.00	**New EU Energy Consumption Regulation and Their Impact on Testing** *Fabian FLIGGE, DI* *TÜV SÜD, Germany*	**Predicaments & Strategies in the Development of Intelligent Lighting** *Sandy ZHONG, MSc* *Lifud, China*		12.00	**Connectivity - The Core Value of New Lighting Solutions** Matthias Natterer, DI(FH) Beckhoff, Germany	*WORKSHOP* **Next Generation Lightguides, OLED and R2R Manufacturing**
12.30					**LUNCH**	
13.30					**CLOSING**	

different time horizons (20, 100 and 500 years), but a usual period is 100 years, which is also used in the Kyoto protocol. A list of GWPs is compiled by theIntergovernmental Panel on Climate Change (IPCC) and it is periodically updated [32,33].

Acidification

Acidification is associated to the capacity of some substances to create and release protons (H^+). For example, sulfur dioxide (SO_2) can react with water in the atmosphere to form acid rain (a process known as acid deposition). Another molecule with a significant contribution to acidification is nitrogen oxide that reacts to form nitric acid (HNO_3). Acid rain can fall a considerable distance from the original location of the gas released. As a consequence, ecosystems can be damaged to different degrees affecting soil and materials (buildings).

Acidification Potentials (APs) are characterization factors used to assess acidification [34]. The AP of a substance was defined by Heijungs et al. [35] as the number of H^+ that can potentially be produced per kg substance with respect that produced per kg of SO_2 [34]. Therefore, AP is expressed as sulfur dioxide equivalents (kg SO_2-eq) [36]. It is worth noting that AP varies according to regional characteristics and atmospheric environments. Several methods as described by Guineé et al. [34] have been proposed to deal with local differences in sensitivity to acidification. Nevertheless, LCA practitioners assume that the life cycle emissions from a global supply chain occur within the continent referring to the geographical scope of the characterization method [37].

Eutrophication

Eutrophication is caused by the release of nitrogen and phosphorus, such as from landfills, sewage, and fertilizers that can cause an enrichment of nutrients in a certain place. It can affect aquatic ecosystems by causing excess plant (algae) growth and depleting oxygen levels. The growth of plants can block sunlight from reaching other organisms, reducing photosynthesis and oxygen levels that further help to decompose dead algae. This depletion of oxygen eventually leads to the death of species, such as fish, and to anaerobic decomposition. The latter generates methane and hydrogen sulfide and can lead to loss of species diversity among other consequences. Eutrophication can also affect terrestrial eco-systems by causing the amount of nitrogen necessary for a maximum harvest to be exceeded. This leads to enhancements of the nitrate concentration in the soil and groundwater, which then contributes to an increase of biomass formation.

The CML characterization model to derive the Eutrophication Potential (EP) characterization factors uses phosphate (PO_4^{3-}) as the reference substance. EP is defined as the ratio between the potential contributions of one mole of substance to one mole of phosphate using the molar mass (kg/mol) [35]. The contribution to biomass formation caused by eutrophication in the EPs considers Nitrogen, Phosphorous and Carbon, which are measured in terms of the Chemical Oxygen Demand (COD). It is based on the average chemical composition of aquatic organisms ($C_{106}H_{263}O_{110}N_{16}P$), assumed to be representative of average composition for biomass [34]. The EPs assume that one mole of Phosphorus contributes as much to the formation of biomass as does 16 moles of Nitrogen and 138 moles of Oxygen to degrade the organic matter emitted assuming that those moles are required to degrade 1 mole of biomass [35].

Abiotic resource depletion

Abiotic resources are defined as inorganic or non-living materials at the time of their extraction [38]. This impact category focuses on the depletion of non-renewable abiotic resources, including fossil energy resources, metals, and non-metal minerals [39]. The risk to the availability of these resources can depend on multiple factors, such as the ability to recover the resource after use (for example fossil fuels are converted to energy and cannot be recovered), the pressure from increasing demand for the resource, and the geographical accessibility of the resource [39]. Abiotic resource depletion is one of the most debated impact categories and there are multiple methods used to derive the characterization factors, each of them originating from justifiable perspectives of the problem definition and none of them able to be empirically verified despite over 20 years of research [29,38,40].

Variation in the problem definition leads to various opinions on whether to include stocks (deposits) in the environment, stocks in the economy, or both in the characterization models, as well as whether to consider material criticality and what reserve value to use as the reference for depletion, being the ultimate reserve, ultimately extractable reserve, reserve base or the economic reserve [40]. The ultimate reserve refers to the quantity of a resource estimated to be available in the earth's crust, the ultimate extractable reserve is the quantity that can be technically extracted, the reserve base is quantity the meets the current requirements for mining regulation, and the economic reserve is the quantity that can be economically extracted [40].

In terms of criticality, the United Nations has created a list of Critical Raw Materials that include chemical elements that have a high supply risk and are also important for the EU economy [41]. This criticality can be a result of geological, technical, environmental, social, economic and/or political aspects. One argument against the inclusion of criticality in environmental LCA studies is based on the fact that it is not only an environmental problem, but also includes both economic and social aspects, and thus criticality does not measure the same environmental problem defined with abiotic resource depletion [40]. However, it is suggested that assessments of criticality may be useful for studies that combine Life Cycle Costing, environmental LCA and social LCA, thus expanding the assessment to include other aspects besides environmental. For this reason, criticality is not included in the CML model of the Abiotic Depletion Potential (ADP) characterization factors.

The CML characterization model defines the problem as the environmental depletion of abiotic resources, considering only stocks in the environment and using the ultimate reserve as the reference to which depletion is measured [40]. The reason for choosing the ultimate reserve in this case is to act as an estimation of the ultimately extractable reserve for which data is not available. In line with this, the focus is placed on the stocks in the environment because of the lack of data. The CML model derives two sets of characterization factors for ADP, being ADP Elements (ADPe) and ADP Fossil (ADPf). ADPe and ADPf are both quantified with reference to Antimony. Antimony was chosen as the reference as it is the first element (alphabetically) that had the required data available for quantifying both its extraction rate and its ultimate reserve [40]. The characterization factors are quantified by dividing the ratio of their extraction rate to square of their ultimate reserve by the same ratio for Antimony. ADPe is expressed in units of kilogram of antimony equivalents (kg Sb-eq.) and ADPf in Megajuoles (MJ).

Ozone depletion

The ozone layer (15-20 km high) surrounds the planet like a bubble and acts as a filter against harmful UV-B radiation produced by the sun. Ozone (O_3) is formed in the stratosphere through the reaction of oxygen (O_2) with oxygen atoms (O) produced from the dissociation of oxygen with exposure to short-wavelength UV-light ($O_2 \rightarrow O + O$), thus giving the simplified reaction mechanism of $O_2 + O \rightarrow O_3$. Anthropogenic emissions deplete the ozone allowing solar UV-B radiation to reach earth´s surface, which causes harmful impacts on human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials [42]. According the Montreal Protocol, 200 individual substances have been assigned an Ozone Depletion Potential (ODP), including chloro-fluorocarbons (CFCs), halons, carbon tetrachloride (CTC), hydrochlorofluorocarbons (HCFCs), hydrobromofluorocarbons (HBFCs), among others [43].

Ozone Depletion Potentials (ODPs) are the characterization factors (expressed in kg CFC-11-eq.) to aggregate and assess the interventions for the impact category stratospheric ozone depletion. The ODP concept was introduced by Wuebbles in 1988 and it is taken by the CML method [34]. The model indicates that the ODPs represent the relative changes in the ozone column due to an instantaneous emission to the atmosphere, i.e., the ratio between the change in the stratospheric ozone column in the equilibrium state due to the annual emissions of a determined substance and the change in this column in the equilibrium state due to the annual emissions of CFC-11 [34].

Photochemical ozone creation

Ozone can be formed from the reaction between volatile organic compounds (VOCs) and nitrogen oxides in the presence of heat and sunlight in the troposphere. This is known as photochemical ozone production, also called as summer smog. Radiation from the sun and the presence of nitrogen oxides (NOx) and hydrocarbons imply complex chemical reactions, producing aggressive products, one of which is ozone.
Although ozone plays an important role to protect the stratosphere, it is classified as damaging at ground level. High concentrations of ozone are toxic to humans and it is suspected to damage vegetation and material.

The characterization factors derived are Photochemical Ozone Creation Potentials (POCPs), and are measured in kilograms of ethene equivalents (kg C_2H_4-eq.). The CML method does not use specific POCPs for volatile organic compounds (VOCs), but an average based on the estimated quantity of ozone formed photochemically by a given VOC [34]. Although, Nitrogen oxides act as a catalyst in the chemical reactions involved in photochemical smog formation, they are not considered in this model. In this sense, Heijungs et al. [35] has also suggested to calculate POCPs on the basis of a marginal approach in which NOx would also be included.

Primary energy demand

Primary energy demand refers the quantity of energy directly from the hydrosphere, atmosphere or geo-sphere or energy source without any anthropogenic changes. Therefore, this category is a useful indicator to estimate the depletion of energy resources considering a whole lifecycle of product or system. PED can be divided in two types of energy requirements, renewable and non-renewable resources. The first one is generally considered separately and includes hydropower, wind power, solar energy and biomass. The second one includes energy source such as natural gas and crude oil, both considered to produce energy and raw materials, for example for plastics, lignite and coal also for energy production and uranium being only used for electricity production in nuclear power stations.

For calculating the primary energy demand, the lower (net calorific value) or to the upper heating value (gross calorific value) of primary energy resources can be used, where the latter includes the evaporation energy of the water present in the flue gases. The net calorific value is the higher heating value minus the heat of vaporization of the water. In the case for standard combustion processes the re-condensation occurs in the surrounding environment, thereby the energy to vaporize the water is not recovered [36,44].

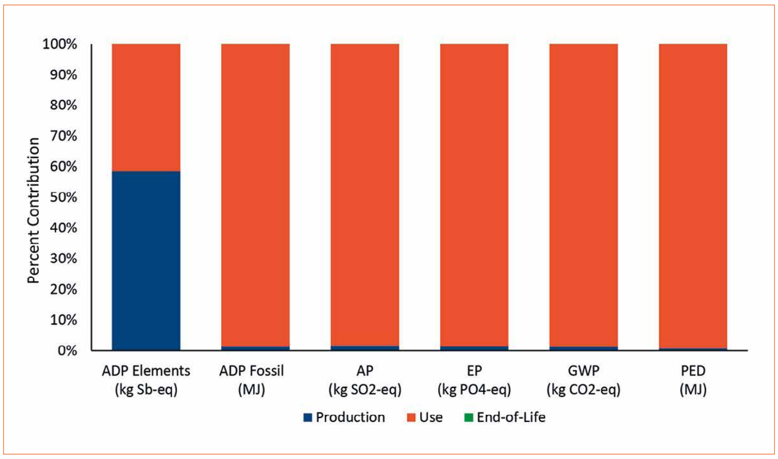

Figure 2: Percent contribution of the production, use and end-of-life disposal life cycle stages to each impact category for conventional LED luminaires studied as part of the Repro-light

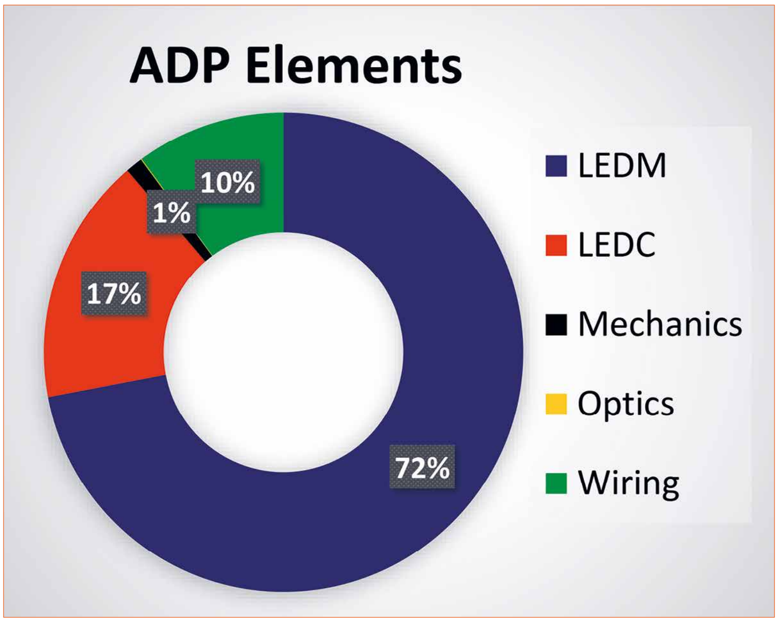

Figure 3: Percentage distribution of each component of the conventional LED luminaires assessed in Repro-light. LEDM: LED Module, LEDC: LED control system, Mechanics: Mechanical parts, Optics: Optical element and Wiring: Copper wires

Discussion and Concluding Remarks

The impact categories discussed in the previous sections can all be included in the LCIA stage of an LCA study. Including these impacts will help reflect the overall environmental impact of a product along its life cycle, including raw material extraction, production, manufacture, transport, use, and end-of-life disposal. Furthermore, including multiple impacts in an LCA study will not only allow for identification of the life cycle stage or process that contributes the most to the overall impact for one category, but also the differences amongst the impact categories. In this sense, comparisons can be used to optimize the design of a product across all impact categories towards the most sustainable option, as well as to avoid shifts of an impact from one category to another.
It should be noted that there are other impact categories that exist that have not been discussed. However, the intention of this paper is to identify the common impact categories that have been used in LCA studies of lighting products and to explain their environmental importance.

For LCA studies of lighting products, results suggest that the use stage energy consumption is the most contributing aspect to the overall impact for most impact categories considered [45][18][46]. Therefore, new technologies that reduce the energy consumed during the use phase will lead to reductions in these impacts. This aspect is being considered in the project, where technological advancements such as daylight control are being included in the LED luminaire design. Furthermore, improvements in the efficacies achieved by LEDs will reduce this use phase impact further. Changing the electricity grid mix may also lead to reductions of the impact due to electricity consumption for some categories, such as GWP. However, this fact should be studied in detail considering all environmental impact categories described above, as some renewable energy sources may vary the requirement for non-renewable raw materials used for electricity production, such as photovoltaic solar panels.

Since LED luminaires consist of electronic components and LED spots that have a specific material composition, the impact of these materials is also important. Assessment of the ADPe can be used to identify and compare the use of these materials in multiple luminaire design scenarios. Studies have further found that the electricity consumed during melting and casting during the production of circuit boards and aluminum heat sinks can have a considerable impact on the GWP and AP for the manufacturing phase [5]. Furthermore, the release of sulfur dioxide emissions during the smelting and converting processes in copper production can contribute significantly to the overall AP of the manufacturing stage [5,47].

For improvements to the impact from the end-of-life for luminaires, some scenarios could be considered that account for recovery of metals. This would be in line with one of the principles of the circular economy keeping materials and products "circulating" in the techno sphere, which avoids the extraction and production of raw materials. There are two methods for modeling end-of-life recycling in LCA studies, including closed-loop and open-loop recycling. Closed-loop recycling can be used if the characteristics of the recycled material are not considerably different compared to the virgin material [48] and thus it is able to be recycled back into the production of the product. Open-loop recycling, on the other hand, models the recovery of a material for use in other applications [48], thus contributing to the global view of the circular economy of keeping materials in use. The impact categories discussed can be used to assess different scenarios for end-of-life disposal and thus provide recommendations for strategies to improve circularity of lighting products. ■

Acknowledgements:
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References:
[1] J. Denneman and D. de Stoppelaar, "Voice of the Lighting Industry in Europe," 2015
[2] ISO-14040, Environmental management - Life cycle assessment - Principles and framework. 2006
[3] ISO-14044, "Environmental management - Life cycle assessment - Requirements and guidelines," 2006
[4] L. Navigant Consulting Europe, "Life Cycle Assessment of Ultra-Efficient Lamps, DEFRA," 2009
[5] Osram Opto Semiconductors: "Life cycle assessment of illuminants -A comparison of light bulbs, compact fluorescent lamps and LED lamps," 2009
[6] P. Principi and R. Fioretti, "A comparative life cycle assessment of luminaires for general lighting for the office - compact fluorescent (CFL) vs Light Emitting Diode (LED) - a case study," J. Clean. Prod., vol. 83, pp. 96-107, 2014
[7] L. Tähkämö and H. Dillon, "Life Cycle Assessment of Lighting Technologies," in Handbook of Advanced Lighting Technology, R. Karlicek, C.-C. Sun, G. Zissis, and R. Ma, Eds. Cham: Springer International Publishing, 2017, pp. 935-956
[8] University of Leiden, "Institute of environmental sciences (CML)." [Online]. Available: cml.leiden.edu
[9] M. Goedkoop and R. Spriensma, "The Eco-Indicator 99: A Damage Oriented Method for Life Cycle Impact Assessment," 2001
[10] M. Goedkoop, R. Heijungs, M. Huijbregts, A. De Schryver, J. Struijs, and R. van Zelm, "ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level," 2013
[11] J. Bare, "TRACI 2.0: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.0," Clean Technol. Environ. Policy, vol. 13, pp. 687-696, 2011
[12] R. K. Rosenbaum et al., "USEtox---the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment," Int. J. Life Cycle Assess., vol. 13, no. 7, p. 532, Oct. 2008
[13] M. Z. Hauschild et al., "Building a Model Based on Scientific Consensus for Life Cycle Impact Assessment of Chemicals: The Search for Harmony and Parsimony," Environ. Sci. Technol., vol. 42, no. 19, pp. 7032-7037, Oct. 2008
[14] R. Hischier et al., Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.2. 2010
[15] H. Zhang, J. Burr, and F. Zhao, "A comparative life cycle assessment (LCA) of lighting technologies for greenhouse crop production," J. Clean. Prod., vol. 140, pp. 705-713, 2017
[16] Z. Y. Yu, V. K. Soo, and M. Doolan, "The Effect of Consumer Behaviour on the Life Cycle Assessment of Energy Efficient Lighting Technologies," Procedia CIRP, vol. 40, pp. 185-190, 2016
[17] K. S. Sangwan, V. Bhakar, S. Naik, and S. N. Andrat, "Life Cycle Assessment of Incandescent, Fluorescent, Compact Fluorescent and Light Emitting Diode Lamps in an Indian Scenario," Procedia CIRP, vol. 15, pp. 467-472, 2014
[18] L. Tähkämö, M. Bazzana, P. Ravel, F. Grannec, C. Martinsons, and G. Zissis, "Life cycle assessment of light-emitting diode downlight luminaire---a case study," Int. J. Life Cycle Assess., vol. 18, no. 5, pp. 1009-1018, Jun. 2013
[19] E. Elijošiutė, J. Balciukevičiūtė, and G. Denafas, "Life Cycle Assessment of Compact Fluorescent and Incandescent Lamps: Comparative Analysis," Environ. Res. Eng. Manag., vol. 61, 2012
[20] United States Department of Energy, "Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products Part 2: LED Manufacturing and Performance," 2012
[21] T. Welz, R. Hischier, and L. M. Hilty, "Environmental impacts of lighting technologies — Life cycle assessment and sensitivity analysis," Environ. Impact Assess. Rev., vol. 31, no. 3, pp. 334-343, 2011
[22] I. Quirk, "Life-Cycle Assessment and Policy Implications of Energy Efficient Lighting Technologies." [Online]. Available: https://nature.berkeley.edu/classes/es196/projects/2009final/QuirkI_2009.pdf
[23] D. Parsons, "The environmental impact of compact fluorescent lamps and incandescent lamps for Australian conditions," Env. Eng, vol. 7, 2006

