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The Global Information Hub for Lighting Technologies
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Tech-Talks Bregenz: Maja Grubisic

Research: Wellness & Performance, Light Pollution

Technology : DC Grids, Smart Lighting & IoT

Applications: LEDs for Horticulture Lighting

PHILIPS FORTIMO LED MODULE SYSTEM SOLUTIONS

LINEAR

Fortimo LED line
Designed to replace fluorescent lighting in new luminaires for office, retail, and industrial applications.

Fortimo LED line high flux high temperature
Ideal for application at elevated installation heights and increased application temperatures where more light is needed.

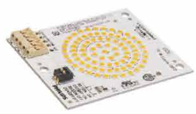
Fortimo LED strip
Enabling design of high-performance slim linear LED luminaires, not possible with fluorescent lighting or Fortimo LED Line.

Fortimo LED strip value offer
Enables economic fixture design meeting DLC requirements for linear troffers.

Fortimo LED strip EdgeLit (EL)
Designed to enable slim and uniform architectural lighting applications like suspended panel LED luminaires.

POINT

Fortimo DLM flex L2 G2 DS
Provides the ease of switching defined flux levels via a dip switch on board. Available in CRI 80 and 90 models.



Fortimo DLM EaseSelect
Integrated module with a 0-10V 1% dimmable driver inside, enabling speed on design, assembly and installation.

Fortimo SLM gen 6
Quality of light and performance in a chip-on-board design, ideal for architectural and retail lighting applications.

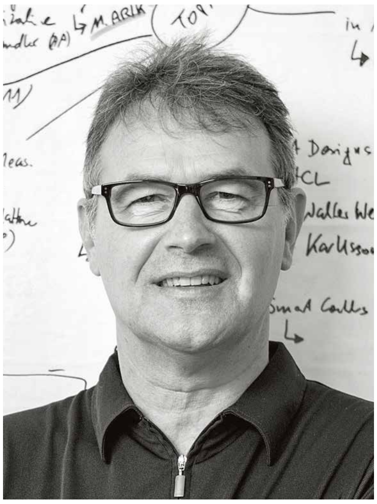
OUTDOOR

Fortimo FastFlex gen 3
Designed for OEMs looking for a "one-stop shop" where board and lenses are provided to help support a short fixture development cycle while enabling good optical flexibility.

For the latest information on Philips products contact your local FLS sales representative.

FUTURE Lighting Solutions
Making LED Lighting Solutions Simple™
www.FutureLightingSolutions.com

signify



Lighting Trends

No sooner was the LpS/TiL event just around the corner than it was over!

If you didn't have the chance to be there, you might be wondering what the findings of the events were and and what trends we were able to identify.

In short, we saw that the light sector is moving into the digital world at a rapid pace. Networking via Bluetooth Mesh, DALI II and the Internet is a must for future lighting systems. This is connected with the mandatory requirements for the security of data and systems. Human Centric Lighting was a key focus of the conference. We are urged to focus on the user and the usage to optimally design lighting according to the requirements.

The European Commission is preparing a new labeling regulation that prescribes the repairability of electrical equipment. Lighting modules and drivers have to be made exchangeable if you don't want to jeopardize the luminaire being put on the market at all. Modularity, dynamism and adaptability are the basic characteristics of new lighting systems.

The further development of LEDs towards miniaturization, performance and color quality are ongoing tasks, but spectral optimization towards sunlight is also becoming increasingly important in order to meet HCL requirements.

Those three days in September were chock full of great encounters and inspiring lectures and workshops. For a detailed report of the show and award ceremony, please read the Post-Show Report in this issue.

As the saying goes, “After the show is before the show”, and we are already looking forward to the coming year and the LpS/TiL2019!

Yours Sincerely,

Siegfried Luger
Publisher, LED professional

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LUXEON V2

Best performance. Most usable light. Proven package.

LUXEON V2 is a Chip Scale Package (CSP) based high power domed LED optimized for directional applications to continue Lumileds leadership in this category. LUXEON V2 delivers high efficacy and robustness in a 3535 package with 3-stripe footprint designed to accelerate time to market by matching the radiation pattern of competitive products, while improving system costs through unparalleled performance (flux and efficacy) at higher drive currents.

- 450lm @ 150lm/W
- CSP 2mm2 die technology delivers high efficacy at high drive current — provides design flexibility and supports high flux density
- Emission and source luminance distribution designed to match competition enabling drop-in compatibility and accelerates time to market
- 3535 ceramic package with 3-stripe footprint for ease of design

Applications

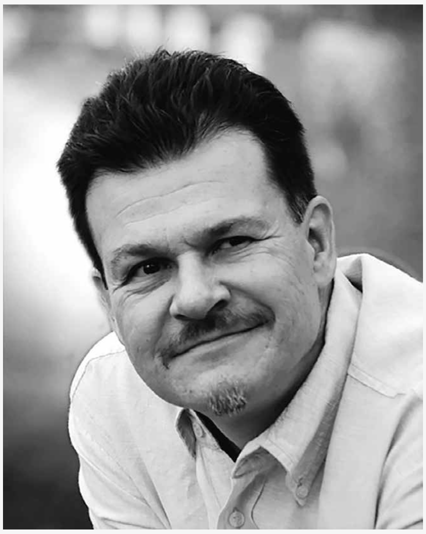
- Architectural
- High Bay & Low Bay
- Outdoor
  - Stadium
  - Street and Area Lighting

To find out more on LUXEON V2,
visit **FutureLightingSolutions.com** or contact your local FLS representative.

FUTURE Lighting Solutions

www.FutureLightingSolutions.com

LUMILEDS



Arno Grabher-Meyer

Arno originally studied biology at the University of Innsbruck. He was involved in several scientific documentation projects for the Alpenzoo (Alpine Zoo) and a documentary film for the BBC with Sir David Attenborough. He worked as a freelance photographer for the Inatura (Museum for Nature, Humans and Technology) in Dornbirn.

He earned his engineering degree through continued education and in 2005 went to work for Luger Research. Here Arno worked on several LED lighting research projects in conjunction with the Austrian Competence Center Light.

His job as Chief Editor started in 2006 when Luger Research initiated LED professional. Part of this multi-faceted job is being responsible for the editorial content of the magazine and online news.

AN INDUSTRY AT A CROSSROADS

We often hear grumbles about the lighting industry suffering under low margins and high costs. Primarily, this is true for most traditional luminaire manufacturers but not as much for innovative controls and driver manufacturers, and even less so for innovative newcomers who understand the semiconductor business that has taken over a share of the luminaire manufacturers' revenue.

The keynotes at the combined LpS/TiL event addressed this situation and I heard many discussions concerning this topic at the show. Several new aspects that might be interesting for the lighting industry, as a whole, to recover were also unveiled.

So what are the lessons learned?

"Be brave and make something different!" Almost every panel discussion, whatever the topic, ended up with a similar conclusion: Keep an eye on other industries because these are the true innovators of today. Stop doing the same thing the lighting industry has done for decades. The technology is here: be creative, otherwise more creative industries will take over your business and blow you away.

"Don't sell lumens per watt - sell light quality!" As efficacy is already at such a high level, the advantages of high quality lighting by far outweigh their efficacy deficits. The lectures and workshops that were paid the most attention to, concerned light quality and the effects of light. As if the award jury for the Scientific Award had foreseen this trend, they honored a research paper on "Lighting and Emergency Department Clinician Wellness and Performance Improvement". The LpS Awards and the TiL Awards were also mostly for products with a focus on light quality.

"Don't sell lumens - sell adequate light!" Recently, the latest study on energy consumption and warming showed dramatic figures and sad forecasts for 2050. The rebound effect that was already announced at the beginning of LEDification seems to have become reality. Add to this, the negative impact that over-illumination is having. Anticipating this issue's feature, one LpS lecture addressed the topic "Effects of Light Pollution on Insects and Agriculture", showing that unpredictable effects could have a negative impact on agriculture. But the authors also point out that an LED's spectrum can be tailored towards lower impact. And that is the big chance. Take it, and differentiate from your competitor!

"Listen to the user!" A luminaire manufacturer talks about the architect, the installer or the operator, but they rarely consider the real user: you and me in the office; the nurse in the hospital; the worker in the factory. What are their true demands? The answer: Simplicity, and again, adequate light. Speakers talked about sophisticated controls options that were not used because they are too complicated or inconvenient. The traditional concept of providing different fixed scenes is not really accepted. Artificial Intelligence is anticipated to solve this issue when it comes to more sophisticated solutions. A broad and interesting field, not just for research! Otherwise KISS: Keep It Simple Stupid.

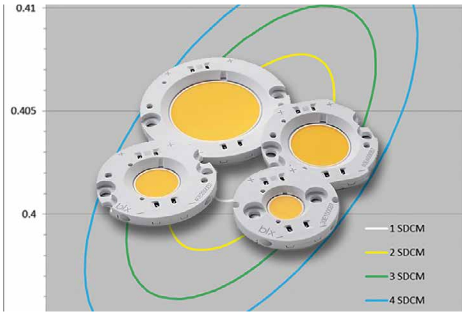
Finally, maybe the most important statement from a panel discussion: "Give the younger generation the opportunity to create the(ir) future!" They think out of the box. Who made computers what they are today? And who paved the way to tablets and the mobile phones of today? The visions of the young Steve Jobs and Bill Gates! So be brave, give young people a chance to become the Steve Jobs' and Bill Gates' of Lighting. The most successful companies in this field have already recognized this and are acting.

Some of you may find these statements blunt and provoking. But sometimes it's necessary to look in the mirror and address issues directly and candidly. That's what happened at LpS and TiL! Let's start an open discussion and take the necessary, brave measures for the benefit of this incredible industry.

A.G-M

Bridgelux Advances 1 SDCM Consistency and New Dynamic White LED Modules

As part of the ongoing commitment to deliver innovative LED solutions and design flexibility, Bridgelux today announces one Standard Deviation Color Matching (1 SDCM) across its core chip-on-board (COB) product families, and two new dynamic white products within the Vesta® Series product family. Bridgelux continues to expand its LED product portfolio products to provide luminaire OEMs with market leading color consistency and dynamic light options that enhance the light quality, experience, and design flexibility of LED lighting.



Bridgelux offers 1 SDCM color consistency for Vero® Series, Vero® SE Series, V Series™ COB and the new tunable white Vesta® Series modules for edge-lit panels

In addition, Bridgelux today announces two new product extensions within the Vesta® Series of tunable white products:

- The new Vesta® Series Edge, a 570 mm linear solution that delivers a uniform and vibrant edge-lit panel lighting experience with a CCT range of 2700–5000 K. Vesta Edge will improve office and commercial applications where low-glare, dynamic white illumination is specified. This product was designed specifically for human centric lighting applications
- The new Vesta® Series Tunable White COB arrays featuring a phosphor dispensed architecture that provides up to 20% greater efficacy and higher lumen per dollar options to equivalent chip scale package (CSP)-based COB products. This new platform provides greater flexibility in being able to specify broader dynamic CCT ranges

As the global leader in LED light sources, Bridgelux will support 1 SDCM on select Vero® Series, Vero® SE Series and V Series™ COB parts starting December 2018.

These parts are ideal for specific indoor applications where exceptionally discerning lighting requires the tightest color binning and white point consistency. These applications include architectural-grade downlight and spotlights.

"As the market continues to pursue more human centric lighting, it is evident that quality of light matters even more, and experiential lighting provides new levels of differentiation and value in our increasingly connected world. Bridgelux is excited to be at the forefront of new LED technology solutions and design choices that increase flexibility and open new dimensions of end user benefit," said Aaron Merrill, Vice President of Marketing at Bridgelux.

Lumileds Drives Efficacy to Over 200 lm/W in Popular 2835 Package

Lumileds has introduced the LUXEON 2835 HE, which achieves unprecedented efficacy of over 200 lm/W, while providing market defining color consistency. Expanding on the successful LUXEON 2835 Line, the new LED is optimized to deliver high efficacy and 2-step MacAdam ellipse color consistency in applications such as troffers and high bay/ low bay fixtures.

LUXEON 2835 HE

The LUXEON 2835 HE delivers the most efficient mid power solution on the market, reducing LED count for general lighting applications

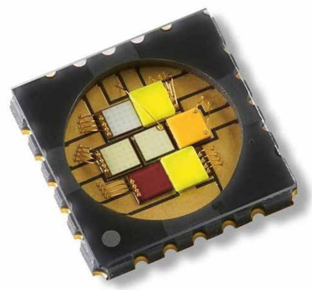
"The LED's tight color point distinguishes it from other mid power devices in its class. Design kits to 2-step MacAdam ellipse are available for the ultimate in color consistency for demanding lighting applications," said Sam Wu, Product Manager of Mid Power Products at Lumileds. The LED delivers 36 lm at 65 mA drive current and 202 lm/W, or 220 lm when driven at 480 mA (4000 K and 80 CRI).

"LUXEON 2835 HE is ideally suited to troffers, downlights and lamps where fixture efficacy greater than 150 lumen per watt is paramount and LED count must be minimized," said Wu. Lumileds' high reliability design enables the LUXEON 2835 HE to deliver more light for smaller profile, general lighting applications. Unlike many 2835 LED packages on the market, LUXEON 2835 HE is lumen maintenance tested (LM-80) to 12,000 hours, ensuring lumen maintenance of 72,000 hours in the field (L70, TM-21 basis).

LUXEON 2835 HE is available in a wide range of color temperatures and CRIs of 70 to 90 to address a variety of general lighting designs. The LED is available immediately as a drop-in replacement for 2835 LED packages (2.8x3.5 mm) or can replace 5630 (5.6x3.0 mm) or 3030 (3.0x3.0 mm) mid power sockets with similar optical requirements.

LED Engin Introduces World's First 50 W Seven-Die LED Emitter

LED Engin, an Osram business, has unveiled the LZ7 Plus, the world's first 50 W seven-die LED emitter. The trend in stage lighting fixtures has evolved from not only delivering ultra-bright light with narrow beam, but also creating more sophisticated color schemes and high CRI white. LZ7 Plus is uniquely designed to address this trend, featuring seven high-power dies in six colors, which can be individually controlled to deliver intense, saturated colors, as well as high quality white light as a result of color mixing. The LZ7 Plus can be used in various stage fixtures, such as static and moving head wash fixtures, as well as profile fixtures.



The LZ7 Plus from LED Engin, the ultimate solution for stage lighting applications, features seven high-power dies in six colors, which can be individually controlled to deliver intense, saturated color

The new LED features a 50 W package with high-current red, green and blue dies, as well as cyan, two phosphor-converted lime dies and phosphor-converted amber die. The dies are closely packed in a low thermal resistance package with an integrated flat glass lens. The addition of high performance cyan, lime and amber to the traditional RGB color in a compact light-emitting surface of 3.4x3.4 mm, when coupled with secondary optics, produces an ultra-bright light with narrow beam, richer and wider color combination, as well as high CRI white, all from a single LED emitter.

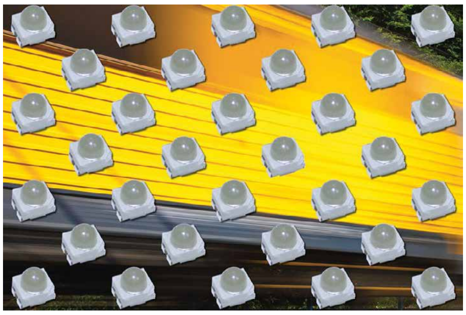
To achieve this unprecedented performance, the underlying powerhouse is LED Engin's proprietary LuxiGen™ platform. Featuring a patented multi-layer ceramic substrate technology, the platform allows all seven dies to be placed closely together, and delivers an ultra-low thermal resistance allowing heat to be dissipated efficiently from the dies.

"There is growing demand for stage lighting with more sophisticated color requirements, without sacrificing brightness and beam quality," said David Tahmassebi, CEO of LED Engin. "The LZ7 Plus offers an unparalleled combination of colors in a powerful, high quality package to deliver performance not seen before in stage lighting." ■

OMC's New 30° Beam Angle SMD LEDs for High-Intensity Applications

OMC, the pioneer in optoelectronics design & manufacture, has introduced a new range of narrow angle, surface-mount LEDs in a variety of package styles and all popular LED wavelengths. The new SMD emitter series features integrated lenses molded into the package that provides a 30-degree output beam. Applications for visible wavelengths include signaling and indication, in which the beam needs to be visible over greater distances, while the company's infrared wavelength versions are used for sensing and data-communication over greater distances and with higher precision than using standard, wide-angle SMD components.

Traditional through-hole (non-surface-mount) LEDs are commonly produced with narrow output angles as the LED body is generally molded around the leadframe using an optical epoxy or silicone. The LED body itself then acts as the lens, focusing the light into beam angles as narrow as 5 degrees, with 30 degrees being a common requirement for many indications and sensing applications. However, with the move to surface-mount components, some design versatility was lost as the LED body is generally injection molded from non-optical material which is pre-manufactured before the LED die is mounted, and does not, therefore, form a lens in the same way. As a result, the majority of SMD packages do not incorporate any lensing, emitting light in a wide beam angle which generally exceeds 100°.



OMC's new 30° narrow beam angle SMD LEDs enable light transmission over greater distances for many applications include signaling, indication, sensing and data-communication

Using a proprietary post die-mount encapsulation process, OMC is able to cost-effectively integrate narrow angle lensing into a range of surface-mount emitters, and can now offer 30 degree beam angles for all standard LED wavelengths, including infrared.

OMC's Commercial Director, William Heath comments: "Providing a clear human-machine interface is vital, as is ensuring precision and accuracy in a sensing system, and so the selection of the correct light-emitting components is a key design task. Narrow angle SMD LEDs are very much in demand across a wide spectrum of applications, such as sensing and communications, signaling and indication, but are less commonly available than wide-angle devices, particularly for custom wavelengths and CCT/CRIs. This new series of 30 degree surface-mount LEDs opens up design possibilities for engineers, and in addition to standard devices, we are able to customize the devices to provide the wavelength or other light characteristics the customer may require." ■

Automotive Lighting of the Future - Osram's Oslon Boost HX for New Concepts

As part of digital mirror device (DMD) systems, the LED enables symbols to be projected onto the road in HD quality. Just like a normal projector can display pictures on a screen, a DMD system with its millions of micro-mirrors can project light onto the road in the form of symbols.

Oslon Boost HX is ideal for use in DMD systems as it provides excellent luminance to bring light-based driver assistance systems on a new level

Thanks to components such as the new Oslon Boost HX, each headlight achieves a resolution of more than one million pixels, offering car drivers not only classic illumination but also optional support from information projected onto the road. For example, future headlights may project two guide lines the width of a car apart, enabling the driver to negotiate roadworks more safely. Projections may also be used to tell drivers that they are too close to the vehicle in front, or warn them that they are approaching roadworks, icy patches or other hazards.

In developing Oslon Boost HX, Osram Opto Semiconductors made use of its extensive know-how in projection technology, in which high-current LEDs have been used for a long time and have been continually optimized. They have now been transferred to the automotive sector and adapted to meet the strict quality requirements. "This first product in the Oslon Boost family addresses the trend for special user experiences with added safety and emotional appeal. This LED is a good example that shows the enormous potential our products will have in automotive lighting", said Stefan Seidel, Senior Manager Marketing Automotive Exterior at Osram Opto Semiconductors.

Oslon Boost HX delivers exceptional luminance of more than 200 cd/mm², taking light-based driver assistance systems and communication with the driver into new territory. Special chip technology with particularly high ampacity can be operated at 3 A/mm², ensuring high luminous flux - and most importantly for this target application - high luminance. Its 2 mm² chip emits at least 1,400 lm at a current of 6 A.

The package has been optimized in order to make use of the high current capability of the chips. An electrically insulated thermal pad and special internal design structures ensure that heat is reliably removed from the component. The 4x4 mm ceramic package is very robust so it is easy to handle.

Passive DMD solutions herald the start of a broad range of applications. More efficient active solutions for glare-free high beam and projection as well as other Oslon Boost derivatives will follow. ■

Luxeon V2, the Only Choice for a 2 mm² High Power LED

Lumileds announced breakthrough high power performance with the new Luxeon V2 LED. With the highest performance in its class for output and efficacy, the emitter easily enables DLC Premium performance at the system level. Luxeon V2 utilizes a 2x2 mm Chip Scale Package (CSP) in a 3.5x3.5 mm standard package. “Luxeon V2 is designed such that 99% of the light is forward directed, resulting in the industry’s most usable light from a compact source,” said Jennifer Holland, Product Line Director at Lumileds.

Luxeon V2 delivers best-in-class performance and the most usable light for street lights, high-bay/low-bay fixtures, sports stadiums and portable applications

Typical output and efficiency of the Luxeon V2 at 4000 K, 70 CRI is 315 lm at 160 lm/W when driven at 700 mA. In addition to high efficiency, the versatility of the CSP die offers high drive current capability (up to 2.4 A) while still maintaining high efficiency across the operating range. At 1 A, Luxeon V2 delivers 150 lm/W and over 10% more flux than similar 2 mm² offerings available on the market. The industry’s lowest thermal resistance substrate (2.6°C/W) simplifies the thermal design of the fixture, from streetlights and sports lighting solutions to portable fixtures.

Luxeon V2 has a Lambertian radiation pattern profile making it possible to leverage the existing optics ecosystem. “By leveraging the existing optical ecosystem, fixture manufacturers can rapidly accelerate time to market while dramatically improving performance,” said Holland. Luxeon V2 also delivers superior color over angle (COA) than competing LEDs, ensuring the best color consistency across the beam.

Luxeon V2 is available in a variety of color temperature and CRI options for unparalleled performance at high drive currents. ■

Luminus' New Horticulture CoB LEDs Promise New Growth for the Cannabis Market

Luminus Devices, Inc. a global manufacturer of high-performance LEDs and solid-state light sources, has released its Horticulture CoBs with spectrums targeted for cannabis production. The new devices are available with 14 mm and 22 mm light emitting surfaces (LES) and provide best in class PPF and PPF/W performance. With operating power from 25 W to 125 W, the PPF range extends from 45 µmol/s to over 150 µmol/s with the larger 22 mm LES.

“Horticulture CoBs are perfectly suited to replace HPS lamps for growing “light-hungry” crops such as Cannabis as they offer high PPF output combined with excellent efficacy. Additionally, CoB’s broad ecosystem makes it easy for fixture manufacturers to develop new lighting solutions for any indoor operation,” said Yves Bertic, senior director of global product marketing. CoBs typically outperform HPS lamps when it comes to power consumption, spectrum, efficiency, and lifespan.

Luminus Devices claims best in class PPF and PPF/W for their new CoBs (left) that are designed for replacing HPS lamps

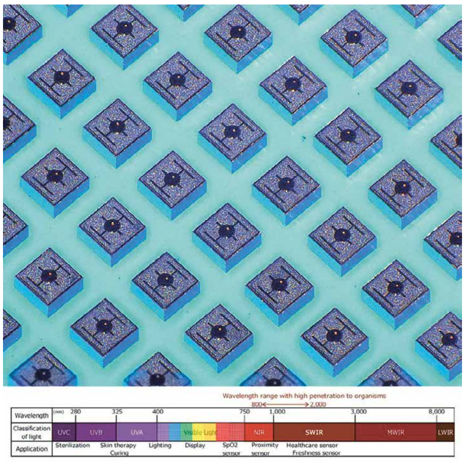
The new CoBs are available with two spectra options; the first is a phosphor-converted Deep Red spectrum with 1:1 Blue to Deep Red intensity ratio and the second has a 1:2 Blue to Deep Red intensity ratio. Though the color of the CoBs is often referred to as “purple”, it has two peaks, one at 450 nm and one at 640 nm.

“Beyond the cannabis market, the need for improved crop yields is more important than ever, and our new horticulture CoBs enable innovative luminaires that directly address the market’s needs,” said Bertic “With the ability to customize spectra to specific crops or classes of crops, we foresee a portfolio that supports growers around the world.”

Luminus continues to expand its horticulture offering by adding new package types and spectrums so that growers and farmers can maximize production yields, become more sustainable and reduce costs. ■

DOWA Announces Short-Wavelength IR LEDs with the World’s Highest Output Power

DOWA Electronics Materials Co., Ltd., a subsidiary of DOWA Holdings, has successfully developed short-wavelength-infrared LED chips with output power that is 3.5 times higher than existing products and is the highest in the world at 6.8 mW (350 µm square size, applying a direct current of 100 mA at room temperature), with a peak wavelength of 1,300 nm. DOWA has started to deliver sample products.



DOWA claims its short wavelength IR LED chips to be the most powerful IR LEDs in their class

LED-based optical sensors feature advantages such as a smaller size, lower power consumption and longer life time. In addition, because near and short-wavelength-infrared light with a wavelength range between 800 nm and 2,000 nm is highly penetrative to organisms, the application of short-wavelength LEDs are proceeding in fields such as agricultural and food analysis, medicine and healthcare (wavelength and major applications). In particular, in the field of healthcare, the market for which is set to expand rapidly, LED-based sensors are expected to enable measurement of blood glucose levels without blood drawing.

The newly developed short-wavelength infrared LED chips can balance higher output power and a smaller chip size, which are usually a trade-off, and are significantly improved the upward optical output, which is required for sensor applications. DOWA will expand these technologies to peak wavelengths of 1,450 nm and 1,650 nm, widening the lineup.

In the field of gallium-based compound semiconductor, DOWA offers an extensive lineup of products, ranging from materials such as high-purity gallium to wafers, LED chips and some lamp modules. DOWA also has abilities to flexibly accommodate a variety of needs, such as customizing wavelengths.

DOWA will focus on enhancing the features of next-generation products and streamlining production to further expand its semiconductor business. ■

Efficient and Tough - Tridonic's New RLE-G2 Modules for Industrial and Outdoor Lighting

The new RLE-G2 modules from Tridonic have been developed for harsh industrial environments and challenging outdoor conditions. They can withstand salt spray, pollutants and extreme temperatures and are easy to integrate in a very wide range of luminaires. With their long life and high efficiency they cover a broad spectrum of potential applications.

Tridonic's new RLE G2 modules for industrial and outdoor lighting are versatile and offer high efficiency and reliability even in harsh conditions

The second generation of the RLE EXC and ADV family of modules for industrial and outdoor lighting has been specifically developed for modular luminaire designs. All the high-power and mid-power modules have passed a demanding series of tests, including exposure to salt spray and pollutants. With their extended temperature range of -40°C to +105°C / +95°C (high power/mid power) they can also handle extreme climatic conditions. While high-power modules are extremely durable with a life of 100,000 hours, mid-power module offer exceptionally high efficiency of up to 190 lm/W and a life of 80,000 hours. Together with a suitable Tridonic outdoor driver, all the RLE G2 modules can withstand surge and burst voltages of up to 6 kV. The modules comply with the ZHAGA standard and are compatible with various standard lenses available on the market.

EXC high-power modules:
The RLE 2x4 / 2x8 EXC2 OTD modules are equipped with 2 x 4 or 2 x 8 high-power LEDs and achieve a luminous flux of 2,000 and 4,000 lm respectively. Their module efficiency is up to 170 lm/W at 550 mA (nominal operation). The LED modules are available in different color temperatures: 2,700 K, 3,000 K, 4,000 K and 5,000 K with a CRI > 80, and 4,000 K and 6,500 K with a CRI > 70. CRI > 70 stands for high efficiency, and CRI > 80 for good color rendering. They are compatible with standard 2x2 lenses, such as LEDIL Strada 2x2.

The RLE 2x6 EXC2 OTD modules with 2 x 6 high-power LEDs achieve a luminous flux of 3,000 lm and a module efficiency of up to 140 lm/W at 700 mA (nominal operation). The cost-effective modules can also be operated without protective glass. They are suitable for standard IP6x lenses, such as LEDIL Strada IP-2x6.

ADV mid-power modules:
The RLE ADV2 OTD modules have 32 or 64 mid-power LEDs on the board and achieve 2,000 and 4,000 lm respectively. They are impressive for their extraordinary efficiency of up to 190 lm/W at 500 mA (nominal operation) and provide more homogeneous light and less glare than high-power LEDs. Standard x16 lenses such as LEDIL Stradella 16 are suitable here. The modules can be used without protective glass.

The manufacturer offers a warranty of 8 years on the high-power modules with a life of 100,000 hours, and a warranty of 5 years on the mid-power modules with a life of 80,000 hours. ■

Acclaim Lighting Introduces Flex Tube Pixel SE™ for Vibrant Outdoor Applications

Acclaim Lighting, a leader in innovative and advanced solid-state lighting technology, introduces Flex Tube Pixel SE™, a flexible, side-emitting LED strip that features RGB control of every 3.27” section for virtually any exterior or interior lighting application. IP68-rated and submersible to 3 feet, Flex Tube Pixel SE has a highly durable, impact-resistant, PVC body that can be ordered to length to suit project requirements for customized lighting applications.

Controlled with a DMX/SPI driver with 100 percent dimming capabilities, Flex Tube Pixel SE provides a 160° beam angle and operates off 24-volt DC power. It produces 90 lumens per foot, while consuming only 5 watts.

Flex Tube Pixel SE features an IP68 submersible and IK08 impact rating, making it suitable for any customized color outdoor or indoor application

Available in 16.4-foot-long spools, or custom built to order lengths, Flex Tube Pixel SE will perform in temperatures of -40° to 122°F. Acclaim Lighting also offers a locking aluminum mounting channel to enable users to cleanly and discretely install the products into a variety of applications for indirect, direct view, and surface-mount.

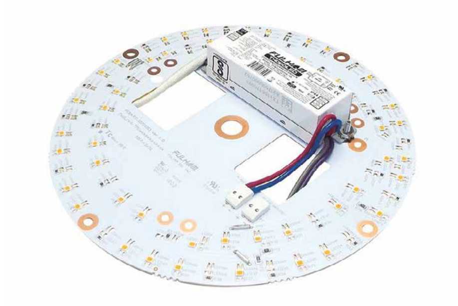
Flex Tube Pixel SE LED circuit strip maintains 70% of their lumens at 50K hours at 25°C. It comes with a limited three-year warranty.

Fulham Expands Line of Vizion LED Universal DC Retrofit Engines

Fulham Co., Inc., a leading supplier of lighting components and electronics for commercial and specialty applications, has released a comprehensive new line of DC Retrofit Engines as part of its new line of Vizion LED DC Retrofit Kits Engines. Available in rectangular and round form factors, the new Vizion DC Retrofit Engines deliver lower power consumption and higher efficacy.

The new DC Retrofit Engines are offered with 0-10 V dimming (100-10 percent) and universal voltage (120-277 V) Class 2 output. They are packaged in six configurations, including four 7.8-inch round retrofit kits (9 W/1400 lm, 13 W/2115 lm, 20 W/2820 lm, and 28 W/4015 lm output) and two 4x7-inch rectangular units (9 W/1400 lm and 20 W/2820 lm output). These Vizion DC Retrofit Engines are suitable for retrofitting wall and ceiling mounted luminaires with or without plastic or glass lenses.

In fact, they can be used for most lighting installations that call for a dimmable, preassembled driver and module in a compact form factor.



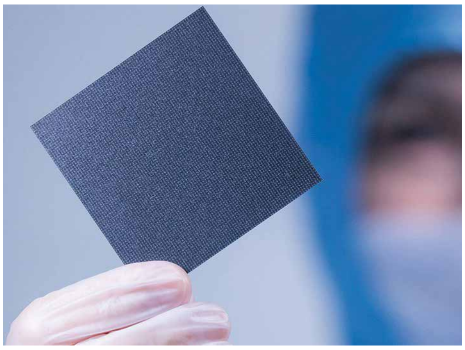
Fulham's Vizion LED Universal DC Retrofit Engines represent a new generation of higher performance LED Retrofit Engines with universal voltage and 0-10 dimming delivering more light and consuming less power

"More and more customers are retrofitting existing luminaires to simplify getting LED lighting into their facilities. Therefore we are seeing a growing demand for LED retrofit kits, with special emphasis on energy-efficiency, said Edwin Reyes, Product Director, LED Light Sources, for Fulham. "These new Vizion DC Retrofit Engines deliver more light with less power, and their versatile design and dimmability gives our distribution and OEM partners new components they can adapt for any type of luminaire or application, including indoor and outdoor applications"

To simplify installation, the DC Retrofit Engines, have an EM connector on board for integrating emergency lighting systems. The kits are specified to meet environmental standards such as California Title 24 and are Energy Star listed and making them eligible for rebates. They also are cULus classified. Custom designs also are available. ■

Lextar to Release Micro LED Chip and UFP I-Mini RGB Display Module

The vertically integrated LED company, Lextar Electronics will be releasing new Micro LED chip technology, with the chip size under 20µm. It will also be releasing two chip technologies: R/G/B Micro LED and Color Conversion Micro LED chip. As for Mini LED products, Lextar will debut the next generation UFP I-Mini RGB display module, and slim Mini LED light board for panel backlights. The series of latest Micro and Mini LED technologies will make their debuts at the Touch Taiwan 2018 exhibition.



Lextar releases UFP I-Mini RGB display module

Lextar announced its ability of Micro LED chip today; its size is as small as under 20 µm, and its luminous efficiency can reach over 30%. In addition, Lextar also announced two new technologies including R/G/B Micro LED chip and color conversion Micro LED chip, which can meet different Micro LED mass transfer processes. The Company is also one of the few in the industry manufacturing flip chip, lateral and vertical Micro LED chip. Micro LED has the advantages of high resolution, high brightness, fast response time, long life, slim and compact. It is a revolutionary display technology applicable for wearing devices, smart phones, VR and automotive displays.

Lextar also released a series of Mini LED products, including UFP I-Mini RGB display module (Ultra Fine Pitch Integrated Mini RGB Display Module) that transferred mini RGB chips onto drive circuit substrates. Not only does this combine traditional SMT and chip level packaging technology, it has even integrated control circuit and LED display chips. The UFP I-Mini RGB display module can realize a minimal pitch to 0.3 mm, allowing high image quality and simplified processes. It is very suitable to apply at indoor and semi-outdoor fields. In terms of backlight application, Lextar will show mini LED light boards for 32 inch and 15.6 inch panels. It is able to realize HDR 1,000 nits high dynamic contrast, and make panels significantly slimmer, reducing the OD area down to under 0.3 mm. It is applicable for high-end notebooks, gaming monitors area down to under 0.3 mm. It is applicable for high-end notebooks, gaming monitors and automotive panels.

Lextar stated that the company has always leads the industry in LED technologies. They have actively invested in the next generation LED miniaturization development trend for the series of Micro and Mini LED products announced this time from chip, packaging, testing, assembly, module, circuit drives to sub-systems, and already have close cooperation in all aspects with several partners. ■

Maxim's LED Backlight Driver - Smallest Footprint for Larger Automotive Displays

Automotive infotainment designers can now upgrade to bigger, higher resolution displays with greater ease, reduced cost and smaller solution size with the MAX20069 from Maxim Integrated Products. The MAX20069 provides the industry's first solution integrating four I²C-controlled, 150 mA LED backlight drivers and a four-output thin-film-transistor liquid-crystal display (TFT-LCD) bias in a single chip. The IC can reduce design footprint up to one-third compared to the closest competitor's parts.

MAX20069 reduces design size by one-third versus competitive solutions

Automotive displays are growing larger and more sophisticated as vehicle manufacturers lure buyers with greater information and entertainment options. Market research suggests a 39 percent compound annual growth rate for the 8-inch display market in vehicle instrument clusters, center stack and heads-up display systems. Instrument clusters are expected to migrate to 12.3-inch displays soon. As a result, automotive infotainment system designers will require power solutions with precision, flexibility and small overall solution size to meet increasingly complex system requirements.

Key Advantages:

- High Integration: Reduces design footprint, providing TFT-LCD bias with four rails plus four 150 mA LED backlight drivers
  - Single board supports panels from multiple manufacturers through a resistor or I²C programmable sequencing to further reduce solution size
  - Utilizes 25 percent of the microcontroller (MCU) register bits versus closest competitor's solution, eliminating the need for a more powerful and costlier MCU in display designs
- Performance: Delivers twice the dimming ratio compared to the closest competitor's offering, maintaining panel readability during transition to different light conditions; MAX20069 supports increased resolution through a 10,000:1 pulse-width modulation (PWM) dimming ratio at 200 Hz
- Safety and Built-in Diagnostics: An easy-to-use I²C interface quickly pinpoints problems, directing the microcontroller to adjust to conditions or alert the driver of a failure
- Electromagnetic Interference (EMI) Mitigation: 2.2 MHz switching frequency, spread spectrum and phase-shift capabilities help mitigate interference and emissions

MAX20069 supports larger screen sizes and higher resolution by providing positive analog supply voltage (PAVVD) and negative analog supply voltage (NAVDD), both of which are required for low-temperature polysilicon panels (LTPS) that deliver higher resolution and lower cost than amorphous silicon panels now currently in use. The IC also supports the high currents that next-generation displays require, with 150mA per channel in the four-channel LED driver for 8-inch or larger displays and higher resolutions. MAX20069 operates over the -40°C to 105°C ambient temperature range and is available in a 6x6 mm TQFN package.

"Automakers are using displays to transform vehicle interiors into a futuristic digital user experience for instrument clusters, center stacks, heads-up displays, eMirrors and other functions," said Kevin Anderson, senior analyst, Power IC Research at IHS Markit. "We forecast that shipments of automotive panels will increase by 12 percent this year to reach 165 million units. Maxim's integrated TFT-LCD bias and LED backlight driver aligns with the growth trends in this category. Anything that helps designers to lower cost, save design space or enhance safety will draw interest."

"Automotive manufacturers are using more screens, larger panels and brighter displays across several vehicle lines to support a safer and more engaging experience on the road," said Szukang Hsien, executive business manager, Automotive Business Unit, Maxim Integrated. "Maxim's integrated LED backlight driver and TFT-LCD bias solution supports newer panel types to help automotive manufacturers adopt lower cost yet higher resolution panels with smaller solution size and a high level of integration."

Fulham Releases BT Bridge to Retrofit any 0-10 V LED Luminaire

Fulham Co., Inc., a leading supplier of lighting components and electronics for commercial and specialty applications, announced availability of a new Bluetooth Bridge 0-10V LED controller, the first in a series of Bluetooth Low Energy (BLE) components designed to connect luminaires into a Bluetooth mesh ecosystem. The new Bluetooth Bridge can be installed in any electrical box or LED fixture to provide wireless 0-10 dimming control and monitoring.

Bluetooth Bridge is the first in a new line of BLE-enabled retrofit products that interoperate with any Bluetooth device or infrastructure to build a Bluetooth Mesh wireless control system

The Bluetooth mesh standard was approved in July 2017 by the Bluetooth Special Interest Group (SIG) and offers a number of advantages for wireless lighting controls. The mesh architecture is inherently reliable with built-in failover so there is no single point of failure and luminaires fitted with the Bluetooth Bridge can be added or removed without disruption. Bluetooth mesh also is secure and highly scalable so it can connect thousands of nodes, and it provides a full stack communications protocol platform so it can support the Internet of Things (IoT) devices as part of the network.

There are 32,000 corporate members of the Bluetooth SIG, and any compatible device that has been qualified by the SIG can connect to any other Bluetooth device over Bluetooth mesh. For example, luminaires equipped with Fulham's new Bluetooth Bridge can be controlled wirelessly by other Bluetooth devices, such as the EnOcean Bluetooth energy harvesting wall switch.

"Bluetooth mesh shows great promise for the lighting industry, making it an ideal solution to add wireless lighting controls as part of new installations or LED retrofits," said Alvaro Garcia, Senior Director, Product Management, for Fulham. "With our new Bluetooth Bridge, installers can convert any 0-10 V dimmable LED luminaire into a Bluetooth mesh node. Since Bluetooth is a recognized standard, we anticipate a number of manufacturers will develop their own BLE lighting solutions, and our new Bridge products make it possible to add any LED luminaires to the mix."

The Bluetooth Bridge is being offered in two configurations. The CTBRCB02JM02 Bluetooth Bridge provides wireless on/off and 0-10 V dimming controls for a transmission range up to 50 meters/160 feet at 2.4GHz. The Bluetooth Bridge has 120 to 277 VAC input, as well as a sensor input for motion controls and daylight harvesting. Fulham's Model CTBRCB03JM03-PC offers additional functionality, including power metering and color tuning. Both units are designed for indoor or outdoor use at operating temperatures from -40 degrees to 140 degrees (Fahrenheit). They both come with Fulham's five-year warranty.

Since Bluetooth mesh supports two-way communications, the Bridge can be commissioned, controlled, and monitored using an app on any Bluetooth-enabled device, such as a tablet or smartphone. Fulham is offering a lighting commissioning app to support its BLE products. Currently available for iPhones, iPads, and other iOS-compatible devices, the app can be used to remotely program and monitor Bluetooth mesh-connected luminaires. Fulham is making the app available at no cost, although fees will be charged based on the number of luminaires being commissioned. ■

EPtronics' LP Series Programmable Drivers - Compatible to EuControls' Zigbee Controller

EPtronics is pleased to announce that its latest LP Series of programmable flicker-free LED drivers are compatible with Zigbee wireless lighting controllers from EuControls, a sister company of EPtronics. EuControls' LCM lighting controllers are ideal for new and retrofit lighting fixture projects that require Zigbee protocol compatible 0-10 V on/off/dimming control with Dim-to-Off support.

EPtronics' LP series programmable LED drivers can communicate with EuControls' LCM-LV-ZB Zigbee lighting controller

The LCM-LV-ZB model lighting controller connects directly to an LP Series driver's 12 V auxiliary power output inside the lighting fixture, eliminating the need for a separate power supply. This LP Driver–LCM combination is a winning solution for any OEM fixture manufacturer wanting to offer simpler wireless fixture control.

The EuControls LCM-LV-ZB Zigbee lighting controller is equipped with a +20 dBm long range radio and is UL, FCC, RoHS, and Zigbee (HA 1.2) certified for worldwide operation. It is compatible with Current by GE's Daintree Networks' ControlScope platform as well as other Zigbee HA 1.2 gateway platforms.

The EPtronics LP Series drivers are part of UL's Class P driver program and are available in 25 W, 40 W, 55 W and 96 W power platforms. These drivers are rated IP20 and can be pre-programmed to customer requirements during manufacturing or re-programmed in the field using EPtronics' USB programming tools. ■

GlacialPower Launches New GP-LE150N LED Driver Series With Isolated Cable

GlacialPower announces the new GP-LE150N DC LED driver suitable for LED strip light, LED signage and moving sign applications. The new series are available in 12 VDC output rated power of 120 W, and 24 VDC output rated power of 150 W. The GP-LE150N is suitable for exterior or interior usage, with a fully isolated plastic case and isolated cable that is IP67 rated for environmental protection from rain, water and dust.

GP-LE150N Series

IP67 protection in addition to over-voltage protection, over-load protection, over-temperature protection, and short-circuit protection make the new GP-LE150N DC LED driver a robust choice for any kind of signage applications

The GP-LE150N supports an AC input voltage range from 180 up to 264 VAC, and also accepts AC frequencies from 47 up to 63 Hz. This driver offers constant voltage mode. The typical efficiency with a 230 VAC input is 87 percent for the GP-LE150N-12V version, and 89 percent for the GP-LE150N-24V version.

Features:

- Universal AC input from 180 to 264 VAC
- Class 2 Power Supply Unit
- Fully isolated plastic case and isolated cable
- Constant voltage mode
- Safety protections include OVP, OCP, SCP, and OTP
- IP67 rated
- No load consumption 0.5 W at 230 VAC
- Suitable for use in LED strip lights, LED signage and moving signs

The GP-LE150N is reliable and durable. In addition to IP67 protection, other features that ensure a safe and maintenance-free lifetime include Over-Voltage Protection (OVP), Over-Load Protection (OLP), Over-Temperature Protection (OTP), and Short-Circuit Protection (SCP).

GlacialPower designed the GP-LE150N to provide optimal electrical stability, with negligible ripple in the clean, stable output voltage, and no load consumption under 0.5 W at 230 VAC. The high output voltage quality makes sure your LEDs reach their full lifetime, cutting maintenance and replacement costs – a particular benefit for expensive custom-built LED signage that may be mounted in locations that are difficult to access. Users will also find the GP-LE150N is highly responsive at switch on: at 230 VAC full load, the set up time will not exceed 0.5 second. ■

New Ophir® FluxGage™ Measurement System for Large-Size Luminaires

MKS Instruments, Inc., a global provider of technologies that enable advanced processes and improve productivity, announced the Ophir® FluxGage™ FG1500, the newest member of the FluxGage family of compact measurement systems for LED luminaires. The FG1500 features an aperture size of 144 x 64cm, allowing for photometric measurement of large-size street and industrial luminaires, LED flat panels, and troffer lights. Photometric measurements include total luminous flux (up to 80,000 lm), spectrum and color parameters (CCT, CRI, TM-30), and flicker.

The new Ophir® FluxGage™ measurement system is especially useful for large-size street and industrial LED luminaires

The FluxGage FG1500 performs fast, photometric measurements in 2π (two pi) geometry. This allows for quick and accurate quality control where measurements of the complete, assembled, large-size LED systems are needed, both during development and directly at the end-of-line in luminaire production.

New Ophir® FluxGage™ FG1500 Measurement System for Large-Size Street and Industrial LED Luminaires"In the past, large LED luminaires could only be tested during the design phase or, once assembled, on a very small number of products," said Isabelle Okashi, General Manager at Ophir. "The FG1500 system allows full end-of-line quality control of large LED luminaires at a form factor and cost previously unachievable with traditional solutions, such as goniophotometers and integrating spheres. FluxGage is a whole new way to measure the light of LED luminaires. The system can be used during development, as well as in production for incoming inspection and quality control of finished goods."

The FluxGage system uses solar panels as light detectors. The panels are arranged on the inside walls of the measurement cavity and are covered with a special black plastic layer with hundreds of transparent pinholes, creating the effect of many tiny radiometers. This design significantly reduces the reflectance of the solar panels, creating a measurement system resembling a goniophotometer in a dark room. Unlike an integrating sphere, the FluxGage is insensitive to reflections going back and forth between the measurement device and the luminaire under test.

The FluxGage system incorporates a spectrometer for measuring spectral flux and other color parameters (CCT: correlated color temperature, CRI: color rendering index, TM-30-15: fidelity and gamut index, Duv, and chromaticity). A fast photodiode sensor is used for measuring flicker.

Integrated application software simplifies set up and operation; all of the photometric data of the light source is displayed. The FG1500 connects to a PC via a USB cable. The Ophir FGC100, a NIST-traceable, broadband LED calibration standard, is used for periodic calibration of the FluxGage system.

LGS 650 - New Goniophotometer for Mid- to Large-Sized SSL Sources and LED Modules

Instrument Systems launches within the LGS series a new goniophotometer. The LGS 650 is perfect for samples up to max. 1300 mm diameter and 10 kg weight.

Instrument Systems, the global market leader for LED metrology, launches with the LGS 650 goniophotometer a new measuring system for solid-state lighting products and LED modules. The LGS 650 is part of the established LGS family and perfect for samples up to max.1300 mm diameter and 10 kg weight. Combined with a spectroradiometer or photometer from Instrument Systems all spectral quantities such as color coordinates, color temperature and even color rendering index can be determined as a function of angle. A comprehensive software package facilitates easy evaluation and reporting of the measured data, which can also be exported in standard file formats like IES and EULUMDAT.

The LGS 650 goniophotometer was developed for the analysis of angle-dependent spatial radiation properties and offers a cost effective alternative to the LGS 1000. The test specimen is operated in a horizontal burning position and measurements can be taken at an angular range of ± 160° in the gamma axis. The angular resolution of 0.01° enables very fine measuring grids recorded with a high level of accuracy and reproducibility. The LGS 650 is compliant with all relevant specifications in conformity with CIE, DIN and IES standards.

The LGS 650 type C goniophotometer with horizontal optical axis for mid- to large-sized SSL products

Combined with a spectroradiometer, e.g. CAS 140D, from Instrument Systems, all spectral quantities such as color coordinates, color temperature and even color rendering index can be determined as a function of angle. Spectroradiometers offer the distinct advantage that all radiometric, colorimetric or photometric characteristics can be determined with maximum precision. Instrument Systems also supplies very fast photometers, e.g. the newly developed DSP 200, for performing integral measurements. They are recommended for pure photometric measurements and for time critical test sequences. Combined with the LGS 650, the photometers allow "on-the-fly" measurements, meaning the measuring system records the light distribution while the goniometer is moving.

The LGS 650 is operated via the goniometer module of the SpecWin Pro software. The software routinely performs measurement sequences to record the spatial radiation pattern of the test specimen. SpecWin Pro controls the power supply to the test specimen and records electrical data. Voltage, current, switch-on and burn-in procedure as well as the sequencing are storable presets and can be retrieved for repeat measurement functions. The graphics window is the central element of the user interface of SpecWin Pro. This window displays all measurements. Several different display options are available for the spatial radiation pattern: Radial display (luminous intensity distribution curve), semi-radial and Cartesian view, and a two dimensional spherical display with Isocandela lines and a 3D view.

MaxLite launches Indirect Troffer for architectural interior lighting applications

MaxLite introduces the Indirect Troffer as a high-performance LED recessed luminaire that adds comfortable light and architectural appeal to commercial spaces. Ideal for office, education, hospitality, health care environments, the Indirect Troffer uses voluminous, high efficiency reflectors to fill the room with visually comfortable, low-glare, LED illumination.

MaxLite's latest troffer offers a high efficiency of 125 lm/W combined with low glare that provides high visual comfort

Available as a 2x2' or 2x4' fixture to fit standard grid applications, the Indirect Troffer achieves exceptional efficacy above 125 lumens per watt, earning the fixture placement on the DesignLights Consortium (DLC) Premium Qualified Products list. In addition to the energy savings, the light quality and fixture aesthetic are best-in-class for the product tier.

"We like to say that our new Indirect Troffer is easy on the eyes in a number of ways," said Director of Indoor Product Management Brendan Drew. "Not only is it an aesthetically pleasing fixture, but the indirect nature of the light reduces glare and makes it a really comfortable light to live, work, learn or relax."

The 25- and 32-watt models ship standard with a 0-10V dimming driver that enables smooth dimming down to one percent of full light output. The Indirect Troffer may be paired with IntelliMax, MaxLite's intelligent wireless lighting controls system, as the simple, scalable way to meet building codes and increase energy savings. Emergency battery backup and integrated lighting control options, such as motion sensors and photocells, are also available to order. The Indirect Troffer is available with MaxLite's 10-year limited warranty.

Lighting Science Launches Cleanse™ Luminaire Retrofit LED Troffer that Sanitizes Air

Lighting Science announced the launch of a revolutionary new LED luminaire that reduces airborne pathogens responsible for numerous illnesses. Cleanse™ is an easy-to-install, air-sanitizing luminaire that decreases the levels of airborne particles, including microorganisms. The spread of illness is a health concern that is widely felt in healthcare, schools, gymnasiums and a multitude of public spaces.

Cleanse helps prevent exposure to dangerous pathogens using an efficient, multi-stage, air circulation and sanitation system. Activated carbon and HEPA filters capture particulates, while UV LEDs (A+C) further clean and deodorize the air. This process achieves a >99.9% elimination rate among the most common airborne pathogens resulting in reduced contamination, less illness and a lower risk of infection, particularly valuable for immuno-compromised individuals.

Lighting Science's new Cleanse™ retrofit luminaire provides 3200 lumens of high quality light combined with activated carbon and HEPA filters to capture particulates and UV LEDs (A+C) for cleaning and deodorizing the air

Cleanse's retrofit design enables most standard 2'x 4' light fixtures to be replaced in as little as 15 minutes, minimizing interruptions to normal operations and decreasing installation costs. Cleanse provides 3200 lumens of high quality light, while only using 60 watts of energy when both illumination and air cleaning mode are operating. In addition, it is available in a wide range of color spectrums to match existing environments, including Lighting Science's alertness-enhancing GoodDay®.

The Hospital-Acquired Condition (HAC) Reduction Program, mandated by the Affordable Care Act, requires the Centers for Medicare & Medicaid (CMS) to reduce payments to hospitals with the highest incidents of HACs. Cleanse represents a viable solution to major hospitals that are being penalized tens of millions of dollars a year. For many medical institutions, the cost of outfitting their facility with Cleanse luminaires would be less than the amount of their annual HAC penalties.

Dr. David Bacon, an active duty military officer and advisor at Lighting Science with more than 20 years of experience in infectious disease research and public health says, “A transformative technology such as the Cleanse system can effectively disrupt the inhalation exposure pathway of potentially life threatening infectious diseases. In a hospital environment, this technology has the capacity to save lives, enhance patient health, reduce time to recovery and lower healthcare costs.”

The Sonder Academy in Melbourne, FL, which has used Lighting Science’s GoodDay® spectrum lighting since opening, has embraced the Cleanse technology for its students. Known for seeking mindful innovative solutions for children and families impacted by Autism Spectrum Disorder, The Sonder Academy’s collaboration with leading LED innovator, Lighting Science, was natural.

“We are particularly sensitive to our students’ needs, given the nature of their disorders and their susceptibility to illness. We are always eager to embrace new technologies that can increase the health and wellness benefits for both our students and our staff,” said The Sonder Academy’s President of Education, Monique Todd. “We have installed Cleanse in one of our three schools and have observed a decrease in the number of sickness-related absences for both students and teachers at this location compared to the other two. This technology has been a blessing.” ■

Rediscover the Beauty of Ambient Light with Soraa VIVID™ Omnidirectional Lamps

Soraa, the world leader in full-spectrum LED technology and illuminator of the world’s most renowned, museums, historical buildings, hotels, and luxury retailers, announces the expansion of our Soraa VIVID line with omnidirectional lamps, delivering ambient lighting with the quality of light you’ve come to expect from all of our professional lamps and fixtures.

Ambient Light, only better:
Soraa omnidirectional lamps feature several key differentiators. Soraa’s very small point source packages give our lamps an uncompromising optical quality, allowing for the unique ability to create perfect center-to-edge light distribution with beautiful colors. This means lighting designers, specifiers, and architects have the ability to deliver beautiful light across a

multitude of environments where ambient light is an essential and highly visible component of a project.

Now available, Soraa VIVID™ omnidirectional lamps for the European and Asian markets

Product Details:

- Classic A60 & A19 Shapes: B22, E27, E26 (100v) bases
- 2700 K, Soft White, with an 800 lumen output range
- Very low Flicker in both dimmed and undimmed states
- Suitable for fully enclosed fixtures in indoor and outdoor locations
- Soraa Vivid Color™ (CRI 95, R9 95) | Soraa Natural White™ (Rw100)

Soraa VIVID omnidirectional lamp design is guided with regard for the presentation of natural light, offering the optimal rendition of colors and shades of white. To achieve this, Soraa harnesses cutting-edge color science, paying special attention to the well-known red-rendering index R9 and to the state-of-the-art TM-30 color rendition method, ensuring a natural saturation and precise rendering of specific colors. Soraa is also leading innovation in the field of white rendering, and has developed its own calculation method to render white tones faithfully, which underpins Soraa's Natural White™ technology. The careful optimization of these techniques results in rich, authentic colors, and infinite shades of white - just like natural light provides.

"Nothing was sacrificed in the design of these products" says Soraa Chief Scientist, Aurelien David. "Designed with guidance from state-of-the-art color science, they offer perfectly accurate colors, especially for reds and warm tones which are most important to our perception. They are also the only ambient lamps in the market to offer perfect whiteness rendering, a concept developed by Soraa to render all shades of white in their full variety."

Soraa's expertise in color science benefits extraordinary destinations across the globe where the precise rendering of true colors and whites play a lead role in the environment, including the Palace of Versailles (Versailles, France), Gieves & Hawkes (London, England), the Conrad Hotel Osaka (Osaka, Japan) and the Pola Museum (Tokyo, Japan).

"Shinko has recognized and appreciated Soraa's LED quality for a very long time now", says Hiroaki Ichikawa of Shinko Electric Co., a leading distributor of general lighting solutions based in Japan. "The full spectrum color, optics, and low flicker are all qualities that only Soraa products can create. These light sources mean we can recommend products with confidence for projects that require truly natural light".

Applications:
Commercial: Hospitality and Restaurant decorative fixtures, general purpose lighting, outdoor venues, and common areas.

Residential: Decorative fixtures, floor and table lamps, and outdoor fixtures with dimmable functionality.

Lighting Science® Launches Good Day&Night Commercial Recessed Luminaires

Lighting Science®, renowned for its suite of human-centric LED lighting solutions, announced the launch of the Good Day&Night™ Troffers, which combine the patented GoodDay® and GoodNight® LED engineered spectrum technologies into one multi-dimensional circadian lighting product. The 2x2 and 2x4 troffers deliver biological benefits with high-quality light for peak visual performance, while providing the ability to control and personalize the spectrum of lighting – truly delivering the right light at the right time.

The Good Day&Night Troffers enable users to transition light according to the natural progression of the sun, helping to synchronize the body's circadian rhythm. Users can easily switch between the focus-enhancing GoodDay and the blue-depleted GoodNight settings. Lighting Science's patented engineered spectra surpass superficial color tuning in circadian impact and quality of light, providing 90+ CRI and an R9 value >50 across the 2300-5000 CCT range. The troffers deliver 2600 lumens (2x2) and 5200 lumens (2x4) in the GoodDay mode. Light settings can be easily adjusted with a standard wall switch or the Lighting Science Wireless Switch for full multi-spectrum and dimming control.

LED lighting innovator, Lighting Science®, releases troffers with multi-spectrum circadian technology

Lighting Science's Good Day&Night portfolio supports the natural sleep-wake cycle, with numerous applications and benefits based on the indoor lives we often lead. For example, in senior living, research has shown that appropriately timed light exposure for Alzheimer's and dementia patients, results in increased sleep and decreased depression and agitation. Additional applications for circadian lighting may include hospital patient rooms, classrooms, offices, spa/wellness centers and training facilities.

"Chronobiological research and education is leading to the inclusion of circadian lighting in compliance standards such as the WELL Building Standards®. It is no longer considered a nice-to-have alternative, but a necessity," says Meggan Kessler, Vice President of Marketing at Lighting Science. "With the expansion of our Good Day&Night product ecosystem, we have broadened our solutions for creating healthier built environments."

New Philips GreenPower LED Toplighting Improving Performance

Signify, the world leader in lighting, announced the introduction of the new Philips GreenPower LED toplighting high output with a light efficacy up to 3.0 µmol/J and an output of 800 µmol/s. The new module will help greenhouse growers improve the growth of vegetables, fruits, flowers and other crops that require a lot of light.

Signify's new Philips GreenPower LED Toplighting offers higher output for light-loving crops like roses

In addition to higher light levels and improved efficiency, the high output modules will have a lifetime of 35,000 hours and give growers greater control over their growing climate because of minimal heat radiation while accelerating the growth cycle and enabling more efficient use of grow space.

Best choice for increasing light or decreasing energy costs:
"For many years, the use of LED toplighting for greenhouse vegetable cultivation has been steadily growing. Now we can offer an even more efficient solution for a variety of growing needs and light-loving crops. Whether growers are looking to apply more light to leafy greens, roses, or bio-based crops, or are focused on reducing their energy costs, the new GreenPower LED toplighting can meet both requirements." states Udo van Slooten, Business Leader Horticulture at Signify.

Uniform light distribution and long lifetime:
This 800 µmol/s version GreenPower LED toplighting module may be mounted on a trellis to deliver uniform light distribution, which gives growers flexibility with installation and adhere to light plans without the use of an additional C profile.

The high output version operates at an input voltage of 277–400 V and will be available in three spectrums: deep red/blue low blue; deep red/white low blue; and deep red/white medium blue. ■

Ledvance DALI High Bay Luminaires Provide Further Energy Savings

New High Bay luminaires from Ledvance for warehouses, factories and logistics centers provide a double whammy of energy savings. Now available at wholesalers, the LED luminaires not only provide inherently high luminous efficiency, but are also controllable via DALI allowing light levels to be adjusted according to need.

Ledvance smart High Bay DALI luminaires provide direct energy savings of up to 90% compared with conventional high bay luminaires. Unlike mercury vapor and metal halide lamps, they are dimmable and switch on and off instantly, allowing further energy savings to be realized through daylight and occupancy-dependent operation. The integral DALI-2 interface allows the Ledvance High Bay luminaires to be readily connected to popular presence and light level sensors. This results in even greater energy savings than the new LED luminaires already achieve with their high luminous efficacy of 140 lpW.

Ledvance High bay luminaires now also with DALI and constant luminous flux

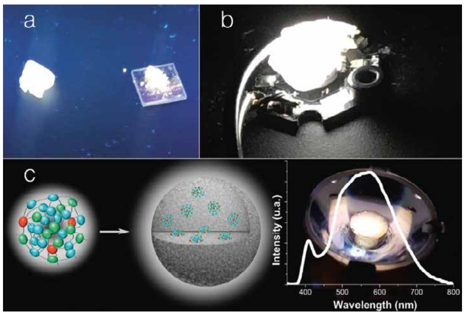
Other features include an easy electrical connection with a push-button connector and the Ledvance 5-year guarantee.

Also new at wholesalers is the High Bay DALI CLO which achieves constant luminous flux throughout its entire life. This makes calculations and planning easier for users as they can rely on the products keeping the same brightness levels throughout their L100 life span of up to 50,000 hours.

Ledvance High Bay luminaires are an ideal replacement for luminaires with mercury vapor or metal halide lamps in warehouses, logistics halls and other industrial applications as well as high ceiling environments such as shopping malls, airports and commercial buildings. In addition to the much lower energy consumption, Ledvance High Bay lights need replacing less frequently leading to maintenance cost savings. ■

Spanish Researchers Develop Sand that Produces White Sun-Like LEDs

The team led by the chemist-technologist Rubén Costa of IMDEA Materials (Madrid) and the chemists Jesús Berenguer of the University of La Rioja and Javier García of the University of Alicante has overcome one of the biggest obstacles in the progress towards new sources of healthier artificial lighting.



White-emitting sand (a) based on silica nanoparticles (right) and the encapsulated material for the LEDs prepared from it (left), a white LED (b) fabricated with a color filter based on the white emitting sand, and the process scheme (c)

The high content of blue light presented by current LEDs can be harmful to the human retina, especially for children, and has a negative impact on our brain´s chemistry. Rubén Costa, researcher at the IMDEA Materials Institute of Madrid; Elena Lalinde and Jesús Berenguer, from the University of La Rioja, and Javier García, from the University of Alicante, have succeeded at producing a material similar to sand (silica nanoparticles) that emits high quality white light for a new generation of LEDs hybrids.
The development of new silica nanoparticles that emit light is one of the most competitive fields and with more applications in the investigation of new sources of artificial light, since they reduce the impact on our visual system and can be manufactured in a more environmental-friendly way.

Within this field, university researchers from La Rioja and Alicante are experts in the use of coordination chemistry called sol-gel, a technique that allows the preparation of metal oxides with new properties. For his part, Rubén Costa, one of the international leaders in the design of luminescent devices, such as LEDs, and in the development of photovoltaic energy, investigates the properties of these oxides together with his research group in IMDEA Materials.

The fundamental contribution of this work is that it has managed to produce white light, which stands out for its stability, excellent quality and that does not harm the eyes. Until now, other researchers had managed to produce similar materials that emitted green, blue or red light, but not white, which is the key color for their future exploitation. In addition, the LEDs prepared with this new material present a record of stability that by far outmatches the previously developed monochromatic ones. The light emitted by these new LEDs is very similar to sunlight, which also makes it healthier. The practical interest of this white light emitting sand is that it could replace the current color filters based on rare earths such as Yttrium, whose extraction and exploitation causes significant negative effects on the environment. ■

Reference:
The work of this team of Spanish pioneers has been published by the magazine Materials Horizons, one of the most important international scientific journals in the field of new material applications. - pubs.rsc.org/en/content/articlelanding/2018/mh/c8mh00578h#!divAbstract

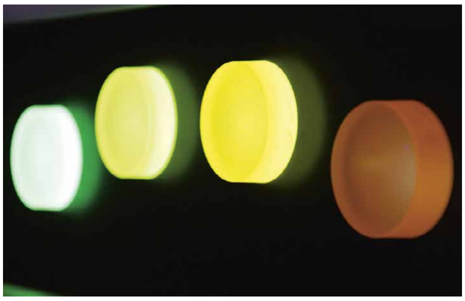
About Rubén Costa:
Rubén Costa (Valencia, 1983) is a chemist and research professor at the IMDEA Materials Institute in Madrid. He obtained his PhD in Molecular Science in 2010 from the University of Valencia and was Humbolt post-doc at the Erlangen-Nuremberg University in Germany where he investigated solar cells based on nanocarbons.
Since 2013 he has worked with his own group in optoelectronics with hybrid materials. In 2017 he moved with his team to the IMDEA Materials Institute in Madrid. Despite his young age, Rubén Costa has received numerous awards such as the 2016 Young Researchers Award from the Royal Spanish Society of Chemistry; the Silver Medal European Young Award 2016; the European Innovator of 2017 or the Spanish Top Talent 2017 of the MIT Technology Review. Recently, Rubén Costa was the only Spaniard elected this year by the World Economic Forum as one of the thirty-six scientist's champions under 40 years of age in the world.