[24] R. P. Pfeifer, "Comparison between filament lamps and compact fluorescent lamps," Int. J. Life Cycle Assess., vol. 1, no. 1, pp. 8-14, Mar. 1996
[25] A. Gydesan and D. Maimann, "Life cycle analysis of integral compact flurescent lamps versus incandescent lamps - energy and emissions," Proc. Right Light, vol. 1, pp. 411-417, 1991
[26] Philips, "ENVIRONMENTAL PRODUCT DECLARATION as per ISO 14025 and EN 15804 (Ledline system)," 2014. [Online]. Available: https://epd-online.com/PublishedEpd/Download/6905
[27] David Trubridge, "Environmental Product Declaration Kitset Pendant Light Fittings," 2015. [Online]. Available: https://www.davidtrubridge.com/assets/resources/DavidTrubridge-EPD.pdf
[28] H. de Bruijn, R. van Duin, and M. A. J. Huijbregts, Handbook on Life Cycle Assessment, 1st ed. Springer Netherlands, 2002
[29] J. Drielsma et al., "Mineral resources in life cycle impact assessment- defining the path forward," Int. J. Life Cycle Assess., vol. 21, pp. 85-105, 2016
[30] Intergovernmental panel on climate change, "How do Human Activities Contribute to Climate Change and How do They Compare with Natural Influences?" [Online]. Available: https://wg1.ipcc.ch/publications/wg1-ar4/faq/wg1_faq-2.1.html
[31] Sustanaible Developement Goals, "Greenhouse gas levels in atmosphere reach new record," 2018. [Online]. Available: https://www.un.org/sustainabledevelopment/blog/2018/11/greenhouse-gas-levels-in-atmosphere-reach-new-record/
[32] N. H. and K. M. (Eds. J.T. Houghton, L.G. Meira Filho, J. Bruce, Hoesung Lee, B.A. Callander, E. Haites, "Radiative forcing of climate change and an evaluation of the IPCC IS92 Emission scenarios," 1994
[33] A. K. & K. M. Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, Climate change 1995: the science of climate change. Cambridge University Press, 1996
[34] J. B. Guinée et al., Handbook on Life Cycle Assessment, 1st ed. Springer Netherlands, 2002
[35] A. W. S. Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes and R. van D. & H. de G. A.M.M. Ansems, P.G. Eggels, Environmental Life Cycle Assessment of products. Guide and Backgrounds. CML, Leiden University, Leiden, 1992
[36] M. G. Martin Baitz, Cecilia Makishi Colodel, Thilo Kupfer, Julia Florin, Oliver Schuller, Morten Kokborg, Annette Köhler, Daniel Thylmann, Alexander Stoffregen, Steffen Schöll, Julia Görke, Matthias Rudolf, "GaBi Database & Modelling Principles," 2016
[37] P.-O. Roy, L. B. Azevedo, M. Margni, R. van Zelm, L. Deschênes, and M. A. J. Huijbregts, "Characterization factors for terrestrial acidification at the global scale: A systematic analysis of spatial variability and uncertainty," Sci. Total Environ., vol. 500-501, pp. 270-276, 2014
[38] M. Klinglmair, S. Sala, and M. Brandão, "Assessing resource depletion in LCA: a review of methods and methodological issues," Int. J. Life Cycle Assess., vol. 19, pp. 580-592, 2014
[39] UNEP, Assessing the Environmental Impacts of Consumption and Production: priority products and minerals. UNEP International Panel for Resource Management, Paris, 2010
[40] L. van Oers and J. Guinée, "The Abiotic Depletion Potential: Background, Updates, and Future," Resources, vol. 5, no. 16, pp. 1-12, 2016
[41] EC, "Report on Critical Raw Materials for the EU- Critical Raw Material Profiles." European Commission: Ref.Ares(2015)3396873, 2015
[42] UNEP, "Environmental effects of ozone depletion, 1998 assessment.," J. Photochem. Photobiol. B Biol., vol. 46, 1998
[43] European Environment agency, "Ozone-depleting substances 2018," 2018
[44] M. Baitz et al., "GaBi Database & Modelling Principles 2013," 2013
[45] L. Tähkämö, M. Puolakka, L. Halonen, and G. Zissis, "Comparison of Life Cycle Assessments of LED Light Sources," J. Light Vis. Environ., vol. 36, pp. 44-54, 2012
[46] P. Principi and R. Fioretti, "A comparative life cycle assessment of luminaires for general lighting for the office - compact fluorescent (CFL) vs Light Emitting Diode (LED) - a case study," J. Clean. Prod., vol. 83, pp. 96-107, 2014
[47] J. C. Molinare, "Sustainability analysis of copper extraction and processing using LCA methods," Imperial College of Science, Technology and Medicine Royal School of Mines, 2014
[48] S. Huysman et al., "The recyclability benefit rate of closed-loop and open-loop systems: A case study on plastic recycling in Flanders," Resour. Conserv. Recycl., vol. 101, pp. 53-60, 2015

Design and Tolerancing of Freeform Microlens Arrays for Solid-State Lighting

Since LEDs were introduced for lighting applications, freeform optics have been recognized as beneficial optical elements when it comes to improved and extended light distribution capabilities beyond what is possible with conventional solutions. Oscar Fernández, Frédéric Zanella, Tamara Aderneuer and Rolando Ferrini from CSEM demonstrate a new design method for freeform microlens arrays (FMLAs) that can be used for a broad range of lighting applications tasks.

Freeform lenses have demonstrated their potential to achieve illumination schemes that are beyond reach with standard, i.e. rotationally symmetric, solutions. On the other hand, freeform microlens arrays (FMLAs), with substantially reduced dimensions, offer additional benefits such as large-area coverage, reduced volume and weight, higher potential for integration, compatibility to cost-competitive manufacturing processes, flexibility and higher robustness upon shocks and vibrations. In spite of these advantages, the application of FMLAs have so far been limited to relatively simple tasks such as laser beam homogenization, light diffusion and de-glaring. Here we present an innovative design method that will extend the applicability of FMLAs to a wider range of tasks, especially in the domain of Solid-State Lighting. This design method is compatible with extended light sources and allows straight forward tolerance analysis for manufacturing.

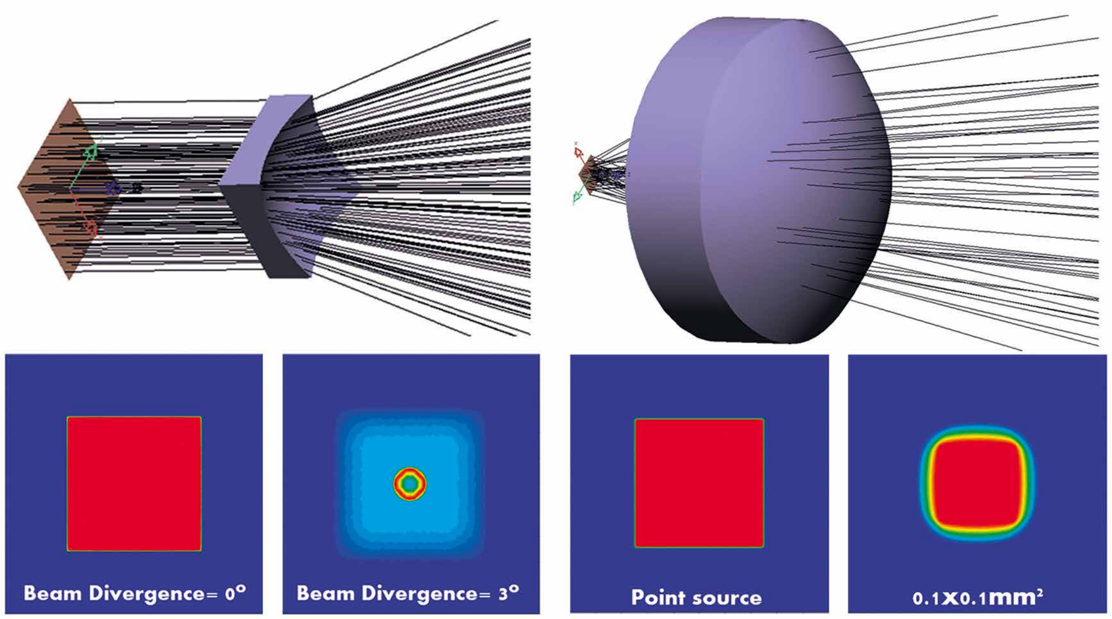


Figure 1:
Non-symmetrical illuminance patterns achieved with freeform optics and pattern degradation arising from the finite étendue of the light source. Left) Large area light source emitting 0° and 3° divergence beams. Right) Point and extended light sources emitting 4° beams

Freeform Optics for Solid-State Lighting

The irruption of LED (Light Emitting Diodes) technology for lighting has risen the expectations of lighting designers eager for innovative "lighting solutions" with truly customized far-field Illuminance, also expressed as Luminous Intensity Distribution (LID).

In order to cope with the generated expectations, optical engineers need to come up with new tools adapted to these "new" light sources [1]. The so-called freeform optical components (e.g. lenses) deserve particular mention for they have demonstrated substantial performance gains when dealing with complex illumination patterns for different applications including office [2], road lighting [3], automobile headlamps [4,5], camera flashes for smart phones [5], image projectors [6], etc.

Freeform Lenses - Design Challenges

Despite the benefits of freeform lenses, their design faces severe limitations. On one side, it is limited to zero-étendue light sources (i.e. either infinitely small or emitting perfectly collimated beams) where each and every point of the lens is interrogated by only one ray. Departure from these tight conditions causes severe degradation of the illumination pattern (Figure 1) and the lens design must be appropriately corrected [i].

On the other hand, freeform lenses for lighting applications are quite often designed using the ray-mapping method [7,8,9] and hence defined as 3D point clouds whereas analytical expressions are more convenient for optimization or fine tuning. In most cases an acceptable fitting can only be achieved for mathematical expressions with unmanageably large number of parameters (Figure 2). Furthermore, the XY coordinates of the freeform surface point cloud are not uniformly spaced for they are dictated by the mapping and ultimately by the angular properties of the source and the targeted irradiance distribution. The typical workaround solution, 3D interpolation, must, however, be performed with special care (Figure 3).

We then see that the benefits of freeform components, brought by the lack of symmetry constrains, are accompanied by a considerable increase in the mathematical complexity (please note the profound implications on manufacturing and quality control aspects).

Fortunately, the design and manufacturability of freeform optical surfaces for complex illumination tasks can be simplified by using

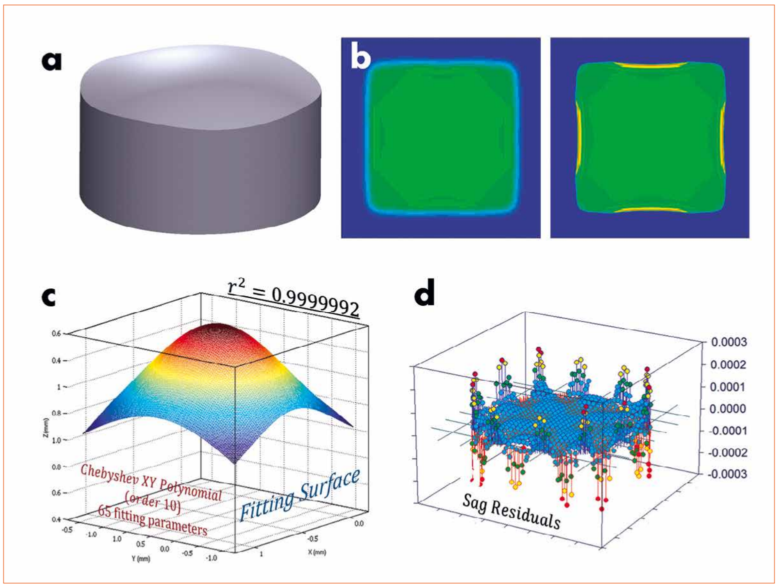
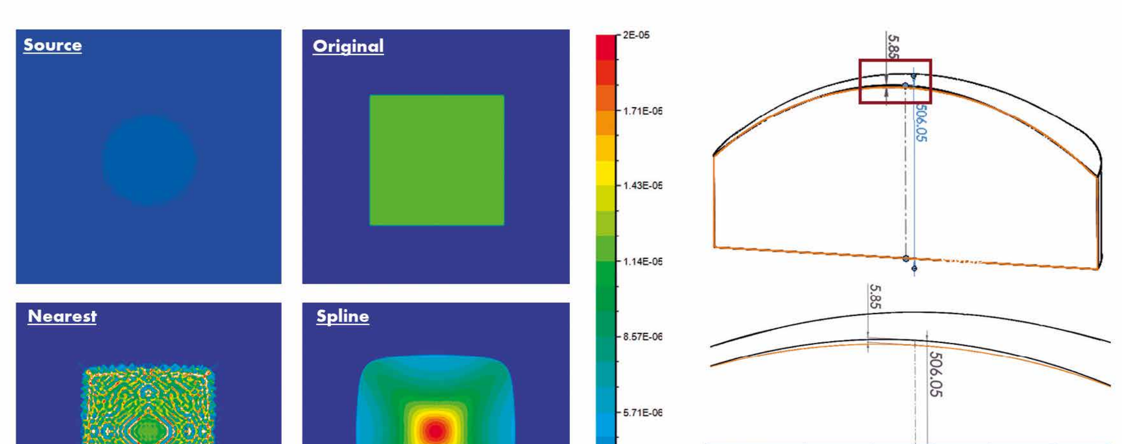
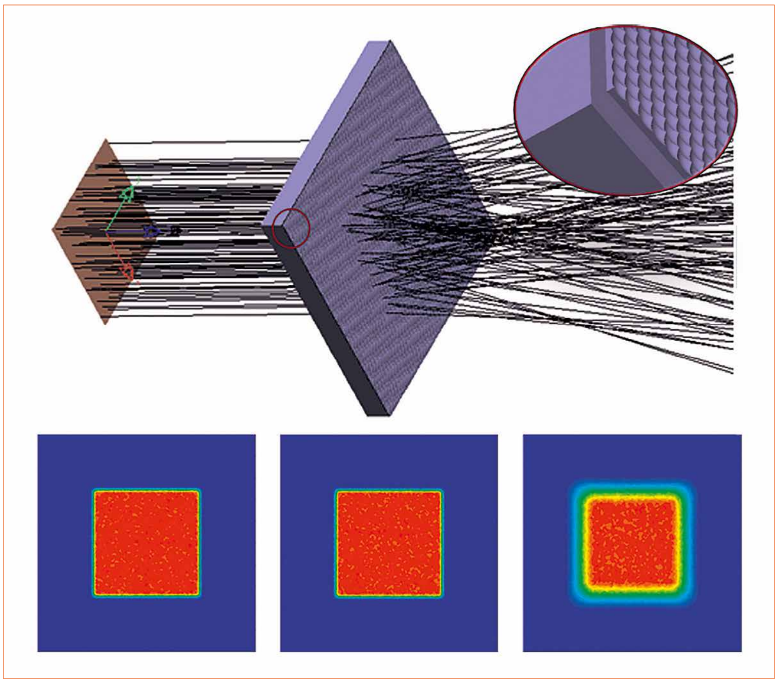


Figure 2:
Fitting freeform surface to analytical expressions.
a) Freeform lens;
c) Best fitting achieved for a 65 parameter Chebyshev polynomial;
d) fitting residuals (in µm) and
b) simulated irradiance distribution with the original lens (left) and with the fitted lens (right)

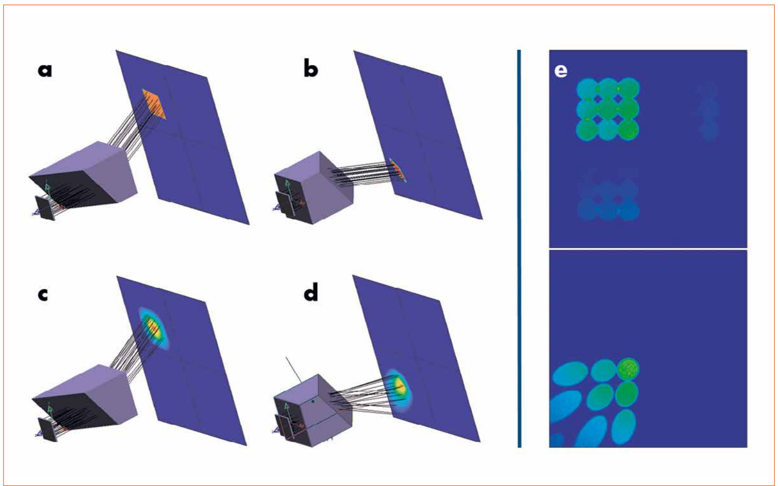


	Original	Nearest	Error (%)	Spline	Error (%)
Surface (mm²)	5.97879	5.98172	0.0490	5.987652	0.1482
Volume (mm³)	0.737854	0.737791	-0.0085	0.737775	-0.0107

Figure 2:
3D interpolation of freeform point clouds. Left) irradiance distribution produced by the source and the source coupled to the original freeform lens and interpolated lenses using different interpolation methods [ii]. Right-top) sketched cross-section view of the original (orange) and spline (black) interpolated freeform surface. Right-bottom) calculated area and volume of the original and interpolated lenses using SolidWorks Material Analysis Tool



Figures 4:
Ray-tracing of FMLA illuminated by a large light source and irradiance distribution over a planar detector located 20 mm away from the source



Figures 5:
Light management using prismatic structures illuminated by narrow-beam square light source

relatively simple optical microstructures as "building blocks" conveniently arrayed.

Freeform Microlens Arrays

The use of optical microstructures arranged following more or less regular 2D patterns is definitely not new. They are, in fact, found in several thin-film solutions for light diffusion/mixing and de-glaring [10] and for laser beam homogenization [4,11]. These so-called (Freeform) Microlens Arrays, (F)MLA, offer a series of advantages over macroscopic lenses including reduced footprint and material usage, compatibility with large area applications and roll-based manufacturing processes to mention just few [2 & references therein].

Figures 4 show ray-tracing of FMLA illuminated by a large light source and irradiance distribution over a planar detector located 20 mm away from the source. Left: Perfectly collimated source with its center located at the origin, Center: perfectly collimated with its center displaced by Δx, Δy=0.2165mm. Right: centered source with a beam divergence of 3°. The dimensions of the sources are 0.5x0.5 mm^2 and the shown part of the detector is 50x50 mm^2

More remarkably, the use of optical microstructures makes it possible to condense all the relevant information into a very small area. Such "unit cell", which contains all the optically relevant information, can subsequently be replicated over a much larger area that then become optically functional.

Because of its small dimensions, the unit cell can be fabricated and characterized timely and cost effectively for preliminary quality assessments [12]. On the other hand, FMLAs are more tolerant to source-lens misalignments and to non-zero étendue sources (Figure 4). Finally, the unit cell can comprise individual microlenses conveniently arranged to render the desired functionality and selected from a large "catalogue" of structures with proven manufacturability and quantified tolerances. We will demonstrate these three advantages with two examples: namely freeform microfacets and microlenses.

Figures 5 demonstrate light management using prismatic structures illuminated by narrow-beam square light source; a) & c) light entering through the tilted face of the prism; b & d) Incoming beam entering through the flat face. On the top figures (a & b) the incoming beam is perfectly collimated and at the bottom has a divergence of ±4°. Right) Irradiance distribution using a 3x3 microprism array illuminated by a collimated round light source though the structured and flat face (top and bottom respectively)

Example 1 - freeform microfacets

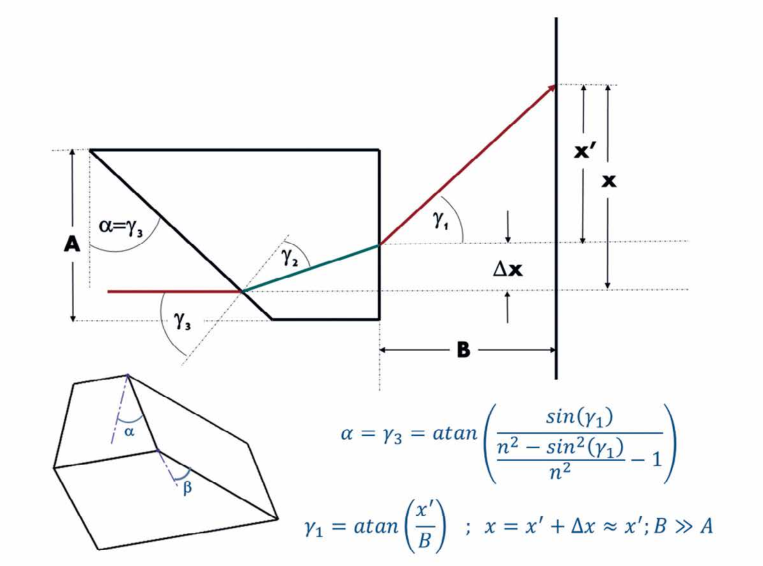
Facets deflect light in directions precisely defined by the angles they form with respect to the incoming light beam [13,14]. Moreover, when the facets point towards the sources the spot suffers only small deformation as compared to the opposite arrangement (Figure 5).

For a given material, the deflection angle of the out-coming beam and hence the position of the resulting spot on the far-field target plane depends uniquely on the prism angles and can readily be calculated (Figure 6).

Because of the small size of the unit cell compared to the incoming beam, the superposition principle holds, i.e. the effect of the unit cell is the sum of the contribution of the individual components tested separately. Therefore, by wisely combining different facets in the unit cell the desired light distributions can be achieved as shown in figure 7.

Although demonstrated here for simple 3x3 unit cells, computational power today enables the design of unit cells with much larger number of facets for more complex light distributions.

Noteworthy, the relatively simple geometry of the individual facet simplifies the tolerancing analysis compared to the case of continuous macroscopic lenses design for the same purpose.



$$\alpha = \gamma_3 = atan\left(\frac{sin(\gamma_1)}{\frac{n^2 - sin^2(\gamma_1)}{n^2} - 1}\right)$$

$$\gamma_1 = atan\left(\frac{x'}{B}\right) \quad ; \; x = x' + \Delta x \approx x'; B \gg A$$

Figure 6:
Top) Sketch of a ray propagation through a facet (n_2=1.5) in air for the simple case of β=0. Bottom) Mathematical expression relating the target position and the required angle of the prism

Example 2 - freeform microlens arrays

Non-uniform light distributions are interesting for many applications [2]. Such light distributions can be achieved by exploiting the superposition principle in a unit cell comprising freeform microlenses.