About IMDEA Materials:
IMDEA Materials (Madrid Institute for Advanced Studies in Materials) is an independent research institute promoted by the Community of Madrid to carry out research in Materials Science and Engineering. The IMDEA Materials Institute belongs to the network of the Madrid Institutes of Advanced Studies (IMDEA).

The IMDEA Materials Institute currently has approximately one hundred researchers from sixteen different nationalities. Their research activity is organized around five programs: Advanced Materials for Multifunctional Applications, New Generation of Composite Materials, Design, Processing and Development of Alloys, Computational Engineering of Materials and Multiscale Characterization of Materials and Processes. These research programs focus on the development of advanced materials mainly for the transport, energy, information technology and manufacturing sectors, as well as in the exploration of emerging materials and processes for sustainable development. - materials.imdea.org/

New Algorithm Can More Quickly Predict Phosphors for LEDs

Jakoah Brgoch, assistant professor of chemistry at the University of Houston, and members of his lab published a paper on Oct. 22 in Nature Communications describing how machine learning speeds discovery of new materials. By scanning a huge number of compounds for their key attributes they were looking for a new light conversion material that could be used in white LEDs.



Phosphors convert blue light into other wavelengths to produce white LEDs. While the first sample produces light that is too blue for practical use, the result is still encouraging because it is a good basis for machine learning based improvements

The researchers have devised a new machine learning algorithm that is efficient enough to run on a personal computer and predict the properties of more than 100,000 compounds in search of those most likely to be efficient phosphors for LED lighting. They then synthesized and tested one of the compounds predicted computationally – sodium-barium-borate - and determined it offers 95 percent efficiency and outstanding thermal stability.

The researchers used machine learning to quickly scan huge numbers of compounds for key attributes, including Debye temperature and chemical compatibility. Brgoch previously demonstrated that Debye temperature is correlated with efficiency.

LED, or light-emitting diode, based bulbs work by using small amounts of rare earth elements, usually europium or cerium, substituted within a ceramic or oxide host – the interaction between the two materials determines the performance. The paper focused on rapidly predicting the properties of the host materials.

Brgoch said the project offers strong evidence of the value that machine learning can bring to developing high-performance materials, a field traditionally guided by trial-and-error and simple empirical rules. “It tells us where we should be looking and directs our synthetic efforts,” he said.

Brgoch collaborates with the UH Data Science Institute and has used the computing resources at the UH Center for Advanced Computing and Data Science for previous work. The algorithm used for this work, however, was run on a personal computer.

The project started with a list of 118,287 possible inorganic phosphor compounds from the Pearson’s Crystal Structure Database; the algorithm whittled that to just over 2,000. Another 30 seconds and it had produced a list of about two dozen promising materials. That process would have taken weeks without the benefit of machine learning, Brgoch said.

His lab does machine learning and prediction, as well as synthesis, so after agreeing the algorithm-recommended sodium-barium-borate was a good candidate, researchers created the compound. It proved to be stable, with a quantum yield or efficiency of 95 percent, but Brgoch said the light produced was too blue to be commercially desirable. That wasn’t discouraging, he said. “Now we can to use the machine learning tools to find a luminescent material that emits in a wavelength that would be useful.

More to the point, the researchers said, they demonstrated that machine learning can dramatically speed the process of discovering new materials. This work is part of the Brgoch research group’s broader efforts to using machine learning and computation to guide their discovery of new materials with transformative potential.

About the Research Team:
In addition to Brgoch, researchers on the paper include Ya Zhuo and Aria Mansouri Tehrani, graduate students in Brgoch’s lab, former post-doctoral researcher Anton O. Oliynyk and recent Ph.D. graduate Anna C. Duke.

Reference:
The original paper has been published on October 22nd at www.nature.com/articles/s41467-018-06625-z

Dynamic In-Car Lighting Scenarios - Osram Prototype with Inova's Serial Control Driver

The more autonomous a car becomes, the more the way in which it is used will change. As developments continue toward autonomous driving, more and more attention is being focused on the passenger cell. Light will become an integral part of the passenger cell, taking on functional and design-specific tasks. Previously static light, which could only be switched on and off, has now been given a dynamic dimension with the prototype of the Osire E4633i – with countless design options for car manufacturer.

“In the future, the interior of vehicles will be more than simply a cabin for the driver and passengers. It will be an extension of our living space in which we will be able to work and relax”, explained Stephan Pawlik, Marketing Manager Automotive Interior at Osram Opto Semiconductors: “Light sources in car interiors will provide ambient lighting and perform a number of additional functions. For example, they could use dynamic and color effects to draw the driver’s attention back to the traffic in good time.”

To make it easier to provide such new functions in vehicles, Osram has installed a serial control driver from Inova Semiconductors in the new E4633i product from the Osire family in addition to the three color chips (red, blue and green). In the lighting solution it is now possible for a large number of separate LEDs to be controlled via a serial bus system either individually or in groups. This provides simple implementation of uniform color rendering across the entire color space as well as dynamic light cases. Control of the desired color and brightness has been simplified because the E4633i is precalibrated and can automatically correct color shifts in the red range caused by fluctuations in temperature. The LED has an extremely compact pre-mold SMT package with a footprint of 4.6x3.3x0.7 mm. The compact package and the link to the serial bus now allow implementations with more LEDs in a much smaller space.

Since September 2018, Osram Opto Semiconductors is a member of the Iseled Alliance (Integrated Serial/Smart Embedded Light Emitting Diode) and will drive development forward in this field.

The prototype of the RBG-LED Osire E4633i, which has installed a serial control driver from Inova Semiconductors, takes automotive interior lighting to a new level

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Regulations	External Power Supplies	Directive 2009/125/EC	Europe	Draft for new ecodesign requirements for external power supplies. Covering among other things following topics: • Multiple voltage output external power supplies to be included in (EC)278/2009 • Harmonisation of energy consumption of external power supplies • Relevant product parameters should be measured • Applicable conformity assessment procedures should be specified • Devices with output power less than 250 W Not covered by this draft are: (a) voltage converters; (b) uninterruptible power supplies; (c) battery chargers; (d) lighting converters; (e) external power supplies for medical devices; (f) active power over Ethernet injectors; (g) external power supplies placed on the market by 30 June 2025 as a service part or spare part for an identical external power supply placed on the market by 1 April 2021 at the latest, under the condition that the service part or spare part, or its packaging, clearly indicates the primary load product(s) the spare part or service part is intended to be used with.
Regulations	Light Sources and separate Control Gears	Directive 2009/125/EC	Europe	Draft for new ecodesign requirements for light sources and separate control gears covering among other things following topics: • Suitable for a wide range of light sources • Covering separate control gears • Even if these products are placed on the market in a containing product • Separate control gear means that this is not a part of a light source Main changes will be: • Information requirements for light sources are shifted to "Label" regulation • Detailed information requirements for control gears are introduced • Efficiency requirements for separate control gears are introduced • A new lifetime test is introduced which combines switching cycles and endurance testing • Flicker and stroboscopic effects are considered • Detailed tolerances, depending on sampling size, needed for authorities are introduced
Regulations	Light Sources / Lamps	(EU) 2017/1369	Europe	Draft for supplementing (EU)2017/1369 with regard to energy labelling of light sources. • Focussing on light sources with or without integrated control gear • Also required for light sources in containing products • Energy label will be in line with (EU) 2017/1369 • Energy label will have classes A (best) to G (worst) • Energy efficiency class will focus on efficacy (lm/W) (with certain correction factors for e.g. non-mains products) • Detailed descriptions of product informations are introduced • Detailed tolerances, depending on sampling size, needed for authorities are introduced • Description on how to separate light source of containing product (e.g. luminaire) has to be provided
Safety Standards	Street Lighting	Portaria No.:20, 2017 and 404, 2018	Brazil	Technical and Conformity Assessment Requirements for Street Lighting using Discharge Lamps and LED Technology. Deadlines for compliance to meet the new requirements: 17th February 2019 : All imported and manufactured products must meet the new requirements 17th August 2019: Manufacturers and importers may only put compliant street lights on the market
Energy Efficiency	Lamps	Disposition No.:4/2018	Argentina	Disposition No.: 4/2018 establishing the maximum specific energy consumption level (minimum energy efficiency for: • Halogen tungsten filament lamps for general lighting • Fluorescent lamps for general lighting with built-in ballasts, within the scope of Resolution No.:86/2007 For these products effective from 1st July 2019 the energy efficiency level must correspond to Class A according to IRAM 62404, Parts 1:2014 and 2:2015
Safety Standards	LED Public Lighting	Disposition No.: 1/2018	Argentina	The new Disposition No.: 1/18 establishes the minimum technical conditions for acquisition of LED luminaries for public lighting within the framework of Efficient Lighting Plan (PLAE). Compared to previous versions (Disposition No.: 6-E/2017) there are changes in the newly-adopted Annex regarding: • General requirements of construction • Closing system • Compliance to standards and certificates • luminous efficacy • Luminaries with remote management system

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

For further information on the latest upgrades and testing standards and training, please contact cps@tuv-sud.com

Visual Appearance: Perception, Measurement and Metrics

Visual appearance is one of the most critical parameters affecting customer choice and needs in products. We use the response from our visual sense to process the complex patterns of light around us into objects, space, location and movement, and from that information, we make judgments leading to a particular course of action. For example, how we perceive the visual appearance of a product may cause us to buy it, reject it or even write to complain about it. We may choose to buy a particular food because its appearance suggests freshness. Our choice of car may have been influenced because its glossy appearance made us think of quality and prestige. Alternatively, we may reject a particular surface finish because its appearance suggested poor quality and the presence of defects. All of these examples represent judgments made on appearance.

Figure 1: **Example of a goniochromatic nail-polisher: The color changes as a function of the observation and illumination angle (©METAS)**

A starting point in assessing the appearance of a consumer product might be the measurement of its color, however, it cannot be achieved by the definition of color alone; other attributes of the material from which it is fabricated contribute to the overall appearance. Additional parameters include surface texture, translucency, gloss, fluorescence, polarization and temporal properties. The appearance of an object is related to the physical structure of the material, the illumination condition, the visual environment, but also relates to the observer: A "trained" observer may perceive differences between similar objects that are not directly perceived by a non-expert.

The relationship between the physical structure of a material and its optical radiation properties (scattering, reflection, etc.) is complex. For example, selective absorption, which is largely responsible for the color of a material, takes place during the passage of light through that material.

In addition, there are a number of modern materials where color measurements made by using a single pair of influx/efflux geometries is not sufficient to describe the perceived colorimetric effect. Examples are effect paintings (i.e. car coating) showing goniochromatic effects (change of color with angle - shown in Figure 1) and sparkle (small bright spots in darker environment).

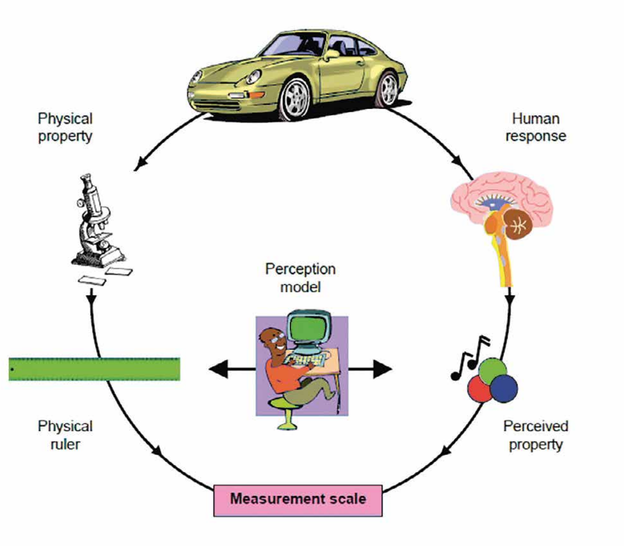


Figure 1: A perception model that relates a physical property of an object as measured, to an aspect of that object defined by a human response [1]

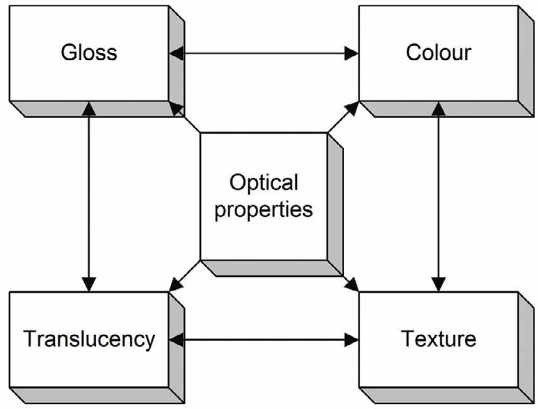


Figure 2: CIE 175 proposal of sub-division of the optical properties of materials into measurement groups - with interactions between those groups

Fields of applications are very broad and include cosmetics, textile, packaging, and consumer electronics, such as laptops or smartphones. A new activity is virtual prototyping: Based on the measurement of optical properties of surfaces at micrometer scale, virtual objects are created and put into virtual reality. This approach allows realistic simulation prior to when the object is physically built.

CIE considers the field of appearance as one of the ten top priorities as outlined in its research strategy [2].

Some key questions defined in the strategy are:

- What are the relevant parameters to describe appearance, gloss and translucency of various materials, including goniochromatic and sparkling samples?
- Which BRDF geometry (size, polarization, shape and uniformity of the illuminated area) according to the type of sample under investigation shall be standardized?
- If a simplified geometry is used as a standardized description of effect materials, how can the “uncertainty” with respect to the real visual appearance, i.e. the proficiency of the test method, be described?

The scientific community is invited to investigate the measurement of appearance and to correlate theses measurements to the visual appearance. A starting point is the CIE technical report 175:2006 [1] which outlines a framework of visual appearance (Figure 2). It proposes four headings under which possible measures might be made: color, gloss, translucency and texture. These groups are perhaps not definitive but they are intuitive and represent useful categories for measurement, especially in view of the fact that measurement techniques already exist for some of them. In addition, note that they are not independent in that there must be links between color and gloss, and color and translucency, etc. (Figure 3).

In addition, CIE has started several technical committees working on some of the aspects appearance [3]:

- The cross divisional JTC 12 "The measurement of sparkle and graininess" will define measurand and requirements for their measurements. The goal is that different instruments can provide the consistent spectrophotometric data from the same specimen. In addition, psychophysical methods will be recommended to obtain visual data to develop the measurement scale for sparkle and graininess.
- TC2-85 prepares recommendations on the geometrical parameters for the measurement of the Bidirectional Reflectance Distribution Function (BRDF)
- A new JTC " Gloss measurement and gloss perception - A framework for the definition and standardization of visual cues to gloss." is presently in approval stage. It will describe recommendations for standardized visual assessment conditions of individual, established cues to surface gloss and suggest optical methods and metrics for describing surface gloss in correlation with the established gloss cues.

The field of visual appearance is complex and highly cross topical. Only a joint international effort that includes all stakeholders (i.e. instrument manufacturers, testing laboratories, national metrology institutes, universities, product manufacturers and user communities) will bring us closer to the goal of better understanding of measuring and quantifying appearance.

References:

[1] CIE 175:2006 A Framework for the Measurement of Visual Appearance

[2] CIE research strategy: http://www.cie.co.at/research-strategy

[3] CIE technical committees: http://www.cie.co.at/technical-work/jtcs

Tech-Talks BREGENZ - Dr. Maja Grubisic, Researcher, Free Univ. Berlin & Leibniz-Inst.

Maja Grubisic

As a biologist, Maja Grubisic has been active in research on light pollution since 2013. She completed her Ph.D. studying ecological effects of artificial light at night on aquatic organisms at Freie Universität Berlin and University of Trento, and since has expanded her research to terrestrial ecosystems. Maja co-chaired a working group within the EU research network "Loss of the Night-LoNNe" (http://www.cost-lonne.eu/) from 2014 to 2016. From 2010 to 2013 she worked as a research and teaching assistant at University of Belgrade. Dr. Grubisic is currently working at Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB) in Berlin and as a guest lecturer at Freie Universität Berlin.

Awareness of the ecological impact of technologies is becoming more important since climate change due to industrialization cannot be denied. LED lighting is one of the technologies that is deemed as a contributor in helping to reduce the impact caused by wasted energy. Unfortunately, light pollution, due to inefficient energy usage, is not the only problem. Besides the more recognized pollution from pesticides and chemical pollutants, light pollution also disturbs ecology and wildlife. Dr. Grubisic, Researcher at the Free University Berlin & Leibniz-Institute, has been working on this problem for more than five years now. She has written an article, also in this issue, concerning this. At the LED professional Symposium she was also good enough to grant this interview, providing some background information, explaining why light pollution is such an issue in biology and why this topic should be of concern to all of us.

LED professional: Thank you very much for taking the time for this interview. We'd like to take the opportunity to talk about what you called "The dark side of the light" in your lecture. But maybe we could start with a short descripton of yourself. Where do you work and what are your main activities?

Maja Grubisic: Thank you for inviting me and giving me the chance to talk about this important topic. I am a biologist and work at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin. I started working on the topic of light pollution five years ago. I came to the institute when I started working on my PhD, which focused on the ecological impacts of Artificial Light at Night. Currently I am continuing with my research as a post-doc. The group that I'm working in has been active in research of light pollution for more than ten years and we work to a large extent with aquatic organisms - fish, aquatic insects, and also algae that are in the base of aquatic food webs. And we also study terrestrial ecosystems and the links between the two.

LED professional: What kind of institute is this?

Maja Grubisic: It's a biological and ecological institute, Germany's largest research centre for freshwaters, so we cover a wide range of topics dealing with freshwaters and fisheries, trying to understand how processes in nature work, and we also look at different effects of humanity on the environment. So our research goes beyond aquatic ecosystems and explores interactions of ecology with society.

LED professional: Does your position as a researcher involve looking at how harmful light can be to the environment?

Maja Grubisic: Yes, my main responsibility is doing research. I study ecological impacts of light pollution on different organisms, mostly invertebrates, like insects and microorganisms from aquatic ecosystems. That is my current expertise, but the group I work in covers a range of different organisms.

LED professional: So your focus is on the influence of light on the ecosystems.

Maja Grubisic: Yes. We are also members of big international networks that include experts not only from biology and ecology, but also physicists, astronomers, lighting designers and social scientists interested in how people perceive artificial illumination. We communicate across different disciplines and try to convey the importance of this topic to a wider audience and society, in general.

LED professional: What does this research look like? Do you do research on individual animals or do you do field tests by counting animals, for example?

Maja Grubisic: We do both studies in the laboratory and in the field. So, for example, we have installed street lamps in the areas that were previously dark. So they would be in rural areas, away from the disturbances of the cities, where natural darkness is still preserved. We would switch on the street lamps in the evening and switch them off in the morning and over time we would collect insects that move in these areas - in illuminated ditch that is next to the field site - and the grassland. We count the insects and identify different species. And over time we compare if there are any differences between the illuminated fields and the control fields.

In the laboratory we try to simulate conditions that are present outside in light polluted areas, so we use light sources that are also used in outdoor illumination, and we apply light intensities and light conditions to mimic those present in the cities. We don't work with very high light intensities, like in horticulture, but we rather look at low light intensity present at the street level or away from the light sources comparable to sky glow. And then we also mimic natural daylight rhythms and apply low level of artificial light during the night and study effects on different, individual organisms and their physiological processes, behavior, biological rhythms and other aspects.

LED professional: How does light influence insects or other animals?

Maja Grubisic: Light is a very important source of information for all living beings. This is the case because, in nature, light regimes have been stable for a very long time. So these dark and light cycles are one of the most stabile environmental changes and many organisms, throughout evolution, have learned to rely on light patterns. Almost every living being has circadian rhythms and they adjust their behaviors and inner processes to the time of the day based on the information that light provides. What we see is that biological rhythms are influenced by artificial light at night in many animals and in insects. Another important aspect is that a lot of species are active at night and they evolved to be active in the darkness. They are very sensitive to light and introducing artificial light into the night can disrupt their natural behavior. The most obvious and most well known phenomenon is that light attracts insects, but it can also disrupt the way they feed and reproduce and communicate with each other. For example,

Circular enclosures to study effects of skyglow (simulated by very low-level LED light at night) on lake ecosystems, including fish, invertebrates and algae. Researchers take samples at night before starting experimental illumination (Credits: Andreas Jechow)

fireflies communicate by flashing light in the dark - this allows them to find each other and reproduce. So there are many ways in which light can influence the environment.

LED professional: The human circadian rhythm is mainly influenced by blue light and high intensities. Is that the same for insects?

Maja Grubisic: There are not many studies on circadian rhythms in insects, much more is done in birds and fish. Blue light is indeed the most powerful part of the spectrum that influences biological rhythms but low light intensities can already have an effect.
An example of extreme sensitivity to this is what we find in fish: they show melatonin suppression already at 0.1 lux at night.
But with fish, when we compare the same light intensity of different colors, blue light seems to have the least effect. So in the spectral composition, it is just the opposite of that of other organisms.

LED professional: I also heard that this is true in connection with insects and street lights and so they shouldn't use bluish light, but rather go to warmer color temperatures.

Maja Grubisic: The impact of blue light on insects is maybe less based on the biological rhythms and melatonin suppression, but rather it is based on the amount of attraction. Their visual systems are very sensitive to UV light and blue light - so in general - shorter wavelengths. For this reason, a high amount of light in this range of the spectrum will be more attractive to insects.

LED professional: Oh - so it is the blue light but it isn't the circadian rhythm.

Maja Grubisic: Yes - the same light, but a different reason.

LED professional: Is there a difference between the nocturnal and diurnal insects?

Maja Grubisic: There are around one million different species and each has its own evolutionary history. Among the different species, we find different photoreceptors in their eyes.
Most commonly, they have three photoreceptors that are sensitive to the UV, blue and green part of the spectrum. But I'm sure there are exceptions.

LED professional: One idea, as mentioned before, is to go to warmer color temperatures, but what about shaping the spectrum of an LED for certain areas?

Maja Grubisic: Depending on the biological value of the area or the presence of endangered or protected species, it might be a solution to design the lights that are suited to the sensitivities of these species. It's not only about insects, though. A lot of other organisms live in nature and in general, the rule is to try to use the warmer temperatures. But areas close to water might have different regulated lights to those that are close to a forest or in areas where we know there is a species conservation that we particularly want to encourage. For example, amber LED lights along the coasts are less distractive for marine turtles that nest on the beaches. And for areas with large numbers of bats, reddish lights would be a better option.

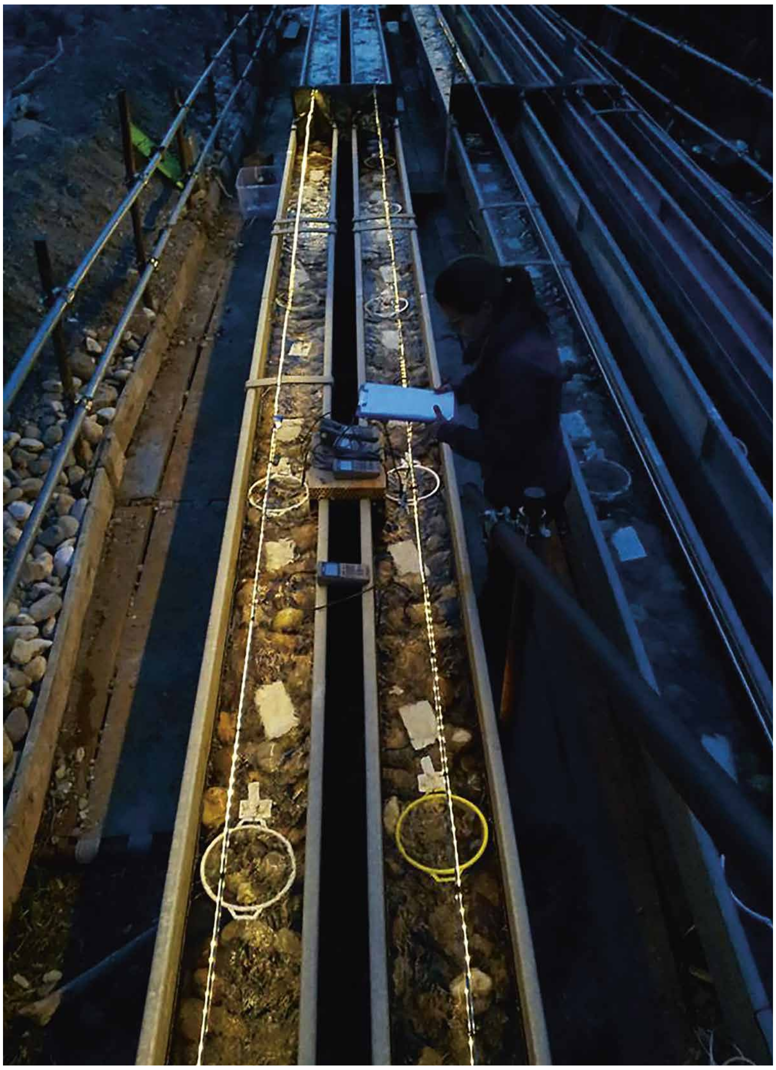
LED professional: Can you tell us a little bit about the effects of light on animals and plants that live on or in the water?

Maja Grubisic: The research on waters is still a bit behind compared to studying effects of light pollution on land. But we have more and more evidence coming from both freshwaters and marine systems and when it comes to plants or microscopic algae, this is one of my fields of expertise. Algae are one of the groups that have been studied the least when it comes to waters. They are very important in aquatic ecosystems because they provide food for aquatic insects and fish, so they are a source of energy; a basic source of energy in the food chain. And if changes happen at this level it can easily reflect on other aspects of the ecosystem. What we found is that proximity of streetlights to water disturbs the growth of algae - which is the opposite of what we expected. We all know that plants like light, they use it for photosynthesis but it seems that this low light level - not giving enough energy for photosynthesis and occurring at an unnatural time - imposes stress on the growth of algae and actually results in an opposite effect. This could mean less food for fish and aquatic insects.

When it comes to the insects themselves, we know that they emerge in higher numbers from waters that are close to the lights and they are attracted to these lights. So in a way, material and energy gets taken from the water into the terrestrial ecosystem, and this change of energy fluxes could change the balance of these connected ecosystems. Water is never just isolated in the landscape. In nature, these processes are connected.

So far, in water, most of the research focuses on fish. Fish change their behavior around the lights. In the seas, for example, we see that some species benefit from the light because they are visual predators and they see their prey better. Then the smaller species swim away and try to hide and don't look for food like they would normally do. So these changes in behavior at different levels of the food chain can also disturb the ecosystem balance.

LED professional: When I look at the general message of the press, it seems like they want to blame the LED for everything. They say it's bad for animals, humans and plants - unless we're talking about horticulture. What is your opinion? Do you see any positive effects of the new technology?



Night measurements during a light pollution experiment in an outdoor, stream-side experimental system, to study effects of low-level LED light at night on stream biota (invertebrates and algae). Such semi-controlled experimental systems that allow for replication and partial manipulation of parameters of interest are invaluable in ecological research (Credits: Alessandro Manfrin)

Maja Grubisic: I don't think that LEDs are bad in and of themselves, but the way we use them may be bad and it definitely could be improved. The problem with LEDs is their bluish spectrum and that they are used everywhere now. It is cheap technology, widely accessible to consumers, and what we see now, based on recent studies, is that people tend to use more and more light because it is so cheap. I think that these are two problematic aspects of the LEDs. On the other hand, I think that the flexibility of this technology will allow for customized solutions. One solution is to optimize the spectrum, moving towards minimizing the blue emissions. Another thing to improve is directing the light and using full cut-off luminaries in order to avoid glare. To eliminate the excess light above the surfaces that need to be illuminated. And to use beaming and timers and motion sensors to adapt lighting scenarios to the needs and purposes of the light -these are also promising approaches. Any measure that reduces waste of light will also reduce light pollution, potential ecological effects of artificial light at night and save energy costs.

LED professional: In connection with obtrusive light - we often hear that we don't see as many stars as we used to. So this could be improved by directing the light downwards.

Maja Grubisic: Yes, and also adjusting the illuminance levels so the light doesn't bounce back up into the sky.

LED professional: Does the direction of light or the waste of light play a role with terrestrial animals?

Maja Grubisic: The waste of light certainly increases the size of areas where light can have an impact. When it comes to direction, insects are still attracted to the light even if it is directed downwards, but the glare has an impact. Shielding and reducing glare makes light itself less visible to insects. Based on the modeling studies it seems that the attraction range of one lamp to the insects, can reach up to 130 meters. For animals that move through the landscape at night, the more lights that are there, the more chance there is that the animals will come into the attraction range.

The main thing that we try to communicate to the public is the responsible use of lighting. This means directing light to where it is needed instead of wasting it and spreading it around. The next thing is only use the amount that is needed and not brighter, and lastly, to use light only when it is needed. An example of this may be that we have nice, decorative lights in the garden and they are on all night, even though there is nobody there to see them. That is a huge waste of light and can be a major disturbance for wildlife in the garden.

LED professional: Is there a difference between the measures being taken (dimming and shielding) and the effects they have on flying animals and terrestrial animals? Is there research going on for this?

Maja Grubisic: Some studies on insects compared different measures, for example manipulating spectra, dimming and switching off lights at certain times during the night and they found that the light still has an effect. So it seems that eliminating effects of artificial light at night is not really possible without abandoning its use overall. But we can minimize its impacts by avoiding it if it isn't necessary.

LED professional: What about measures like education or ideas of making "Dark Zones" - that are only illuminated when they are occupied by people.

Maja Grubisic: Of course, it is very important to educate people, especially to increase awareness that light has an influence on nature and other organisms as well as on ourselves. Many are still not aware of these issues and still more can be done to improve this. There are many activists involved in spreading these messages, many come from astronomer communities. There is also the International Dark Sky Association - IDA - that is based in the U.S. This association promotes the value of darkness. They work on getting the idea across that darkness has its value in nature and that it should also have a place in our lives. They also work on establishing "dark sky" parks in areas with little light pollution where people can go to look at the stars and enjoy the view of the night sky. I think we are becoming more and more disconnected from darkness, and it would be good to educate people they don't have to be afraid of the dark and that darkness should have a place in our lives.

LED professional: It must have been around fifteen years ago that I heard the first lecture on obtrusive light and I don't think that over the last fifteen years there has been a big increase in awareness of it. Why do you think that is?

Maja Grubisic: The interest in the scientific community was definitely there fifteen years ago but it wasn't the focus of their work. But now, over the last couple of years, it is becoming one of the hot topics. I wondered about it myself, but it's similar to what I've observed while attending this conference. This is the first industry-focused lighting conference I've attended and it's the first time I've heard about human centric lighting. One of the points raised on a panel discussion was that human centric lighting was a concept that was also mentioned fifteen years ago and it's still not on the market and people outside of this industry still don't know about it. In addition to talking to each other about these concepts inside our communities we should also spread the word outside to other industries and public.