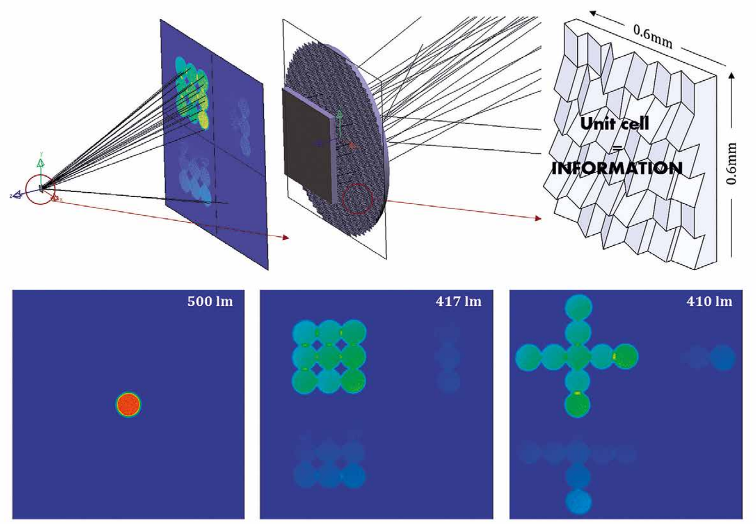


Figure 7:
Ray trace propagation of a collimated beam through a faceted surface, the light-source-FMLA system, the unit cell and three irradiance distributions

Figure 7 shows the ray trace propagation of a collimated beam through a faceted surface (top-left) and close-up view of the light-source-FMLA system (top-middle) and the unit cell (top-right). The bottom images show the irradiance distribution on the detector produced by the light source alone and coupled with two different faceted surfaces purposely designed to produce an off-axis 3x3 and cross dot arrays

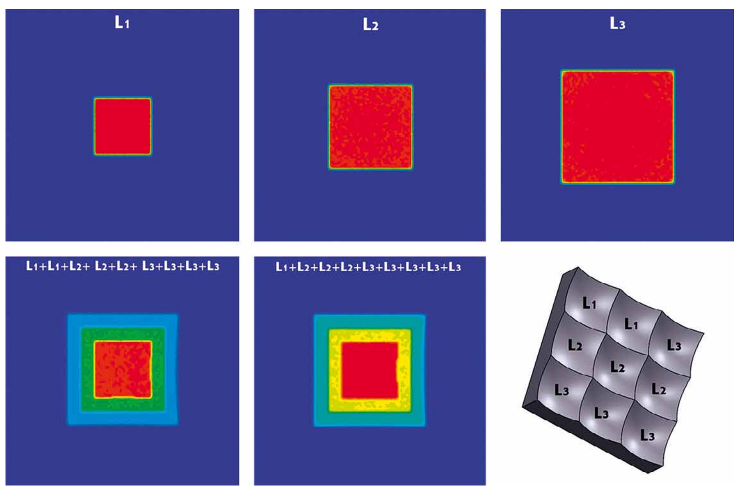


Figure 8:
Superposition principle applied to achieve customized non-uniform irradiance distributions

Figure 8 explains the superposition principle applied to achieve customized non-uniform irradiance distributions. Top) Irradiance distributions achieved by lenses L1, L2 and L3. Bottom) Light distribution achieved with an FMLA arrays combining the three lenses in the specified manner and 3D CAD model of one of the FMLAs

As exemplified in figure 8, freeform lenses designed for uniform illuminance over zones of different areas can be combined to produce different non-uniform patterns. As already highlighted, increasing the number of individual components in the unit cell (e.g. from 3x3 to 10x10) expands the design possibilities substantially thus enabling more complex illuminance distributions.

Conclusions

Freeform optics and freeform lenses, in particular, enable light distributions beyond the reach of standard symmetric components. However, the available design methods are rather limited for real lighting problems that involve light sources of finite dimensions and/or divergent beams.

The use of freeform microlens arrays can, to a great extent, alleviate these limitations.

The possibility to achieve prescribed illuminations patterns has been demonstrated, including precisely non-uniform ones of much benefit in several situations. In addition, FMLAs offer unique advantages for fabrication and metrology, in general, and for preliminary assessments, in particular.

It must be noticed that the cases used in this article were selected for demonstrative purposes and serve no other purpose. Nonetheless, FMLAs are currently being designed at CSEM with relevant optical functionalities for real lighting applications. ■

Remarks:

[i] All the ray-tracing simulations shown in this article were performed with LightTools software assuming BK7 for the lens material and using 15 million rays.

[ii] https://www.originlab.com/doc/Origin-Help/Math-2D-Inter-extrapolate#Interpolate_From_XY

References

[1] M. Škereň, LED Lighting Requires New Approaches in Optics, LED Professional Review, Issue 67, pp. 88-91 (2018)

[2] O. Fernández, T. Aderneuer and R. Ferrini, Freeform optics for precise non-uniform illumination patterns, Proceedings of the LED Professional Symposium and Exhibition, Bregenz Sept. 24-26 (2019)

[3] Z. Feng, Y. Luo, and Y. Han, Design of LED freeform optical system for road lighting with high luminance/illuminance ratio, Opt. Express 18, 22020-22031 (2010)

[4] P. Ge, Y. Li, Z. Chen and H. Wang, LED high-beam headlamp based on free-form microlenses, Appl. Opt. 53, 5570-5575 (2014)

[5] R. Mohedano, J. Chaves and M. Hernández, Free-form illumination optics, Adv. Opt. Techn. 2016; 5(2): 129-13

[6] J. Ye, L. Chen, X. Li, Q. Yuan and Z. Gao, Review of optical freeform surface representation technique and its application, Opt. Eng. 56 (11) 110901 (2017)

[7] F. Fang, Y. Cheng and X. Zhang, Design of freeform optics, Adv. Opt. Techn. 2013; 2(5-6): 445-453

[8] J.-J. Chen, Z.-Y. Huang, T.-S. Liu, M.-D. Tsai and K.-L. Huang, Freeform lens design for light-emitting diode uniform illumination by using a method of source-target luminous intensity mapping, Appl. Opt. 54 (28), E146-E152 (2015).

[9] D. Ma, Z. Feng and R. Liang, Tailoring freeform illumination optics in a double-pole coordinate system, Appl. Opt. 54 (9), 2395-2399 (2015)

[10] https://www.brightviewtechnologies.com/

[11] T.R.M Sales, S. Chakmakjian, G. Michael Morris and D. J. Schertler, Light Tamers. Engineered microlens arrays provide new control for display and lighting applications, Photonics Spectra, June (2004). Available on-line: https://www.rpcphotonics.com/pdfs/Light_Tamers.pdf

[12] O. Fernández, T. Aderneuer and R. Ferrini, Semi-Empirical Characterization of Freeform Microlens Arrays, LED Professional Review, Issue 72, pp.42-48 (2019)

[13] L. Liu, T. Engel, M. Flury and M De Visser, Faceted structure: a design for desired illumination and manufacturing using 3D printing, OSA CONTINUUM 1 (1), pp.26-40 (2018)

[14] M. De Visser, R. van der Hilst and S. Christopher, Additive Optics Design and Fabrication for Smart Lighting Systems and Tailored Project Solutions, LED Professional Review Issue 68, pp. 82-86 (2018)

Spread Spectrum Frequency Modulation Reduces EMI

LED drivers are often accused of producing terrible EMI and THD on the power grid. There are different methods to suppress or filter these undesired modulations and effects. However, it is always the better solution not to produce them rather than repair afterwards. Spread Spectrum Frequency Modulation (SSFM) is a method to reduce EMI right at the "place of origin". Greg Zimmer, marketing manager for Analog Devices' Battery Management Systems Group, and Kevin Scott, product marketing manager for the Power Products Group at Analog Devices, have a lot of experience in this field and explain what SSFM is, how it works, how EMI is measured and how SSFM regulators and LED drivers can be designed based on the Analog's SSFM in silicon oscillators and LED controllers with SSFM.

Electromagnetic radiation (EMR), electromagnetic interference (EMI), and electromagnetic compliance (EMC) are terms that pertain to energy from electrically charged particles and the associated magnetic fields that can potentially interfere with circuit performance and signal transmissions. With the proliferation of wireless communications, the plethora of communication devices, and the growing number of communication methods (including cellular, Wi-Fi, satellite, GPS, etc.) using more and more of the frequency spectrum (with some bands overlapping), electromagnetic interference is a fact of life. To mitigate the effects, many governmental agencies and regulatory organizations have set limits on the amount of radiation that can be emitted by communications devices, equipment, and instruments. One example of such a specification, CISPR 16-1-3, deals with radio disturbance and immunity measuring apparatuses and measuring methods.

Electromagnetic interference can be characterized as conducted (transmitted via the power line) or radiated (transmitted through the air). Switching power supplies (SMPS) generate both types. One technique to reduce conducted and radiated interference is spread spectrum frequency modulation (SSFM). This technique is used in several of inductor- and capacitor-based SMPS, silicon oscillators, and LED drivers to spread the noise over a wider band, thereby reducing the peak and average noise at a particular frequency.

SSFM improves EMI by not allowing emitted energy to stay in any one receiver band for a significant length of time. The key determinants for effective SSFM are the amount of frequency spreading and the modulation rate. For switcher applications, spreading of ±10% is typical and the optimal modulation rate is dictated by the modulation profile. Various methods of frequency spreading are used for SSFM, such as modulating the clock frequency with a sine wave or a triangular wave.

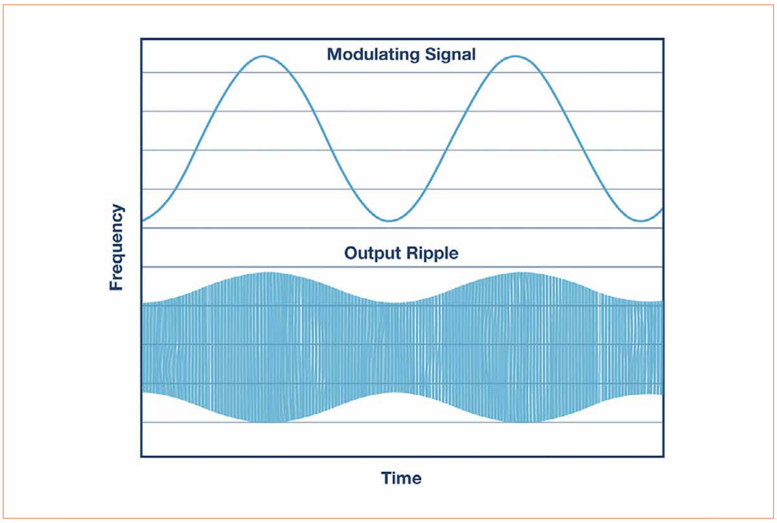


Figure 1:
Illustration of switching regulator ripple due to sinusoidal frequency modulation of the clock

Modulation Method

Most switching regulators exhibit ripple that is frequency dependent: more ripple at lower switching frequencies and less at higher switching frequencies. As a result, a switcher's ripple will exhibit amplitude modulation if the switching clock is frequency modulated. If the clock's modulating signal is periodic, such as a sine wave or triangle wave, there will be a periodic ripple modulation and a distinct spectral component at the modulating frequency (Figure 1).

Since the modulating frequency is much lower than the switcher's clock, it may be difficult to filter out. This could lead to problems, such as audible tones or visible display artifacts, due to supply noise coupling or limited power supply rejection in the downstream circuitry. A pseudo-random frequency modulation can avoid this periodic ripple. With pseudo-random frequency modulation, the clock shifts from one frequency to another in a pseudo-random fashion. Since the switcher's output ripple is amplitude modulated by a noise-like signal, the output looks as if there is no modulation and the downstream system implications are negligible.

Modulation Amount

As the range of SSFM frequencies increases, the percentage of in-band time is reduced. In figure 2, note how the modulated frequency appears as a wideband signal with a 20 dB lower peak value when compared to the single unmodulated narrowband signal. If the emitting signal enters the receiver's band infrequently and for short periods (relative to its response time), significant EMI reduction occurs. For example, frequency modulation of ±10% will be much more effective at EMI reduction than frequency modulation of ±2%. However, switching regulators have a limited range of frequencies that they can tolerate. As a general rule, most switching regulators can easily tolerate frequency variation of ±10%.

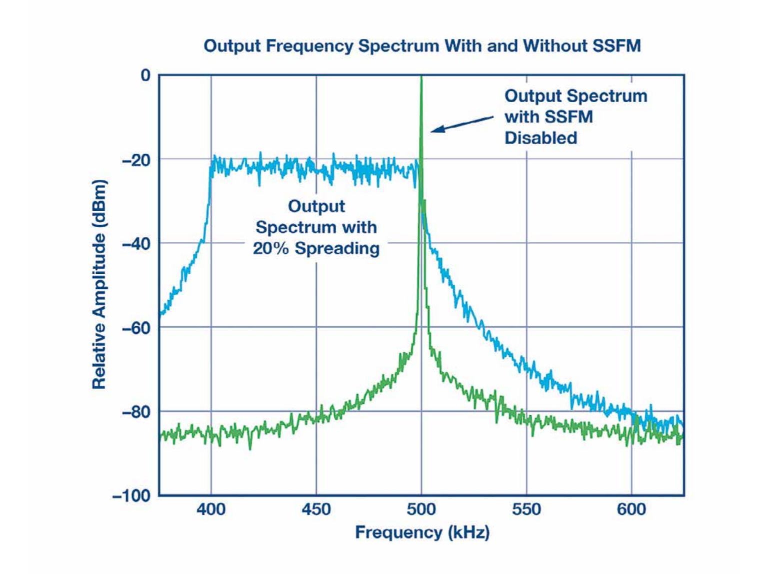


Figure 2: Spread spectrum modulation results in a wider clock frequency band with lower peak energy

Modulation Rate

Similar to the modulation amount, as the rate of frequency modulation increases (the hop rate), the time that EMI will be in-band for a given receiver will decrease and EMI will be reduced. There is a limit, however, to the rate of frequency change (dF/dt) that a switcher can track. The solution is to find the highest modulation rate that does not impact the switcher's output regulation.

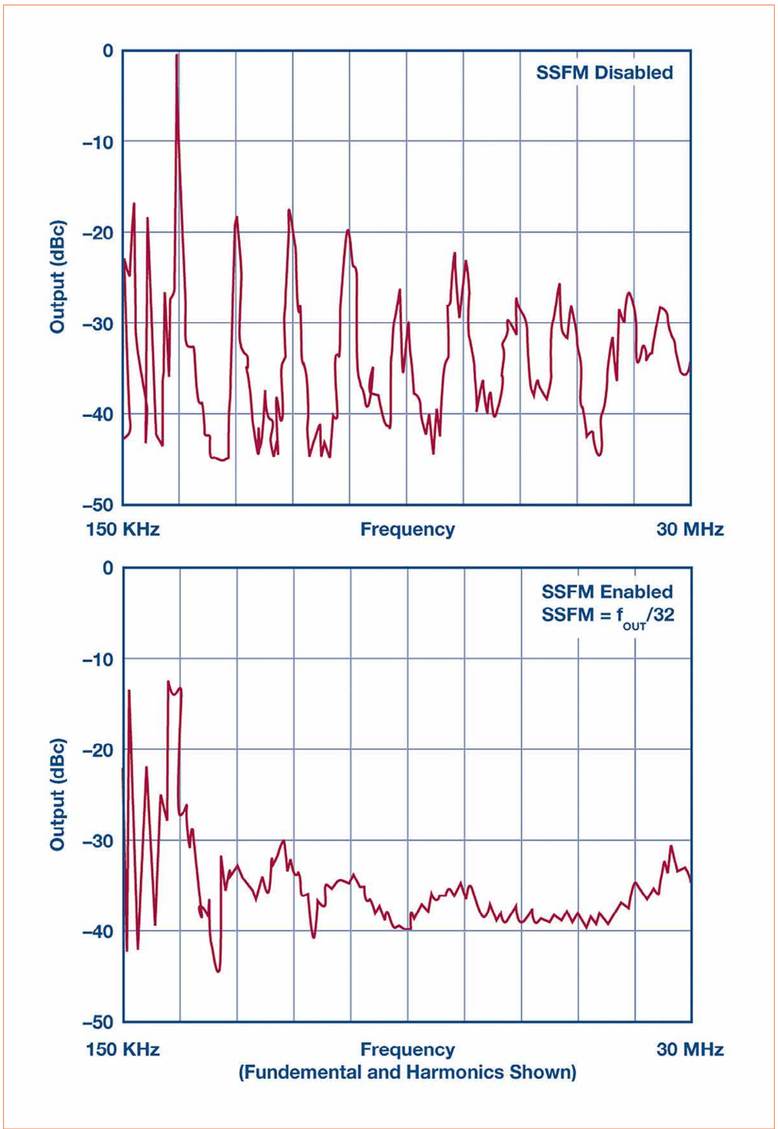
Measuring EMI

The typical methods for measuring EMI are referred to as peak detection, quasi-peak detection, or average detection. For these tests, the bandwidth of the test equipment is appropriately set to reflect the real-world bandwidth of interest and determines the effectiveness of SSFM. When frequency modulated, the detector responds as the emissions sweep through the detector's band. When the bandwidth of the detector is small compared to the modulation rate, the detector's finite response time results in an attenuated EMI measurement. In contrast, the detector's response time does not affect a fixed frequency emission and no EMI attenuation is observed. The peak detection test shows an improvement with SSFM that directly corresponds to the amount of attenuation. The quasi-peak detection test can show even further EMI improvement since it includes the impact of the duty cycle. Specifically, a fixed frequency emission produces a duty cycle of 100%, while the duty cycle from SSFM is reduced according to the amount of time that the emissions are within the detector's band. Finally, the average detection test can show the most dramatic EMI improvement since it filters the peak-detected signal with a low pass, resulting in the average in-band energy. Unlike fixed frequency emissions, where average and peak energy is equal, SSFM attenuates both the peak detected energy and the amount of in-band time, resulting in a lower average detection result. Many regulatory tests require that systems pass both quasi-peak and average detection tests.

SSFM and Receiver Bandwidth

At any instant in time, peak emissions from a switching regulator may appear to be the same, whether or not SSFM is enabled. How is the possible? The effectiveness of SSFM is in part dependent upon the bandwidth of the receiver. To receive an instantaneous snapshot of emissions requires an infinite

Figure 3: Switching regulator output spectrum (9 kHz resolution bandwidth) with and without SSFM enabled



bandwidth. Every practical system has a limited bandwidth. If the clock frequency changes faster than the bandwidth of the receiver, the reduction in received interference will be significant.

SSFM in Silicon Oscillators

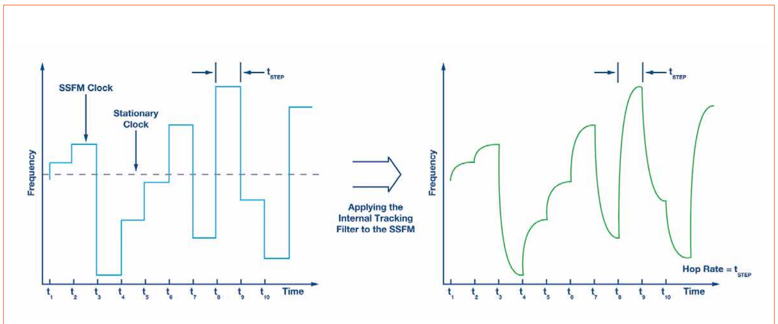
SSFM multiphase silicon oscillators are, for instance, available in eight, four, and two output versions [1,2,3]. These devices are often used to clock switching power supplies. Multiphase operation effectively increases the system's switching frequency (since the phases appear as an increase in switching frequency) and spread spectrum modulation causes each device to switch over a range of frequencies, spreading the conducted EMI over a wider frequency band. The frequency range may cover some kHz up to several MHz (e.g. 20 MHz). The two output versions may 180° or 90° phase shift between them. The former is ideal for synchronizing two single switching regulators and the latter is ideal for synchronizing two dual, 2-phase switching regulators. The proposed quad multiphase silicon oscillator can be programmed for 2-, 3-, or 4-phases that are equally spaced. The respective eight output version with a 12 kHz to 6.67 MHz frequency range can be programmed for up to 8 phases.

To address the periodic ripple mentioned above, these silicon oscillators use a pseudo-random frequency modulation. Using this technique, the switching regulator clock is shifted from one frequency to another in a pseudo-random fashion. The higher the rate of frequency shifting, or the hop rate, the less time the switcher is operating at a given frequency and the less time EMI will be in-band for a given receiver interval.

There is a limit, however, to the rate of frequency hopping. If the frequency hops at a rate beyond the switching regulator's bandwidth, output spikes may occur at the clock frequency transition edge. Lower switcher bandwidths result in more pronounced spikes. For this reason, proprietary tracking filter smooths the transition from one frequency to the next (the LTC6902 uses an internal 25 kHz low-pass filter). The internal filter tracks the hop rate to provide optimal smoothing for all frequencies and modulation rates.

This filtered modulating signal may be acceptable for many logic systems, but the cycle-to-cycle jitter issues must be considered carefully. Even with the tracking filter, the bandwidth of a given regulator may still be insufficient for high rates of frequency modulation. For bandwidth limitations, the frequency hop rate can be reduced from a default rate that is 1/16th of the nominal frequency, to a rate of 1/32nd or 1/64th of the nominal frequency.

Figure 4: Pseudo-random modulation illustrating the effect of an internal tracking filter



SSFM in Power Supplies

Switching regulators operate on a cycle-by-cycle basis to transfer power to the output. In most cases, the frequency of operation is either fixed or constant based on the output load. This method of conversion creates large components of noise at the frequency of operation (fundamental) and multiples of the operating frequency (harmonics).