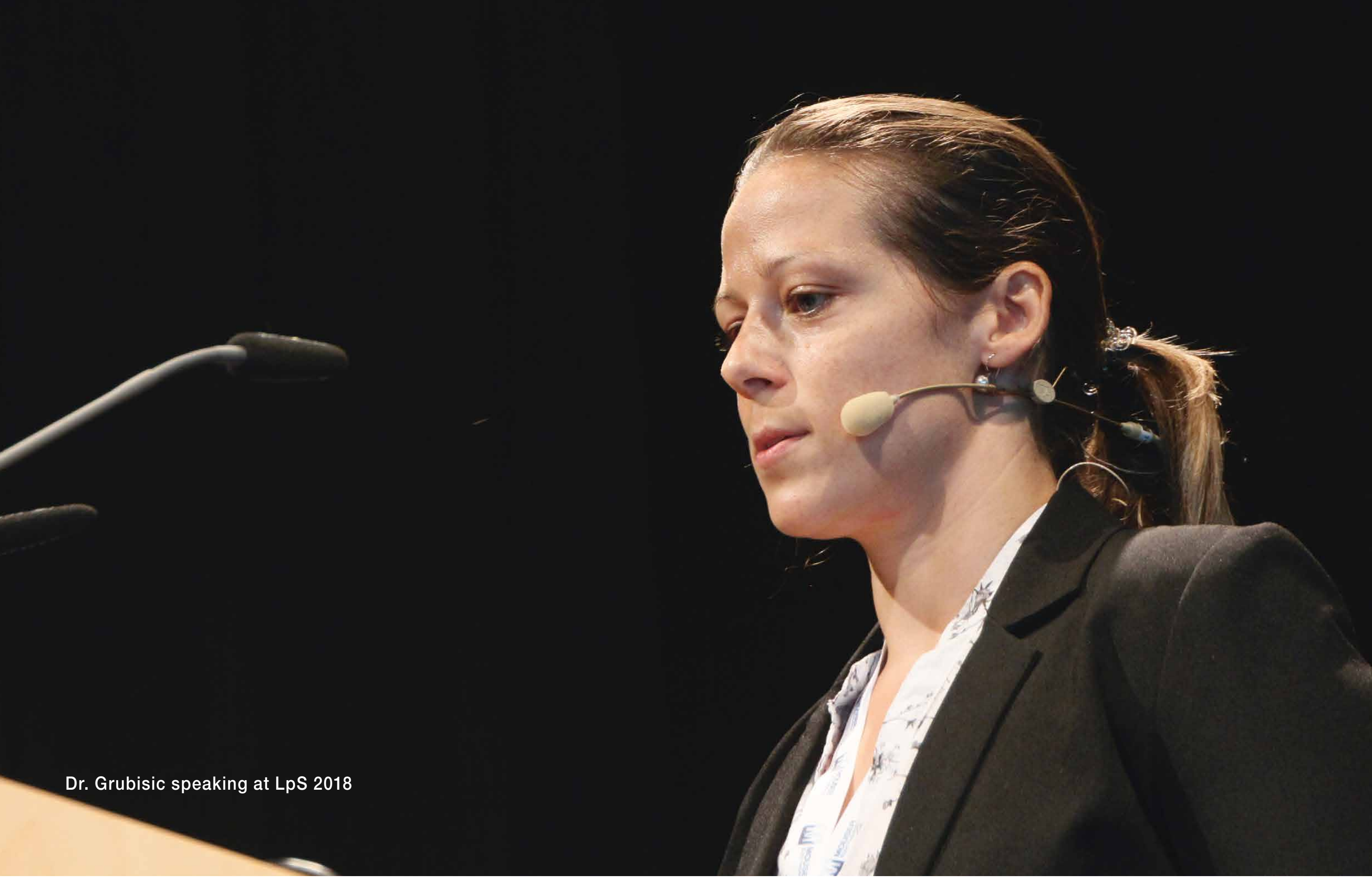
LED professional: Coming back to the insects: you can read in all kinds of media, not just scientific papers, that the number of insects is rapidly decreasing. Some are saying that there are up to 90% less insects today than there used to be. I'm sure that there are multiple reasons for this phenomenon, but how much do you think lighting has played a role in it?

Maja Grubisic: We know that insects are declining from several locations and there is no clear answer why. Agriculture, pesticides, climate change and habitat destruction are considered to be the main reasons.
One of the most recent reports on insect declines came from Germany last year. Researchers looked at trends in insect populations in protected areas across Germany, in areas that are supposed to have little human influence. In these protected areas there is no use of herbicides. Habitat change, also whether and climate change explained part of the decline.
But a large amount of variation in the data could not be explained by all these commonly considered factors. So we looked at the locations of these sites and what we noticed was that most of the locations were in areas that experience high night sky brightness. Much higher than what natural light would be. These protected areas are relatively small and they are surrounded by agricultural fields and urban structures.
The light spreads from the cities is in the form of sky glow and influences the area around them. We don't have clear data that shows that insects are declining because of light pollution but together with the other stress factors they endure, light pollution is definitely another form of imposed stress. This is why it must be considered as an influential factor in the future.

When it comes to moths - there we see a link between the population trends and their behavior towards light at night. We have seen from several different countries that there is a decline in moths and a very recent study done in The Netherlands shows that the biggest declines are in those species that are attracted to light at night. So this clearly indicates that light pollution is a significant factor in moth declines.

LED professional: Do you know of any research that considers the light level?

Maja Grubisic: Identifying a minimum impact threshold is a big question in this type of research and we don't have these values yet. The values depend on the lamp itself and the organism itself and their sensitivity throughout the year. It also differs from season to season depending on their biology. But maybe one of the reasons that we still don't have these thresholds is the exceptional sensitivity that we observe in more and more experiments, where we find effects even on very low light levels. The experiment that I just finished before coming to this conference is related to algae in waters where I tried to identify the minimum amount of light that will have an impact so that I can say - okay, lower than a certain level is safe, at least where algae is concerned. I did a laboratory study with a range of different intensities of white LED at


Dr. Grubisic speaking at LpS 2018

night and I see the same response, no matter if it's 20 lux or 10 lux or 1 lux. All of them influence the growth of algae, so the threshold seems to be lower than 1 lux - which is extremely low.

LED professional: There is a map you can look at online where you can see night light all over the world and you can see how big the area is that is influenced by light.

Maja Grubisic: Most studies that we have by now look at the effects of direct light, but the indirect light or sky glow is of much lower intensity. There have hardly been any studies about light that scatters through the atmosphere and spreads hundreds of kilometers from the light source. We are running an experiment where we illuminate a lake with such low light levels, slightly higher than moonlight, which is of maximum 0.3 lux. So we illuminate the large experimental facilities in the lake with these intensities and then look at the whole food web, from microorganisms, algae, zooplankton, small moving invertebrates and fish, and we tried to see what it means to lakes that are in the surrounding of cities; how the lights from the cities influence their functioning.

LED professional: You have told us about the mechanisms and possible measures, so now it would be interesting to know what your future research plans are, the plans for the institute and what else do you think should be done? Also, how can conferences like this, along with industry, help in your work?

Maja Grubisic: This is a very dynamic field of research, we are just starting to understand effects of artificial illumination and there are still so many open questions. Any experiment that we do and the results that we get just lead to more questions. There are plenty of things that we have to study and I am personally interested in continuing work on this topic. I am currently involved in designing experiments at my institute and we are reaching out for funding and potential collaborators. This is a very interdisciplinary field that has a strong link to society and I think that experts from different industries could play an important role. The lighting industry can develop and test technical solutions for the ecological problems and they could also offer these solutions to the market. When it comes to ecological research, it is always the combination of laboratory and field studies because in the laboratory we can study mechanisms that are underlining certain impacts and in the field we can study what the real effects are on nature, in the complex systems where species interact and are influenced by many factors. This research is very relevant from an ecological point of view, but it is also very expensive because the building and the infrastructure is expensive: We have to go to dark areas that don't have light at all, then we bring the lighting there to see the changes made to the environment. So collaboration with the lighting industry to test different

Early morning at a test site: Researchers collect insects at an experimental field in a remote rural area to study effects of street illumination on insect populations

light sources or different lamp designs could be one of the ways that we could both benefit.

For the institute partners and programs: I mentioned that we are involved with several networks with interdisciplinary approaches and experts from different fields that are interested in the subject of light pollution, preserving darkness, recognizing the value of darkness. We also make recommendations for the adequate use of outdoor lighting and we try to push those to become policy. At the moment we are running a petition for better regulation against light pollution at the European level, because there are no laws concerning this issue at a European level.

Some countries have good examples of the national laws: for example, Slovenia has very strict regulations about lighting and they are a good example of pushing for dark sky friendly lighting - outdoor lighting that reduces light pollution, with lower impact on the environment and the visibility of the stars.

LED professional: It might be a good idea to move from Human Centric Lighting to Life Centric Lighting!

Maja Grubisic: Absolutely! I was positively surprised to see that there were so many talks about human centric lighting and the circadian rhythms at this conference. I think that if importance of lighting is slowly being recognized for humans, then perhaps there is hope that we will recognize its importance for other organisms and ecology as well.

LED professional: It is important that people like you keep coming to these types of conferences to boost awareness of this topic.

Maja Grubisic: I completely agree. I was very pleased to have been invited and given the opportunity to talk about the ecological perspective of lighting at the industry-focused conference. I learned a lot by attending the talks over the last couple of days. I think it's very important that our two communities communicate to each other because only by working together we can address this issue which affects us all.

LED professional: Thank you for taking the time to come to Bregenz and for consenting to this interview.

Maja Grubisic: Thank you.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Lighting and Emergency Dept. Clinician Wellness and Performance Improvement

Short wavelength ("blue") light is known for its strong impact on humans covering "visual" function, wellness and performance of humans. Lighting has been recognized to have an effect on clinician wellness and performance as well as the occurence of medical errors. In a pilot study, Octavio L. Perez, Ph.D, WELL Accredited Professional and Adjunct Researcher at the Department of Population Health Science and Policy, and his team of scientists and physicians, Christopher Strother, Richard Vincent, Barbara Rabin and Harold S. Kaplan, from the Mount Sinai Hospital, New York, systematically investigated if and how a radically new lighting concept could improve wellness and performance in an emergency department.

This multidisciplinary study is focused on the potentially beneficial "non-visual" effects of lighting in the clinical environment, to improve clinician wellness and performance, and advance patient safety.

The hypothesis of this study was that clinician wellness and performance in the execution of clinical procedures at the emergency department (ED) could be improved through controlled, indirect, "blue-regulated", full visible spectrum, tunable, solid state, "white" lighting, compared to prevalent fluorescent lighting conditions.

To conduct our inquiry, we performed a randomized AB/BA crossover experimental study with ten (10) ED clinicians that executed clinical procedures, under two lighting conditions, in a realistic ED clinical setting. The experiments took place at the Emergency Department Simulation Teaching and Research Center (ED-STAR) at Mount Sinai Hospital in New York City, NY, USA, with a high fidelity human patient simulator.

The main observed outcomes of this study were: a significant reduction in clinician sleepiness perception (Karolinska Sleepiness Scale, "KSS", –15.94%, $p = 0.022$), a significant reduction in workload perception (NASA-TLX, –21.87%, $p = 0.009$), a reduction in clinical procedures execution time (–21.04%), and a reduction in the occurrence of medical error. The experimental condition (78,000 K) was also preferred by the clinicians compared to the prevalent fluorescent lighting (4000 K), favoring the translatability from the simulation setting to the clinical environment.

We concluded that controlled lighting environments may contribute to improve clinician wellness and performance, reduce medical error, and improve patient safety. Therefore, lighting should be considered a critical factor in the design and operation of health care facilities, far beyond energy savings.

Abstract

Short wavelength ("blue") light is known to mediate "non-visual" effects of light in humans [81,16]. These effects that go beyond the pure "visual" function can affect human wellness and performance, as it has been reported in previous scientific research in laboratory, office, education, clinical and aero-space setups [54,47,29,60,80, 4,5,6,83,44,17,45,11]. In healthcare research, lighting has been recognized in the fields of human factors, ergonomics, and systems engineering, as an environmental factor that can affect the quality of the delivery of care; in particular, clinician wellness and performance, and the occurrence of medical error. The aim and novelty of this research is to study the potentially beneficial "non-visual" effects of lighting in the clinical environment to advance patient safety.

The hypothesis of this study was that clinician wellness and performance in the execution of clinical procedures at the emergency department (ED) can be improved through controlled, indirect, "blue-regulated", full visible spectrum, tunable, solid state, "white" lighting, compared to prevalent fluorescent lighting conditions.

To conduct our inquiry, we performed a randomized AB/BA (2×2) crossover experimental lighting study with ED clinicians that executed clinical procedures, in a realistic ED clinical setting, under two lighting conditions. We used the existing fluorescent lighting as control condition. To provide the appropriate experimental lighting condition, we developed a novel multichannel solid state lighting (SSL) system for precise control and assessment of the light spectrum, with specific emphasis in the short wavelength spectral area.

The results of this study suggest that it is possible that indirect, "blue-enriched", full visible spectrum, tunable, solid state, "white" lighting, can contribute to reduce clinician sleepiness and workload perceptions, might reduce clinical procedures execution time, and might reduce the occurrence of medical error (compared to prevalent fluorescent lighting conditions).

Background

Health care is a critical burden for modern societies, and patient safety has become a main concern in the last decades [48]. The study of the (internal) environment of care is emerging and has not been properly addressed, even if research in human factors and ergonomics points it out as a critical factor [12,13,14]. In addition, lighting, as a key factor of the environment (more specifically, of the "exposome" [86], has not been paid enough attention except for the considerations of "adequate lighting levels" for the visual task and for visual performance [13]. Improving the environment of care can have a positive impact in the quality of care and therefore in patient safety [68,42]. Other studies propose that enhancing clinician wellness might contribute to this goal [84,69]. And this is also a goal of our research, to see if through controlled lighting interventions clinician performance and clinician wellness can be improved with the final objective of having a safer delivery of care, and improvement in patient safety.

The recent adoption and development of simulation centers as part of the medical training and research provides a very appropriate setting to conduct research without the risk of harm to patients and with a high level of translatability to the real clinical setting [34,32]. For these reasons, we have conducted our research at the ED simulation center, to provide a realistic reproduction of the clinical environment. We know that the human "visual" system has, at least, a dual function, the "visual" and the "non-visual" [50,70,23]. Besides the known pure visual effects (mainly visual task and aesthetics), and the non-visual or non-image-forming (NIF) effects of light and lighting on circadian rhythms that can affect, entrain and regulate sleep patterns, disorders and disturbances (such as shift work and jet-lag) [35], research is developing in the fields of effects on human mood, cognition, performance and wellness and wellbeing [82,18]. Although there has been extensive research and development of lighting for health care delivery, mostly for the patient [80,4,5,6,83,44,17,45,11], there is no prior interventional research that specifically addresses the NIF effects of the lighting environment in the ED clinician performance and wellness in relationship with patient safety, what represents one of the main contributions of this study. The field of research on NIF effects of light and lighting is emerging, and has several limitations that will need further research. Appropriate research in the NIF effects on lighting has only been possible since the recent discovery in 2002 of the ipRGC [39,7], the photoreceptors that mainly mediate these effects, and their presumed "action spectra" (related to the photopigment melanopsin [8,78], also recently discovered in the late nineties by Ignacio Provencio, Ph.D [63,64,65], a reason why some researchers call the ipRGC Ignacio-Provencio-RGC). While the precise underlying neural pathways and systems and associated "pharmacodynamics" remain unclear and will need further research from multidisciplinary approaches (such as architecture, design, engineering, physics, medicine, biology, cognitive sciences and psychology), it is known that these ipRGC photoreceptors innervate into different areas of the brain far beyond the well-known visual pathways [24].

There is a general lack of methodology in lighting research, particularly in NIF. Replication and reproducibility are basic pillars in the scientific method that must be addressed in this field. Uniformity is needed in lighting studies to allow repetition and replication and conduct proper metaanalysis [66]. Methodology becomes essential for lighting studies in the field of NIF effects. The following are proposed factors that have to be carefully considered [66,53], as subjects' psycho-physiology plays a major role: participant's chronotype (morningness/eveningness); sleep schedule of the participants during previous days, circadian time of day (CT) for the participant (time since wake-up) and other stimuli influence such as caffeine intake (in the form of coffee or other caffeinated beverages and/or supplements), Indoor Environmental Quality (IEQ), with factors such as room temperature, relative humidity and carbon dioxide (CO_2) and noise; appropriate method of light measurement, preferably based on spectral power distribution (SPD). Control conditions are also critical for the estimation of the effects beyond the classical "statistical significance" research drivers. Using darkness [71] or unrealistic environments as controls is not ethical. These are factors that need to be properly considered in future studies. We have seen the same lack of rigorous methodology in the review of most of the studies referenced related to the effects of light and lighting in the health care environment.

One of the main limitations in current research is the paradigm, and prevailing mindset, of photometry and colorimetry in the lighting community. Light and lighting are mainly measured, and understood, in terms of illuminance (unit lux) and color appearance (correlated color temperature, "CCT", unit Kelvin) [27]. The "action spectra" of the ipRGC, characterized now in relationship to melatonin suppression [8,78], a point that is beginning to be questioned [67,87], is totally different from the action spectra of the classical visual photoreceptors that are the foundation for photometry and colorimetry. New metrics, such as the melanopic function (and the associated melanopic lux), or the "melanopic equivalent daylight (D65) illuminance" to be introduced in late 2018 by CIE JTC-09, have been proposed for the measurement of light at the eye/cornea level in laboratory studies [53], but there is no common standard for measuring the field of view (FOV) and the whole lighting environment, particularly with spectral resolution (SPD). Future advancement in this field will require proper assessment of the directionality and of the whole lighting environment to better characterize the dynamic stimuli for the different space stakeholders "competing demands", such as patient vs. caregiver in the patient room or the emergency department, and the surgeon vs. anesthesiologists vs. nurses in the operation room.

Technology availability by lighting researchers has constituted an additional limitation. Most of the previous studies in real or realistic environments have been done by nonexperts in lighting with commercial light sources and fixtures designed for the visual-task function and performance. Little attention has been paid to these factors in lighting design improvement, limiting interventions (control vs. experimental setting) to lamp substitution or fixture retrofitting. Solid state lighting, and particularly LED (light emitting diode) facilitates a radical change in this limitation, particularly the "full spectrum tunable" (not the inappropriate "white-tunable") systems that will allow targeting specific SPDs.

Due to this current limitation, and to our experience in the development and commissioning of lighting systems, we decided to set up in our research environment an innovative lighting system that provided enough flexibility for our research at an affordable budget. We describe this in more detail in the methods section.

Research Questions, Hypothesis and Objectives

Research questions

The main research question of this study was: "to know if there is a difference in clinician wellness and performance during the execution of clinical procedures at the ED Simulation Center due to the lighting environment". Performance was measured in qualitative terms (medical evaluation), and in differences in execution time, together with subjective workload and sleepiness/alertness metrics for wellness evaluation. Medical error occurrence was also surveilled.

We were on an exploratory research path and this was a screening experiment. Therefore we were not interested at this stage in knowing the optimum spectrum or the most efficacious system. If we obtained satisfactory proof of concept findings, as it happened, this matter would open other research oriented to optimization of our research question, to estimate the best control variables (factors) and to get the optimum values for them.

There are two additional research questions of interest:

- What is the effect of "blue-enriched" indirect lighting in lighting quality perception?
- "Blue-enriched" lighting, associated with high CCT, has generally not been liked by previous study participants. Is our lighting environment, diffused lighting, going to be accepted by our participants?

These secondary questions are critical for the translatability of the results into the real clinical environment.

Hypothesis

The research hypothesis was: "the clinician wellness and performance outcomes will be significantly improved with the indirect, "blue-enriched", full visible spectrum, solid state, "white" lighting (experimental treatment condition) compared to the existing fluorescent lighting (control treatment condition)." Based on our previous experience and in the literature research, already discussed in the backgrounds section, we presume that "blue-enriched" lighting can be adequate to be part of our research. And we also know that this particular region of the spectrum can be difficult for our visual system if not delivered properly. That is why we chose to research with an indirect delivery of the lighting conditions, with no direct exposure of the light sources to the participants. This also minimizes the controversial "Blue Light Hazard" (BLH) risks [62].

Objective

The objective of the study was "to investigate the efficiency of indirect, "blue-enriched", full visible spectrum, solid state, "white" lighting in clinician wellness and performance, and patient safety, during the execution of a single-clinician clinical procedure, "chest-tube", in the Emergency Department simulation lab." The first procedure was taken as a "warm-up".

Methods

We will discuss here the experimental design (AB/BA crossover, within subjects), the research tools (with a special emphasis in the lighting intervention and the lighting system), the population, and the statistical model for the study (that has to be properly defined before running the tests)[i].

The whole experimental flowchart is shown in figure1. There are three main processes, the experimental design and IRB (Internal Review Board), the experimental runs, and the data analysis, though we will not explore them here in detail.

Experimental design

We conceived, designed and conducted "proof of concept" experimental research. We had two lighting conditions (control and experimental), and we randomized our sample of participants (real ED clinicians) into two groups, sequences AB and BA. Group AB performed the test (two sequenced clinical procedures "airway" + "chest-tube") first under control lighting condition (fluorescent) and then under experimental ("blue-enriched" LED), and BA group did the reverse order/sequence. Participants took a "washout" period of at least one full week (7 days) between the treatments/ conditions (tests). The process flow is shown graphically in Figure 2.

Research tools

For the experimental lighting condition (treatment), we developed our own instruments and systems and used as the control the existing lighting system (fluorescents). This system will be described in the next subsection.

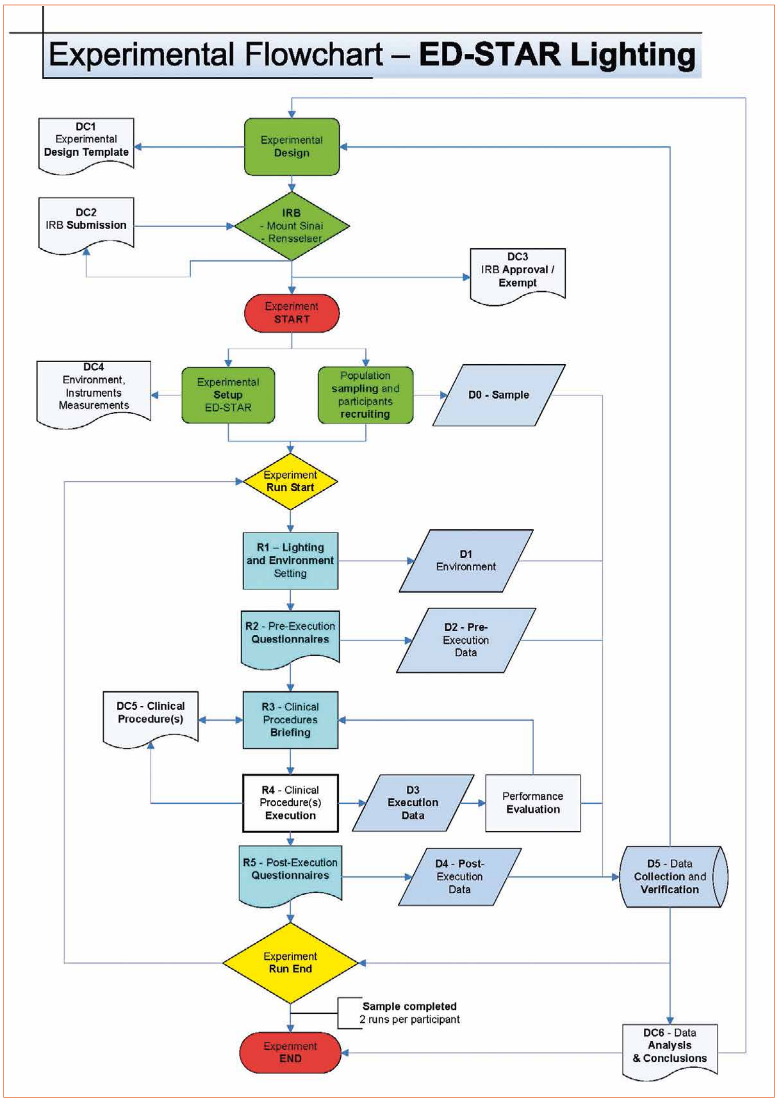


Figure 1:
ED-STAR Experimental Methods Flowchart

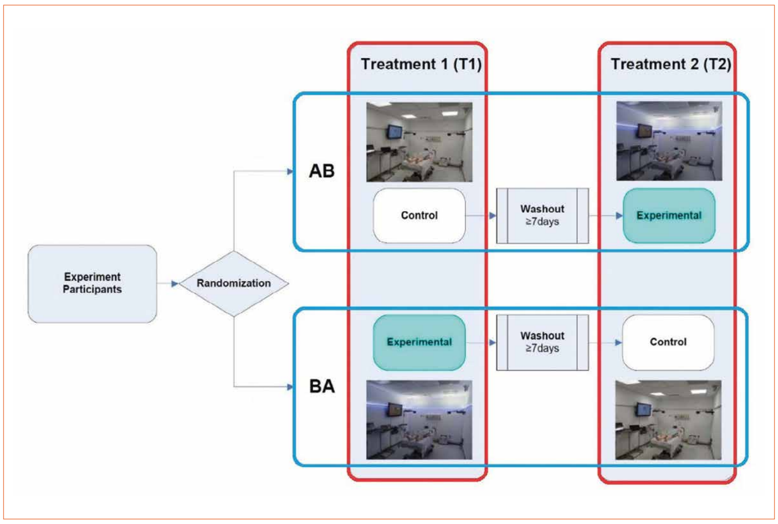


Figure 2:
Experimental design AB/BA crossover flow

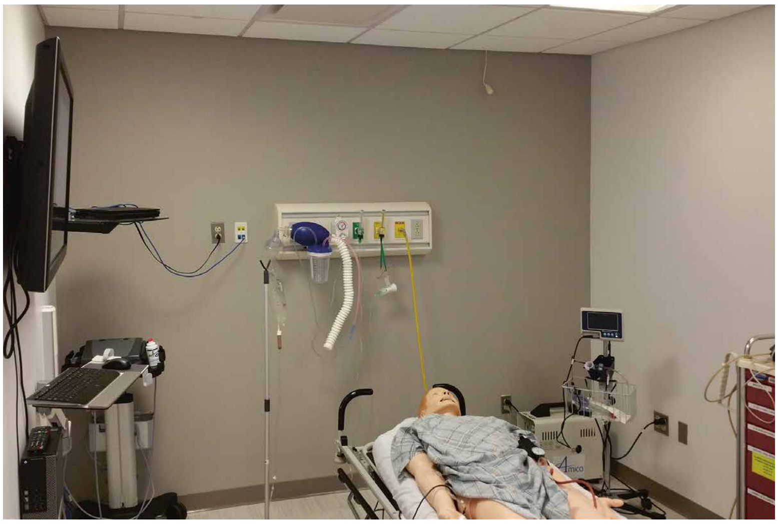


Figure 3:
ED-STAR room before the lighting intervention

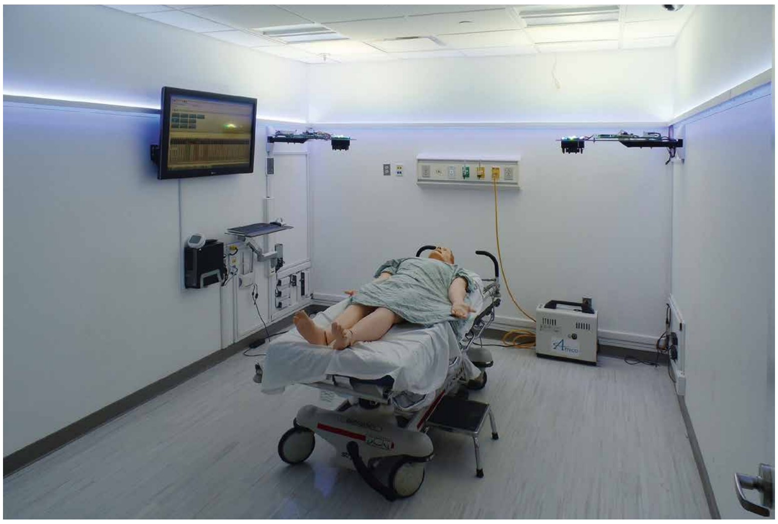


Figure 4:
ED-STAR room after the lighting intervention

For the experimental instruments, we used validated surveys and questionnaires: the “Karolinska Sleepiness Scale” (KSS) for subjective assessment of sleepiness/alertness [2,46,75,41], the “NASA-TLX” (“TLX”: “Task Load Index) for subjective workload perception [37,38,49], a modified version of the “ASHRAE IEQ survey” [88] for subjective assessment of the environment, and a “Lighting Perception Survey” for the subjective perception of lighting, based on the initial work by Prof. Peter R. Boyce [30], that we updated to gather additional information. We used custom ED-STAR tables for clinician performance and time evaluation.

Lighting intervention and lighting system

At the time of the study, there were no commercial options to provide illumination levels of a room such as the ED-STAR “simlab” for the purposes of the experimental framework proposed here, with full control over the visible spectrum (SPD). The only existing systems that were able to provide room level “color tuneability” (different from SPD control) were the Philips “Healwell” and the Telelumen “Penta” that provide color (perceptual) tuneability, but not detailed spectral tuneability. This, as discussed, is particularly relevant on the “blue” region of the visible spectrum (short wavelengths) that is critical mediators of the “non-visual” effects of light. Besides the SPD limitation, both systems are based on direct ceiling light emission, contrary to the IESRP-29 recommended practice for healthcare facilities, which prioritizes indirect lighting for spaces that have interactions with patients. For these reasons, we proceeded to build a custom system at the “simlab” which provided full SPD controllability with an indirect lighting strategy.

Figure 3 shows the “simlab” room as it was in May 2015 prior to proceeding with Mount Sinai facilities to retrofit the room for this research. The room was originally illuminated by four recessed ceiling troffers (2’×2’ fixtures). The walls were painted in an unspecified “off-white” with the head wall painted (arbitrarily) in a “beige” color.

The first intervention was to paint all the walls of the room with a “high reflective white” (Light Reflectance Value, LRV = 94%) paint to make the room an integral part of the lighting system. We also painted two ceiling tiles with the same paint, as they were going to be working as primary reflectors of the light engines that were providing full spectrum tuneability. This also provided maximum spectral fidelity of the reflected light and minimum absorption by the surfaces (a factor that should be considered also for energy efficiency). Figure 4 shows the final configuration of the system as conceived for the experimental condition with two main sources of light (besides the existing fluorescent that was used as control condition, and turned off in the experimental condition.

Final configuration of the system:
- Two full spectrum light engines in the front side of the room shining upwards at above average eye level to prevent direct eye exposure to the LED light sources
- A perimeter lighting profile to provide indirect lighting and uniformity perception across the room

Both sources of light had different control systems and were commanded through the same communication and control bus (through standard DMX512 protocol). A schematic of the system is depicted in Figure 5 where we can see the two lighting sources and their associated control systems, the DMX communication bus, system controller (lighting controller), the networking interface and the control software interfaces (android/ iPhone "apps" and PC software). The reason to use the wireless network layer instead of a cabled layer for the control was to provide full electrical isolation between the user interface and the lighting system (lighting as a medical device safety).

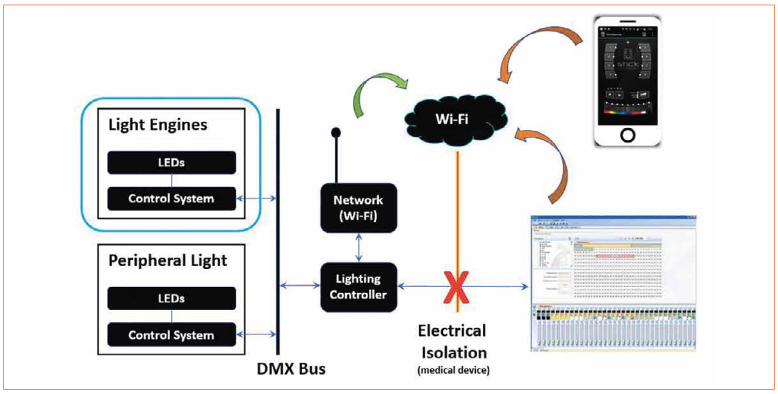


Figure 5:
Lighting system schematic

Light quality

The light quality of the two lighting conditions is shown in figures 6 and 7. The measurements were taken with a calibrated Konica-Minolta CL-500A spectrophotometer. We can see that even if the experimental condition was with a high "blue" content, and at the limit of the black body line (BBL) to be considered "white" (78 000 K), the color fidelity was higher than the conventional fluorescents. Of particular interest for the health care environment is the R9 parameter associated with "red" perception (skin/blood). We did not calculate the "Cyanosis Observation Index" (COI) from Australian regulations (AS/NZS 1680.2.5), as it does not affect USA and EU countries.

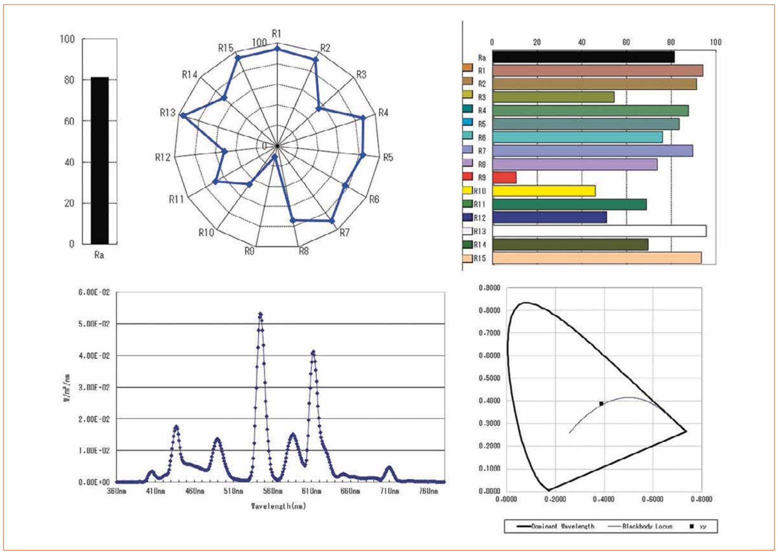


Figure 6:
Control condition light quality

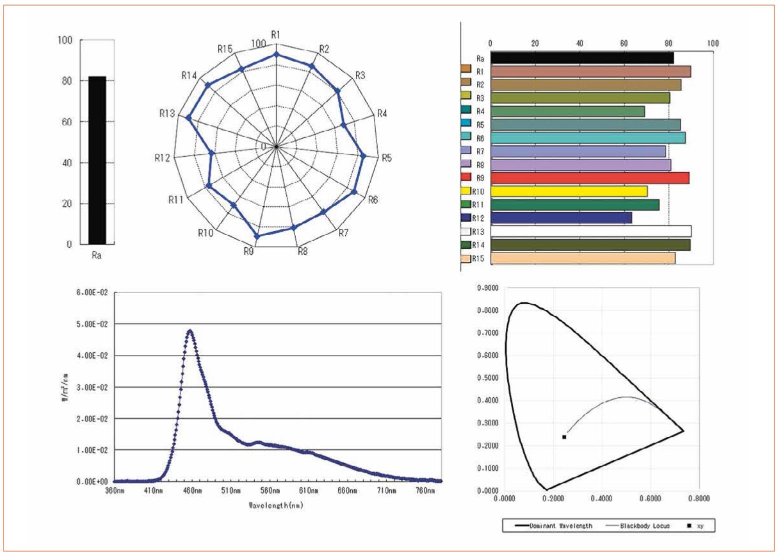


Figure 7:
Experimental condition light quality

Lighting System Commissioning in the Clinical Health care Environment

Once the system was built and installed, we proceeded with the commissioning (programming). Our target for the experiment was to have the same illuminance levels (lux) at the task under both lighting conditions (880 lx), as we can see in figure 8.

The fluorescent lighting had no control, besides the classical on/off, and we manually adjusted the new experimental lighting system until it achieved the desired experimental condition, with the constraint of providing the same illuminance as the fluorescent system (at the task). This setting was saved as a preset in the lighting system controller (Nicolaudie Stick KE1 with network adapter). The ED-STAR staff was able to setup the room with the push of a button ("mode 5") in the smartphone "app". This was

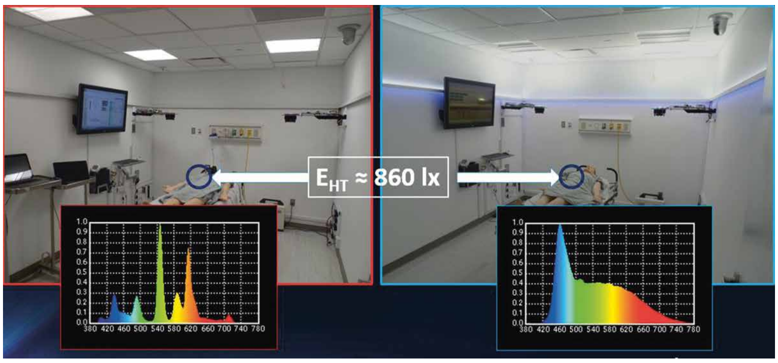


Figure 8:
Equilux lighting conditions control (left) and experimental (right)

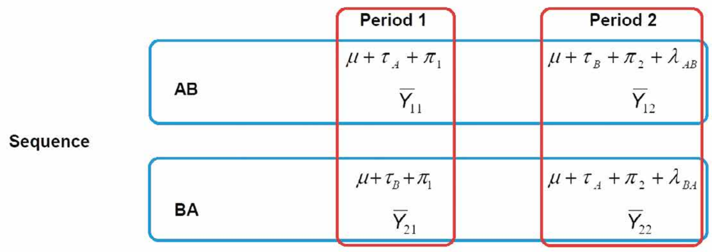


Figure 9: Cell means and expectations for a cross over design

Name	Definition	Expectation
CROS	$[(\bar{Y}_{11}-\bar{Y}_{12})+(\bar{Y}_{22}-\bar{Y}_{21})]/2$	$(\tau_A-\tau_B)-(\lambda_{AB}-\lambda_{BA})/2 = \tau-\lambda/2$
SEQ	$(\bar{Y}_{11}+\bar{Y}_{12})-(\bar{Y}_{22}+\bar{Y}_{21})$	$(\lambda_{AB}-\lambda_{BA}) = \lambda$
PAR	$\bar{Y}_{11}-\bar{Y}_{21}$	$(\tau_A-\tau_B) = \tau$

Figure 10: Estimation of parameters of interest from the cell means for a cross over design

demonstrated to be a very robust procedure with no possible mistakes. The staff was very confident about this way of operation.

Subjects: Study population

The research study enrolled emergency department clinicians following the Institutional Review Board (IRB) approved protocol. The study was performed in the Emergency Department Simulation Teaching and Research Center (EDSTAR), a teaching simulation center at Mount Sinai Hospital in NYC, NY, USA. Our experimental setup is a permanent installation that will enable further research with the goal of rapid translatability into the real ED clinical environment.

Statistical model: AB/BA crossover

An AB/BA crossover study is defined as one experiment or clinical trial in which there is an interest in determining differences between two treatments that are given in alternate order to two groups of participants. One group, AB, received first treatment A and then treatment B. The other group, BA, received the treatments in reverse sequence (first B and then A) [73,74,57,51]. Each participant on a crossover acts as his/her own control eliminating the between-participant's variability, needing fewer observations than the parallel design to get the same precision in estimation. A crossover study is therefore more efficient than a parallel group study.

The statistical model for the AB/BA crossover is summarized in figures 9 and 10 [73]. Figure 9 shows the four cells, with the means and expectations for each cell.

The variables in this figure are:

- General level parameter: μ
- Treatment contrast (treatment effect): $\tau = \tau_A - \tau_B$
- Period effects: π_1 and π_2

Figure 10, shows the estimation of the parameters of interest ("treatment effect" and "carry-over") based on the four cell means $\bar{Y}_{11}$, $\bar{Y}_{12}$, $\bar{Y}_{21}$, $\bar{Y}_{22}$ (where $\bar{Y}_{11}$ is the mean of the first group/sequence, AB, in period 1, and so on).

Continuous and discrete variables:
In a crossover study, we have to differentiate carefully between continuous and discrete variables.

Discrete Variables:
For the discrete variables, we did a study based on contingency tables.

Continuous Variables:
For the continuous variables, we evaluated first the treatment effect ("effect size") provided by the crossover analysis and the 95% confidence interval. The "effect size" provides the magnitude of the treatment effect and the sign indicates the direction of the effect (higher or lower under experimental compared to control).

Then we proceed with the null hypothesis statistically significance testing: Null hypothesis H0: mean difference is zero (no statistical significant difference) Alternate hypothesis H1: we have two different alternate hypothesis.

The two different alternate hypotheses are:

- Mean difference is less than zero (one sided) for:
  - KSS ("Karolinska Sleepiness Scale")
  - NASA-TLX ("Task Load Index")
  - Clinical procedures "execution time"
- Mean difference is greater than zero (one sided) for:
  - Clinical procedures "performance"

The reason for the two different criteria for the alternate hypothesis is due to the expected hypothesized effects:

- For KSS (sleepiness/alertness) we expect a lower sleepiness (higher alertness) with the experimental treatment. Same with NASA-TXL where a lower score will indicate a lower perceived workload. Lower "execution time" (in seconds) for the clinical procedures is also expected under the experimental condition
- For clinical procedures "performance" evaluation we hypothesize to have higher scores under experimental conditions compared to control.

We calculate the "p-value" that will be communicated as exact value [79,36,85]. With the treatment effects information (magnitude and direction) and the statistical significance, we will discuss the results and relevance in the next section.

Example of Communication of Crossover Results for Continuous Outcomes:
As there is no standardized way for communicating crossover study results, besides the tables, we will summarize the results in the following format.

In the crossover analysis of outcome yyy, measured zzz, (n = ww) we obtained the following results:

- Treatment effect = x.xx95% CI [x.xx, x.xx]
- Mean C (Control) was higher/ lower (MC = x.x, SDC = x.xx) than Mean E (Experimental) (ME = x.x, SDE = x.xx), by (xx%), t(DF) = x.xx, p = .xxx

Experimental Runs, Results, and Data Analysis

Experimental conditions

All participants had a minimum "wash-out" period of at least seven (7) days between experimental runs in order to preclude "carry-over" effects. "Carry-over" can be associated with the learning process (cognitive/psychological) more than the physiological "carry-over" of typical drug crossover studies. Participants were not on night-shifts for at least two days prior to either of the two treatments. The ideal situation would have been to avoid all night-shifts, but this could not be accomplished with active ED clinicians, and it is also closer to the real conditions of the ED environments where experimental results will be translated. We also arranged the timing of the experiment in terms of days of the week and time frames within the day (noon-4pm). All the experiments were conducted during weekdays, excepting Mondays to avoid the potential "post-weekend" effect, also known as "Monday effect" [10].

	Group	Karolinska Sleepiness Scale (KSS)								
Study	Seq	Control		ΔKSS-C	Experimental		ΔKSS-E	KSS - C-E	Period	
#	AB/BA	Pre	Post	C	Pre	Post	E	C-E	T1	T2
01	**AB**	2	4	2	5	4	-1	3	2	-1
03	AB	4	4	0	5	4	-1	1	0	-1
05	AB	5	4	-1	4	3	-1	0	-1	-1
06	AB	7	3	-4	7	4	-3	-1	-4	-3
07	AB	3	3	0	4	4	0	0	0	0
09	AB	3	3	0	3	3	0	0	0	0
02	**BA**	6	6	0	3	2	-1	1	-1	0
04	BA	6	6	0	6	5	-1	1	-1	0
08	BA	6	5	-1	7	4	-3	2	-3	-1
10	BA	1	2	1	4	4	0	1	0	1
		43	40	**-3**	48	37	**-11**	**8**		
			Effect	**-6.98%**		**Effect**	**-22.92%**	**15.94%**		
			Mean	-0.3		**Mean**	-1.1	0.8	**Mean Diff**	
			SD	1.57		**SD**	1.10	1.35	**Pooled SD**	

Table 1: Within participants' experimental runs KSS differences within test

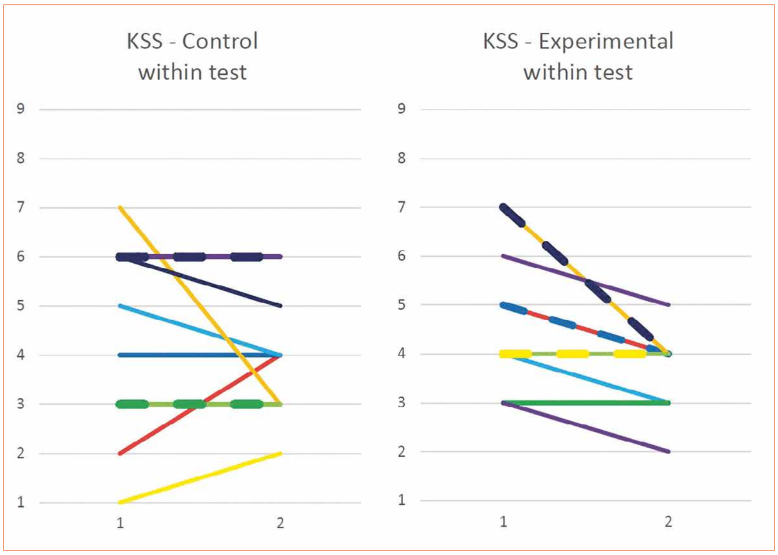


Figure 11: Within participants' experimental runs KSS differences within test (1 = baseline (pre-test), 2 = after procedures (post-test)): Control (left) vs. Experimental (right). Dotted lines represent more than one test with exact results: two 3-3 and two 6-6 occurrences under control (left); two 7-4, two 5-4 and two 4-4 under experimental (right)

Sample/participants

Our sample was composed of ten active clinicians (n = from the ED department at Mount Sinai Hospital in NYC (even if ten subjects could be seen initially as a low number, the fact that they were actual clinicians in a realistic clinical environment adds robustness to our study, that is exploratory). All of the participants were volunteers and did not receive any compensation for participation. They were very helpful in accommodating their busy and sometimes unpredictable working schedule to the experimental research agenda, with the strict limitation of the two night shifts.

Characterization of the sample:

- Size: ten (n = 10) participants (equivalent to 20 on a double arm experiment)
- Experimental runs: twenty (20), two per participant, following the AB/BA crossover design
- Age: average 35.10 years (SD = 4.95, min = 28, max = 44)
- Gender: seven males and three females
- Experience level: five residents (3th and 4th year) and five faculty members
- All participants were healthy, and none declared having diabetic conditions, nor color vision problems
- One participant had light-colored eyes: There was no participant drop-out.

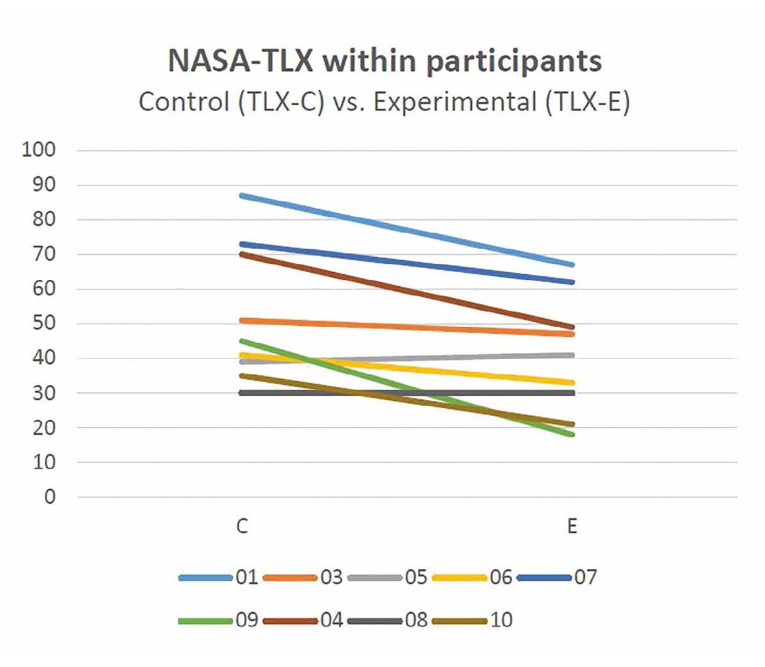
Experimental results and data analysis

The data collection and initial processing of the data was done in "MS Excel" and the statistical analysis was performed using "Minitab v17". As the experimental design was AB/BA crossover, we have used the crossover statistical analysis methodology for the inferential statistics analysis of the data. The crossover design has the unique characteristic of having each participant as its own control, reducing the variability between participants and the sample size required compared to double-arm designs. Besides the conventional inferential study of "p-values", statistical significance, that has become controversial, yet pervasive, we have also conducted a study of the "treatments effects" to discuss practical significance [56,21,40,55,79,77,22,61,36,85].

Table 2:
Within participants' experimental runs NASA_TLX differences within test (missing data for participant #2 experimental condition)

	Group	NASA-TLX Raw (TLX)				
Study	Seq	Sum of scales			Sum of scales	
#	AB/BA	C	E	C-E	TLX1	TLX2
01	AB	87	67	20	87	67
03	AB	51	47	4	51	47
05	AB	39	41	-2	39	41
06	AB	41	33	8	41	33
07	AB	73	62	11	73	62
09	AB	45	18	27	45	18
02	BA	50	*	*	*	50
04	BA	70	49	21	49	70
08	BA	30	30	0	30	30
10	BA	35	21	14	21	35
		521	368	103		
		471	**368**	**103**	**-21.87%**	(exc #02)
	Mean	52.33	40.89	11.44		
	SD	19.69	17.07	18.43	**Pooled SD**	

Figure 12:
NASA-TLX within participants (Control vs. Experimental: TLX-C vs. TLX-E) (missing data for participant #02 experimental condition)



Figures 13:
Crossover data analysis results summary for KSS and NASA-TLX

Crossover Data Analysis Results Summary

1. Sleepiness Perception (KSS)

In the crossover analysis of KSS, (measured in a scale 9-1), n=10, we obtained the following results:

- Treatment effect -0.875, 95% CI [-1.7174, -0.032555]
- The Mean under Control (M_C = -0.3, SD_C = 1.57) was higher than the Mean under experimental (M_E = -1.1, SD_E = 1.10), by 15.94%, DF(8), T-value=-2.3951, p-value=0.022

We observed in our sample that the experimental condition reduces the KSS (sleepiness perception) as hypothesized, in the terms described above.

2. Workload Perception (NASA-TLX)

In the crossover analysis of NASA-TLX, (measured 1-126), n=9 (1 participant's score missing), we obtained the following results:

- Treatment effect -11.5, 95% CI [-20.393, -2.6074]
- The Mean under Control (M_C = 52.33, SD_C = 19.69) was higher than the Mean under experimental (M_E = 40.89, SD_E = 17.07), by 21.87%, DF(7), T-value=-3.0579, p-value=0.009

We observed in our sample that the experimental condition reduces the NASA-TLX (workload perception) as hypothesized, in the terms described above.

Experimental data for KSS and NASA-TLX is shown in different figures and tables in this section: KSS differences within test in Table 1 and Figure 11, the KSS equivalence test in Figure 14; NASA-TLX differences within test in Table 2 and Figure 12, the NASA-TLX equivalence test in Figure 15; crossover data analysis results summary for KSS and NASATLX in Figure 13; the summary of inferential statistics in Table 3. Detailed data for clinical performance execution time and evaluation and for the surveys is not presented here.

The observations of reduction of sleepiness (KSS) and workload (NASA-TLX), factors that may be associated with clinician wellness/ stress and medical error causation in the health care environment, are of special interest in the emergency setting. In the ED environment, clinicians work under high levels of stress [19]. The potential increased ability of saving lives is a major component of the practical significance of our study.

The experimental lighting environment was positively accepted by the study participants and our indirect, "blue-enriched", full visible spectrum, solid state, "white" lighting (experimental condition) was evaluated in our sample as better than the existing and prevalent fluorescent lighting (control condition). There were slight differences in perception of temperature and humidity: the environment was perceived as more humid and warmer under control (fluorescent) conditions. The experimental condition was accepted by all the participants of our study, except one, and had less claims for controllability. Also, the experimental condition was evaluated as better than the control in the "compared to other workplaces" survey. It is the first time in lighting research that "blue-enriched" full visible daylight lighting delivery has been reported under experimentation with an


```
Equivalence Test for 2x2 Crossover Design: CD, KSS-T1, KSS-T2

Method
Treatment order for subjects in sequence AB: KSS-C, KSS-E
Treatment order for subjects in sequence BA: KSS-E, KSS-c

Descriptive Statistics
          KSS-T1                KSS-T2
C1  N      Mean    StDev         Mean     StDev
AB  6  -0.50000  1.9748       -1.0000   1.0954
BA  4   -1.2500  1.2583   0.000000000   0.81650
Within-subject standard deviation = 0.40020

Effects
             Effect        SE  DF  T-Value  P-Value         95% CI
Carryover   0.25000    1.6809   8  0.14873    0.885    (-3.6262, 4.1262)
Treatment  -0.87500   0.36533   8  -2.3951    0.044  (-1.7174, -0.032555)
Period      0.37500   0.36533   8   1.0265    0.335   (-0.46744, 1.2174)

Difference: Mean(KSS-E) - Mean(KSS-C)

Difference       SE  95% Upper Bound  Upper Limit
  -0.87500  0.36533         -0.19566            0

Upper bound is less than 0
Can claim Mean(KSS-Exp) < Mean(KSS-Ctrl)

Test
Null hypothesis:          Mean(KSS-E) - Mean(KSS-C) ≥ 0
Alternative hypothesis:   Mean(KSS-E) - Mean(KSS-C) < 0
α level:                  0.05

DF  T-Value  P-Value
 8  -2.3951    0.022

P-Value ≤ 0.05. Can claim Mean(KSS-Exp) < Mean(KSS-Ctrl)
```

Figures 14: **KSS Equivalence Test from Minitab**

```
Equivalence Test for 2x2 Crossover Design: CD, TLX-T1, TLX-T2

Method

Treatment order for subjects in sequence AB: TLX Ctrl, TLX Exp
Treatment order for subjects in sequence BA: TLX Exp, TLX Ctrl


Descriptive Statistics
           TLX-T1          TLX-T2
CD  N    Mean    StDev    Mean    StDev
AB  6  56.000  19.545  44.667  18.250
BA  3  33.333  14.295  45.000  21.794
Within-subject standard deviation = 3.76070

Effects
             Effect      SE  DF   T-Value  P-Value          95% CI
Carryover   -22.333  25.461   7  -0.87714    0.410    (-82.540, 37.873)
Treatment   -11.500  3.7607   7   -3.0579    0.018   (-20.393, -2.6074)
Period      0.16667  3.7607   7  0.044318    0.966    (-8.7260, 9.0593)

Difference: Mean(TLX Exp) - Mean(TLX Ctrl)

Difference      SE  95% Upper Bound  Upper Limit
   -11.500  3.7607          -4.3751            0

Upper bound is less than 0. Can claim Mean(TLX Exp) < Mean(TLX Ctrl)

Test
Null hypothesis:         Mean(TLX Exp)-Mean(TLX Ctrl) ≥0
Alternative hypothesis:  Mean(TLX Exp)-Mean(TLX Ctrl) <0
α level:                 0.05

DF  T-Value  P-Value
 7  -3.0579    0.009

P-Value ≤ 0.05. Can claim Mean(TLX Exp) < Mean(TLX Ctrl)
```

Figure 15: **NASA-TLX Equivalence Test from Minitab (missing data for participant #02 experimental conditions)**

equivalent CCT of ≈ 78 000 K (seventy-eight thousand Kelvin) at the task. This setting was considered better than the conventional lighting (control condition).

We observed in our sample a reduction in sleepiness (alertness? increase) in the KSS scale (–15.94% observed effect with p-value = 0.022), Figure 11, and a reduction in workload perception in the NASA-TLX sum of scales (–21.87% observed effect with p-value = 0.009), Figure 12. We cannot claim a statistically significant reduction in execution times for procedure two and total execution times (–21.04% observed effect with p-value = 0.094). Also, there was no improvement seen in the clinical performance evaluation, even if we can see an observed effect improvement in our study in the scores from control to experimental lighting conditions. Finally, two medical errors occurred under control conditions and none under experimental conditions.

Table 3: **Summary of inferential statistics**

Summary of inferential statistic tests						
Control: Existing fluorescent (4,000K) Experimental: Solid State (LED) lighting system (78,000K)						
H_0 Null hypothesis: Mean(Experimental) - Mean(Control) ≥ 0 H_1 Alternative hypothesis: Mean(Experimental) - Mean(Control) < 0						
	Values	Effect	Effect %	alpha	P-Value	Result
Karolinska Sleepiness Scale						
KSS	9-1	-0.88	**-15.94%**	**0.05**	**0.022**	**Can Reject H_0**
NASA-TLX (workload perc.)						
Sum of scales	1-21 x 6	-11.50	**-21.87%**	**0.05**	**0.009**	**Can Reject H_0**
				0.01	**0.009**	**Can Reject H_0**
Clinical Performance Execution Time	seconds					
Procedure 1 (P1): Airway		-6.17	**-21.35%**	0.05	0.252	*Cannot Reject*
Procedure 2 (P2): Chest-tube		-101.46	**-21.02%**	0.05	0.090	*Cannot Reject*
Total Execution Time (P1+P2)		-107.63	**-21.04%**	0.05	0.094	*Cannot Reject*
H_0 Null hypothesis: Mean(Experimental) - Mean(Control) ≤ 0 H_1 Alternative hypothesis: Mean(Experimental) - Mean(Control) > 0						
Clinical Performance Evaluation						
Procedure 1 (P1): Airway						
Checklist (P1C)	1-12	0.21	**1.77%**	0.05	**0.182**	*Cannot Reject*
Psychomotor (P1P)	1-7	0.17	**1.64%**	0.05	0.239	*Cannot Reject*
Novice to Expert (P1N)	1-5	0.25	**7.32%**	0.05	**0.138**	*Cannot Reject*
Procedure 2 (P2): Chest-tube						
Checklist (P2C)	1-34	0.63	**4.04%**	0.05	**0.160**	*Cannot Reject*
Psychomotor (P2P)	1-7	-0.04	**0.00%**	0.05	0.534	*Cannot Reject*
Novice to Expert (P2N)	1-5	0.21	**5.26%**	0.05	**0.182**	*Cannot Reject*

Discussion

We have obtained results from our experimental research that are supportive of our hypothesis about potential “non-visual”/“non-image-forming” (NIF) beneficial effects of “blue-enriched” full visible spectrum “white” lighting in clinician wellness and performance, and improvement in patient safety. The observed reduction in sleepiness (increase in alertness? wakefulness?) and the observed reduction in perceived workload, the effect in clinical performance, and the acceptance and preference of the experimental condition (indirect, "blue-enriched", full visible spectrum, solid state, "white" lighting) compared to the control condition (fluorescent lighting) are discussed here. These results may contribute to the translatability of the findings from the simulated to the actual clinical environment.

Our experimental lighting condition suggested an aggregate set of beneficial results for clinician wellness and performance that supports our research hypothesis. Using the existing fluorescent lighting as control reinforced the validity of our study, as these are ubiquitous conditions in the current health care environment.

The acceptance of the experimental lighting condition is critical for its practical feasibility. Also, our lighting conditions provided general lighting performance, while results from previous research that has been conducted in lightboxes [71] or on "ad-hoc" laboratory setups (static subjects with fixed chin) [8] are difficult to be translated into real-world environments.

The observed reduction in sleepiness, associated with an increase in alertness (wakefulness?), might initially seem inconsistent with the observed reduction in workload perception, as alertness could be erroneously associated with stress and arousal. In our study, the participants interviewed agreed that the experimental lighting provided a "calming effect" that empowered them to better focus on the execution of the clinical procedures. This "calming effect", which at the same time improves alertness (wakefulness?) and focus, requires further research and analysis (explored in fields such as mindfulness). Another potential explanation can be found in the (controversial?) field of "Syntonic Optometry" where the effect of "blue" visible radiation is associated with the activation of the parasympathetic nervous system activation (PSNS), [76,52,33]. The field of pharmacodynamics [28] becomes relevant here as perhaps the same wavelength/relative SPD can create different effects depending on levels/dose (and timing).

Taking into account that we performed all of our experiments between noon and 4pm (trying to have a similar circadian time, "CT", lapse for the participants), we presume that melatonin suppression, or reduction, was not the cause of the effect measured. Melatonin levels are high in the human body during the night and remain low during the day [43]. In the selection of our timeframe we were also careful to not target the morning peak of cortisol. Considering that our timeframe was coincident with the "post-prandial" dip, previous research suggests that the orexin/hypocretin neurons that are associated with wakefulness [25,15,26,72,20] might be inhibited by higher glucose levels associated with high carbohydrate meals [9]. Monk [58] recognizes the post-meal effect, and also the carbohydrates factor, but also proposes that the decrease in performance in the early afternoon could be driven by a 12-hour circadian harmonic that could also be higher in morning-type individuals, and that is not necessarily caused by the post-meal event. Monk also proposes ("bright") light as a coping mechanism for the "siesta" effect. To the best of our knowledge, only one previous lighting research [66] considers the orexin wakefulness mechanisms in association with lighting, beyond the effects of light in melatonin.

This is clearly an area of future research related to the study of the neurological mechanism underlying the effects of light in human psycho-physiology that would be difficult to conduct in other organisms (such as mice) due to the high level cognitive functions associated with the research, and the fact that mice are nocturnal creatures. Techniques such as fMRI (functional Magnetic Resonance Imaging) have been proposed in the field of neuroscience, even if the statistical methods in neuroimaging have been put recently into question [31]. Other neuro-physiological metrics, such as heart rate variability (HRV), eye tracking (pupillary response), electroencephalography (EEG), and skin conductivity, look very promising to evaluate sympathetic and parasympathetic nervous system activation and should be explored in future studies.

Conclusion and Future Work

We have seen in this exploratory research that controlled lighting environment can be beneficial in the health care environment, particularly in the execution of ED clinical procedures. These environments can improve clinician wellness and performance, and advance patient safety.

This can have a huge impact in the field of health care ergonomics and particularly in the emergent burden of clinician burnout, a topic that has become a priority to the National Academy of Medicine (NAM) [59].

Future work is to expand the scope of our study to advance patient safety in related clinical situations, such as: clinician cognitive recovery from medical error, hand-offs, and improvement of teamwork conditions. These are known clinical scenarios where prevalence of adverse events has been observed, that might be prevented and precluded through environmental interventions such as controlled lighting. Dynamic lighting, temporal effects, ethics, human variability factors, and the interoperability between lighting systems and human objective psycho-physiological variables will be considered. ■

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Results of the presented work have been published in the doctoral dissertation of Dr. Octavio L. Perez (under publication embargo until December 2018).

Citations:

[I] "To call in the statistician after the experiment is done may be no more than asking him to perform a post-mortem examination: he may be able to say what the experiment died of." Ronald Fisher (1890-1962)

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Hazard or Hope? LEDs and Wildlife

The introduction and widespread uptake of LEDs as outdoor lighting has caused no small amount of concern amongst conservation biologists. The prevailing impression that LEDs are always blue-white is well founded as adoption of LEDs for streetlights were invariably high color temperatures and with the deterioration of phosphors the blue wavelengths penetrated even more. But LEDs do have characteristics that differentiate them from other light sources and may allow for the reduction of environmental effects of lighting on species and habitats: direction, duration, intensity, and spectrum. Travis Longcore, Assistant Professor at the University of Southern California's School of Architecture, sheds light on all these aspects.

Outdoor lighting sources that have been in use for the better part of a century or more are rapidly being phased out in favor of LEDs. The industry has delivered consistent improvements in efficiency extending across a wide spectral range and with control capabilities unimaginable to previous generations of lighting designers. Yet, the introduction and widespread uptake of LEDs as outdoor lighting has caused no small amount of concern amongst conservation biologists. Leading bat researchers wondered if LEDs were "conserving energy at the cost of biodiversity" [1]. Another group investigating insects declared "LED lighting increases the ecological impact of light pollution" [2]. A horizon scan of threats to urban ecosystems listed LEDs and the associated profusion of bright white light [3]. Most of these concerns, however, are based on the experience of the general public that LEDs used in outdoor lighting can only be blue-white - or on studies of instances where the switch to LEDs is in fact to high color temperature whites [4,5].

The prevailing impression that LEDs are always blue-white is well-founded. Early adoption of LEDs for streetlights was invariably high color temperatures as a result of their higher efficiency during that phase of technological development. As these products aged and the phosphors deteriorated, the blue wavelengths penetrated even more. It is no surprise that the public, and wildlife researchers included, perceived high color temperatures to be an inherent attribute of LEDs. This misconception continues today, even though a wider range of spectral configurations of LEDs are competitive and installed across the world.

It seems possible, as well, that LED professionals are unfamiliar with the concerns about the effects of outdoor lighting that motivate conservation biologists to regard LEDs with suspicion. The purpose of this essay is to reconcile these two realms by addressing the question of whether LEDs pose a risk or opportunity to wildlife conservation. LEDs do have characteristics that differentiate them from other light sources. The influence of these characteristics fall into the four major attributes that have been identified as important to reducing environmental effects of lighting on species and habitats: direction, duration, intensity, and spectrum [6].

Figure 1:
A hatchling loggerhead sea turtle crawls toward a high-pressure sodium luminaire on the Florida coast (Photo Credits: Blair Witherington)

Direction
LEDs as currently deployed in street lighting tend to be quite directional, casting most light on the ground and little light at the horizontal or higher. In this regard they can be an improvement over other lamp types that have drop lenses resulting in more light scattering to locations where it is not useful. With the use of microlens arrays, the focus of LED streetlights on the street and adjacent pedestrian zones could be nearly perfect [7]. So long as lights are not pointing downward into a sensitive habitat (e.g., a wetland [8]), the directionality of LED streetlights can be an improvement in terms of wildlife impacts. Bulb-type LED lamps, however, offer no such benefit and their deployment in unshielded fixtures presents the same challenges as previous technologies.