8 A, 2.7 V to 5.5 V_{IN} DC-to-DC µModule® buck regulator with SSFM

To reduce switching noise, the proposed device [4] can operate with spread spectrum enabled by tying the CLKIN pin to SVIN (low power circuitry supply voltage pin). In spread spectrum mode, the internal oscillator is designed to produce a clock pulse whose period is random on a cycle-by-cycle basis but fixed between 70% and 130% of the nominal frequency. This has the benefit of spreading the switching noise over a range of frequencies, thus significantly reducing the peak noise. Spread spectrum operation is disabled if CLKIN is tied to ground or if it's driven by an external frequency synchronization signal. Figure 5 shows the operating circuit with spread spectrum operation enabled. A capacitor value of 0.01 µF must be placed from the PLL LPF pin to ground to control the slew rate of the spread spectrum frequency change.

Component values are determined from the equation:

$$R_{SR} \geq \frac{1}{-(\ln(1-0.592/V_{IN})\cdot 500\cdot CSR)}$$

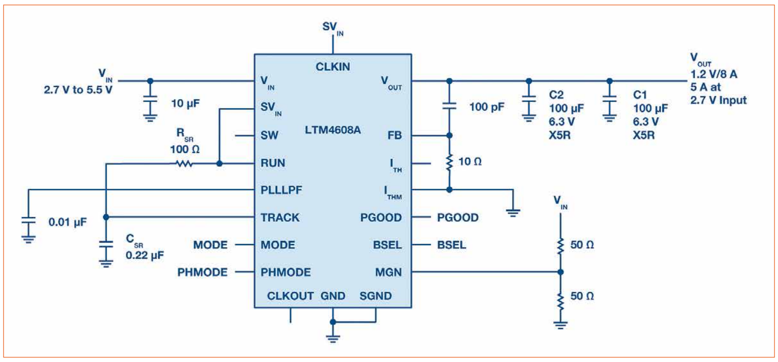


Figure 5: Schematics of the synchronous buck converter circuit with spread spectrum enabled

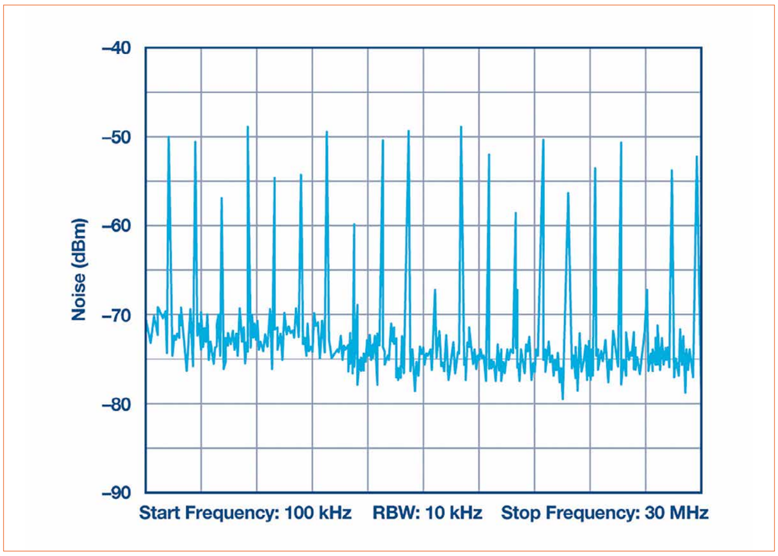


Figure 6: Harmonic noise measurement with SSFM disabled

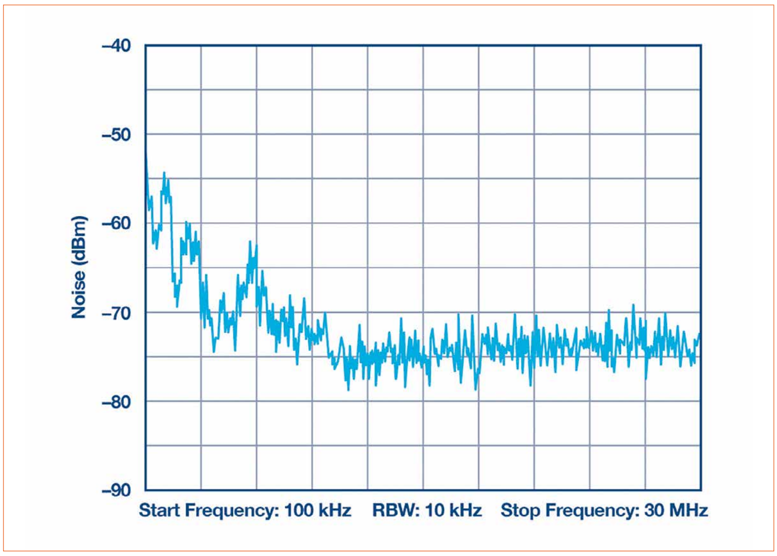


Figure 7: Harmonic noise measurement with SSFM enabled

42 V input, 2 A synchronous buck converter with SSFM

The used micropower step-down converter [5] in this example maintains high efficiency at high switching frequencies (93% at 2 MHz), allowing smaller external components. SSFM mode operates similar to pulse skipping mode operation, with the key difference that the switching frequency is modulated up and down by a 3 kHz triangle wave. The modulation range is set at the low end by the switching frequency (which in turn is set by the resistor on the RT pin), and at the high by a value of approximately 20% higher than the frequency set by RT. To enable spread spectrum mode, tie the SYNC pin to INTVCC or drive it to a voltage between 3.2 V and 5 V.

Charge-Pump Step-Down Regulators with SSFM

The regulator used in this example [6] is a 2.7 V to 5.5 V, single 500 mA or dual 250 mA charge pump-based step-down regulators produce a clock pulse whose period is random on a cycle-by-cycle basis, but fixed between 1 MHz and 1.6 MHz. Figures 6 and 7 show how the spread spectrum feature significantly reduces the peak harmonic noise and virtually eliminates harmonics compared to a conventional buck converter. Spread spectrum operation is selectable with the LTC3251, but is always enabled with the LTC3252.

SSFM in LED Drivers

110 V multi-topology LED controller with SSFM

Switching regulator LED drivers can also be troublesome for automobiles and display lighting applications concerned with EMI. To improve EMI performance, this multi-topology LED driver [7] controller includes SSFM. If there is a capacitor at the RAMP pin, a triangle wave sweeping between 1 V and 2 V is generated. This signal is then fed into the internal oscillator to modulate the switching frequency between 70% of the base frequency and the base frequency, which is set by the clock frequency setting resistor, RT.

The modulation frequency is set by the equation:

$$\frac{12\ \mu A}{2 \cdot 1\ V \cdot C_{RAMP}}$$

Figure 8 and Figure 9 show the noise spectrum comparison between the conventional boost switching converter circuit (RAMP pin tied to GND) and a spread spectrum modulation enabled boost-switching converter (6.8 nF at the RAMP pin). Figure 8 shows the average conducted EMI and figure 9 shows peak conducted EMI. The results of EMI measurements are sensitive to the RAMP frequency selected with the capacitor. 1 kHz is a good starting point to optimize peak measurements, but some fine tuning of this value may be necessary to get the best overall EMI results in a particular system.

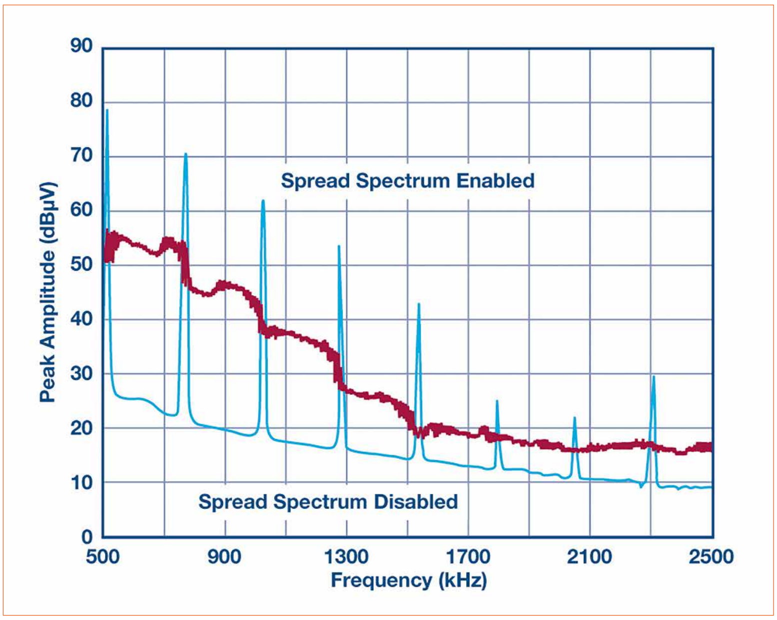


Figure 8: Average conducted EMI comparison between a conventional boost switching converter circuit (RAMP pin tied to GND) and a spread spectrum modulation enabled boost-switching converter

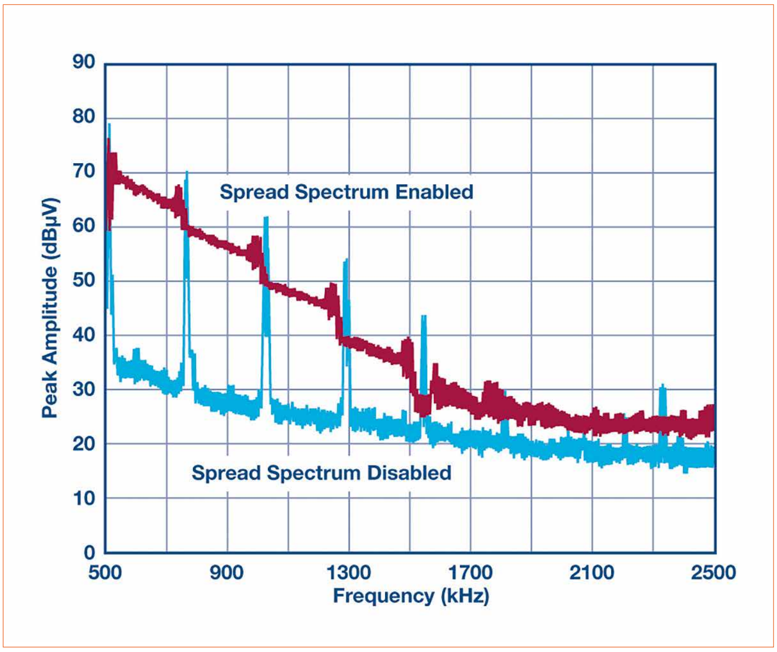


Figure 9: Peak conducted EMI comparison between a conventional boost switching converter circuit (RAMP pin tied to GND) and a spread spectrum modulation enabled boost-switching converter

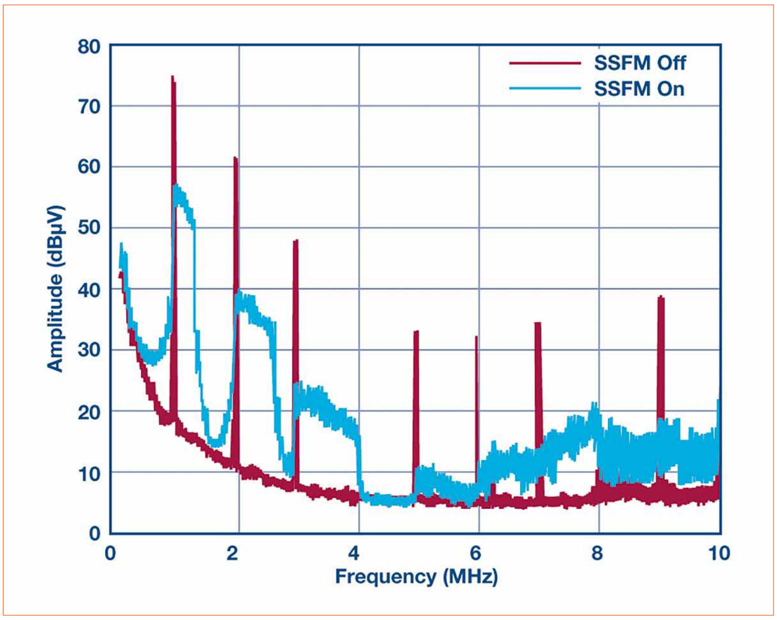


Figure 10: Average conducted EMI comparison

Multi-topology 42 V_{IN}, 60 V/4 A LED driver with SSFM

The used driver [8] is a 60 V / 4 A power switch, constant current, constant voltage multi-topology LED driver that features optional SSFM. The oscillator frequency is varied in a pseudo-random manner from the nominal frequency (fSW) to 31% above nominal in 1% steps. This unidirectional adjustment allows to avoid a sensitive frequency band (such as the AM radio spectrum) in the system simply by programming the nominal frequency slightly above it. The proportional step size allows the user to easily determine the clock frequency value (RT pin) for this specified EMI test bin size, and the pseudo-random method provides tone suppression from the frequency variation itself.

The pseudo-random value is updated proportionally to the oscillator frequency, using a rate of fSW/32. This rate allows multiple passes of the entire group of frequencies during standard EMI test dwell times.

Conclusions

Using SSFM is a very efficient approach and technique but there are also other methods as slowing down fast internal clock edges and internal filtering.

Other novel techniques like the Silent Switcher® [9] technology use the layout to effectively reduce EMI. So, the next time EMI is an issue in your design, be sure to look for low EMI products that make it easier for you to be compliant to EMI standards. Tackle the problem early in the design process at the point of origin before fixing it afterwards with costly additional filters. The required solutions are available. ■

Notes:

- ±2% SSFM is common for microprocessors and data clocks because they cannot tolerate large frequency variation.
- The repetition rate of the full pseudo-random sequence is guaranteed to be less than 20 Hz

References:

[1] LTC6909: https://www.analog.com/en/products/ltc6909.html
[2] LTC6902: https://www.analog.com/en/products/ltc6902.html
[3] LTC6908: https://www.analog.com/en/products/ltc6908-1.html
[4] LTM4608A: https://www.analog.com/en/products/ltm4608a.html
[5] LT8609: https://www.analog.com/en/products/lt8609.html
[6] LTC3251: https://www.analog.com/en/products/ltc3251.html
LTC3252: https://www.analog.com/en/products/ltc3252.html
[7] LT3795: https://www.analog.com/en/products/lt3795.html
[8] LT3952: https://www.analog.com/en/products/lt3952.html
[9] LT8640: https://www.analog.com/en/products/lt8640.html

12 Years of Progress in Manufacturing White LEDs

In the early years of LED lighting, between 2000 and 2010, attention was focused on high-power LEDs (HP LEDs). Driving LEDs at roughly 350 mA was required as the efficacy was still low. Much effort went into processing research for production to increase both yield and performance. In 2007, in one of the first issues of LED professional Review, a very extensive study on the available LEDs was performed. Now, 12 years later another comparison demonstrates enormous progress. Rob Alferink, Independent designer for LED applications, founder and owner of PicusLED, and Arno Grabher-Meyer, Editor in Chief at LED professional, demonstrate and explain the progress made over the past 12 years.

As in the early days of LED lighting the application of the LED was still an issue. Lamp designers and professional users did not know how to handle them from the aspect of optics, thermal and electronics. So many LED manufacturers supported those early adapters with their designs. One of these applications was flat panel displays, either for TV screens or computer screens. At that time, one used either plasma or small CFL tubes to make flat backlights. This made backlights heavy. Nowadays one can hardly remember the bulky CRT's on the desk. The application of LEDs reduced the weight and increased the freedom of design of displays, but costly HP-LEDs, driven at 350 mA, were needed. To do this, various optical techniques were used. There were two main techniques: direct backlighting and edge lit.

As for edge lit a series of LEDs are placed in a row along the rim of the lightguide. For light uniformity reasons the pitch between the LEDs had to be small and it became clear that HP-LEDS were overrated. So the development of mid power LED (MP-LEDs) became evident. With the increased efficacy one could step down from 350 mA to 65 mA. This also meant that because of a lower thermal load the LED package could be made from plastic instead of ceramics. Pricing went down because of the volume and use of materials: At the moment MP-LEDs are made in high volume for less than 10 cts.

A point of interest investigation was done on the performance of HP-LEDs versus MP-LEDs from various suppliers. Looking at the data from 2007 on HP-LEDs it is interesting to monitor the enormous increase in performance. As a definition for this paper LEDs are single package dies of roughly 4x4 mm^2 and a nominal drive current of either 700 mA or 65 mA. The investigation is based on available datasheets from the internet as this is the first means of data gathering.

Looking back in history, the major development of the lightbulb lasted from the end of the 19th century till the late thirties in the 20th century. So, what progress can we expect for LED?

An Historical Review

Many reviews were made on the actual performance at certain moments in time. One set is used as a reference [1]. It shows the performance of HP-LEDs from a series of suppliers. All data are processed in neutralized form to avoid complaints.

Looking at the data in table 1, one sees that the efficacy is low. Not only is this due to the flux output but it is also due to the significant impact of forward voltage. The voltage is quite high compared to the actual standards. At the moment typical values are around 2.9 V. This makes a 10 % impact.

At that time, when no standardized data was provided, several calculations, often using the graphs from datasheets were necessary to make these data comparable. Even more effort was required to come to relevant data for the practical application.

Evaluation of LED Datasheets

Reading data from datasheets

In the past, HP-LEDs were first specified at 350 mA and mostly at T_j = 25°C. With a forward

Supplier	Product	V_f [V]	Flux [lm]	Efficacy @700 mA/85°C [lm/W]
Supplier 5 (2007)	HP-LED 1 (2007)	3,15	88	40
Supplier 6 (2007)	HP-LED 2 (2007)	3,11	80	37
Supplier 3 (2007)	HP-LED 3 (2007)	3,22	58	26
Supplier 10 (2007)	HP-LED 4 (2007)	6,76	105	22
Supplier 11 (2007)	HP-LED 5 (2007)	7,63	88	17
Supplier 2 (2007)	HP-LED 6 (2007)	3,81	102	41

Table 1: Some data from 2007 with efficacy at 700 mA and Tj = ca. 85°C (order by efficacy rank)

voltage of 3 V it means a power consumption of 1 W. Over the years it has become clear that a specification at 700 mA and 85°C at the solder point is more appropriate. Nevertheless, various manufacturers are still hassling over this.

As power LEDs can normally be driven at currents up to 1 Amp or higher, the specification at 350 mA makes no sense. A specification at 25°C is also not really helpful. In a typical application the junction temperature will be close to 85°C. A variety of specifications do exist. It is up to the customer to make a valid comparison between the various suppliers; one needs to dig into the details of the datasheet.

Calculations with the means of droop (flux versus current) and hot-cold (flux versus temperature) are still obligatory. Not only the flux needs to be derived but also the forward voltage. The efficacy in terms of lm/W is by far the best way to compare.

As for all suppliers they deliver the full range of either color temperature (CCT) or color quality (CRI). It is known that based on the phosphor system that is used to come to the final CCT and CRI the dependency for temperature and current should be different. But this is not expressed in the datasheet. They could have done a better job.

Another struggle in some cases is to determine the typical value for parameters like flux, V_f and efficacy. This is good for comparison but for the final engineering of the application one needs the minimum and max. value (of course) as these are the bases for specification of the final application. Some suppliers come up with a lot of data on their binning definition but this does not tell much on the availability. Which bins can be used and what would be the average performance to finalize the performance of my own application.

Deriving the data from the datasheets

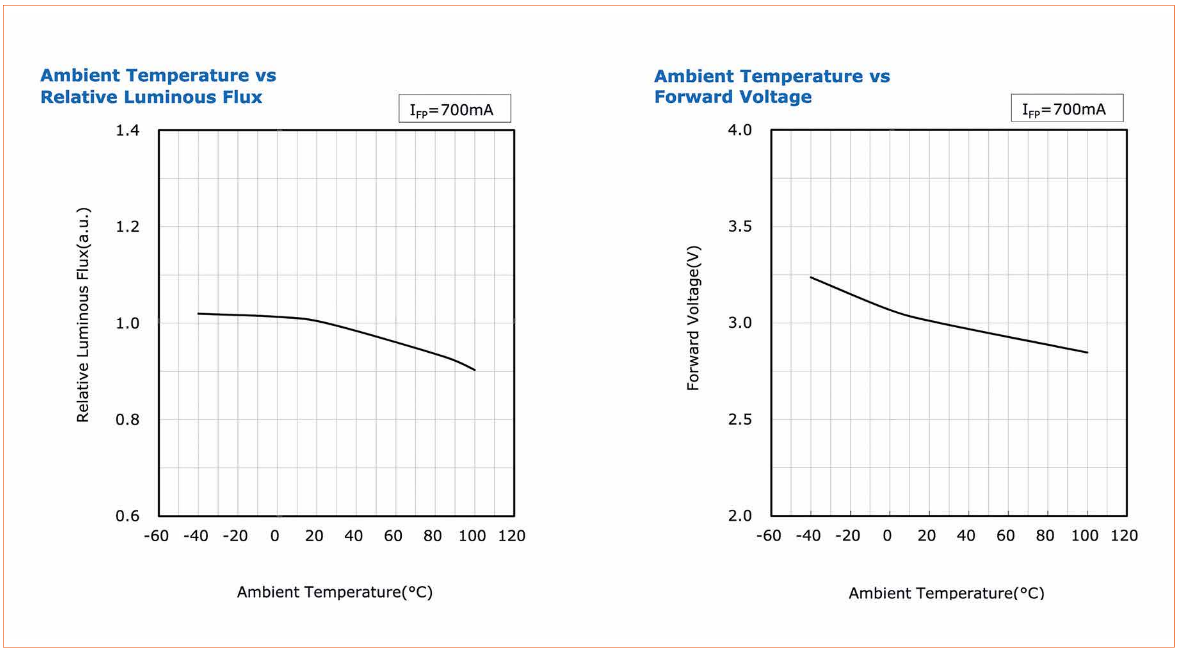
The quality of data sheets still varies dramatically between suppliers. From some, all relevant data can be taken easily and directly; from others, one still has to take the provided charts to calculate the significant data. For example, from the datasheet in figure 1 one can directly read the required data (case 1), while some manufacturers still bin at 25°C and with 700 mA (case 2). In these cases, the graphs from the datasheet are required to estimate/calculate the final data for a practical application (Figure 2).