Duration
One of the most effective ways to reduce the unintended adverse effects of lighting is to turn lights off when they are not needed. For most lamp types previously used for municipal outdoor lighting, turning the lamp on and off comes with an energetic penalty or warmup period. In contrast, LEDs can easily be extinguished and illuminated without delay. Consequently, LEDs are suited to the use of controls that use either timing or motion/heat detection to extinguish lights when they are not needed.

Intensity
Intensity of light is easily controlled in LEDs, they are dimmable without difficulty. So from the perspective of reducing lighting levels to the minimum needed for required tasks, they are ideal. Yet, the tendency is for designers and end users to use more light with LEDs because they are so energy efficient [9]. This phenomenon is well-known in environmental economics, known as the “rebound effect” [10]. It seems that users find that it is preferable to use a brighter bulb when the energy savings are great. LEDs represent an era of cheap light and when a product is inexpensive, the tendency is to overconsume. Just as cheap (fast) food has resulted in an obesity epidemic in the United States and elsewhere [11], cheap light has the potential to result in unnecessarily bright nights.

Spectrum
The flexibility of LEDs when it comes to spectrum, contrasts dramatically with the perception that LEDs used for outdoor lighting are intrinsically bluish white. Rather, the rapid development of a range of spectral combinations offers many possible options that could be exploited to reduce impacts on wildlife and the environment.

Insect attraction to LEDs is lower across the board when compared with lamps that emit ultraviolet light. Both “warm” and “cold” LEDs have been compared with metal halide and mercury vapor lamps and found to attract less than a tenth of the number of insects, a finding that is attributable to the difference in ultraviolet emissions [12]. Conversely, most broad spectrum LEDs used in outdoor lighting do have a potential to adversely impact the perception of daylength (and thus seasonality)

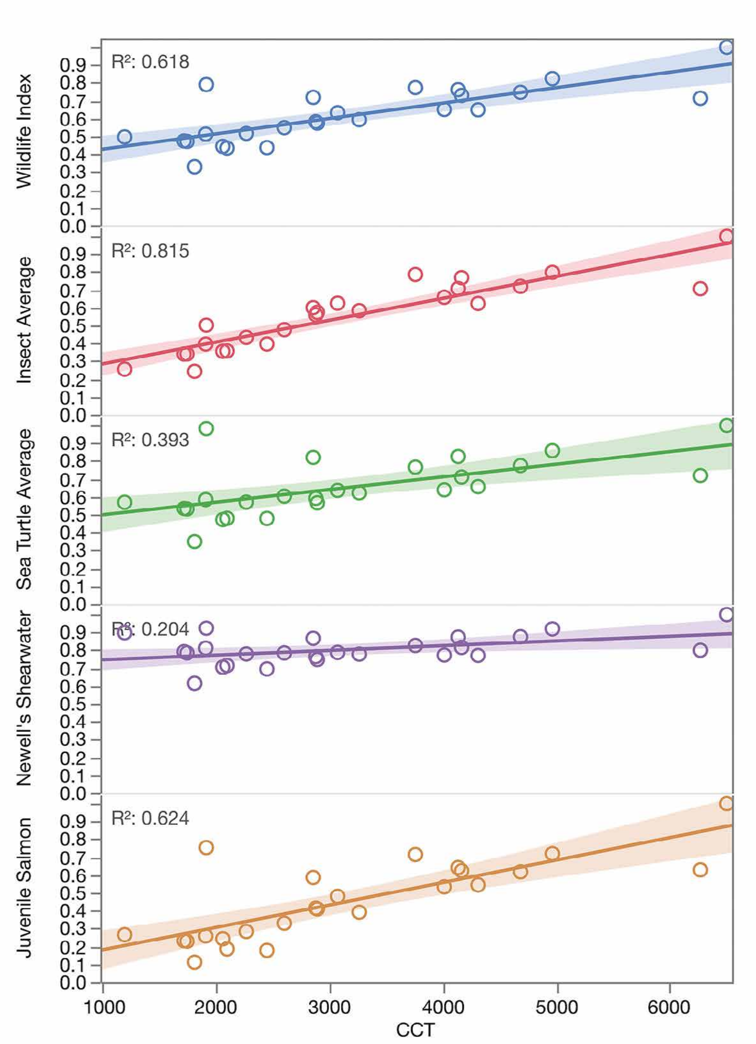


Figure 2: Relationship of modeled effect of lamps on different wildlife species or groups (juvenile salmon, Newell's shearwater, sea turtles, insects, and their average) with Correlated Color Temperature (CCT) of the lamps. Data from [14]

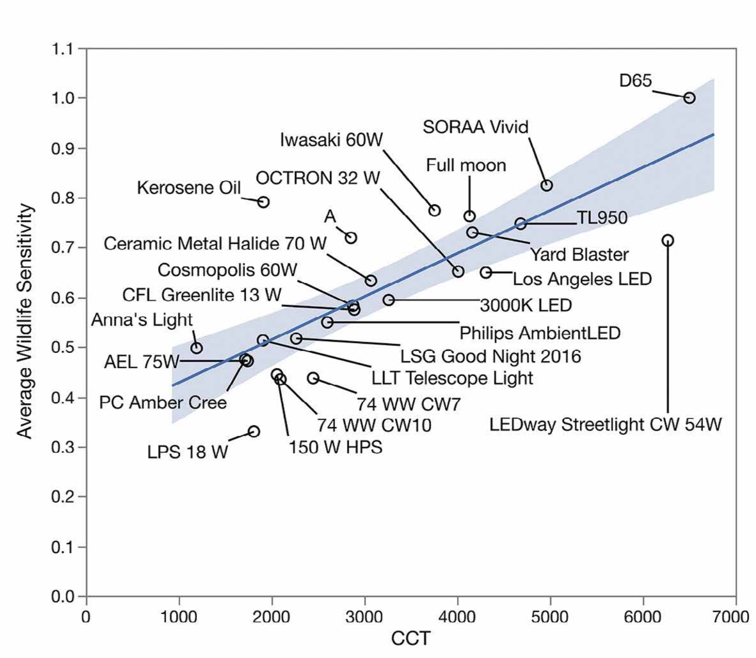


Figure 3: Relationship of correlated color temperature to average wildlife sensitivity with lamps and illuminants labelled. Data from [14]

in plants, because the peak sensitivity of the phytochromes that detect daylength are in range of LED peak emissions for most full-spectrum LEDs.

Beyond these two examples, the combination of tunable LEDs, filters combined with LEDs, and colored LEDs such as PC Amber offer unique opportunities. Spectrum can be controlled by combining different colored diodes in many configurations (red, blue, green, and perhaps also white, amber with white). The number of combinations far outstrips previous technologies, where the spectral output of high pressure sodium, low pressure sodium, metal halide, xenon, fluorescent, and incandescent lamps were well-known and inflexible.

Choosing Spectrum to Reduce Wildlife Disruption

To take advantage of the range of possibilities from LEDs, the quantal flux at different wavelengths can be compared with the behavioral responses of wildlife across those wavelengths. A generalized response curve for all insects was just published [13] and curves exist for other species [14]. The intersection of the response curves with the spectral power distribution of the lamps (converted to photons) can be compared with the same calculations for an equal lux of a standard illuminant to provide a comparison of the effects of different light sources [14]. Response curves for insects (averaging three curves in the literature), sea turtle (averaging three curves in the literature), juvenile salmon, and a visual response curve for the endangered seabird Newell's Shearwater were used to construct a composite metric of wildlife impacts and compared with a range of lamp types and standard illuminants. Plotting the results relative to Correlated Color Temperature (CCT) reveals two characteristics of the impacts of lights (Figure 2). First, on average and for each species or group, lower CCTs had lower predicted effects. Second, the slope of the relationship between CCT and wildlife influence was greater for some groups than others, indicating that spectrum could be a more effective tool to reduce impacts on insects and juvenile salmon than on Newell's Shearwater.

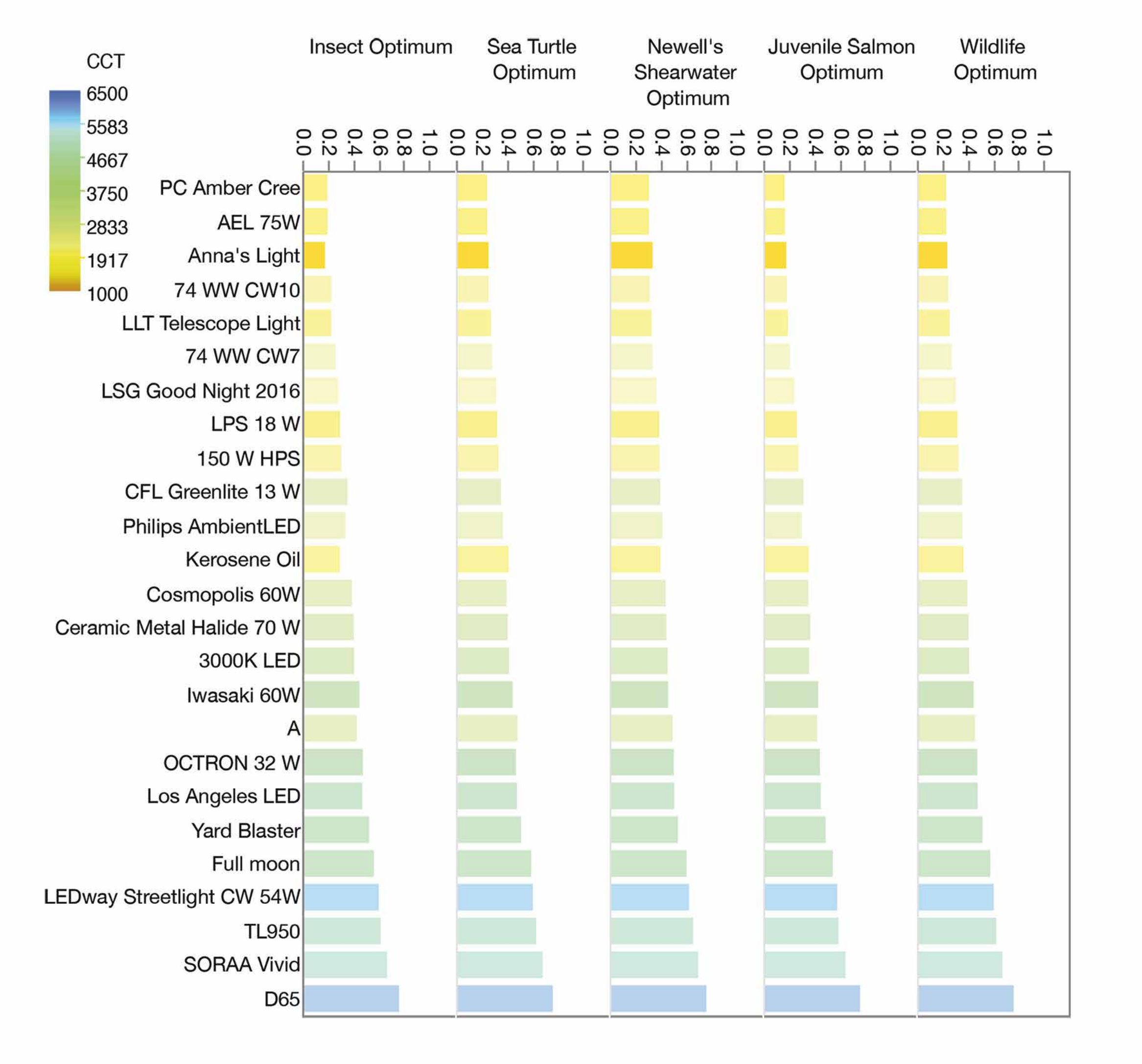


Figure 4: Ranking of lighting sources that equally weighs wildlife response, melanopic response, astronomical light pollution (Star Light Index [15]), and Color Rendering Index. Reprinted from [14]. Shorter bars represent a combination of lower wildlife responses and higher CRI

CCT is not a perfect predictor of effects on wildlife, but it is a reasonable rule of thumb that lower CCT will be less disruptive to wildlife (and we already know that it will be less disruptive for circadian rhythms and astronomical observation [15]). The lamps with the lowest projected influence on wildlife overall were low-pressure sodium (which is being phased out), high-pressure sodium, PC amber LEDs, and filtered LEDs (Figure 3).

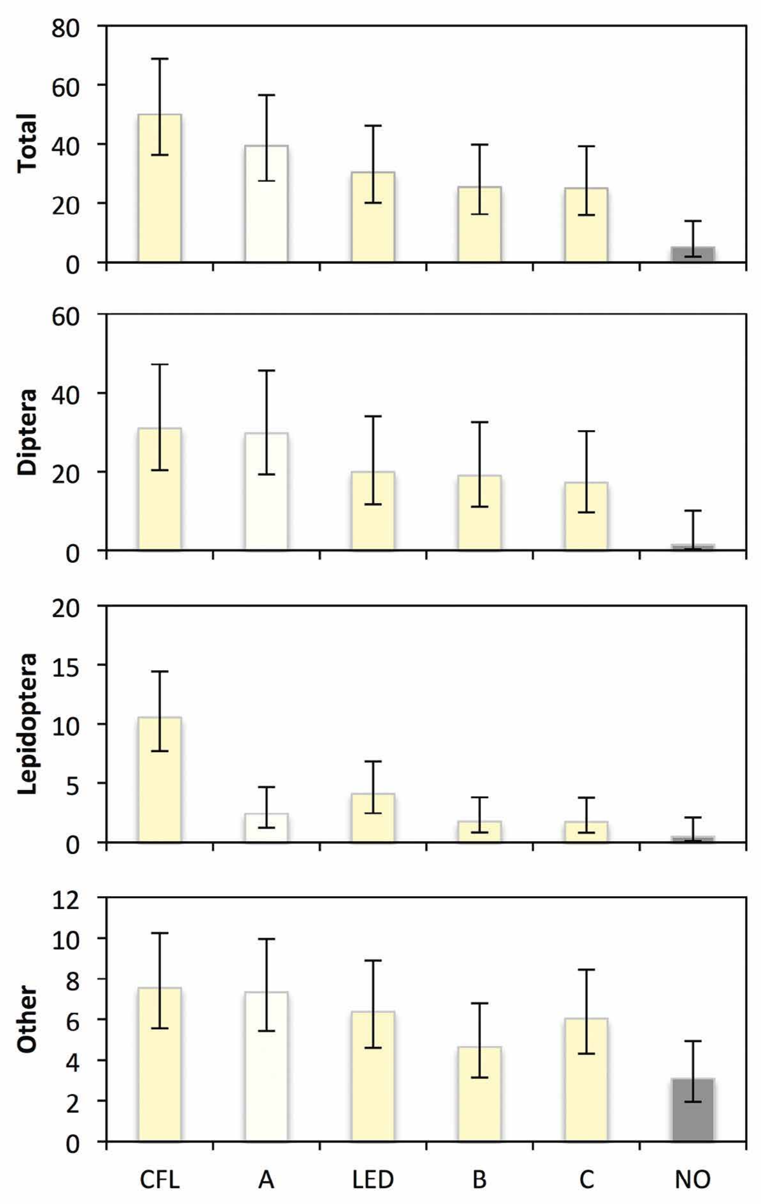
Figure 3: Thus far, the results represent the predicted effects of the lamps on wildlife. To account for preferences in outdoor lighting, another ranking was created that incorporated a penalty for low color rendering index (CRI). Any lamp with a CRI over 75 was assumed to have adequate color rendering, while those with lower CRI were penalized in the overall index. The resulting ranking of lamps is notable in that low pressure sodium ranks lower because of its extremely low CRI, while PC Amber and filtered LEDs rank the highest, balancing both lower wildlife impacts with reasonable if not high CRIs (Figure 4).

As a rule of thumb, CCT can be used as an indicator of wildlife effects, but this may not hold true across all applications. Migrating birds cannot orient under red light and therefore solid red lights are to be avoided on communication towers [16]. Green light has support for minimizing attraction of nocturnal migrant birds [17]. Other special cases exist and would require consultation with experts on a particular taxonomic group or species at risk.

Tuning Within the Same CCT

An additional useful feature of LED lamps is that they can be configured to produce the same CCT with different spectral outputs. To demonstrate this approach to minimize insect attraction, the spectral response curves for bees and moths were used to choose between configurations of two 2700 K LEDs (produced with a prototype tunable lamp with RGB diodes) and one 3000 K LED in a manner predicted to reduce insect attraction. The custom configurations were then compared in a field study with an off-the-shelf 2700 K LED and 2700 K fluorescent lamp [18].

The results of this field experiment showed that a tunable LED attracted 20-21% fewer insects than a similar LED not designed with minimizing



Figures 5: Comparison of attraction of insects, and subsets of flies (Diptera), moths (Lepidoptera), and other insects to 2700 K compact fluorescent (CFL), custom 3000 K LED (A), off-the-shelf 2700K LED, two custom 2700 K LEDs (B and C), and a control (NO). Average catch per night with 95% confidence intervals (see [18] for details)

insect attraction as an objective (Figure 5). This effect was large for moths, similar to the findings when comparing different CCT lamps. These results are especially important for the choice of indoor lighting in the tropics, where glass and screens on windows is not common. Using indoor light that provides adequate color rendering for work while reducing insect attraction would reduce the probability of exposure to phototactic insect vectors of disease [18]. LEDs offer this possibility because of the spectral flexibility in their design.

Certainly, conservation scientists have more work to do on spectral responses. The number of species response curves available needs to be increased, which requires experts across taxonomic groups to engage the topic. The relationship between light intensity and spectral responses is largely unknown and needs research across nearly all wildlife groups. Even the perception of light by different groups of wildlife species is not fully described and taxonomic-specific metrics of both radiance and irradiance are needed. Nevertheless, a “no regrets” approach can be taken to guide the choice of spectrum that LEDs make possible, which is to reduce blue content. With amber and filtered products on the market, low color temperatures ≤2200 K are feasible and desirable to minimize adverse impacts.

Conclusions

The efficiency benefits of LEDs and the resulting economic incentives will drive further conversion of outdoor and indoor lighting to the technology. If the tendency to light more when light is cheaper can be overcome, the other attributes of LEDs hold significant promise for reducing environmental effects. Realizing that promise requires designers and manufacturers to learn about and embrace the guidance that wildlife scientists can provide. In some instances it will be challenging - resisting the desire to up-light, using no more light than necessary, and educating clients on the benefits of spectral choices that do not look like daylight. In other contexts, environmental regulations are likely to dictate lighting choices and offer an opportunity if the industry is prepared to seize it. On each of the mitigation approaches - duration, direction, intensity, and spectrum - LEDs will inherently or can be designed to perform well. Whether they do in practice will be up to the LED professional.

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When Nights Are No Longer Dark: Effects of Artificial Light at Night on Agroecosystems

In recent decades, artificial lighting has become an integral part of the modern world. While the use of artificial light at night (ALAN) greatly benefits people, it often has unintended, negative consequences for wildlife and ecosystems. In particular, the increasing use of LED lighting raises ecological concerns due to its high content of blue light, to which many organisms are sensitive. Dr. Maja Grubisic, Researcher at the Leibniz-Institute and Guest Lecturer at Free University Berlin discusses how ALAN can directly and indirectly influence agroecosystems, with potential consequences for food production and biodiversity. Given the current lack of integrative studies on this important topic, the better understanding of effects of ALAN in agroecosystems is urgently needed.

Darkness has been an integrative part of natural history of our planet for billions of years. Until recently, it has also been an integrative part of our daily lives. Now, we are one flip of a switch away from replacing darkness of the night with bright light that brings comfort and familiarity to billions of people around the globe.

Artificial lighting greatly benefits humanity; for a typical day-active species such as humans, it allows us to prolong our activities into the night and increases our feeling of safety. With the growth of the human population, increasing urbanization, access to electricity and to affordable lights, use of artificial light at night has exponentially increased in the last decades. This has transformed the nighttime environment relatively quickly, shaping the modern, urban lifestyle, but also leading to light pollution that obscures the view of the night sky and raises concerns about negative effects of night lights on our health and environment.

Figure 1:
Not only mega-cities cause sky-glow at night and undesired light pollution with negative impact on ecosystems and wildlife

Introduction: On Darkness, Light and Artificial Light at Night

Light pollution is caused by inadequate or excessive use of artificial lights, such as street and road lights, residential lights, decorative and security lights, lights from vehicles, boats, off-shore platforms etc. It disrupts natural light/dark cycles, and increases nocturnal illumination above natural levels in many regions of the world. In nature, where environment changes all the time, light/dark cycles are among most stable and predictable environmental changes.
Hence, almost all life on Earth, including humans, evolved to use light as a cue to anticipate environmental changes and adapt their activities and biological rhythms to daily, monthly, seasonal and annual cycles of ambient light. Disruption of these cycles by artificial light at night can impact living beings from microorganisms to humans, in complex ways that we still don't understand. In addition, many species evolved to be night-active, timing their activities to exploit benefits of darkness. An impressive 30% of vertebrates and 60% of invertebrates, including half of almost 900,000 currently described species of insects, are night-active [1]. Nocturnal animals are adapted to dark and dimly-lit environments; they are able to navigate under faint light of stars and the moon which can easily be outshined by artificial lights or masked by urban skyglow. Due to their exceptional sensitivity to light, nocturnal animals may be particularly sensitive and negatively affected by artificial light at night. We are all familiar with attraction of insects to outdoor lights - but many more subtle impacts on movements and activities of nocturnal insects, e.g. feeding, reproduction and communication, remain hidden from our eyes.

The nighttime environment is a precious resource for most living beings on our planet; but erosion of darkness by the use of artificial lights is one of most rapidly increasing types of environmental degradation. In the second half of the 20th century artificial illumination quickly became widespread, increasing globally by 6% per year (0-20% depending on the region) [2]. Urban centers became flooded with light that reflects and scatters in the sky, extending hundreds of kilometers from its source as low-intensity skyglow. Today, as almost a quarter of the world's land experience unnaturally bright skies due to artificial lights, and this includes 88% of Europe and almost half of the US, artificial light at night is recognized as a component of global change and a biodiversity threat [3] (Figure 2). And the world keeps getting brighter: although the spread of lighting into new areas has slowed down to 2.2% over the last 5 years, the total radiance keeps increasing globally by 1.8% per year [4]. This increase in radiance coincides with the "lighting revolution", the transition to solid-state technology which aims to reduce costs and energy consumption of artificial lighting; however low costs of LEDs seem to, instead, result in greater light use - a so-called rebound effect, which was historically observed to occur in response to increased luminous efficacy [4].

Evidence is accumulating that low-level artificial light at night, as present in urban and sub-urban areas, affects a range of organisms, processes and ecosystems in their surroundings; from microorganisms, plants and animals to humans; from the flowering of plants and migrations of fish and birds to the feeding of bats and moths; from sub-alpine streams and alpine meadows to grasslands and agroecosystems. Direct effects on individual organisms are studied most, while the effects of indirect skyglow on the ecosystems are still largely unknown.

Figure 2: View of Europe at night, composite image from Suomi NPP satellite data from 2012. Resolution approx. 750m per pixel (Credits: NASA)

Figure 3:
Illuminated road and visible skyglow in a suburban area in the US (Photo Credits: Mark Tuzman/Unsplash)

Importance of Insects for Food Production and Agriculture

Humanity depends on ecological services from natural and managed ecosystems; countless organisms are involved in these complex interactions. Managed ecosystems - agroecosystems - are immensely important for the production of food, timber and fibers, which largely depend on natural processes and wild organisms. For example, around one third of our food, including animal products, relies on crops pollinated by animals. As much as 85% of crops cultivated in Europe rely on animal pollinators for producing seeds and fruits. Not only crops, but most flowering plants - over 90% of around 250,000 species - are pollinated by animals [5].
Animal pollinators thereby sustain much of biodiversity on Earth and help maintain the integrity of most terrestrial ecosystems. Despite the common opinion that bees are the most important pollinators, food production benefits from a variety of pollinators which includes both flying and ground-dwelling arthropods such as moths, butterflies, wild bees, flies, wasps, beetles and ants, but also bats and birds. Agroecosystems therefore greatly benefit from biodiversity - a rich diversity of biological resources, species and natural habitats.

Biodiversity is therefore fundamental to agricultural production and food security. As most diverse and successful organisms on the planet, insects are largely involved and contribute to these processes. Apart from pollination, insects help maintain soil fertility and structure, enhance nutrient cycling and dung burial. They also act as natural enemies of agricultural pests, or as pest species themselves.

Agricultural areas cover 11% of the Earth's land. Spanning across large areas, they are often illuminated by artificial lights from sub-urban areas, road networks and lights from vehicles (Figure 3). Effects of such exposure on agroecosystems have not been systematically studied, however a growing amount of research indicates that streetlights can, directly and indirectly, significantly impact different levels and processes in agroecosystems - most importantly crops, their pests and natural enemies, and pollinators - ultimately affecting food production and biodiversity [6]. These impacts are often species-specific and depend on the spectral composition of the light source.

Effects of Artificial Light at Night on Insects in Agroecosystems

Both flying and ground-dwelling insects provide important ecosystem services to agriculture and can be directly and indirectly affected by artificial light at night.

Aphids, commonly known as greenflies or blackflies, are among important pests of agricultural crops. They are often used in ecological studies as a model species for studying plant-insect interactions and trophic cascades. Experiments showed that artificial light at night can have bottom-up effects on aphids, mediated by plants these insects depend on for food, but also top-down effects mediated by their predators (e.g. ladybugs or slugs) or parasites. For example, exposure to artificial

Figure 4:
Experimental field to study effects of artificial light at night in a rural setting in Westhavelland (Brandenburg), Germany

light at night can reduce food availability and enhance predation control by ladybeetle, a known visual predator, reducing the numbers of aphids and their parasites over multiple generations [7]. Furthermore, streetlamps can change the composition of insect and invertebrate communities roaming beneath them: light-sensitive species can retreat to the dark areas, while visual predators become abundant and increase their activities at night, or extend their activities into the day. Day-active predators may also extend their feeding times into the night [8, 9]. Spiders stay close to the lamps and benefit from insects attracted to the lights that end up caught in their webs; while invertebrate pests such as slugs increase in abundance, attracted to artificial lights. By directly affecting their behavior and changing complex interaction networks between the species, artificial light at night can alter abundance of pests and their natural enemies present in the agroecosystems, as well as predatory control between them. These impacts may have complex consequences for agricultural production, and deserve more attention in future research.

Among nocturnal insects, impacts of artificial lighting have been most studied on moths, and several different effects have been documented. As with many other insects, many species of moths are attracted to streetlights at night. Species that are not attracted become inactive under nocturnal illumination; they feed and reproduce substantially less than moths in naturally dark areas [10,11]. Moths are important night-active pollinators, but attraction to lights drives them away from the field margins and reduces interactions with the plants they pollinate. Disruption of nocturnal pollen transport and a reduced number of flower visits by moths carrying pollen was confirmed to reduce fruit development in plants [12]. Interestingly, reduced plant reproduction was evident despite the same plants receiving the same number of pollinator visits by other insects during the day. This indicates that both day- and night-active pollinators play complementary roles in plant reproduction and that disruption of nocturnal pollination may propagate to diurnal pollinators through plant-mediated interactions. That artificial light at night can disturb pollination, such an important ecosystem service, can have important consequences for biodiversity, but implications for food production remain to be determined.

Pollinators, moths and insect populations have been declining over several decades at alarming rates. The main causes of such concerning biodiversity loss are considered to be agricultural intensification leading to habitat loss and fragmentation for many species, use of pesticides and climate change; however light pollution could be an important contributor to these negative trends. In the Netherlands, moth species that show the strongest declines in numbers over time were shown to be the same species that are attracted to artificial lights at night [13]. In Germany, areas where dramatic declines in insects were recently observed are also among

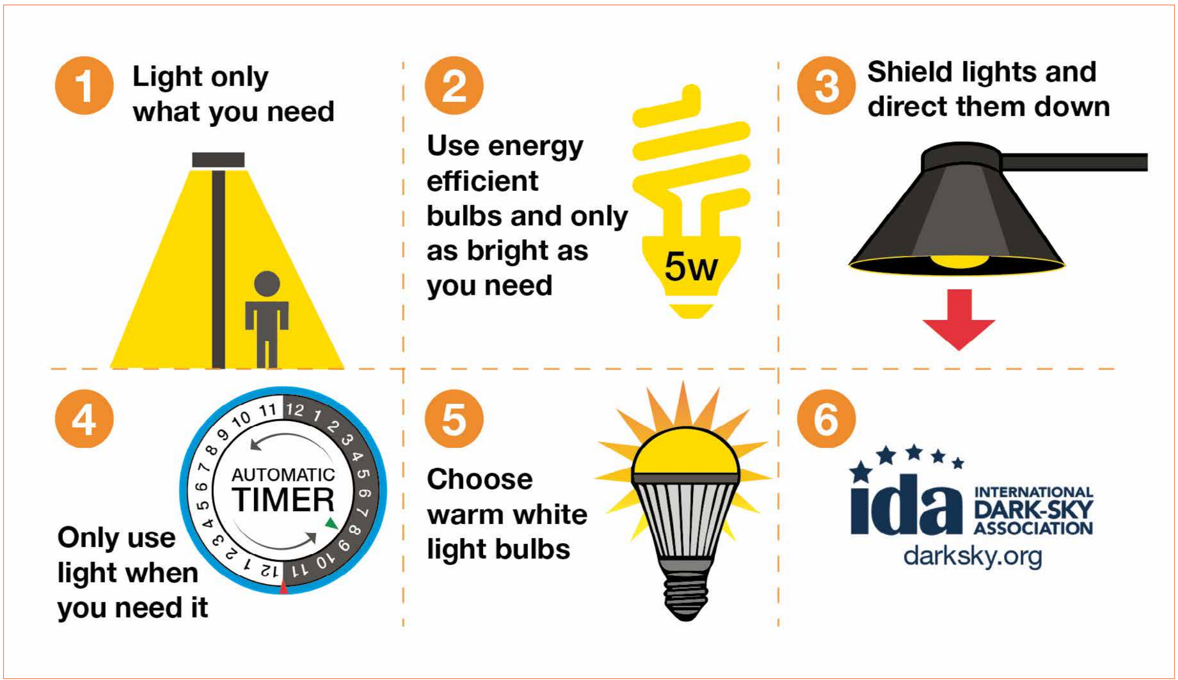

Figure 5: Lighting recommendations for minimizing light pollution by International Dark Sky Association IDA (darksky.org)

the most light-polluted areas in the country [6]. Given the many negative effects artificial light at night has on insects, light pollution has to be considered as a large-scale factor and a potential contributor to insect declines. This is particularly important in agroecosystems, where insects are of key importance to biodiversity and food production, and are already under substantial environmental pressure. We may need to develop nocturnal management strategies in agricultural practices to mitigate the negative effects of artificial light on insects and help conserve insect fauna in our landscapes. Recognizing the value of darkness for nature and people and actively preserving dark places, e.g. through establishing dark sky parks and reserves [14] not only provides refuges for nocturnal animals, but also rare and precious places for stargazing and appreciation of the unspoiled night sky, our common and universal heritage.

Effects of Artificial Light at Night on Crops

Plants also rely on seasonal light/dark cycles to determine the length of their growth season, and time phenological phases during their life history, such as leaf occurrence in spring, flowering, leaf senescence and leaf loss towards winter. In road-side agricultural fields, proximity to streetlights was found to enhance growth while delaying flowering, reproduction and ultimately yield of crops such as soybean and maize [15]. Grasses grow differently when exposed to artificial light at night, they were found to grow less and also form less leaves. Urban trees close to the streetlights extend their vegetation season compared to those in darker areas: they open leaves earlier in spring, change timing of flowering, and delay and prolong leaf loss [16,17]. These subtle shifts in timing of life events can have major implications for health and survival of plants - for example, earlier leaf opening may increase the risk of damage by frost, while delayed flowering may cause a mismatch with the occurrence of key pollinators necessary for the plant's reproduction. In this way, artificial light at night may directly influence crop production in illuminated agroecosystems.

Reducing Light Pollution - Reducing Light Waste

The first step towards reducing light pollution is recognizing that light can be a pollutant. Effects of light pollution are hard to be eliminated without avoiding use of artificial light at night overall, but they can be minimized by responsible and adequate use of lighting. Any measure that reduces light waste will reduce light pollution and its effects on the environment. These include using light when it's needed, in the amount that is needed for its purpose, directing it where it is needed and using warm colors to avoid harmful short wavelengths in nocturnal illumination (Figure 5).