Table 1. Product performance of LUXEON TX at 700mA and 350mA, T_j=85°C.

NOMINAL CCT	MINIMUM CRI [1, 2]	LUMINOUS FLUX [1] (lm) MINIMUM (700mA)	LUMINOUS FLUX [1] (lm) TYPICAL (700mA)	TYPICAL LUMINOUS EFFICACY (lm/W) (700mA)	TYPICAL LUMINOUS FLUX (lm) (350mA)	TYPICAL LUMINOUS EFFICACY (lm/W) (350mA)	PART NUMBER
2700K	70	240	266	136	146	153	L1T2-2770000000000
3000K	70	260	297	151	163	171	L1T2-3070000000000
4000K	70	280	312	159	172	180	L1T2-4070000000000
5000K	70	280	312	159	172	180	L1T2-5070000000000
5700K	70	280	312	159	172	180	L1T2-5770000000000
6500K	70	280	312	159	172	180	L1T2-6570000000000

Figure 1: Example of a datasheet of a product that was not part of the investigation

Figure 2:
Details of a datasheet that were needed to calculate "useful" efficacy values at a realistic working temperature



For the second case, the flux drops approx. by 7 % from 25°C to 85°C. And the V_f drops with 2.1 mV/°C from 3 V to 2.85 V. Another issue that has to be considered is that one does not always get typical data from a number of companies. So, to get the typical data one could assume that the top bin would be cherry picking. Taking the data one bin below would be more valid.

In this comparison, the data for all seven suppliers was extracted from the given graphs in the datasheets.

Analysis of High-Power LEDs

All data for the comparison were gathered for 3000 K and 80 CRI from several suppliers.

For highest fairness in the comparison, the latest available data sheets at the time of the investigation were used. It is possible that one of the data sheets was outdated because the latest available data sheet was from 2016. It is also noteworthy that some manufacturers do not have a single die HP-LED but apply 4 dies in 5 x 5 packages. Nevertheless, for comparison reasons, the data is incorporated.

The graph for the nominal luminous flux shows little variation between the suppliers. Supplier 7's HP-LEDs perform slightly low but this might be due to the outdated datasheet. Only Supplier 6 scores significantly lower than the others.

The best performer is Supplier 1 but this can be explained with the use of 4 medium power dies in one package. This demonstrates the advantage of driving several dies at lower current. Due to droop it is still true that the lower the current, the better the performance.

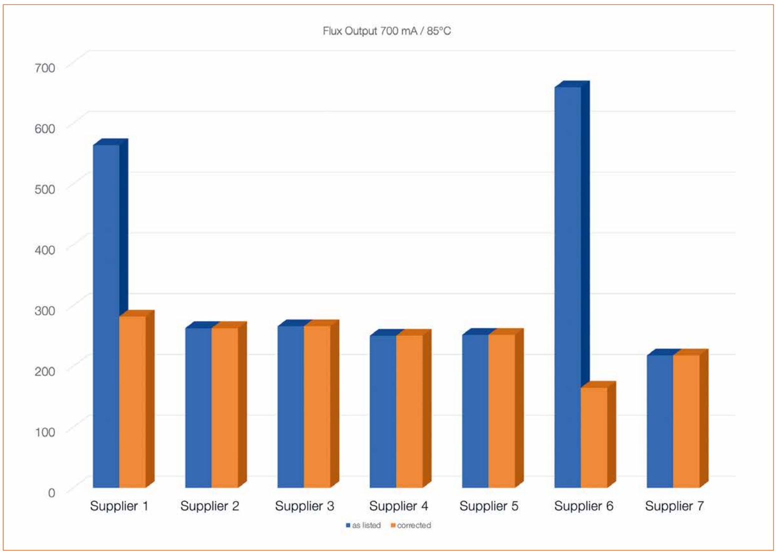
However, the forward voltage varies a little bit from supplier to supplier and has to be taken into account. Therefore, the best way to compare the products in regards to performance remains to look at the efficacy in terms of lm/W as shown in figure 4.

This comparison shows that Supplier 3 is the best performer with 136 lm/W with Supplier 1 as a runner up at 134 lm/W but with the advantage of 4 dies driven at lower current and the disadvantage of a bigger package. Detailed figures are listed in table 2.

Analysis of Mid-Power LEDs

The same procedure was applied for a bunch of MP-LEDs as for the HP-LEDs. Again, the latest data sheets from the main manufacturers were investigated. For MP-LEDs some other manufacturers pop up - the two most important suppliers

Figure 2:
Graph with flux performance of 3000 K and CRI 80 at 700 mA and 85°C



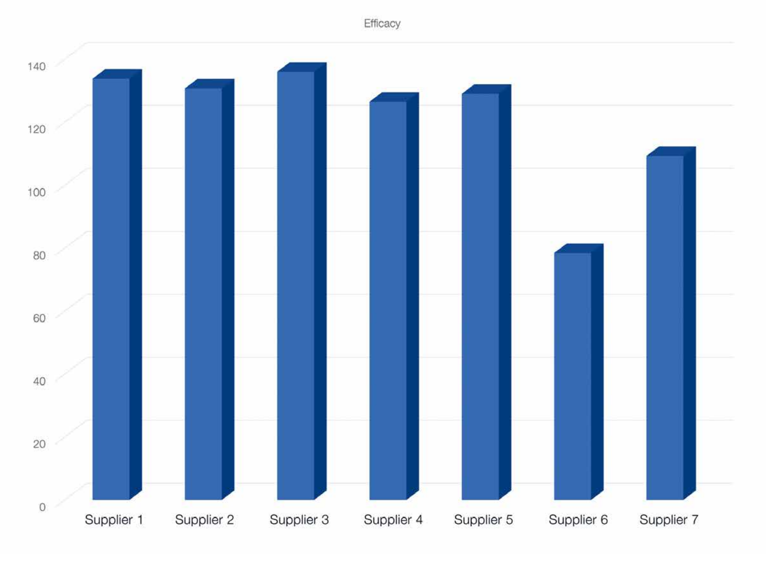


Figure 4:
Efficacy in lm/W for the different suppliers at 3000 K with CRI 80 at 700 mA and 85°C

were also recognized for this comparison, listed as Supplier 8 & 9. Due to the lower current (density) these LEDs are more efficient. The comparison again concerns LEDs with 3000 K and 80 CRI which are listed in table 3.

It is a bit odd that the various suppliers still use different currents to specify the LED performance. It varies between 60, 65, 75, 100 and 125 mA. To make the results comparable requires some calculation respectively the provided charts of the datasheets. Furthermore, these data are mostly still given for Tj = 25°. As a reference, the analysis

Table 2:
Data per supplier

					Flux Calculation for 3000 K & CRI 80					Vf Data for Calculation				Efficacy
Supplier	Product	Size [mm]	Dies	Imax [mA]	I [mA]	@T [°C]	Flux [lm]	Flux @85°C/ 700mA [lm]	Flux per Die	I [mA]	T [°C]	Vf	V_f @85°C/ 700mA [V]	Efficacy @85°C/ 700mA [lm/W]
Supplier 1	HP-LED 1	5x5	2x2	800	640	25	585	564	282	640	25	6.1	6.02	134
Supplier 2	HP-LED 2	2.1x2.1	1	1400	700	25	284	263	263	700	25	3	2.847	131
Supplier 3	HP-LED 3	3x3	1					266	266					136
Supplier 4	HP-LED 4	3.45x3.45	1	2000	350	85	139	251	251				2.83	126
Supplier 5	HP-LED 5	3.7x3.7	1	1500				252	252				2.8	129
Supplier 6	HP-LED 6	5x5	4	700	700	25	690	659	165	700	25	12.8	12	78
Supplier 7	HP-LED 7	3.05x3.05	1	1500				218	218				2.85	109

Table 3:
Raw data on the various manufacturers for 3000 K and 80 CRI

Supplier	Product	Size	CRI	CCT [K]	max I [mA]	T [°C]	I [mA]	flux [lm]	Vf [V]	Eff [lm/W]	Flux [lm]	Vf [V]	Efficacy 65 mA / 25°C [lm/W]
Supplier 2	MP-LED 2	3.5x3.5	80+	3000	200	25	75	77	5.73	179	68	5.68	184
Supplier 5	MP-LED 5		80+	3000		25	100	52	2.80	186	34		191
Supplier 5	MP-LED 5A		90+	3000		25	100	44		158			
Supplier 4	MP-LED 4	3x3	80+	3000	175							3.1	152
Supplier 3	MP-LED 3		80+	3000			120	55.2		161	31	2.75	173
Supplier 3	MP-LED 3A		90+	3000			120	41		120			
Supplier 6	MP-LED 6	3.5x2.8	80	3000	90		60	24	3.2	125			
Supplier 8	MP-LED 8	5.6 x 3	80	3000	200	25	65	34	2.85	184			184
Supplier 7	MP-LED 7		80	3000	200	25	100	81	6.1	133	57	5.88	149
Supplier 1	MP-LED 1		80	3000			150	73	3	162			
Supplier 1	MP-LED 1A		80	3000			60	24	3	133			
Supplier 1	MP-LED 1B	5.6x3	80	3000	300	25	65	35.5	2.8	195			195
Supplier 9	MP-LED 9	5.6x3	80	3000	200	25	65	31.5	2.8	173			173

Table 4:
Comparison of the efficacy between HP and MP LEDs (the third column gives an estimation for T_j = 85°C by simply reducing the efficacy given in the data sheet by 12%)

Supplier	HIGH	MID
	Efficacy @85°C / 700 mA [lm/W]	Efficacy @25°C / 65 mA [lm/W]
Supplier 1	134	195
Supplier 2	131	184
Supplier 3	136	173
Supplier 4	126	152
Supplier 5	129	191
Supplier 6	78	
Supplier 7	109	149
Supplier 8		184
Supplier 9		173

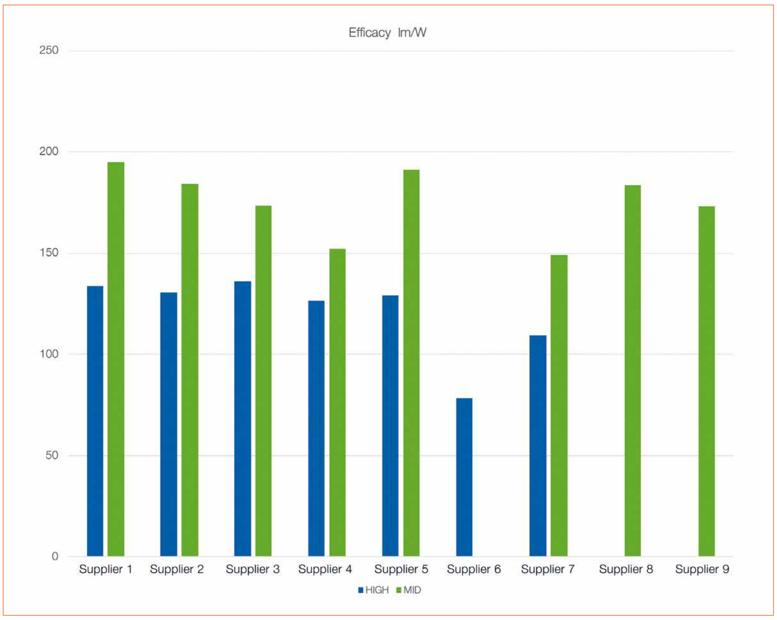


Figure 5:
Comparison of the efficacy data from the data sheets between HP and MP LEDs for various manufacturers from table 4

of the MP-LEDs includes a comparison with the HP-LEDs.

Comparing High-Power LEDs and Mid-Power LEDs

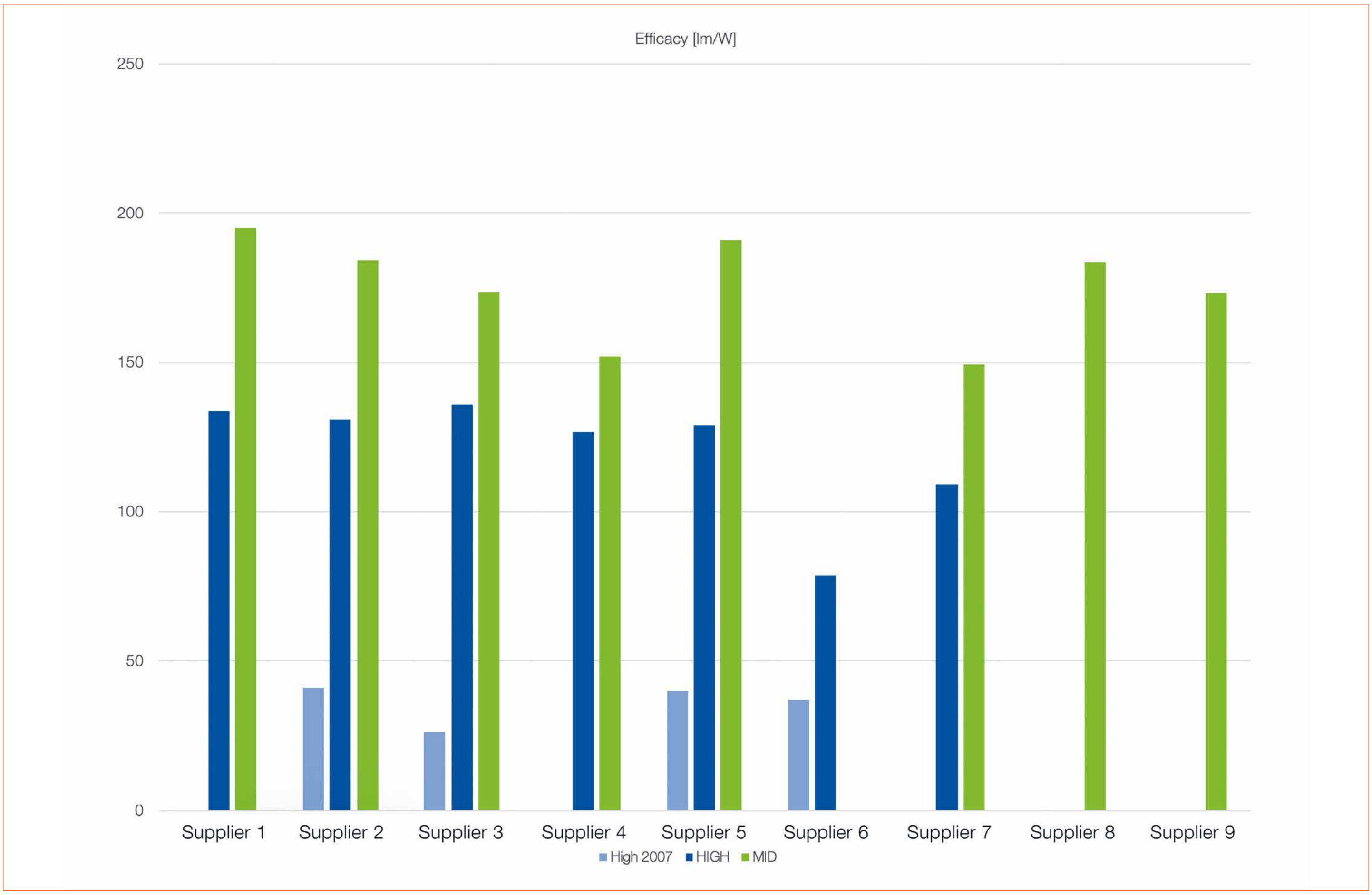
The reduced data is expressed in the following table and it includes the data from the HP-LEDs as well. When comparing these results, it is relevant to understand that the efficacy of all MP-LEDs is calculated for T_j = 25°C which means that it will be approx. 12% lower at T_j = 85°C!

These data presentations state very well that one supplier performs better than the other. When the HP-LED performances are good the mid power performs accordingly in line. It seems that Supplier 4 slightly lags behind Supplier 1, Supplier 2 & Supplier 3 in regards to efficacy.

Demonstration of the Progress since 2007

To demonstrate the progress in performance over the years the data

Figure 6:
Progress of efficacy since 2007 for various suppliers



of 2007 is also added. It is interesting to see that most top players that provided HP-LEDs in 2007 are are still the same today and that new companies mainly entered the playground in the MP-LED domain.

So, the efficacy has tripled or more since 2007. With a major improvement by increase of the light output. The drop in forward voltage has only a small impact. Much more striking is the fact that the recent MP-LEDs, due to an up of almost five times higher efficacy driven at their maximal current (often at least two to four times the current where efficacy is specified in the data sheet), provide, in practice, a similar or even higher maximal lumen output as their HP relatives from 2007.

Conclusion

It is an understatement that since 2007 the performance has increased significantly from a level of max. 40 lm/W to the level where we are now, approx. 130 lm/W for HP-LEDs and almost 200 lm/W for MP-LEDs. The efficacy has tripled, respectively, quintupled since 2007 with a major improvement by the increase of the light output. The drop in forward voltage has a smaller impact today. Current MP-LEDs can deliver approx. the maximum luminous flux of their HP relatives from 2007.

While Supplier 3 performed relatively poorly in the 2007 comparison, they are now leading the HP-LEDs performance rating with 136 lm/W at Tj = 85°C. It has to be noted that in this category is little variation between the suppliers. This picture changes a bit when it comes to MP-LEDs. The variations between suppliers increases. Top scorer is Supplier 1 with 195 lm/W at Tj = 25°C.

As these are all typical values from the datasheets for all suppliers, one can make a deal by cherry picking to obtain even better results, although it is questionable whether this makes much sense when the performance level is so high. ■

Inspiration from a Parallel Universe: Reviving the Vision of OLED

Once considered the rising star of the lighting world, OLED has arguably contributed more to elevating lighting design to an art form than any other single component. So why then isn't it more prolific? This article explores the advantages and disadvantages of OLED lighting technology and Matt Hanbury, founder and Engineering Director at Lightly Technologies, proposes a potential successor to carry on the ultra-thin design movement that it has inspired, Hikari SQ. He explains the new technology and gives an idea about future prospects.

When OLED came to market in 2012, the vision, as with any emerging tech, was to enable mainstream adoption of the technology over time as the price decreased and performance improved. Global market leaders such as Philips, Osram and LG saw the potential for OLED technology to be used across a range of lighting, smartphone and TV applications.

While surface light sources were not new, in contrast to the high-intensity, point light source of LEDs, OLED modules produce a native surface light source. This makes OLED ideal for diffuse, low-glare lighting designs; a more sophisticated, ultra-thin alternative to LED. The ultra-thin profile of OLED modules has been used to great effect in creating unique luminaire designs where the light source is a design feature in itself. Equally, the flat surface of OLED modules offers the additional benefit of creating the appearance of a recessed light source when surface mounted without the need for the same level of structural integration more commonly associated with traditional recessed light fixtures. OLED has also enabled the development of new styles and applications for automotive and aviation lighting where reduced volume and mass is a benefit and new technology is seen as a valuable differentiator between competing brands. In addition, mirror reflective surfaces in the off state, transparent in the off state and flexibility were all possibilities that added to the excitement around the great potential for this new technology.

Despite OLED's aesthetic virtues, the technology has struggled to achieve the optical performance, lifetime and commercial viability of LED; the competitive benchmark. High production costs and inferior performance, when compared to LED technology, have resulted in a cost per lumen that, to this day, remains an order of magnitude greater than its LED equivalent. As a consequence, the application of OLED technology in lighting design has been largely limited to art installations and prestige luminaires where cost and performance are less critical considerations than the visual impact and exceptional design that OLED enables.

By 2017 Philips and Osram had divested their OLED R&D business units. More recently the closure of LG Display's OLED lighting division has left OLEDworks as one of the few remaining companies pursuing decorative lighting applications. This raises the question about the future of OLED and if there is a practicable substitute on the horizon.

The Cost of Beauty

To understand the challenges to OLED becoming a mainstream lighting technology platform, it is necessary to understand the complexities behind it. As the name "Organic Light-Emitting Diode" implies, the fundamental physics behind the creation of photons of visible light is through a diode structure, in a similar way to a conventional LED. When a potential difference is applied over the anode and cathode of the OLED module, free electron and electron hole recombination results in a raised electron energy level. When the electron then falls back to a stable energy level a photon of light in the visible spectrum is emitted. The material difference of the diode junction between OLEDs and LEDs is that while LEDs use silicon-based inorganic crystal substrates, OLEDs use organic (complex hydrocarbon) molecules that have electroluminescent properties.

The design architecture of OLED (Figure 1) is a key contributor to the barriers preventing it from becoming a mainstream component. For OLED modules, the substrate is a glass or plastic coated with a layer of transparent, electrically conductive material, typically indium tin oxide (ITO) which acts as the anode. This is followed by a number of layers of the electroluminescent OLED compounds as well as carrier layers for free electrons and electron holes. The cathode is typically a metal layer such as aluminum, which also serves as a reflective back film to maximize light extraction from the module. The material costs for the substrate and OLED compounds have remained high and there is typically significant yield loss during the manufacturing process.

The active layers of the OLED module, including the anode and cathode, are typically under 100 µm thick, while the OLED compounds are less than 1 µm. The precise, nanometer scale application of the active layers is equivalent to applying a uniform 1 mm layer of paint over a wall 1 km squared and then repeated for each of the 8 active layers. The process involves a technique called "vapor deposition" where the individual OLED molecules are essentially sprayed onto the substrate in near-vacuum conditions.

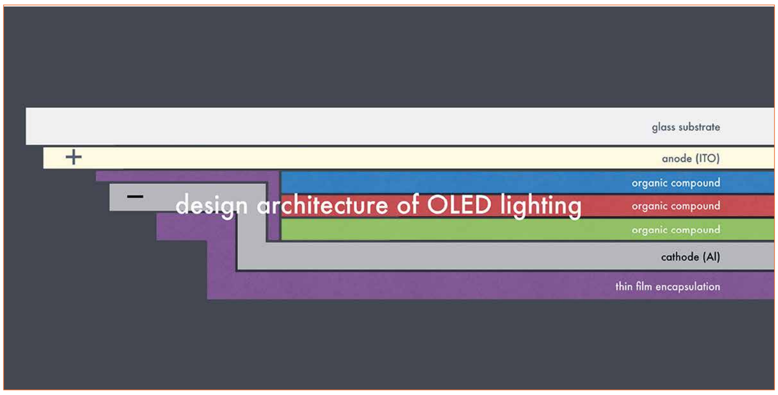


Figure 1: OLED Design Schematic

The final stage of this highly complex process is to encapsulate the OLED module in a thin-film that creates an airtight seal and prevents oxidization and other reactions with moisture in the air.

Limitations of OLED: A Blueprint for what Needed to Come Next

While manufacturing complexities contribute to the high unit cost of OLED modules, it is arguably the underwhelming optical performance of OLED technology that has prevented mass adoption of the technology within the lighting industry.

The three main areas where LED continues to outperform OLED are:

- Light output
- Lifetime
- Efficacy

OLED has constantly been trying to catch up with the continued performance improvements of LED technology. The ever-increasing delta between LED and OLED lighting performance makes investment into OLED lighting a higher perceived risk and, as R&D activity declines, so do the chances of OLED technology making the breakthrough that it needs to become a challenger in the lighting space.

Inspiration from a Parallel Universe

While OLED's runway as a light source may be coming to an end, the designs that it inspired have left an indelible mark on the lighting industry. From OLED, a new style was born. It opened up an opportunity for a new tech solution to fill; an ultra-thin light source that did not compromise on performance.

The Japanese art of chindōgu involves combining products that are completely unrelated to create inventions that are wonderfully unusual. A convergence of ideas from two parallel universes; smartphones and lighting design, inspired a journey to create an ultra-thin light source with the performance, manufacturing and commercial advantages of LED while maintaining aesthetic qualities that, until now, were limited to OLED lighting designs.

A paradigm shift was needed in how the OLED module appearance and form factor was created, as the desire was for ultra-thin surface light sources, not necessarily for a light source that uses OLED technology. Finally, the solution to OLED's stagnation was found in its predecessor, LED. The market interest had been created by the OLED manufacturers, but this did not mean that OLED was the right technology for the commercialization of ultra-thin light sources. The engineering skills gained at Philips Lighting,

Figure 2:
This is what the potential successor for OLEDs looks like

and inspired by advanced smartphone display technologies at Apple combined with a determination to deliver a commercially viable and functional solution, led to the development of an ultra-thin light source with the performance, manufacturing and commercial advantages of LED.

An LED Solution that really Challenges OLEDs

The proposed OLED successor (Figure 2) is an advanced, miniaturized form of edge-lighting technology. It uses a light guide plate and a unique combination of optical films to maximize light output and uniformity as well as controlling the beam angle. With a profile of just 3.2 mm and weighing only 35 g, each module emits up to 450 lm of low-glare, CRI 93 light. No additional heat sink or optics are required, and they are compatible with standard LED drivers and DALI dimming. It out-performs existing ultra-thin technology in every metric including light output, efficacy, lifetime, beam control, uniformity, color stability, thermal management, bezel width and module robustness. In short, it is a versatile alternative technology that maintains the core design ethos of OLED without the compromise on performance.

Cross Pollination of Technology: A Catalyst for Evolution

OLED technology carved out a niche and introduced new ways to use light to create art. However, as with nature, when evolution meets a barrier, sometimes it needs to choose a different path in order for it to continue prospering. In the case of OLED lighting, it was arguably the ultra-thin design concept that needed a new host. By looking outside of the OLED box, the solution was found in advanced smartphone LCD displays (Figure 3).

Liquid Crystal Display (LCD) technology utilizes a homogenous backlight module to provide illumination for the pixels of the display. Millions of red, green and blue sub pixels are controlled by varying the voltage across that sub pixel, which controls the amount of light that is transmitted. The backlights for LCD displays were originally direct lit, with an array of LEDs or fluorescent tubes behind a diffuser panel to create uniformity. With the development of smartphones, tablet and laptop displays, this moved to edge lit technology, where the LEDs would emit light into a Light Guide Plate (LGP) where they are then extracted by surface features that prevent total internal reflection. This has been continually refined over the last 10 years to their current stage of being incredibly thin so as to minimize the volume taken up by the display within the smartphone housing.

Re-Engineering LCD Technologies for the Lighting Industry

There were significant challenges faced in re-engineering LCD backlighting technology before it could successfully make the transition from smart phone displays to functional lighting (Figure 4).

The main optical differences were in the LED types used. Backlight applications typically have high CCT between 8000 K and 10000 K as this improves the saturation of the blue colors in the display. The lumen output is also lower in comparison to lighting applications so that smartphone displays are not too bright. These differences led to a change in the individual LEDs used in the module so that warmer color temperatures could be achieved and a color-rendering index (CRI) of 93.

The selection of LEDs also led to changes in the thermal and

Figure 3:
Transition over 15 years from Nokia 3310, through LED LCD displays to OLED

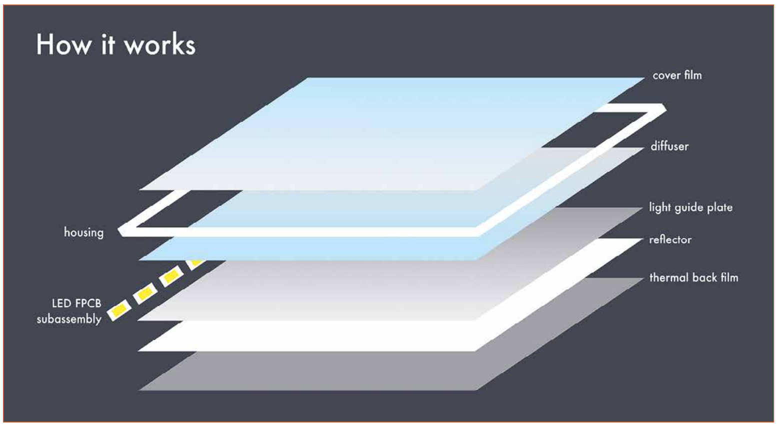


Figure 4: Design architecture inspired by the technology in smartphone displays

OLED vrs LED Comparison	Lightly Technologies Hikari SQ	LG Display LL056RS1	OLEDworks FL300
Nominal Output (lm)	300	75	300
Efficacy (lm/W)	88	90	75
Lifetime (hrs L70B50)	60,000	40,000	30,000
CRI	90+	90+	90+
CCT (K)	2700, 3000, 4000	3000, 4000	3000, 4000
Beam Angle (degrees)	110	~120	~120
Dimensions (mm)	100 x 100	100 x 100	127 x 127
Bezel (mm)	5.0	~5.0	9.0
Module Thinness (mm)	3.2	N/A	1.4

Table 1: Benchmarking Hikari SQ module performance vs OLED

electrical performance. Alternative ways of thermally managing the LEDs to prevent excessive temperatures, and the subsequent impact on lifetime reduction, had to be developed.

The electrical layout was redesigned to ensure that these new light sources would be compatible with LED drivers already on the market (unlike OLED modules) and could be wired in series and parallel configurations. The electrical design also had to enable full controllability with DALI and other dimming technologies as well as being future-proofed for IoT systems.

To achieve the ambitious optical performance that were key to the vision behind the new product, a combination of optical films was developed to achieve the uniformity and beam angle to suit customer applications and reduce glare while maintaining a high, functional lumen output.

It was critical (Figure 5) to continue the design journey that OLED began, while also becoming a scalable lighting engine. Like OLED modules, its ultra-thin housing has a flush bezel to enable front mounting to glass. It can accommodate different form factors such as linear and circular versions as well as larger sizes and mirrored finishes for a wide range of design applications. Future product generations will include features such as flexibility and dynamic white CCT control.

Benchmarking vs OLED Modules

If lighting designers are to have a seat at the table with architects and engineers, lighting solutions need to be functional as well as decorative. The challenge for the design specification was to surpass OLED lighting performance (Table 1) while keeping the lighting designer in mind and ensuring the easiest installation and creative flexibility.

One of the core ambitions in the development of this technology was to broaden the potential applications for ultra-thin lighting. While OLED lighting had its foundations in decorative luminaires, the opportunity for the new product was to achieve a functional light output that delivered useable lux levels on the working surface. The first product generation produces up to 450 lm from a 100x100 mm module with an optimum balance of light output and visual comfort and low glare. This lumen density has opened up new applications for ultra-thin lighting designs such as open-plan office lighting and functional hospitality luminaires.

Applications for Surface Light Sources

This new technology fulfills the promise of OLED by enabling unique, visually impactful lighting designs while at the same time providing functional levels of light. This combination of functionality and form has already captured the imagination of the automotive and aviation industries along with the more traditional hospitality and residential applications (Figure 6).

Figures 5: Ultra-thin LED light modules offer similar design options to costly models

Figures 6:
Applications for the new technology and product (Photo credits: Gavriil Papadiotis - www.gavriilux.com)

Benefits and opportunities:

- Lighting system manufacturers can upgrade existing product lines with a high performance, commercially viable, ultra-thin lighting engine
- The automotive industry benefits from a lightweight, uniform surface of light for interior and exterior automotive lighting products.
- Decorative and architectural lighting designers enjoy maximum creative freedom without having to compromise on form or function

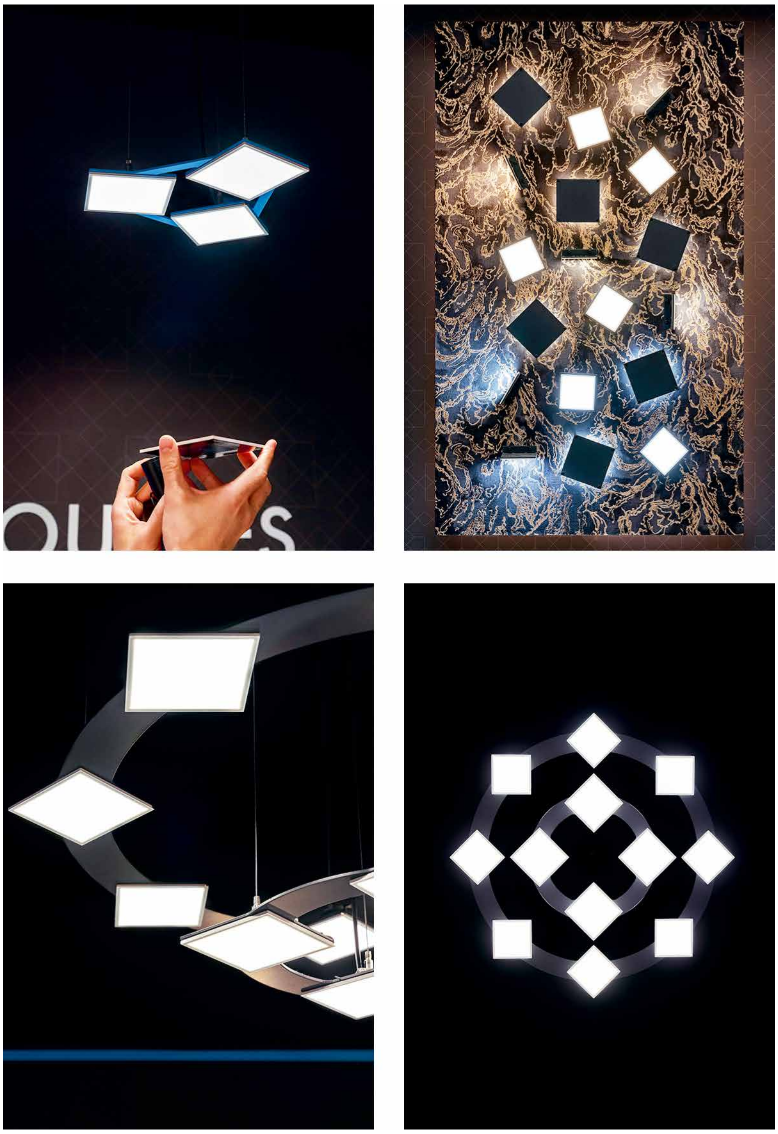
Also, considering modern LED light sources have a lifespan ranging from 10 to 15 years, this new product offering provides retailers with the opportunity to generate new sales by giving their customers a reason to want new light bulbs before their existing ones have expired. The technology opens doors to new customers that demand the latest innovations and the newest designs.
The re-introduction of old-style filament light sources with new LED components have done this to great effect and are expected to reach a market value of $1.8B - $2B by 2020.

Conclusion

OLED technology is an exciting feat of engineering. As the technology has industrialized over the last 10 years it has enabled thinner display panels, richer colors and deeper contrast. In the Lighting industry, OLED has created an awareness of the opportunities for ultra-thin, surface light sources, with both the design freedom and low glare, high quality light that it provides.

The research and development investment into OLED technology has paved the way for the future of displays technology, but perhaps not the future of lighting. As major lighting companies have withdrawn from OLED, a market opportunity has emerged: a desire for modern, elegant lighting design with ultra-thin, surface modules, but with the performance benefits that can only be found in LED.

OLED lighting created a new generation of lighting design but, by shifting the paradigm of how this is engineered, a new technology based on LEDs can fulfill this exciting opportunity across multiple industries and applications.
By reaching beyond the normal circle of innovators, advisers and creatives for solutions to challenges and opportunities that could not be found within existing lighting technologies, This new technology and product breathes new life into a design movement that was created by OLED but will flourish with LED (Figure 7).



Figures 7:
"Poseidon", "Dynamic Canvas" and "Corona" luminaires based on Hikari SQ (from top left to bottom right. Photo Credits: Gavriil Papadiotis - www. gavriilux.com)

Lighting the Way to Greater Well-Being

Organizations across the world are increasingly aware of the need to create workplaces that promote employee wellbeing, comfort and productivity. This has led to a focus on human-centric lighting (HCL); here Makoto Ogawara, Assistant Manager, and Giovanni Vecchio, Head of Sales and Marketing at Nichia explain its importance and look at how pioneering research in LED spectrum optimization is helping to achieve more beneficial lighting outcomes.

With recently published figures by Grand View Research suggesting that the global LED lighting market is expected to reach $105.66bn by 2025 [1], the benefits of this technology's longer lifespan, low heat emissions and low energy consumption are now widely understood. However, for those seeking to push the potential of LED as far as possible, the focus has turned towards the role of lighting in improving wellbeing, comfort and productivity, with specific attention being directed towards creating artificial lighting solutions that mirror the effects of natural lighting as closely as possible.

Understanding the Circadian Rhythm

The Earth has a regular rhythm: every 24 hours it spins on its axis and we experience daylight and darkness. Like most other organisms, we have an internal clock that adapts to day and night - a cycle that is called "circadian", which comes from the Latin words circa, meaning around, and diem, meaning day. Our master biological clock, based in the brain's hypothalamus, comprises 20,000 nerve cells that form the suprachiasmatic nucleus, which receives input from our eyes and sends out signals about the time of day, so that our body reacts accordingly [2].

Early morning light also induces the release of cortisol, which works together with melatonin suppression to make individuals more alert [3]. For most adults the biggest falls in energy happen in the middle of the night, between 2:00am and 4:00am, and just after lunchtime. When it's dark at night, the eyes send a signal to the hypothalamus that it's time to feel tired, and the brain in turn sends a signal to release melatonin, which makes a person feel tired. That's why the circadian rhythm coincides with the cycle of day and night.

All living things - from algae and tiny microbes to birds and human beings - are affected, and it is this

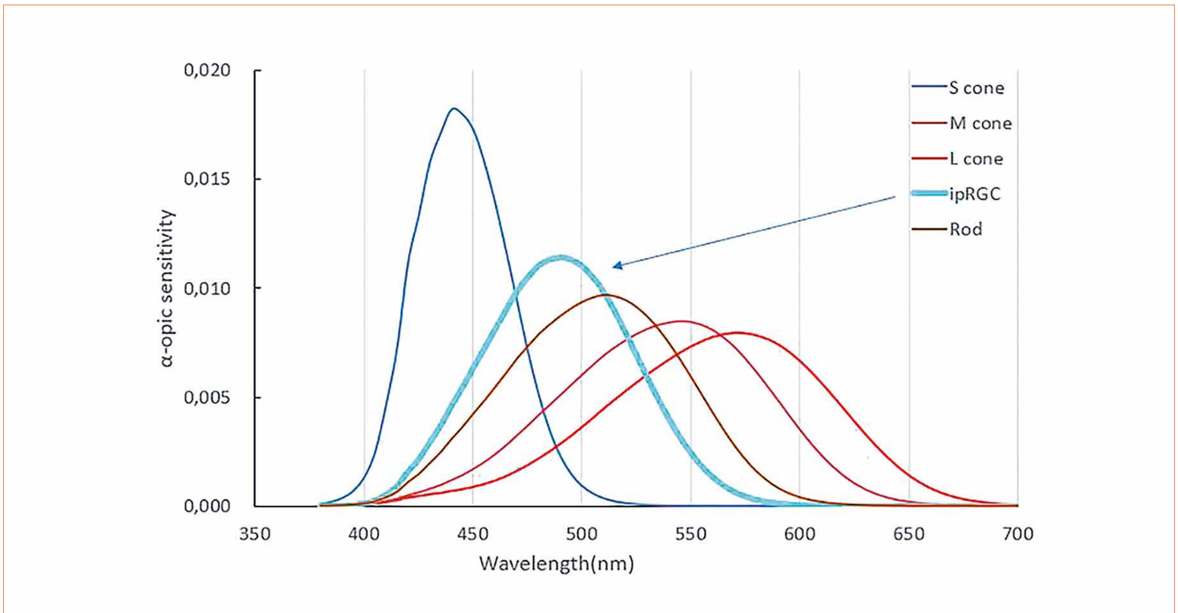


Figure 1: The spectral sensitivity of human retinal photoreceptors

circadian rhythm that creates physical, mental and behavioral changes [4]. The circadian rhythm has a massive effect on our bodies and can influence hormone release, sleeping and waking cycles, eating habits, urine production, our ability to digest food and even body temperature. An irregular circadian rhythm has been linked to various health conditions such as sleep disorders, obesity, diabetes, depression, bipolar disorder and seasonal affective disorder (SAD).

Although the concept of the circadian rhythm is nothing new, recent years have witnessed a great deal of interest in how light and dark affect aspects of our behavior. In fact, the Nobel Prize in Physiology or Medicine 2017 was awarded jointly to Jeffrey C. Hall, Michael Rosbash and Michael W. Young for their discoveries of molecular mechanisms controlling the circadian rhythm [5]. It is even moving into the consumer sector, with some smartphones able to shift display color to the warmer end of the light spectrum at night.

The Rise of HCL

Homo sapiens has lived on the planet for at least 200,000 years, and the majority of this time we have spent outside as hunters and gatherers - our ancestors lived in temporary structures and would travel to wherever the best food and resources happened to be. Fast forward to the present day, and according to the Building Research Establishment (BRE), people in Europe spend around 90 per cent of their time indoors [6] - with our lack of exposure to natural light having negative consequences on our health and wellbeing.

The emotional and biological effects of lighting that mimics the changes in color temperature found in natural daylight are proving positive, and have led to a focus on HCL solutions. LightingEurope defines HCL as lighting that "supports the health, wellbeing and performance of humans by combining visual, biological and emotional benefits of light" [7]. It addresses both the visual and non-visual effects of lighting, and LED is the driving force behind developing solutions that support human circadian needs.

When integrated with lighting control technology it is possible to automatically change tone and color in tune with any available natural light, taking into account the time of day, the position of the sun and even the time of year. Put simply, controllable, adaptable lighting systems create more comfortable environments for people and can be used to stimulate them during daytime through the use of bluer wavelengths, and calm them at night with amber and red wavelengths.

Diverse Applications of HCL

By integrating a lighting system into the internet of things, lighting can be customized in real time, with employees able to control their local light levels and color temperatures using their PCs and smartphones. By controlling both the intensity and the color of the light, a lighting design can provide an additional improvement in occupant satisfaction and productivity. According to LightingEurope, HCL benefits performance and wellbeing to the point of enhancing productivity by 4.5 per cent and reducing errors by two per cent, while lowering absentee rates and improving health and safety [8].