According to the latest estimates, artificial lighting consumes still around 20% of global electricity [2]. Streetlights are the biggest single source of light pollution, but often up to 35% of emitted light is wasted due to poor lamp design. Transition to solid-state technology is expected to reduce costs and increase the energy efficiency of artificial lighting, and in many regions of the world, LEDs are replacing traditional streetlights. However, the spectrum of commonly used white LEDs in this application is substantially different from those of traditional lamps, typically with significant amounts of short (blue) light that is known to disrupt biological rhythms in many organisms, including humans. Therefore, a shift to LEDs is expected to increase ecological impacts of light pollution.

Additionally, a rebound effect can outweigh energy savings on global and national scales.

Tuning the spectral composition of LEDs to avoid harmful short wavelengths or choosing warm colors are promising approaches to reduce adverse ecological effects of nocturnal LED lighting. Shielded and full cut-off lamps would minimize light trespass, glare and skyglow. Dynamic and adaptive solutions, such as dimmers, timers and motion sensors would further cut energy costs, reduce nocturnal illumination levels and minimize unnecessary illumination in rural and suburban areas. ■

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User Evaluation of the OpenAIS Pilot Installation

The OpenAIS project (2015-2018) has developed an open IoT lighting solution to enable a wider community to deliver the smartness of light, allowing easy adaptability to cater for the diversity of people and demands. The project is a cooperation between seven leading companies in the European industry and two academic partners: Signify, Zumtobel, Tridonic, Johnson Controls, Dynniq Belgium, NXP, ARM, Eindhoven University of Technology. Thomas van de Werff, Harm van Essen and Berry Eggen from the Eindhoven University of Technology describe the evaluation results of the pilot installation in a real office building in Eindhoven (The Netherlands), a former Philips factory.

The Internet of Things is rapidly entering the lighting domain. An Internet of Lighting is expected to have significant benefits for its users, such as advanced automated lighting and personal lighting control.

The OpenAIS project developed an IP-based lighting architecture and realized a large-scale pilot implementation of an IoT lighting system with advanced sensor-driven controls and user control in a real-life office. Two user control apps were developed and deployed in the open office, individual offices, and meeting rooms: a smartphone application for personal lighting control and an app for dedicated room control tablets. This article reports on an extensive study that evaluated peoples' use and experiences with the lighting system.

The results show that people appreciate personal lighting control and that they adjusted the lighting regularly using both the phone application and the control tablets. Furthermore, lighting control was experienced differently in different workplaces. In general, the level of lighting appraisal increased when more control was available. We argue that the flexibility will be a key success-factor for improving the lighting experience, that human-in-the-loop control strategies need balanced automated system behavior and user control, and interfaces should support shared lighting control by including the social context.

Introduction

Following the trends of rapid penetration of Solid-State Lighting (SSL) and the Internet of Things (IoT), lighting in buildings is becoming connected, creating an Internet of Lighting (IoL). This transformation opens up new opportunities and value propositions for the broad group of stakeholders in the lighting value chain. Moreover, office buildings are transforming into open-plan office floors with flex-working policy, increasing office workers' need for personalization of the workplace. With the office lighting domain transitioning from an industrial to a knowledge paradigm, it becomes essential to take the human experience as a focal point: value for users, customers, and all stakeholders involved. A major opportunity of IoL is the data it can generate. Performance data can inform manufacturers and facility managers, and energy data can inform building owners of their carbon footprint, to name a few. Moreover, the flexibility of IoL allows building owners to reduce their CapEx by installing basic lighting systems and update them based on the building users' needs throughout the lifecycle of the system. For office workers, IoL can allow for personal lighting control at their workplace. Personal lighting control is known to decrease energy consumption, increase the level of work comfort, appraisal of the work environment, and job satisfaction.

This article presents the results of an extensive user evaluation of personal lighting control of a state-of-the-art IoT lighting system, as part of the final evaluation of the project. A large-scale pilot was realized in a real-life office in Eindhoven, the Netherlands. Two user applications were developed and deployed: A lighting control phone app allowed people to scan a QR code and control the lighting at their workplace, and tablets dedicated to room control presented people with lighting scenes and dimming controls for the meeting rooms.

Pilot Installation

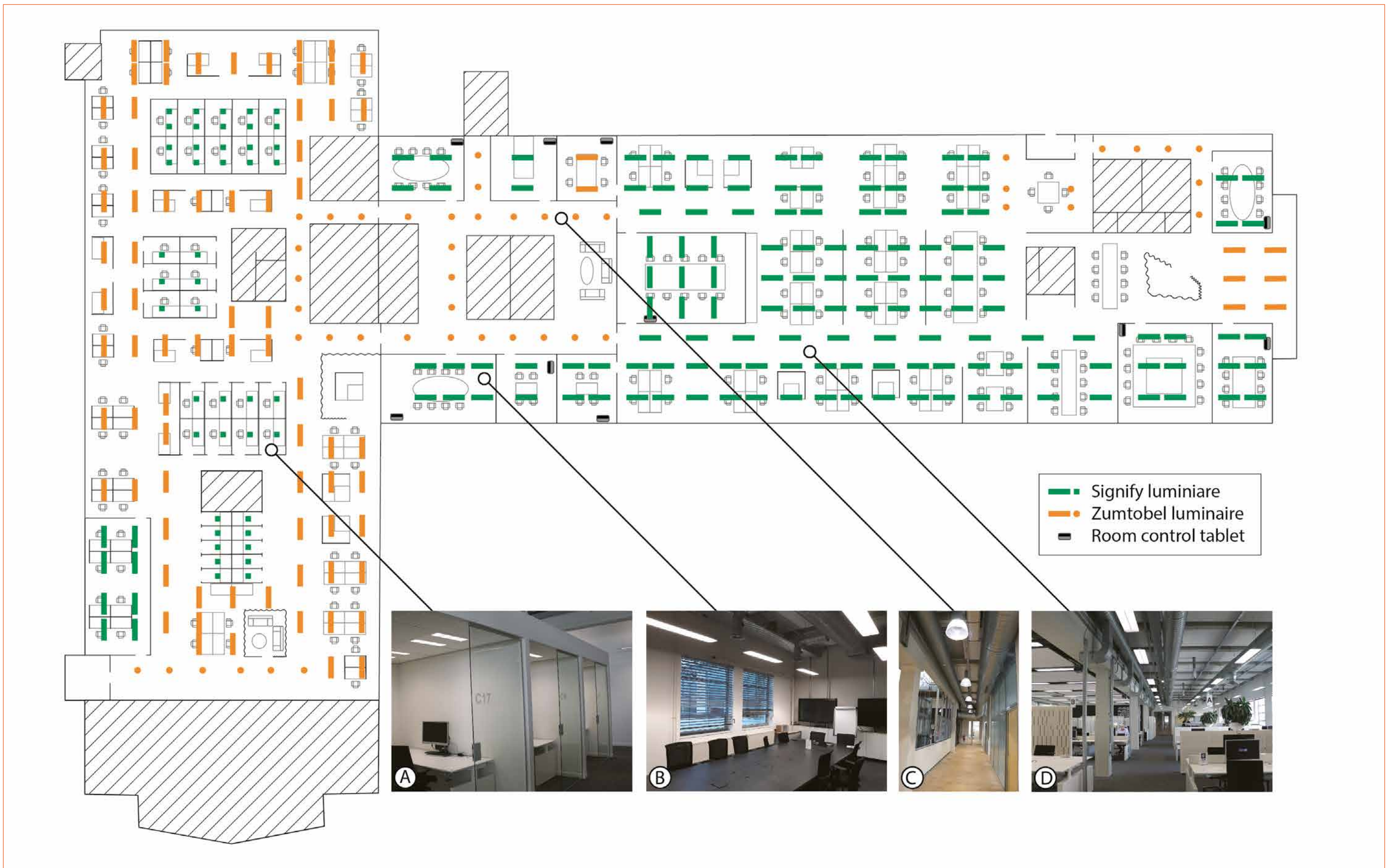
The solution was validated with a full-scale office lighting system in a real office in Eindhoven, the Netherlands. Figure 1 shows a map of the office floor. The modern office is primarily open-plan with flexible workplaces. Next to 120 desks in the open space, the workplace offers a variety of workplaces: several open meeting cubicles in the open office, 24 individual offices, and ten meeting rooms. Initially, before the pilot, the office was equipped with a tube-lighting system providing 350 lx on desk level with 2700 K. People used regular lighting switches to turn on and off groups of around 20 luminaires. In total, 302 people work on the office floor (average age of 47 years, 10% male), but occupancy varies per day.

The implementation

The installation comprised 400+ luminaires with presence sensing, daylight regulation, and user control. The suspended tube-lighting was replaced using the original lighting grid. The open office area and meeting rooms were equipped with Zumtobel and Signify suspended luminaires (Figure 1B & D), and the individual offices were equipped with recessed luminaires by Signify (Figure 1A). The corridors were equipped with Zumtobel pendant luminaires (Figure 1C).

The new lighting system provided 500 lx on desk level with 4000 K, and was commissioned in two phases. First, after basic commissioning, luminaire groups of 2 to 4 luminaires were controlled through presence-sensing with an on-state (500 lx), background-state (350 lx), and an off-state with delay times of 15 minutes. Corridor areas used presence-based controls with “corridor holding” logic. Luminaire groups were configured according to the light plan during the commissioning phase of the installation. Second, after advanced commissioning, the apps made personal lighting control available in the open office, individual offices, and meeting rooms. Luminaires close to the windows applied daylight regulation. When someone made a lighting adjustment with a user app, the automatic control (presence & daylight regulation) was disabled for that area until the sensors in that area detected an absence. Only then, automatic control would take over using the defined delay times.

Figure 1:
Floorplan of the office and photos of the different workplaces: (A) individual office; (B) meeting room; (C) corridor; (D) open office



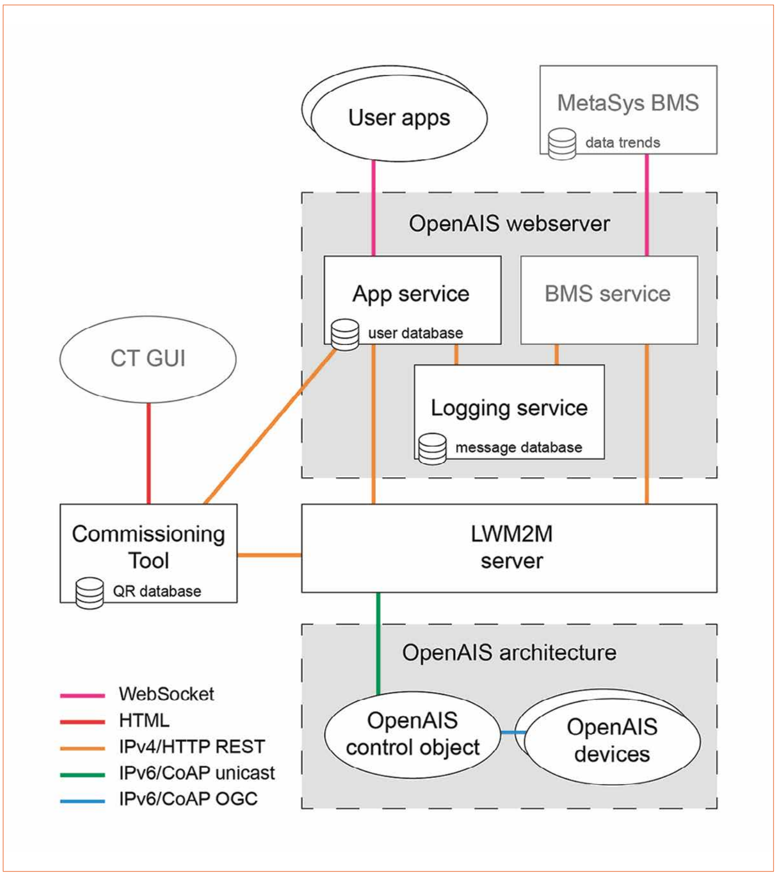


Figure 2:
System overview of the OpenAIS pilot installation components and connections

Figure 2 shows a schematic overview of the implementation at the pilot location. A separate IPv6 network was set-up for the lighting system, next to the regular IPv4 network that was already in place. To maximize the availability of user apps to the office workers, the OpenAIS Webserver was accessible from the regular network, allowing the user apps to connect with the OpenAIS system using the existing corporate and public Wi-Fi SSID

- Architecture - The architecture uses LWM2M as its basis and entirely relies on standard internet technology with IPv6-based communication, UDP as its transport layer, and the CoAP protocol. The Group Communication protocol (OGC) was developed to allow for high speed, low-latency, secure and reliable communication between large sets of devices. More details can be found in the reference architecture report [5]
- LWM2M server - The LWM2M server receives RESTful requests from the webserver and translates these to CoAP messages that are directly usable by the control objects
- Webserver - A webserver allowed third-party applications to interface with the OpenAIS pilot solution using a predefined user control API. Its primary function was to translate incoming lighting adjustment messages from user apps to RESTful requests for the LWM2M server. Next to this, the webserver managed user authentication. The webserver stored all messages from and to user apps in the message database for research purposes
- Commissioning Tool - To allow users to control the lighting system, stickers with QR codes on all the desks in the open office and the individual offices (Figure 3) linked to the ID of the control objects and devices on that location in the QR database. The webserver relayed a QR-code message form a user app to the commissioning tool, which returned object ID in JSON format.

User apps

The Eindhoven University of Technology developed two types of user apps to control the light in the open offices, individual offices and meeting rooms. The apps were compatible with any luminaire in the area, no matter the type or vendor.

The phone app was available in the Google Play store and the Apple Appstore for people to install it on their smartphone (Figure 3 left). After opening the app and scanning a QR-code on the desk, the app showed a control screen with sliders to adjust the intensity of the luminaire(s) on the location between 0% and 100% of the light intensity. The number of sliders shown in the control screen depended on the number of luminaires present at the user's location. In general, the first slider could be used to change the intensity of the complete luminaire group at once, while the second slider allowed for controlling the luminaire closest to the user's desk. In case there was only a single luminaire (in most individual offices) the app showed only one slider. The webserver kept all apps in sync, so after a lighting adjustment, all apps logged in to the same location received an update from the webserver and updated their control page to reflect the current lighting conditions.

The ten meeting rooms in the office were equipped with tablets for room control (Figure 3 right). The control screen shows several buttons that allow for applying predefined scenes, customized to the meeting room (e.g., on, discussion, presentation). A slider allows for dimming the scene. A QR-code on the bottom of the screen allows people to control the luminaires in the room individually using the phone app.

User Evaluation

The goal of the study was to gain insights into people's experiences with the lighting systems and to gather rich scenarios of using the provided user apps. Therefore, we applied a qualitative approach to the data collection by conducting semi-structured interviews with open questions to encourage

Figure 3:
User apps: (left) the phone app, and (right) the room control tablet in a meeting room

people to provide rich feedback in the form of empirical data. An accompanying questionnaire structured to the interview. This questionnaire allowed participants to rate and note their appraisal of the lighting system (between 1 and 10), and included statements like "I feel in control of the lighting at my workplace" and "When I adjust the lighting, I feel limited by the presence of others" that participants scored using Likert scales. The study method is described in more detail in a separate article [1].

Firstly, before the installation, surveys were distributed in the office, allowing people to score the original tube-lighting system with light switches on several aspects and to rate the system between 1 and 10. A total of 19 completed surveys were completed before the installation took place. Secondly, the office workers evaluated the basic commissioned solution through interviews and questionnaires eight weeks after the installation. Finally, they assessed the advanced commissioned system after five weeks of use through interviews and questionnaires. 26 participants voluntarily signed up for the study (average age of 47 years, 19 female & 7 male), resulting in 25 interviews about the basic system, and 23 interviews about the advanced system. The group included 4 iPhone users, 22 Android users, and 1 Windows phone user. Participants spent 1-5 days of the week in the office, had a variety of job types, e.g., doctor, secretary, manager, and project-assistant, and did not have a fixed workplace. During the study, participants worked on their day-to-day jobs. Meanwhile, the webserver logged all user interactions with the phone apps and the room controls. As people filled in the first surveys anonymously, we cannot say whether they are the same people as the participants of the further evaluation of the system.

Results

The results of the study are presented as follows: First, we discuss how people experienced the system in its basic commissioning state. Next, we present quantitative results that display the lighting appraisal for the three data inquiries, and the logged data from the phone apps and room control tablets. The section concludes with insights from the qualitative data about how people experienced the two different user apps in the different types of workplaces.

Basic configuration of the system

It took some time getting used to the change in lighting intensity and color temperature of the new luminaires during the installation of the system. Nevertheless, this was a temporary issue, as people were very positive about the lighting during the final interview as it felt more "professional", "productive", and "activating". Overall the automatic control with presence sensors was preferred to controlling the lighting with the switches. Almost every participant expressed a wish for controlling the light intensity on their desk, and many expressed a need for tunable color especially in less formal areas. Unlit areas in the offices were only noticed by those who first arrived early in the morning or left the office last. Participants were positive about the energy-saving approach. Moreover, the automatic off-switching even helped some people to estimate whether a meeting room was vacant.

Lighting appraisal

Figure 4 shows the lighting appraisal scores from the questionnaires for the original lighting system and the two states of the OpenAIS system. In general, the appraisal for the lighting system increased after the

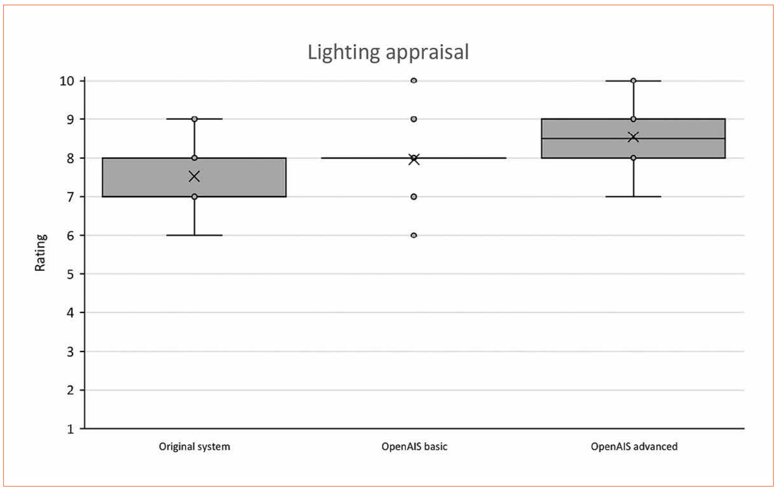


Figure 4:
Lighting appraisal scores for the old lighting system and the two OpenAIS solutions. The rating scale ranges from 1 to 10

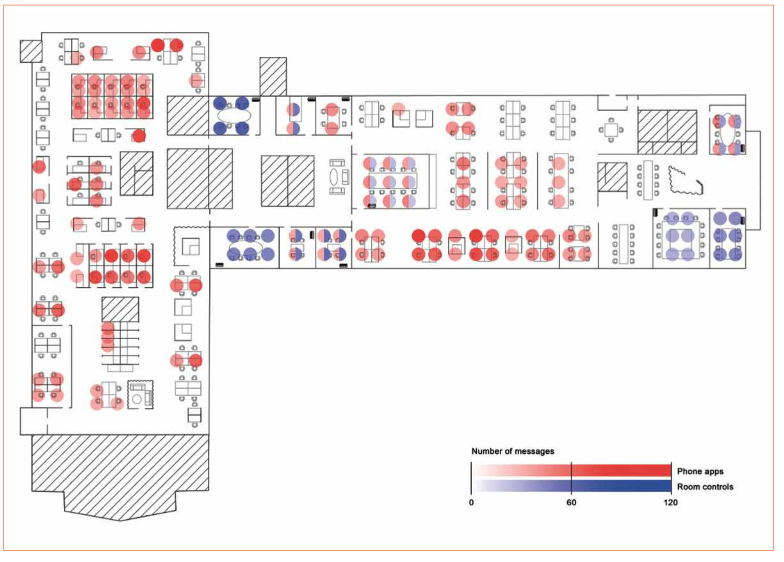


Figure 5:
Heat map of user interactions with the OpenAIS system with the phone apps (red) and the room controls (blue) over a 3-month period

Table 1:
Number of lighting adjustments by phone apps and room controls in the open office, meeting rooms and individual offices

	Phone Apps	Room Controls	Total
Open Office	1579 - (49 people)	-	1579
Meeting Room	307 - (16 people)	1225	1532
Individual Office	826 - (43 people)	-	826
Total	2712 - (93 people)	1225	3937

new lighting system was installed, and again after people interacted with the user apps. While only lighting appraisal showed statistically significant improvements in comfort, the qualitative analysis showed a high appreciation for personal lighting control.

User app usage

People made a total of 3937 lighting adjustments over the 3-month period: 93 people made 2712 lighting adjustments with the phone apps and 1225 lighting adjustments with the room control tablets (that is about 24 adjustments per day). Figure 5 shows a heat map of the lighting adjustments that people made throughout the office floor. Table 1 provides an overview of the number of lighting adjustments. In general, people like to have control over the lighting at their workplace, and the feedback on the user apps was very positive. Surprisingly, participants mentioned that they expected to be using the apps even more than they actually did, even though they used the phone app and room controls quite often. The phone apps allowed them to increase the light intensity at locations and times that there was less natural lighting, and to create spotlight-like settings when they wanted to concentrate on their work.

User control in an individual office

Personal lighting control was valued in individual offices in particular, as people felt that this was their workplace and they would not disturb anyone by making lighting adjustments. In total 43 people made 826 lighting adjustments in the individual offices. Especially the individual offices with more than one luminaire were valued as it allowed people to adjust light distribution as well. Participants mentioned that, before lighting control, some individual offices felt dark and remote as there was little natural lighting. Interestingly, people were able to make those workplaces more pleasant by increasing the lighting intensity and were, therefore, less reluctant to work in those offices.

User apps on the phone

Although the phone app was easy to use, people indicated that controls ready at hand (e.g., tangible lighting controls on the desk, or the room control tablets) might be more appreciated. Benefits of dedicated lighting controls compared to a phone app include that they can be easier to access by everyone, with less effort. The interactions in the meeting rooms illustrate the effect: The room control tablets (that were accessible for anyone in the office and ready at hand) were used significantly more (1225 lighting adjustments), compared to 307 lighting adjustments made with the phone app by 16 people. The OpenAIS standard, which utilizes standard IoT principles, allows third-party developers to easily integrate any user app, whether it is on a phone or a dedicated tangible device, as it allows for the integration of a vast already existing collection of microcontrollers and protocols.

Autonomous system behavior

The combination of autonomic, sensor-driver controls and user control caused some issues every once in a while. The presence-driven controls sometimes overruled a user setting, and the luminaires would revert their initial on-state. These situations, although sporadic, were experienced negatively and sometimes, when it happened twice or more times to one person, people started to lose interest in personal lighting control. Some participants even mentioned feeling less in control with the OpenAIS system as the system can never be truly turned off anymore, and they felt like the system was able to ignore user control if it wanted to.

IoT lighting systems can offer a solution for this, as it allows for easy updating control software over the air throughout the system's lifecycle. The OpenAIS solution can continuously improve controls and fine-tune autonomous behavior to make it fit better to the occupants' wishes, and in this way can minimize the number of negative encounters.

Luminaire groups

Not every participant agreed with the pre-defined luminaire group, especially in the open office where the lighting grid did not always match the office layout. In particular, people generally used one of the corridor areas in the east wing for receptions and other informal occasions and wished to dim the lighting during those occasions. However, user control was not possible. As with most lighting installations, the luminaire groups were defined according to the lighting plan during the commissioning phase.

The flexibility of an IoT lighting solution allows for a relatively effortless recommissioning. Moreover, the OpenAIS standard allows flexible and layered grouping, which makes it easy to change luminaire groups on the fly according to the users' wishes.

User control in the open office

During the interviews, people were divided about personal lighting control in the open office, as generally, nobody wanted to disturb colleagues with their lighting adjustments. Despite their concerns, people used the phone app extensively in the open office (1579 lighting adjustments by 49 people). Occasionally people started a discussion with every colleague that might be affected by the lighting change, but they mentioned that this was often too much effort and decided not to interact at all. Nobody knew who made a lighting adjustment when it happened since the lighting control app was hidden in someone's phone, while in a meeting room, the control tablet and the person interacting were visible from anywhere, serving coordination of shared lighting control amongst everyone in the area.

Concluding Remarks

OpenAIS has successfully implemented a fully-functional multi-vendor IoT lighting system in a large-scale pilot in a real-life office. Two novel user apps were designed, fully integrated into the OpenAIS system, and deployed in the office for three months: the phone app allowed office workers to change lighting intensity at their flexible workplace anywhere in the office, and tablets with room controls allowed for adjusting the lighting in meeting rooms.

The solution was evaluated extensively with 26 office workers. The results from assessing the original tube-lighting system, a basic installation of the system (with presence controls), and an advanced installation of the system (with daylight regulation and user control), show a significant increase in lighting appraisal as the amount of user control increased and illustrated a growing need for personal lighting control in the office.

In general, people working in the office were very positive about having the possibility to adjust the lighting in their workplace, even though some had expected to use the apps more than they actually did. The room control tablets in the office were highly appreciated. The phone app was especially useful in individual offices. People expressed concerns about disturbing others with lighting adjustments in the open office. The study showed that the design of the user app and control tablets influenced the shared use of the lighting system, which is in line with previous studies [2,3]. With this in mind, we want to bring particular attention to the importance of the design of interfaces for lighting control, as it is up to the developers to consider the social context in which the interfaces are used, and to design them accordingly so that they fit the context and can allow for shared use of the lighting system.

Figure 6: Open office in the White Lady pilot site

THE OpenAIS CONSORTIUM & THE OpenAIS PROJECT

The OpenAIS project started in 2015 as a response to the emergence of IoT as a leading force in the digitalization of buildings and homes. OpenAIS is a European Community supported project that is partially funded through the Horizon2020 program. The project team started from the assumption that further developments in IoT-infrastructure would drive a revolution in connected lighting solutions, moving these to open (IoT) standards and off the shelf Internet technology. Additionally, the project definition included the vision that the ubiquitous lighting infrastructure would be an ideal platform to integrate multiple IoT-devices and deliver additional functionality beyond lighting. Such a development would revolutionize the lighting business, moving it away from vertical silos and proprietary (and closed) solutions towards the use of (open) IoT- ecosystems and standards. As has happened in many "digitized" domains, this transition would, in the view of the project consortium members, also greatly shake up the entire value chain and stimulate demands for openness and interoperability by professional customers keen to avoid lock-in.

The OpenAIS project runs from 2015 to mid-2018 and is coordinated by Signify (formerly known as Philips Lighting). The OpenAIS consortium includes partners from all segments of the lighting industry and its adjacencies:
facility management, installation, lighting manufacturing, technology suppliers and two academic partners.
As a carrier case for the project Professional Indoor Office lighting in Europe has been chosen.

The OpenAIS consortium

The OpenAIS partners are Signify (formerly known as Philips Lighting B.V.), Zumtobel Lighting GmbH, Tridonic GmbH & Co KG, Johnson Controls Systems and Service Italy SRL, Dynniq Belgium N.V., NXP, ARM Ltd, Eindhoven University of Technology and TNO-ESI

Another main insight from this work is that, to unlock the benefits of personal lighting control, human-in-the-loop control strategies need to balance autonomous system behavior and user control. This also shows the importance for IoT lighting systems to allow for updating firmware and control software throughout a system's lifecycle, to adapt a system's behavior and control strategies to the people working in the office.

Moreover, we want to highlight that the integration of IoT to lighting in the office brings changes to the entire lighting value chain. Lighting systems no longer deliver value to the customer only but create value for the users (office workers, installers, and commissioning agents), the customers (building owners, tenants), and all stakeholders involved, including new stakeholders (e.g., third-party developers). This is especially apparent in the opportunities that the flexibility of IoT systems brings. A variety of stakeholders can stay involved with the use of the system throughout its lifecycle and optimally update control strategies, luminaire grouping, and user control to make it fit the users' needs. We want to urge the office lighting value chain to take a holistic perspective and to develop the lighting systems of the future with the human experience as the focal point. ■

Acknowledgments:
This article is the result of three and a half year close cooperation between the partners in the OpenAIS project. We want to thank all team members for their contribution and collaboration. We also want to thank the people of the office building for their cooperation, and the participants of the study for their openhearted accounts. The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 644332.

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LpS & TiL 2018 - An Industry Is Repositioning Itself

In 2018, for the second time in a row, TiL joined LpS, extending the offerings of both to exhibitors, speakers and attendees. Interesting talks, panel discussions and networking opportunities brought insight to the current status of the industry and showed some self-reflection and future perspectives. Arno Grabher-Meyer, editor-in-chief at LED professional, explored the exhibition floor for interesting products, joined several sessions and participated in a panel discussion. Below is a summary of his impressions.

"The Lighting Industry in a Crisis", "A Sells Shares from B", "C Initiates Sale of Luminaire Business", "D Announces Revenue Decline for 3rd Quarter" ... - headlines like these are just a few of what we have been seeing lately, giving anyone involved in the lighting industry reason to wonder what is going on.

Many traditional luminaire makers, especially in Europe, but also in North America, seem to be in trouble. They are struggling with increasing costs and reduced sales prices resulting in lower profit margins. While they propose added value, and seek solutions in IoT, they have started offering services beyond their core business, such as surveillance and occupation control with facility management tools. This business does relatively well, but its growth is too slow to compensate the decline of revenue from the core business. What is going wrong?

Many theories are already circulating - some more plausible than others. LpS & TiL as a joint meeting point for specialists from industry, science, creative people, architects and planners opened new opportunities to discuss these theories, to propose solutions, to pool forces that could help the industry get out of this sad situation.

The extensive mix of lectures and workshops concerning technology, science, applications, and practice, offers the basis for new ideas and solution approaches. Leading specialists in the different fields discussed the findings in interesting panel discussions where the attendees asked the questions.

It has to be mentioned that six informative events took place during the 2 ½ days of the LpS and TiL events, resulting in approximately 100 hours of valuable information while, in parallel, almost 90 exhibitors with over 100 booths used the exhibition hours to display their products. From a bunch of submissions, finally six papers were nominated for the Scientific Award, and thirteen exhibitors were nominated for the three LpS Awards and three TiL Awards that were handed out at the Get Together Evening at the Eil Gut Hall in Lindau.

While all aspects of the show and all lectures would be worth being discussed here, only a small fraction can be considered as both the exhibition and the conferences need to be covered in a balanced manner.

Opening, Keynotes and Exhibition

Traditionally, the opening ceremony with the keynote lectures was held in the "Großen Saal" at the convention center. Event Director, Siegfried Luger, opened the event and introduced the new format in 2018, followed by Guido van Tartwijk, CEO at Tridonic, who represented the technology viewpoint, and then Rogier van der Heide, the curator of Trends in Lighting, who focused on the creative and application related parts of the show. While Guido van Tartwijk addressed new technologies and frankly pronounced some deficits in the traditional lighting industry in this respect, Mr. van der Heide proposed overcoming these challenges with creativity, in adding true value for the real end-user like you and me, using the skills and innovative power from other industries.

The mixed exhibition of the "more technical" LpS exhibitors and the "application focused" TiL exhibitors showed that some companies have already recognized and reacted on the ongoing transition. As it is not sufficient anymore to just exhibit the components, the product presentation is moving increasingly from the unemotional technology focused display of the components to the more appealing and meaningful presentation in their applications. Therefore, in some cases, the line between LpS and TiL exhibitors was completely blurred.

The exhibition show floor was very attractive again this year, with many interesting products and some distinct highlights. First of all, it would only be prudent to mention the finalists for the three LpS Awards and the three TiL Awards: Bilton, Bartenbach, Future Lighting Solutions, GL Optic, Insolight, Khatod, Lumitronix in cooperation with Toshiba Materials and Seoul Semiconductor, Nichia, Physionary in cooperation with Luximprint, Selteka, Silvair, Tridonic and Trilux. The winners were honored during the Get Together Evening together with the Scientific Award winner.

Selected LpS Lectures

Once again, the organizer was able to select the most relevant topics from a large number of high-quality submissions from science and industry. Unfortunately, space-constraints and don't allow for a complete picture of all lectures. The examples below are deemed as an overview of the multiplicity of relevant topics.