As well as being useful in commercial premises, HCL is particularly important for environments such as hospitals and schools. In the former it can aid the patient recovery process by positively influencing sleep/wake cycles, hormone release, eating habits and digestion. In a situation where mains power is lost and subsequently restored, luminaires can return to the light level they were in prior to the outage, which avoids disturbing sleeping patients. Meanwhile, depending on the time of day, schoolteachers can use it to either keep students calm or alert [9].

The Role of Spectrum for Human Activities

Although it is now at the forefront of discussions among lighting professionals, our understanding of the impact of light on the human body is still quite limited. There is a need for more researches when it comes to the effects of different types of illumination, the complexities of mimicking natural light, and what's needed to apply artificial lighting safely and effectively. To achieve this, researchers and manufacturers must factor in complex metrics such as circadian action factor, circadian light, melatonin suppression index and the melanopic sensitivity function [11].

What we do know is that humans not only recognize the brightness and color of light, but the circadian rhythm can be affected by different wavelengths. Although LEDs with a color rendering index (CRI) of 80 have been widely adopted, to bring solutions for further market growth manufacturers must focus on added value, with a higher CRI LED acting as a technical differentiator. Some LED manufacturers are closing the performance gap between CRI ≥80 and higher CRI, with some already achieving a performance gap of only of 20 lm/W between an LED with CRI ≥80 and an LED with CRI ≥90. This efficacy gap should not be neglected when designing luminaires, and it has been found that the role of cyan is key in improving spectral distribution.

Research has highlighted the relationship between spectral bandwidth and the response of human eyes, and according to Aggarwala et al [12], the eye accommodation response is faster with a broad spectrum. The response of the eye accommodation for two subjects with respect to bandwidth has also been studied, and by increasing the bandwidth of the spectrum, the gain that corresponds to the response of the accommodation increases. Additionally, the phase lag, which is a time lag of the response, decreases. This research indicated that a broader spectrum is better for human eye accommodation response.

Furthermore, Kubo et al [13] found that human eyes become less fatigued as a result of a broad-bandwidth light source and also investigated the relationship between spectral bandwidth and the decline rate of eye accommodation after a visual task. By considering the decline rate as fatigue level, it was found that a wider spectrum is optimum for visual fatigue reduction.

The International Commission on Illumination (CIE) also discovered that the total transmission of the eye with advancing age shows that transmission of the crystalline lens between 400 nm and 500 nm decreases and changes into a yellowish color [14]. Consequently, emphasizing the cyan component in the spectral bandwidth provides clearer vision for middle-aged and older adults.

In addition to transmission, Lucas et al. focused on the absorption properties of the human eye, finding that it is possible to refer to the absorption spectrum of the human retinal photoreceptors - the intrinsically photosensitive retinal ganglion cells (ipRGC). When analyzing the absorption in the visible light spectrum, the peak wavelength of spectral sensitivity of ipRGC is located at around 480 nm. Because ipRGC is considered as a specific photoreceptor for controlling circadian rhythm, the conclusion is that the cyan component of the spectrum must be increased for higher sensitivity [15].

Achieving an Improved Spectrum to Benefit Human Activities

It is important to remember that the emission spectrum of a typical CRI ≥80 LED does not have strong cyan and red components, in order to avoid efficacy loss - something that results in a low spectral sensitivity for human eyes. Conversely, a typical CRI ≥90 LED includes more green and red components, which is achieved through the use of silicate-based phosphor and optimized SCASN phosphor. However, even in this situation spectral modification still generates an efficacy drop of about 13 per cent from a CRI ≥80 LED [16].

To broaden the spectral region from cyan to green Nichia used additional cyan phosphor - strontium aluminate was activated with europium phosphor (SAE: $Sr_4Al_{14}O_{25}$:Eu^{2+}) [11]. SAE phosphor has an emission peak at about 495 nm and its introduction improved the cyan region and increased the spectral bandwidth. The relative efficacy of the CRI ≥80 + SAE phosphor LED is 96 per cent of a typical CRI ≥80 LED. Additionally, the spectral bandwidth of the CRI ≥80 + SAE phosphor LED is wider than a typical CRI ≥80 LED.

The details of the joint research conducted with the help of a collaborative academic partner in Japan will be disclosed in the near future [i, ii].

Putting this Innovation to the Test

Notwithstanding - after considerable research and testing - a final optimized spectrum has been developed to stimulate human activities in harmony with the human circadian rhythm. With high color rendering, the spectrum evidently results in benefits including a reduction in eye fatigue and drowsiness, while also promoting better work performance and stimulation - particularly when undertaking visual tasks that are relatively strenuous.

As already discussed, lighting can have an influence on activity levels throughout the day, including waking up in the morning, being active during the day, and encouraging sleep at night. The circadian rhythm can be regulated when specific wavelengths are addressed, especially within the cyan region. For instance, Nichia's sophisticated Vitasolis solution provides a natural white color, and a significant part of its spectrum contains cyan wavelengths. Its unique spectral distribution also illuminates objects effectively while maintaining a high luminous efficacy.

By combining such technologies into tunable fixtures and IoT systems (including the use of networked daylight sensors), an 'ideal human centric lighting experience' could be implemented into offices, schools,

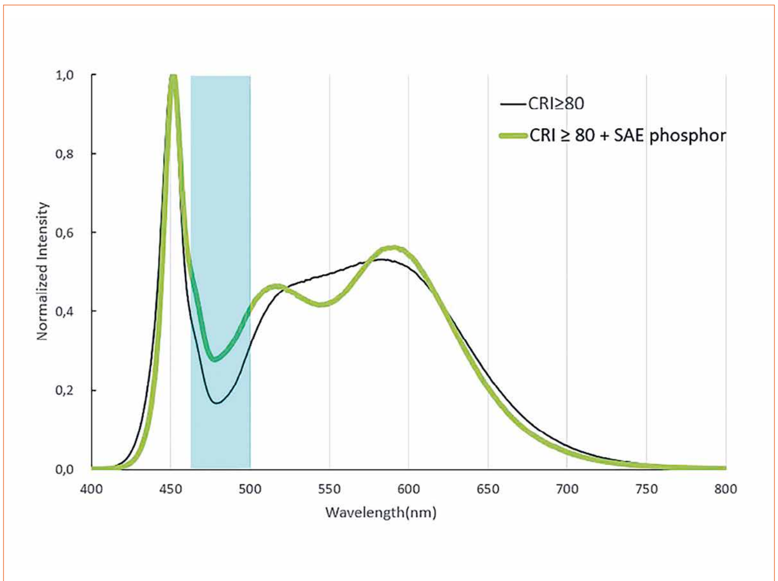


Figure 2: Spectrum comparison of conventional CRI 80+ LEDs and the new CRI 80+ SAE phosphor LEDs

hospitals, and other locations [11] where the most suitable light can positively support wake-sleep patterns and other complex behaviors. While further research is required on how humans behave to spectral changes in light, it is an exciting prospect to think that customized shifts in spectrum can generate a slightly different mix of signals from various eye cells to produce subtle positive changes in a person's internal clock.

The Next Generation of HCL

In summary, LED continues to be one of the most exciting areas of modern technology, and is already identified as a major factor in the creation of smarter buildings, and therefore smarter occupants. A new developed phosphor composition offers an optimized spectrum for human circadian activities by implementing improved cyan emission SAE phosphor, with a negligible efficacy drop from a typical CRI ≥80 LED. Test results so far indicate that the optimized spectrum LED is a better choice for human eyes in terms of physiological and psychological fatigue, as well as for working efficiency, making it a suitable solution for HCL schemes in a diverse range of applications where efficiency, productivity and wellbeing are vital. ■

Remarks:

[i] Follow-up article in LED professional Review (LpR)
[ii] Presentation on "LED spectrum optimisation for improvement of human performances and psychophysiological responses" at LpS 2019 by Nichia's Makoto Ogawara at the Opera House Bregenz, Austria

References:

[1] Grand View Research, 'LED Lighting Market Size, Share & Trends Analysis Report by End Use, by Design, by Application and Segment Forecasts, 2019-2025'
[2] National Institute of General Medical Sciences (NIGMS) https://www.nigms.nih.gov/education/pages/factsheet_circadianrhythms.aspx
[3] BakkerElkhuizen, 'The Effect of Light on Performance'
[4] Frontiers, 'Circadian Rhythm: From Microbes To Hosts'
[5] The 2017 Nobel Prize in Physiology or Medicine
[6] BRE Group, 'Human-Centric Lighting: The Future of the Workplace'
[7] LightingEurope, 'Human Centric Lighting', https://www.lightingeurope.org/images/HCL/14_LE_HCL2017.pdf
[8] LightingEurope & ZVEI, 'Quantified Benefits of HCL'
[9] NHS Greater Glasgow and Clyde, 'Staying Alert in the Classroom'
[10] MarketsandMarkets, 'HCL Market by Offering, Application and Geography - Global Forecast to 2024'
[11] Ogawara et al, 'Improvement of Human Performances and Psychophysiological Responses', LED Lighting Technologies - Smart Technologies for Lighting Innovations. Luger Research e.U., 2019
[12] Aggarwala et al, 'Spectral Bandwidth and Ocular Accommodation', Journal of the Optical Society of America
[13] Kubo et al, 'Effect of Spectral Radiant Distribution of Lighting on Visual Fatigue', Journal of the Illuminating Engineering Institute of Japan
[14] The International Commission on Illumination, 'CIE 203:2012 A Computerized Approach to Transmission and Absorption Characteristics of the Human Eye'
[15] Lucas et al, 'Measuring and Using Light in the Melanopsin Age', Trends in Neurosciences
[16] Wakui, 'Can Human Performance be Improved by Light?', Phosphor Global Summit & Quantum Dots Forum

The Adverse Ecological Impacts of Light Pollution: LEDs' Role in Mitigation

With the negative effects of artificial light at night on ecosystems increasingly well-understood, attention is now turning to the ways in which these impacts can be mitigated through uptake of novel technology and lighting strategies. Dr. Callum J. Macgregor, post-doctoral research associate at the Department of Biology of the University of York, and Dr. Darren M. Evans from the School of Natural and Environmental Sciences of the Newcastle University, discuss the current evidence for costs and opportunities associated with uptake of LED lighting and highlight important directions for future investigation.

Humans have produced artificial light at night (ALAN) for millennia, and for almost 150 years, this light has been powered by electricity. The global scale of light pollution continues to grow to this day, with large-scale encroachment into regions of high biodiversity [1]. This continuing rise has led to an increasing focus of research into the ways in which ALAN can have negative impacts both on ecological systems and on human health and wellbeing [2]. Today, ALAN is viewed as an important "driver of environmental change" alongside the likes of climate change and habitat degradation. The scale of concern is so great that ALAN has been implicated in the widely reported declines in insects, dubbed "insectageddon" by the media [3].

In general, ALAN affects ecosystems through two pathways. Direct emissions from lights can be perceived by organisms or can alter the lightscape of their ecosystem. Meanwhile, light can be reflected back from the atmosphere, altering ambient light levels at night in a process known as "sky-glow".

Figure 1:
There are not many places left on planet Earth like this one in the southeastern part of Madagascar. The darkness of the night is almost undisturbed so that taking a picture of the Milky Way is easy for anyone - even without any experience in astro-photography (image: ©Arno Grabher-Meyer)

Light Pollution and Ecosystems

Organisms can have their perception of the natural cycles of light and dark disrupted by light pollution (including both direct emissions and sky-glow), or they can be directly impacted by interaction with light sources, which can alter their behavior. Two well-known examples illustrate how these interactions can impact both nocturnal and diurnal organisms: the attraction of night-flying moths to light sources, and the early onset of the "dawn chorus" of songbirds. The reason why moths exhibit "flight to light" behavior remains uncertain, but all currently-prevailing theories relate to the ways in which moths could make use of natural sources of (emitted or reflected) light at night. Regardless of the mechanism, research has shown this phenomenon impacts moths in multiple ways [4], including by impeding both feeding [5] and reproduction [6]. In the case of day-active songbirds, the territorial singing that comprises the dawn chorus takes place at both dawn and dusk, when ambient light conditions are changing. Singing behavior may also vary between seasons, to coincide with the timing of the breeding season, which is often guided by changes in day length. ALAN can mask both of these signals, effectively by extending the period perceived as daylight; this leads both to earlier singing at dawn on a daily basis [7] and to earlier singing within the year [8].

As well as directly affecting organisms, ALAN can also have indirect or cascading effects by disrupting the interactions between species that underpin crucial ecological processes. For example, many fruiting plants rely on animals to disperse their seeds effectively: animals eat the fruit, move onwards, and pass out the seed in a new location where it may germinate, away from the competition of its parent. However, by discouraging fruit-eating bats from foraging, ALAN reduces the proportion of fruits that are harvested, and therefore the proportion of seeds that may be dispersed [9]. Similarly, many plants rely on insect visitors for pollination (the process by which seeds are fertilized), and nocturnal moths provide a substantial part of this pollination service [4]. However, around street lights, the behavior of moths changes so that they carry less pollen from fewer plant species [10], leading plants to set fewer seeds, even in species that are mostly pollinated by day-flying bees [11].

Impacts of ALAN have been demonstrated throughout the natural world: in vertebrate and invertebrate animals, plants, and microbes alike. The complex webs of interactions between species that tie ecosystems together also provide pathways for these negative impacts to indirectly affect more species, and even the assembly of whole ecological communities [12].

Mitigation of Light Pollution

Although levels of concern about the ecological impacts of light pollution have grown substantially [2], reducing these impacts poses a substantial problem. Put simply, ALAN is perceived to be highly desirable for human nighttime safety and security (despite recent concerns about health and wellbeing [2]), putting it into stark contrast with other pollutant drivers of environmental change (e.g. noise or air pollution), which are considered to be undesirable for both humans and ecosystems. As a consequence, much of the recent research in this field has focused, not on the simple effects on ecosystems of ALAN when compared to natural darkness, but on the relative effects of different types of ALAN. An understanding of which lighting systems are least disruptive to the ecology of nocturnal and diurnal organisms will allow us to adopt best practices that mitigate the negative effects of light pollution on biodiversity and human health alike.

In particular, there is a growing focus surrounding the adoption of novel technologies in street lighting, and the potential for these to mitigate - or indeed, worsen - the impacts of ALAN. The increasing use of part-night lighting is one such focus, and several recent studies have suggested that its uptake may be beneficial to ecosystems by allowing a period of full natural darkness, even if this period is somewhat curtailed [13,14]. Most prominent, however, is a focus on the introduction of LED street lights, which have been enthusiastically adopted due to features including greater energy efficiency, long life-span, and "whiter" emissions spectra, benefitting human color perception [15]. Initially, this transition was viewed as unfavorable for biodiversity, even being labeled as a major emerging threat to urban ecosystems [15], because early commercially-available LED street lights mainly emitted light across a broader range of wavelengths than incumbent technologies such as high-pressure sodium, and in particular, contained a greater proportion of blue wavelengths to which many organisms are particularly sensitized [16]. More recently, there has been a growing acceptance that as well as dangers, LED technology also holds considerable potential for developing mitigation strategies, because of its great flexibility. In particular, it has been proposed that LEDs provide opportunities to tune the emissions of lights to specific, customized spectra which are least ecologically damaging [17], and that they are well-suited to adoption of variable lighting strategies that include periods of dimming or switching off [18].

Figure 2 shows the difference between the spectral composition of two lamp types (LEDs and high-pressure sodium) and change in light intensity at different distances from the light (when mounted at 4 m height) are shown. LEDs emit a greater proportion of light at shorter blue wavelengths (to which

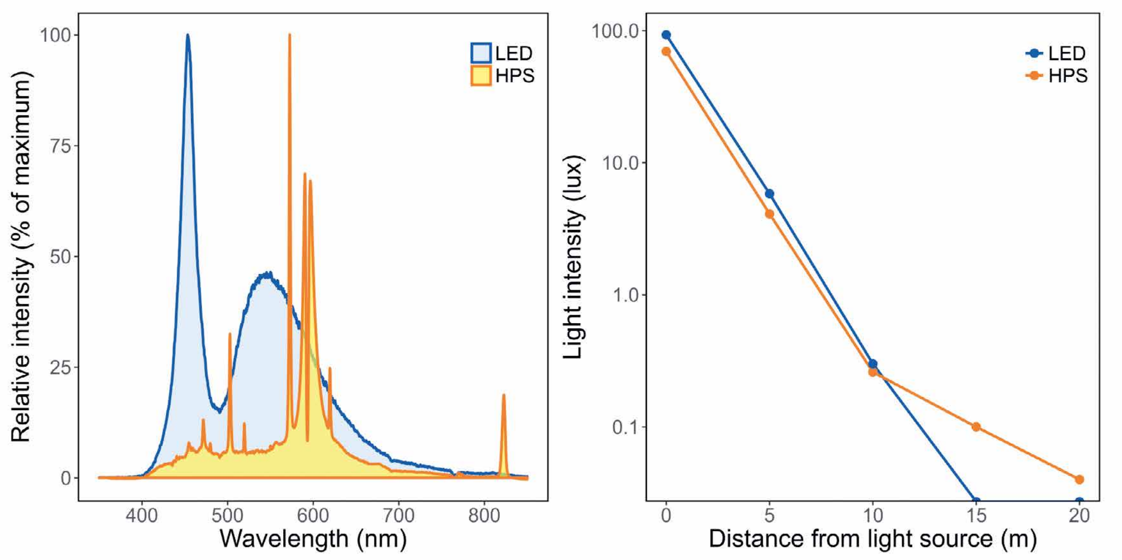


Figure 2:
Differences between the properties of LEDs and existing street lighting technologies may provide both threats and opportunities to ecosystems.

nocturnal wildlife may be particularly sensitive) than HPS lamps. However, HPS lamps scatter light over greater distances, meaning they may affect ecosystems further away.
To measure spectral composition, irradiance was measured in the laboratory for one light of each type (in its fixture) in μW/cm^2 per nm. Intensity is shown as the percentage of the irradiance measured at the wavelength of peak emission.
For change in light intensity, measurements of light intensity were taken at ground in the field, at night, beneath a light of each type.
Five measurements of light intensity were taken using a handheld light meter (Holdpeak HC-881C, Holdpeak, Hong Kong), at intervals of 5 m between 0 m (i.e., directly under the light) and 20 m from the light. The mean recorded light intensity (lux) across those five measurements is shown;
values plotted on the x-axis were measured at 0 lux across all readings (this figure is reproduced from [13] under a CC-BY-3.0 license)

Current Evidence for Impacts of Switching to LED Street Lights

Costs

Research focusing on the costs and opportunities surrounding adoption of LED lights has already revealed substantial complexity in the responses of ecosystems to this new technology, especially when compared to the impacts of ALAN from other types of light source.

A key risk associated with transitioning to LED lighting is that, because LEDs are more versatile and cheaper to run than existing technologies, their adoption directly leads to the use of ALAN over greater geographic areas and at higher radiance [19], thereby exposing a larger number of ecosystems to the disruptive influence of light pollution, and to a larger extent. In addition to simply increasing the rate at which additional lighting is installed (because of savings made elsewhere by increased energy efficiency) [19], LEDs may also encourage the use of lighting in novel settings, such as for solar-powered ornamental garden lighting, where species may be exposed to ALAN in environments where they previously experienced natural darkness, leading to direct impacts on their behavior [20].
LEDs may also contribute to increasing sky-glow, because they typically contain a greater proportion of short wavelengths [19]. However, with careful design (e.g. proper shielding), LEDs can enable lighting installations that are less wasteful and produce lower sky-glow: for example, a switch to LEDs from a mixture of metal halide and high-pressure sodium lights for aesthetic lighting of a church in Slovenia reduced waste light by a factor of at least 30 [21].

Beyond the potential impacts of increasing ALAN as a whole, some studies have identified ways in which switching to LED from other lighting technologies directly increases disruption to the ecosystem. Periphyton is the layer of algae and other photosynthetic microorganisms that grows underwater, coating the surface of objects that project above the sediment, including larger plants, and forms an important component of marine and freshwater food webs. The total quantity (or biomass) of periphyton decreases by over 60 % following the introduction of white LEDs (4000 K color temperature), but is unaffected by high-pressure sodium lights, probably because the blue light content of the LEDs, but not the HPS lights, is sufficient to disrupt perception of day-night cycles [22]. At the opposite end of the food chain, LEDs can increase the night-time activity and/or hunting success of visual predators (such as ground-beetles), leading to greater predation, and consequently reduced abundance, of herbivores such as slugs and aphids [23].
The wider impacts of such "top-down effects" on different species as they cascade through a food web can be difficult to predict.

Figure 2:
An increasing number of studies have examined differences between the ecological impacts of commercially available LEDs and existing street lighting technologies. Here, lighting rigs (L: high-pressure sodium; R: commercially-available LED) used in a study of impacts on nocturnal pollination by moths [13] are shown

Opportunities

By contrast, the effects of LEDs on the growth and flowering of terrestrial plants may be lower than other light sources [23]; an effect which may also be linked to the spectral composition of LEDs, because blue wavelengths are less important to plant photosynthesis. In the same way that effects on predators can lead to top-down effects in ecosystems, effects on plants (and other primary producers) can lead to cascading "bottom-up effects" which are equally unpredictable. Therefore, LEDs may cause less severe bottom-up effects than other lighting technologies in some settings.

Indeed, several studies appear to show that LEDs are less disruptive - or at least, no more disruptive - to certain elements of ecosystems than the incumbent lighting technologies. Commercially available LED street lights are significantly less attractive to nocturnal insects (including flies, beetles, moths, and other groups) than metal halide lights, and no more attractive than high-pressure sodium (HPS) lights [24]. This effect is the same when comparing domestic lights, with LEDs being less attractive than traditional tungsten filament bulbs and novel compact fluorescent bulbs, regardless of color temperature [25]. Similarly, LEDs had no more impact upon seed set in a nocturnally pollinated plant than HPS lights [13]. Many bat species are also sensitive to ALAN: some (such as the greater and lesser horseshoe bats, Rhinolophus ferrumequinum and R. hipposideros) will avoid light sources, whereas others (such as the common pipistrelle Pipistrellus pipistrellus) are tolerant to lights and may even preferentially hunt in their vicinity (probably responding to the high attracted densities of their insect prey) [26]. LEDs caused less disruption to the activity of both light averse and light-tolerant groups than mercury vapor lights in some studies [27] (but not all [28]), although there was no change to the activity of light-tolerant bats following a switch from low-pressure sodium lights to LEDs [29]. On the whole, these results do not support the widely held expectation that blue-rich LED lighting will increase the disruptive effects of ALAN on insects and other nocturnal wildlife, but more research is necessary.

Most studies to date have pertained to the comparison between the current field of commercially available LEDs and existing lighting technologies. However, some research has also begun to explore the effects of the flexible options available with LEDs. Top-down effects caused by increased nighttime activity of spiders and beetles can be partially reduced both by 50% dimming of LEDs and by manipulating their emissions spectra to reduce the content of blue light [30]. Both of these strategies have independently been shown to have benefits in other systems. Dimming LEDs also reduces impacts on the activity of some bat species (though not all) [31,32]. Red LEDs cause less disruption to mating behaviors and growth of immature stages in various moth species than either green or white LEDs (though even red LEDs caused some disruption compared to natural darkness) [6,33,34]. Most encouragingly, LEDs that had been specifically customized to reduce the attraction of nocturnal insects did indeed attract fewer insects than commercially available LEDs and compact fluorescent lamps, even though the color temperatures were comparable [17]. These results illustrate the great potential for LEDs to enable lighting design that is sensitive to, and actively avoids, the disruption of nocturnal ecosystems.

Unanswered Questions

Whilst much of the early research into the possibilities of LED technology to mitigate ecological impacts is promising, there is much that remains to be investigated before optimal lighting systems can be confidently designed. It is notable that studies comparing the effects of LEDs to existing light types are highly idiosyncratic with regards to which technology forms the comparison group. This variation probably reflects regional variation in incumbent lighting technologies, with researchers tending to draw comparisons between LEDs and the prevailing local technology (e.g. low- and high-pressure sodium lights, in many studies from the UK [13,24,29]). Since the conclusions of similar studies are sometimes different depending on the baseline lighting type (e.g. LEDs disrupt activity of light-tolerant bats less than mercury vapor lights, but no difference to low-pressure sodium [27,29]), there is a need for further research to establish how the impacts of LEDs on a wide variety of species and ecosystem processes differ from the full range of existing lighting technologies.

The scale of the impacts of ALAN may also vary regionally, and is likely to be more acute in regions of higher biodiversity. For example, a far greater proportion of moths transport pollen in Mediterranean regions [35,36] than in the UK and northern Europe [37], where much of the research into the effects of ALAN on nocturnal pollination has taken place [10,13], so cascading ecosystem-level impacts could be larger in the Mediterranean. Understanding the degree to which such variation exists, and how it alters the impacts of ALAN on ecosystems, may enable tailored, context-specific mitigation to be implemented in different regions.

Looking further to the future, there has, to date, been extremely little research into the potential ecological effects of the many novel lighting strategies that are made more feasible by the rise of LEDs. Dimming LEDs by 50 % reduced top-down effects on ecosystems, especially when paired with part-night lighting [30] and reduced impacts on the activity of some (but not all) bat species [31,32]. No further studies have yet been conducted into the broader implications of dimming, whilst no studies at all have to date investigated the ecological effects of motion-sensitive street/footpath lighting, even though this technology is already in use in some locations.

Conclusions

There is great potential for LEDs to enable lighting design that is sensitive to, and actively avoids, the disruption of nocturnal ecosystems, in combination with existing benefits including improved energy efficiency. Current evidence suggests that even the currently available blue-rich LEDs may be less harmful than initially feared, though some studies have found detrimental effects. However, dimming LEDs or tuning their emissions spectra to avoid the wavelengths that nocturnal organisms have high sensitivity to are both viable options to reduce impacts, especially if paired with other, more general, mitigation strategies such as part-night lighting. Other possibilities (e.g. motion-sensitive street lighting) remain to be rigorously tested. In some cases, research in this field has benefitted considerably by active partnership with the lighting industry, and there is a clear and important role for further industry involvement in developing, testing, and ultimately promoting environmentally friendly lighting solutions. ■

References

[1] Koen EL, Minnaar C, Roever CL, Boyles JG. Emerging threat of the 21st century lightscape to global biodiversity. Glob Chang Biol. 2018; doi:10.1111/gcb.14146

[2] Davies TW, Smyth T. Why artificial light at night should be a focus for global change research in the 21st century. Glob Chang Biol. 2017; doi:10.1111/gcb.13927

[3] Grubisic M, van Grunsven RHA, Kyba CCM, Manfrin A, Hölker F. Insect declines and agroecosystems: does light pollution matter? Insect declines and agroecosystems. Ann Appl Biol. 2018;8: e67798

[4] Macgregor CJ, Pocock MJO, Fox R, Evans DM. Pollination by nocturnal Lepidoptera, and the effects of light pollution: a review. Ecol Entomol. 2015;40: 187-198.

[5] van Langevelde F, van Grunsven RHA, Veenendaal EM, Fijen TPM. Artificial night lighting inhibits feeding in moths. Biol Lett. 2017;13: 20160874

[6] van Geffen KG, van Eck E, de Boer RA, van Grunsven RHA, Salis L, Berendse F, et al. Artificial light at night inhibits mating in a Geometrid moth. Insect Conserv Divers. 2015;8: 282-287

[7] Da Silva A, Samplonius JM, Schlicht E, Valcu M, Kempenaers B. Artificial night lighting rather than traffic noise affects the daily timing of dawn and dusk singing in common European songbirds. Behav Ecol. 2014;25: 1037-1047

[8] Da Silva A, Valcu M, Kempenaers B. Light pollution alters the phenology of dawn and dusk singing in common European songbirds. Philos Trans R Soc Lond B Biol Sci. 2015;370. doi:10.1098/rstb.2014.0126

[9] Lewanzik D, Voigt CC. Artificial light puts ecosystem services of frugivorous bats at risk. Pocock M, editor. J Appl Ecol. 2014;51: 388-394

[10] Macgregor CJ, Evans DM, Fox R, Pocock MJO. The dark side of street lighting: impacts on moths and evidence for the disruption of nocturnal pollen transport. Glob Chang Biol. 2017;23: 697-707

[11] Knop E, Zoller L, Ryser R, Gerpe C, Hörler M, Fontaine C. Artificial light at night as a new threat to pollination. Nature 2017;548: 206-209

[12] Sanders D, Gaston KJ. How ecological communities respond to artificial light at night. J Exp Zool A Ecol Integr Physiol. 2018; doi:10.1002/jez.2157
[13] Macgregor CJ, Pocock MJO, Fox R, Evans DM. Effects of street lighting technologies on the success and quality of pollination in a nocturnally pollinated plant. Ecosphere. 2019;10: e02550
[14] Azam C, Kerbiriou C, Vernet A, Julien J-F, Bas Y, Plichard L, et al. Is part-night lighting an effective measure to limit the impacts of artificial lighting on bats? Glob Chang Biol. 2015;21: 4333-4341
[15] Stanley MC, Beggs JR, Bassett IE, Burns BR, Dirks KN, Jones DN, et al. Emerging threats in urban ecosystems: a horizon scanning exercise. Front Ecol Environ. 2015;13: 553-560
[16] Gaston KJ, Duffy JP, Gaston S, Bennie J, Davies TW. Human alteration of natural light cycles: causes and ecological consequences. Oecologia. 2014;176: 917-931
[17] Longcore T, Aldern HL, Eggers JF, Flores S, Franco L, Hirshfield-Yamanishi E, et al. Tuning the white light spectrum of light emitting diode lamps to reduce attraction of nocturnal arthropods. Philos Trans R Soc Lond B Biol Sci. 2015;370: 20140125
[18] Gaston KJ, Davies TW, Bennie J. Reducing the ecological consequences of night-time light pollution: options and developments. J Appl Ecol. 2012; doi:10.1111/j.1365-2664.2012.02212.x
[19] Kyba CCM, Kuester T, Sánchez de Miguel A, Baugh K, Jechow A, Hölker F, et al. Artificially lit surface of Earth at night increasing in radiance and extent. Sci Adv. 2017;3: e1701528
[20] Eccard JA, Scheffler I, Franke S, Hoffmann J. Off-grid: solar powered LED illumination impacts epigeal arthropods. Insect Conserv Divers. 2018; doi:10.1111/icad.12303
[21] Kyba CCM, Mohar A, Pintar G, Stare J. Reducing the environmental footprint of church lighting: matching façade shape and lowering luminance with the EcoSky LED. International Journal of Sustainable Lighting. 2018;20: 1-1
[22] Grubisic M, van Grunsven RHA, Manfrin A, Monaghan MT, Hölker F. A transition to white LED increases ecological impacts of nocturnal illumination on aquatic primary producers in a lowland agricultural drainage ditch. Environ Pollut. 2018;240: 630-638
[23] Bennie J, Davies TW, Cruse D, Inger R, Gaston KJ. Artificial Light at Night Causes Top-down and Bottom-up Trophic Effects on Invertebrate Populations. J Appl Ecol. 2018; doi:10.1111/1365-2664.13240
[24] Wakefield A, Broyles M, Stone EL, Harris S, Jones G. Quantifying the attractiveness of broad-spectrum street lights to aerial nocturnal insects. J Appl Ecol. 2018;55: 714-722
[25] Wakefield A, Broyles M, Stone EL, Jones G, Harris S. Experimentally comparing the attractiveness of domestic lights to insects: Do LEDs attract fewer insects than conventional light types? Ecol Evol. 2016;6: 8028-8036
[26] Haddock JK, Threlfall CG, Law B, Hochuli DF. Light pollution at the urban forest edge negatively impacts insectivorous bats. Biol Conserv. 2019;236: 17-28
[27] Lewanzik D, Voigt CC. Transition from conventional to light-emitting diode street lighting changes activity of urban bats. J Appl Ecol. 2016; doi:10.1111/1365-2664.12758
[28] Haddock JK, Threlfall CG, Law B, Hochuli DF. Responses of insectivorous bats and nocturnal insects to local changes in street light technology. Austral Ecol.; 2019; doi:10.1111/aec.12772
[29] Rowse EG, Harris S, Jones G. The Switch from Low-Pressure Sodium to Light Emitting Diodes Does Not Affect Bat Activity at Street Lights. PLoS One. 2016;11: e0150884
[30] Davies TW, Bennie J, Cruse D, Blumgart D, Inger R, Gaston KJ. Multiple night-time light-emitting diode lighting strategies impact grassland invertebrate assemblages. Glob Chang Biol. 2017;23: 2641-2648
[31] Stone EL, Jones G, Harris S. Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. Glob Chang Biol. 2012;18: 2458-2465
[32] Rowse EG, Harris S, Jones G. Effects of dimming light-emitting diode street lights on light-opportunistic and light-averse bats in suburban habitats. R Soc Open Sci. 2018;5: 180205.
[33] van Geffen KG, van Grunsven RHA, van Ruijven J, Berendse F, Veenendaal EM. Artificial light at night causes diapause inhibition and sex-specific life history changes in a moth. Ecol Evol. 2014;4: 2082-2089
[34] van Geffen KG, Groot AT, van Grunsven RHA, Donners M, Berendse F, Veenendaal EM. Artificial night lighting disrupts sex pheromone in a noctuid moth: Moth sex pheromone in illuminated nights. Ecol Entomol. 2015;40: 401-408
[35] Banza P, Macgregor CJ, Belo ADF, Fox R, Pocock MJO, Evans DM. Wildfire alters the structure and seasonal dynamics of nocturnal pollen-transport networks. Funct Ecol. 2019; doi:10.1111/1365-2435.13388
[36] Banza P, Belo ADF, Evans DM. The structure and robustness of nocturnal Lepidopteran pollen-transfer networks in a Biodiversity Hotspot. Insect Conserv Divers. 2015;8: 538-546.
[37] Macgregor CJ, Kitson JJN, Fox R, Hahn C, Lunt DH, Pocock MJO, et al. Construction, validation, and application of nocturnal pollen transport networks in an agro-ecosystem: a comparison using light microscopy and DNA metabarcoding: Constructing nocturnal pollination networks. Ecol Entomol. 2019;44: 17-29

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Cover-page

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Perfectly designed optics like Bartenbach's "Light Disc" are an essential part of sustainable and environmentally friendly illumination as they direct light to where it is necessary, avoid stray light and undesired glare

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VISUAL PERFORMANCE & COGNITION
Issue 76 - Nov/Dec 2019

EVENTS

LpS & TiL Post Show Report

The LpS post show report gives an overview of the event for all those that could not attend. This is also an opportunity to identify upcoming and fading trends, hot topics, new technologies and approaches. Interesting discussion panels and the participation of famous lighting designers guarantee an exciting journey through the three days of the event. ■

RESEARCH

"Best Papers" at LpS 2019: The Winning Paper

This year many of the submitted articles were concerned with "Freeform Optics" and "Micro Optics". Other interesting topics were: "Degradation of Green High-Power LEDs", "Metrics in Melanoptic Stimulus Evaluation for HCL", " Circular Economy", "A Novel Thermal Transient Measurement Method" or "Measuring Multichip LED Light Engines", to name just a few. The winner will be presented at the LpS Get Together & Award Ceremony on September 25th, 2019. Whichever paper wins, it will - once again - be very interesting for the industry. ■

TECHNOLOGIES

A White Light Tuning Strategy that Fuels Human Centric Lighting

Dynamic tuning of the white light spectrum is an indispensable tool for lighting designers striving to improve user experiences and add value to lighting applications. Up until now, tunable LED light has had some significant drawbacks. It is complicated to follow the Planckian Locus and provide a constant CRI. Efficiency drops with lower CCT and it is difficult to keep the lumen output constant while changing the CCT. A new approach presented in this article addresses all these issues. ■

STANDARDIZATION

New Ecodesign Regulation on Flicker and Stroboscopic Effects in LED Lighting

As light quality continuously becomes more relevant, flicker also comes into focus of the Ecodesign and Energy Labelling regulations. Flicker and Stroboscopic Visibility Measure (SVM) will be introduced by the revised Ecodesign Regulation for light sources by the end of 2019. The authors explain what this means, how to measure correctly, and which equipment is appropriate. ■

SPECIAL TOPICS

Fluorescence-Free Measurement of UV Radiant Flux

With the improvement of UV LEDs within the last two years, the number of possible applications increased and performance measurement became more important. Radiant flux measurement is compromised by fluorescence of the measurement equipment, namely the integrating spheres. This article discusses a more suitable sphere material as well as its peculiarities in order to be able to perform spectral radiant flux measurements with the lowest possible measurement uncertainty. ■

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71 Jan./ Feb.	**TECHNOLOGIES FOR HEALTH & WELL-BEING** Efficient lighting has become a prerequisite. Ongoing discussions question whether efficient lighting is also healthy lighting and if it supports well-being. Findings, technologies, designs and applications supporting health and well-being are the focus of this issue.	Oct. 15, 2018	**Oct. 22, 2018**	Jan. 15, 2019	Feb. 01, 2019
72 Mar./ Apr.	**FUTURE PROOF SYSTEMS & SOLUTIONS** Most buildings are constructed to last at least four decades. Owners and operators are only willing to invest in long lasting future proof solutions for the infrastructure. The topic of this issue is the question of if and what future-proof solutions and technologies are available.	Dec. 17, 2018	**Jan. 04, 2019**	Mar. 15, 2019	April 01, 2019
73 May./ June	**DISRUPTIVE TECHNOLOGIES & APPROACHES** A good part of the lighting industry suffers from high production costs – especially in Europe and the US. New concepts, designs, materials and manufacturing methods may be advantageous. This issue reveals the most ingenious approaches.	Feb. 25, 2019	**Mar. 04, 2019**	May 15, 2019	June 03, 2019
74 July/ Aug.	**TECHNOLOGIES FOR SPECIFIC TASKS & APPLICATIONS** Light is not only used for illuminating rooms and open spaces. The applications of LEDs are manifold. This issue acknowledges the importance of LED light sources in automotive, horticultural, medicinal, cosmetic, and environmental applications, to name just a few.	April 24, 2019	**May 06, 2019**	July 16, 2019	Aug. 01, 2019
75 Sept./ Oct.	**ENVIRONMENTAL FRIENDLY DESIGN & ENGINEERING** The EU Commission supports the move towards a more circular economy. Additionally, research demonstrates that artificial light may negatively affect the environment. Technologies, designs and solutions that recognize these two aspects are addressed in this issue.	June 26, 2019	**July 05, 2019**	Sept. 02, 2019	Sept. 24, 2019
76 Nov./ Dec.	**TECHNOLOGIES FOR VISUAL PERFORMANCE & COGNITION** Some research results suggest that the spectral properties of a light source have great influence on visual performance, cognition and arousal. But it is more than just the spectrum that counts. This issue presents supporting concepts, technologies and solutions.	Aug 06, 2019	**Aug 26, 2019**	Nov. 15, 2019	Dec. 02, 2019

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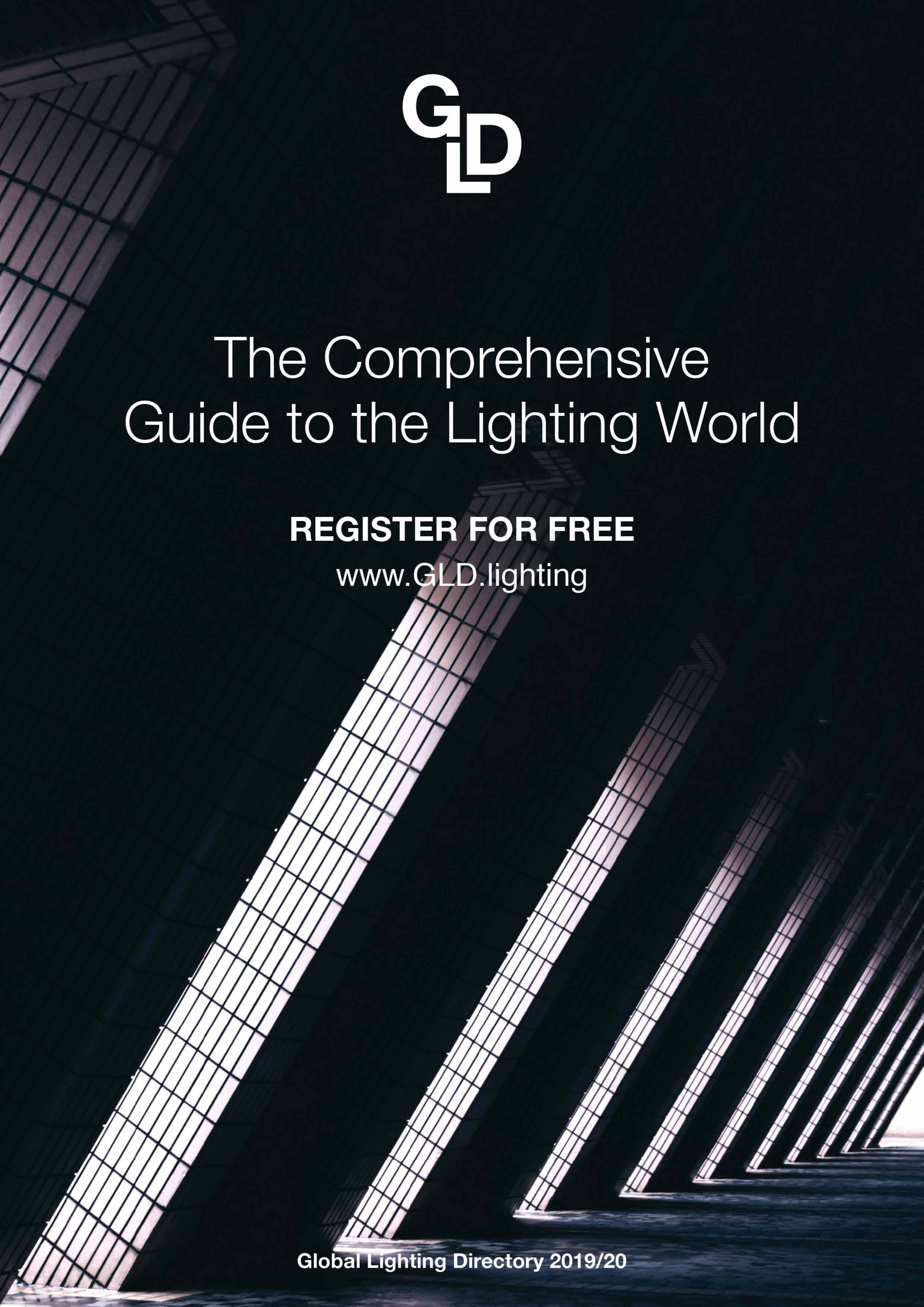
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