In his lecture "The Technology and Implementation of Dynamic Beam Shaping", LensVector's Architectural Engineer, David Kriebel, showed how LCD technology can be utilized for beam shaping. After explaining the basic mechanisms of an LCD, also mentioning that they usually suffer from poor efficiency because of the necessary inclusion of linear polarizers, he explained the adaptations for a beam shaping LED lighting lens, like using more than one "liquid crystal sandwich" to correctly process non-polarized light. He demonstrated that the color shift introduced by such a system is negligible, and that the additional light losses compared to a plane cover glass are typically between 6% and 10% corresponding to the LCD state. Overall transmission is between 78% and 90%. He concluded that the advantage of beam shaping clearly exceeds the quantitative and qualitative impact on the light. Finally, he showed how to control the LCD and that the system is not only a circular zoom lens, but may, in the future, really be used as a beam shaping lens that can provide different light distributions.

"The Latest Developments in Laser Light Sources for Industry-Leading Luminance" was the topic of Julian A. Carey's presentation. Mr. Carey is Product & Technical Marketing Manager at SLD Laser. In his company there are currently two types of implementation for lighting applications available: A blue laser fiber module with phosphor at the distal end which is mainly used in automotive applications, and a SMD laser light component that is also used in many other lighting applications. He explained that while the optical efficacy is currently still clearly lower than that of a white LED, if a compact and lightweight solution with a narrow angle and high luminance is required the system efficacy is already competitive, and laser is the way to go.

Osram's Principal Key Expert for Power Topologies & Controls, DI Markus Heckmann, talked about "Influence of Converter Topology on the System Interactions". While one might think that driving LEDs and driver topologies are not a relevant topic anymore, this is a big misconception. He started with explaining a driver's operating




▶ **A novel approach for using LCD technology was presented for beam shaping. There are many interesting applications and it is not limited to only changing the beam angle. Overall light distribution can also be changed, as shown in these images**

Lyteus, formerly LG Display, promoted their latest versions of flexible LED modules, demonstrating their versatile application opportunities

In addition to the established luminaire manufacturers, startups, like Sarafelli, displayed their design oriented concepts at TiL

▲ In his status report on laser lighting, Julian A. Carey showed that this technology is becoming increasingly more interesting. Currently, it is predominantly used in automotive high-beam applications, like this example of LED headlights in a BMW. In addition, there are some advantages in special applications, like searchlights

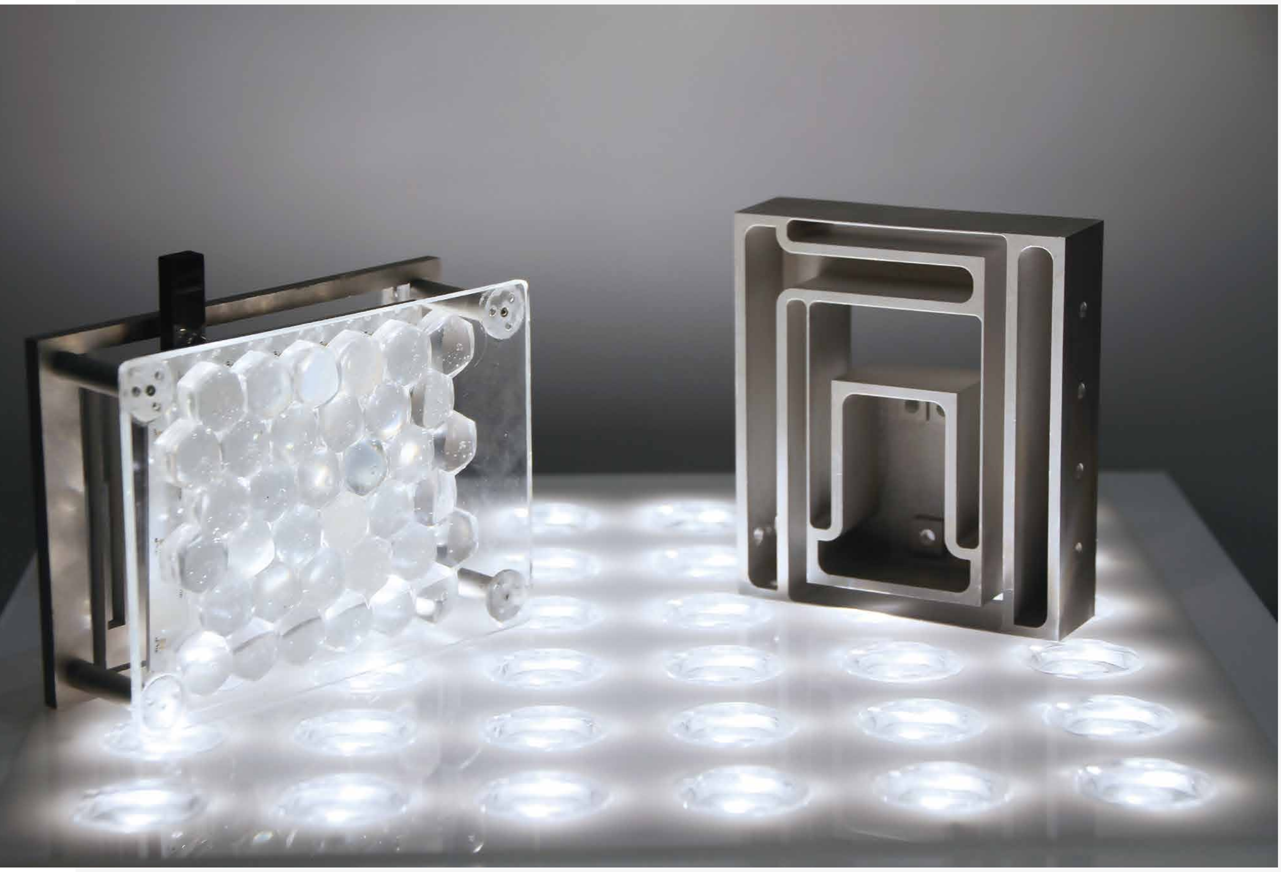
window, the topology basics, and the behavior of LEDs, pointing out that there are huge differences, depending on LED type and LED generations.
Then he showed different control loop approaches and demonstrated how the differential resistance of an LED, the driver topology and control loop design can lead to an unexpected system instability that could have been predicted by a consequent, detailed analysis of the Nyquist plot, respectively, Bode diagram. The presentation was an impressive explanation of why it is important that MD-SIG has defined a method of how to specify converters and modules, including the differential resistance.

DALI is dead - long live DALI.
Dr. Scott Wade, Technical and Certification Manager at DiiA, talked about “DALI-2: Standardized, Interoperable Components and Smart Luminaires”. While a lot would already have been possible with DALI, beyond classical lighting controls, a proper standardization was missing. This has now been changed with DALI-2. Dr. Wade explained how DALI-2 has brought standardization to products such as sensors and other input devices, as well as application controllers, which are the “brains” of a DALI system. But beyond this, the most important improvement in DALI-2 is that for every component in a DALI-2 network a specified test sequence must prove compatibility. Some sequences are still under development, but finally, this testing guarantees interoperability and compatibility. This and the additional backwards-compatibility to DALI makes DALI-2 truly future-proof.

DI Volkmar Keuter, Head of Department Photonics and Environment at the Fraunhofer-Institute for Environmental, Safety and Energy Technologies held a speech entitled “Plants’ Responses to Exposure to Different Lighting Conditions”. While photosynthesis and most mechanisms on this topic with interaction to light are well known, less is known about the production of “non-vital” substances in plants that still fulfill relevant tasks and that can be of high value for human nutrition and health. Two such examples are carotenoids or anthocyanins, which are able to scavenge radicals. Mr. Keuter presented results using six different LED modules to grow spinach, chard, lovage, buckwheat and lambs lettuce under controlled conditions in a climate chamber. Just one module met the necessary requirements to emit the light evenly distributed without degradation over the whole testing period. It was shown that the formation of anthocyanins and flavones is definitely affected by light compositions, i.e. by varying the ratios of the red:blue ratio and adding IR.

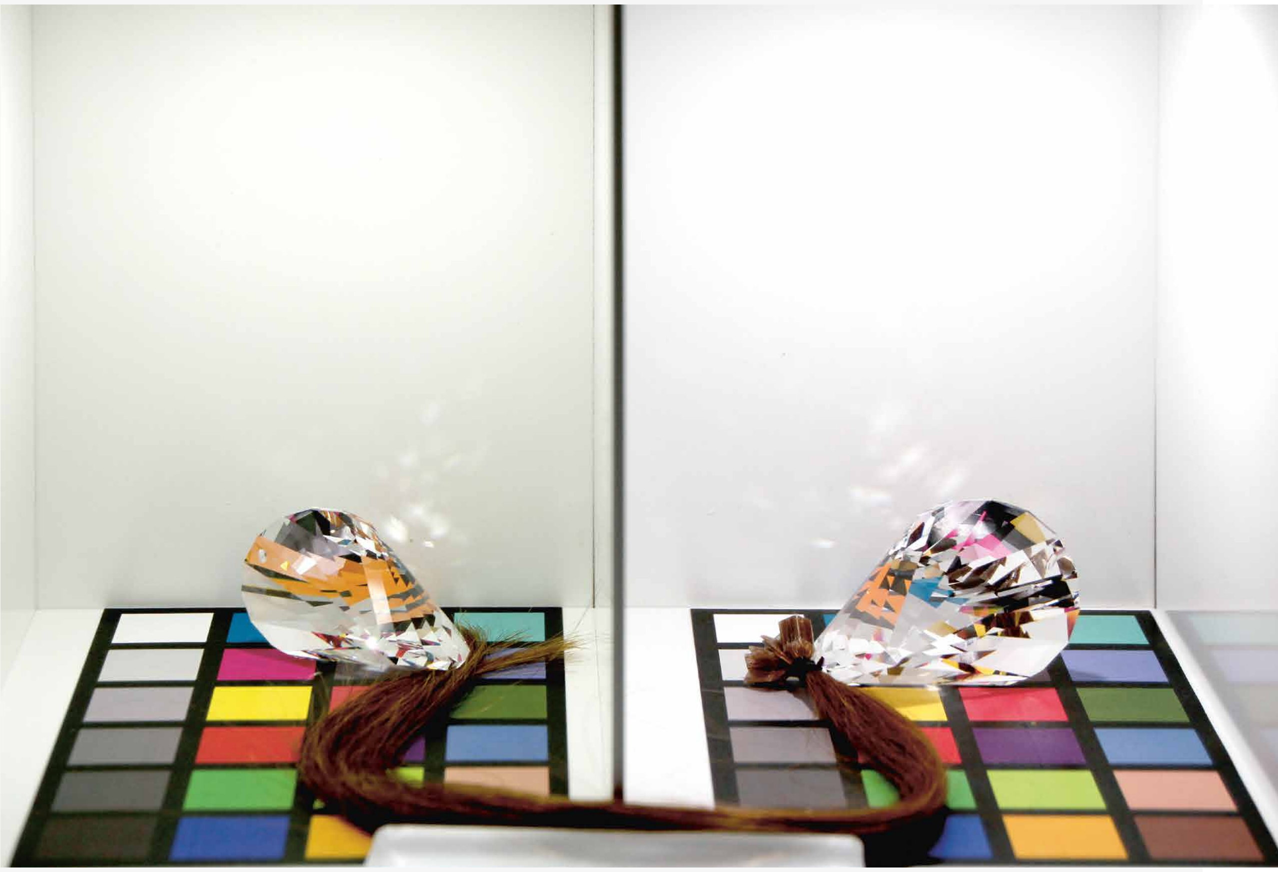
Some submissions were certainly equally relevant for both LpS and TiL attendees. But as they may be less recognized and understood by technicians and the industry as a whole, they were slotted into LpS sessions.

Two exemplary examples should be mentioned:
Dr. Stephen Mason addressed a topic, the industry might not be aware of. The Optometrist and



Beam shaping is always a hot topic, and Insolight's approach that allows for changing the orientation of a light beam remotely by just moving the lenses, was nominated for the LpS Award. This approach makes it easy to set new scenes, make dynamic changes or follow a moving object

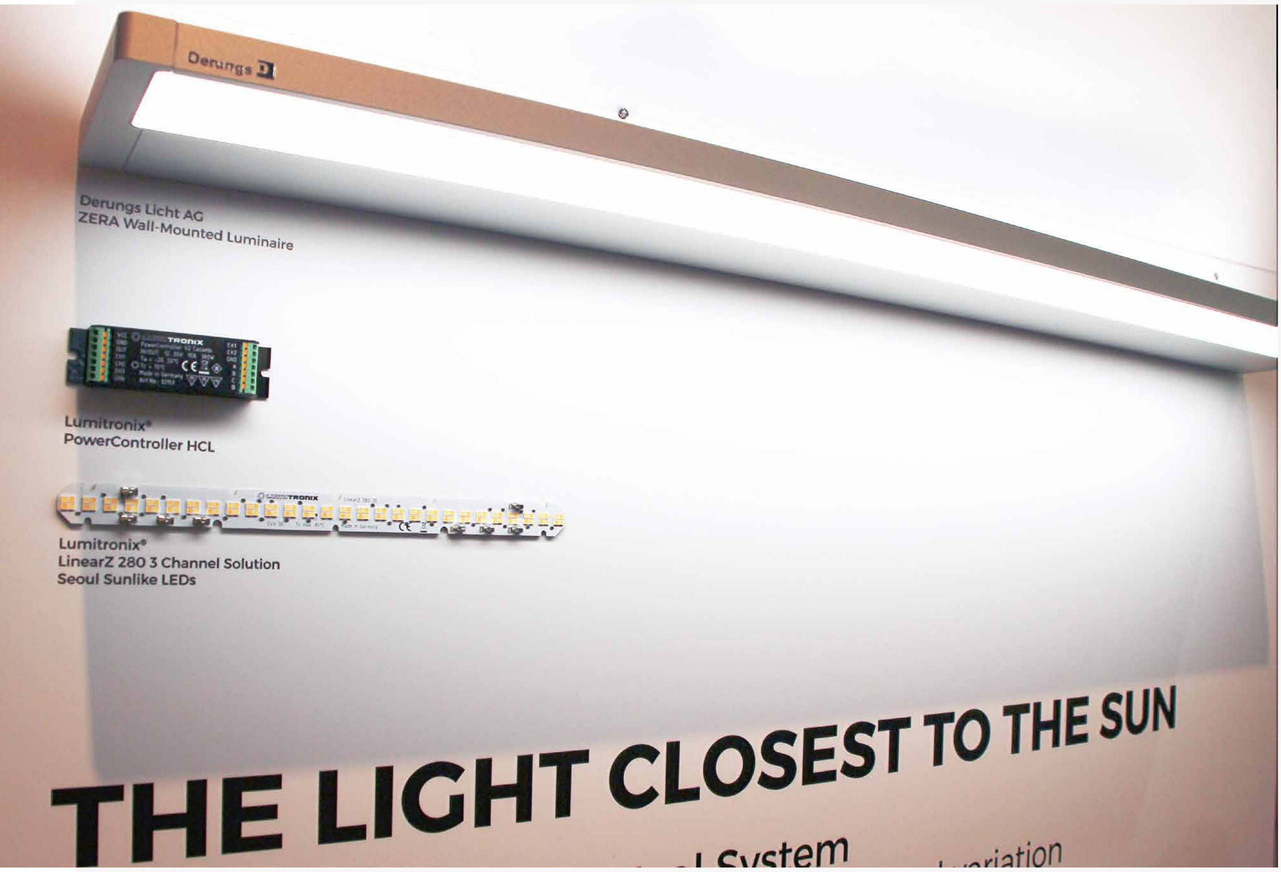
A show box at the Nichia booth allowed the visitor to experience the distinct differences in light quality between the new Optisolis (right) and a conventional LED (left). The properties of the Optisolis make it a preferred choice for museum applications and art lighting. The unique spectral properties were a pivotal reason for Nichia being chosen for the LpS Award



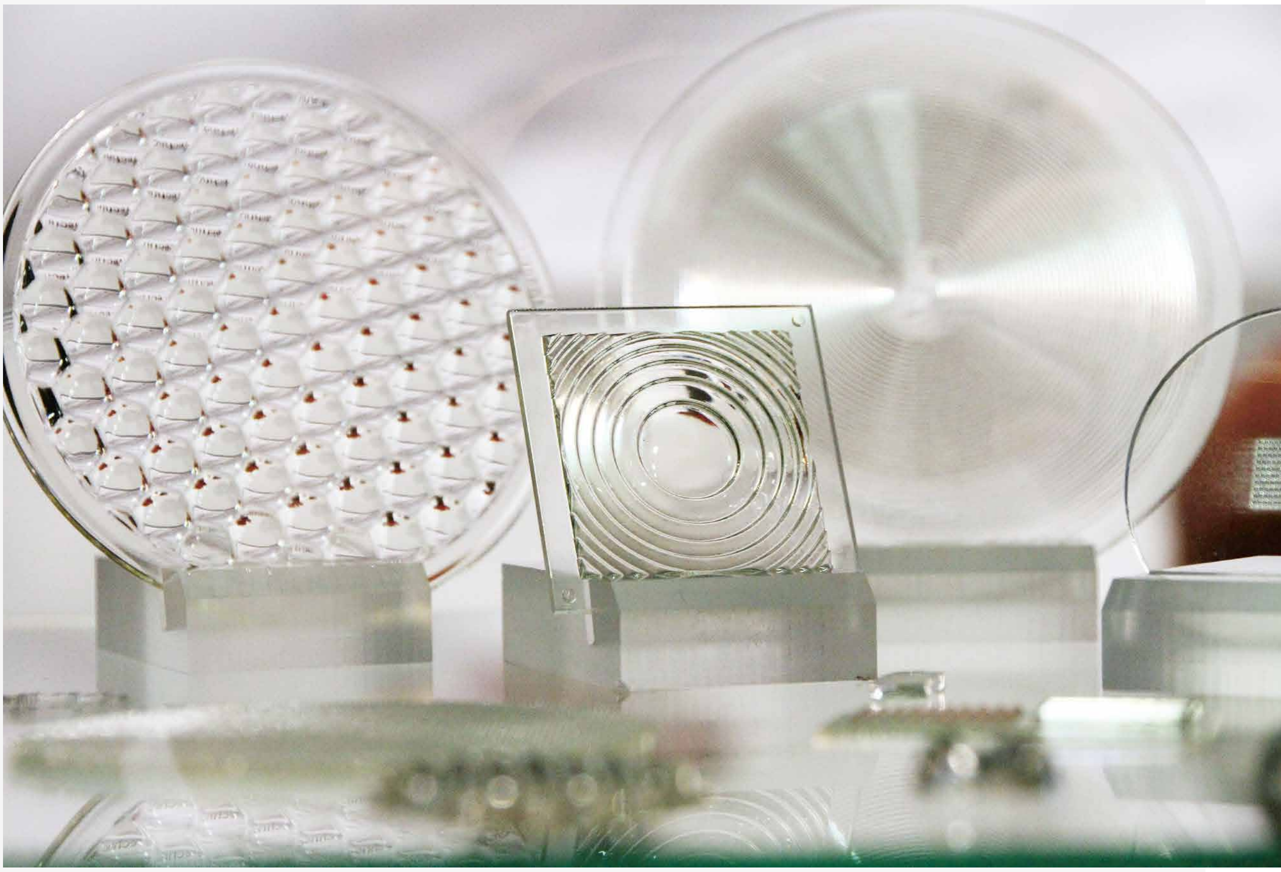
▲ **Optometrist, Dr. Stephen Mason, showed several interesting correlations between lighting conditions and the increase of myopia**

Managing Director at Sustainable Eye Health Pty talked about "A Design for Tunable LED Lighting that Reduces the Incidence of Myopia". Myopia is steadily increasing and reaching alarming levels, especially in Asia where 80% of high school graduates and 95% of university graduates are myopic. He showed that two hours of sunlight a day can dramatically reduce these figures. While the reasons are certainly manifold, the low light levels in the Asian learning environment - typically below 100 lux - are a big problem. Increasing the light levels clearly above 500 lux - 880 lux and 1455 lux in a test environment - dramatically reduced the problem. He also addressed another issue that especially concerns typical white LEDs: Most white LEDs show a radiation peak at the blue pump LED's wavelength of 440-460 nm but they have a depression between 480 and 500 nm. Unfortunately, this is just the wavelength range that controls eye growth and if adequate exposure to this wavelength is missing, the growth is too high, causing myopia. His appeal to the industry: Design LEDs that provide an adequate light output at this wavelength.

The topic of light pollution became increasingly important with the rise of LED outdoor lighting. "The Dark Side of Light: Effects of Light Pollution on Insects and Agriculture" is the topic that was presented by Dr. Maja Grubisic, Post-Doctoral Researcher at the Leibniz-Institute IGB. Recently the news that, for different reasons, the biomass of flying insects in Germany decreased by 75% within 30 years, received attention in the media. In nocturnal species, one important reason is light pollution. As insects are an important factor in our ecosystem, this also affects our agriculture. Dr. Grubisic pointed out that not the LED per se causes these issues - it is how they are used. Instead of replacing conventional lights providing a similar usable light level, intensity is often increased and lights are not switched off anymore. Furthermore, especially to speed up the transformation, the early LED installation used cold white LEDs that are especially attractive to insects. In her talk she showed that an insect's eye is sensitive to UV, blue and green but less or not sensitive to yellow and red. They are also sensitive to very low light levels. Therefore they are attracted by the light and they are stressed, affecting the normal feeding and mating behavior significantly.
In one slide she demonstrated that metal-halide lamps and fluorescent lamps have a greater impact than LEDs with a CCT of less than 4000 K while high-pressure sodium lamps are even less intrusive.
In the last part of the lecture she gave advice on how to improve the situation. Adequate light levels, spectral tuning of the LED, dimming, intelligent usage and intelligent controls are just some possibilities. Dr. Grubisic's lecture shows that while a negative impact of artificial light at night on insects cannot be denied, further research and a close cooperation with the industry is needed and desired to minimize the impact to avoid unpredictable long-term ecological and economic damage.



◀ In cooperation with Toshiba Materials and Seoul Semiconductor, Lumitronix designed their Circadian Light Module & Controller which might become a preferred solution for human centric lighting; therefore, it deservedly received an LpS Award



▶ The combination of Physionary's unique software solution, nominated for the TiL award, that simplifies the design process significantly, with Luximprint's printed LED optics technology is an extremely user-friendly option for low to mid-volume projects

Highlights from the Scientific Submissions to LpS

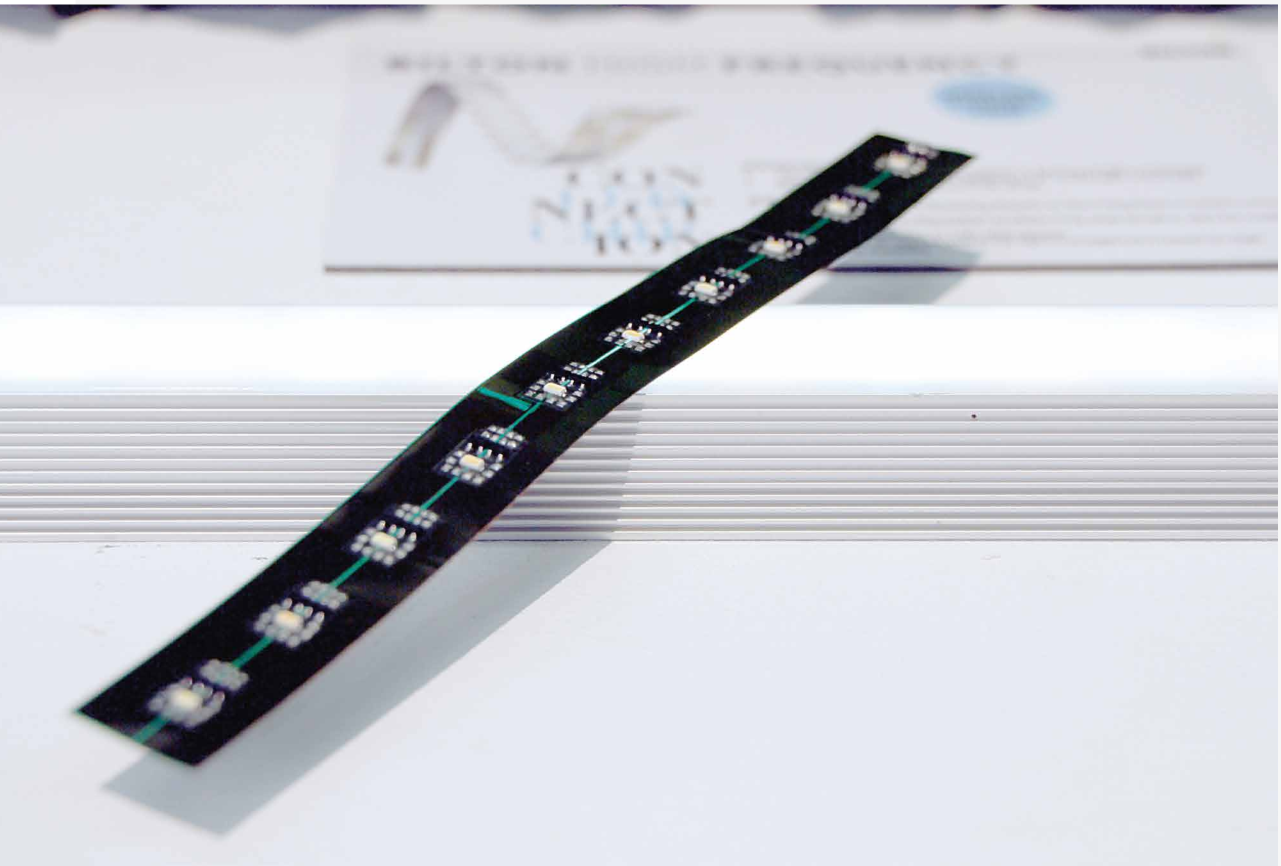
Six submissions were nominated for the Scientific Award. Unfortunately the tightly packed program did not allow me to attend all six nominated lectures. Fortunately, though, these six papers will be published, one after the other in the relevant, upcoming six LpR issues. Here is a brief summary of each for an idea of the interesting topics that will be shared with you over the next twelve months.

Octavio Perez, Ph.D., Adjunct Researcher at the Department of Population Health Science and Policy from Well AP and the Mount Sinai Hospital reported on the research results of a pilot study in his lecture "Lighting and Emergency Department Clinician Wellness and Performance Improvement". In the perfectly structured article and lecture, he showed that a radically new lighting approach dramatically improves both wellness and performance: A significant reduction in clinician sleepiness perception (Karolinska Sleepiness Scale, "KSS", –15.94%, $p = 0.022$), a significant reduction in workload perception (NASA-TLX, –21.87%, $p = 0.009$), a reduction in clinical procedures execution time (–21.04%), and a reduction in the occurrence of medical errors, were observed. The study compared the existing fluorescent lamp installation with the new indirect lighting approach with CCT = 78,000 K at the same light level of 880 lx in a randomized AB/BA (2×2) crossover experiment. He announced that the extreme approach of radically changing several light parameters was chosen to get distinct and significant results. As the answer to the question of if and how a changed lighting environment improves the situation is yes, further investigations can be performed to define which factors are most relevant and what an optimized system should look like.

"Implications for Human-centric Lighting Design in Tropical Nursing homes: A Pilot Study" is the title of Dr. Chien Szu-Cheng's lecture. Dr. Chien pointed out that the pilot study concentrates on the visual perception comparing compact fluorescent light with color tunable LED downlights and was based on pre- and post-modification surveys. While the original lighting design mainly considered the requirements of the staff supporting visual acuity and to minimize hazards, the new light with its HCL approach also takes the special requirements of elderly people into account. The predominantly positive feedback demonstrates the improvements achieved with HCL. Nevertheless, the pilot study also shows that there are still open questions: Especially effective methods to maintain the circadian rhythm should be further explored.

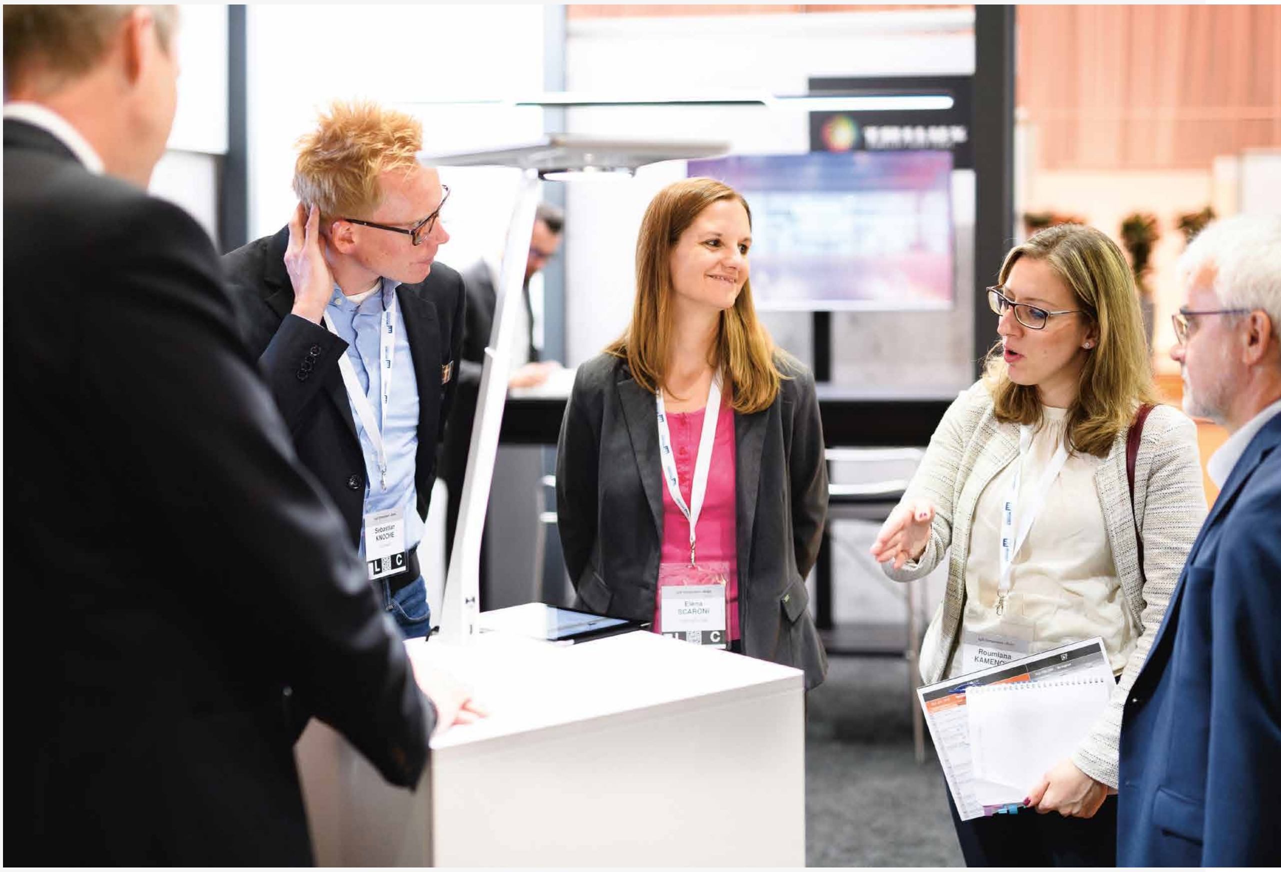
CSEM Senior R&D Engineer, Dr. Oscar Fernandez talked about "Semi-Empirical Characterization of Freeform Microlens Arrays". He explained that while microlens

▼ **This interesting topic, and its findings raised several questions concerning the extreme CCT as well the resulting subsequent future research**



◀ Bilton's flexible LED stripe and their inductive powered and sealed, bendable LED module attracted many people to their booth. In combination with an HF modulated driver, this TiL Award winning module allows for individual or group dimming of LEDs by modulating the driver frequency

▶ TRILUX's TiL Award winning Bicult LED, an office desk luminaire, garnered a lot of attention and was the subject of many interesting conversations



arrays (MLA) have long been used for imaging and non-imaging applications and can be produced easily and cost-efficiently, freeform microlens arrays (FMLA) often fail to comply with stringent requests. This is especially an issue as manufacturing of the large area FMLA molding tools is rather costly and the experimental characterization of small samples is normally unrealistic due to handling issues and experimental errors. Dr. Fernandez and his team propose a method based on 3D surface sampling, computer generation of a ray-traceable model and ray-tracing performance simulation. The approach was experimentally validated based on two commercially available micro-structured optical foils. In conclusion, he criticized that several CAD software packages are currently needed to build such ray-traceable CAD models and he asked for a single CAD software package able to make the complete process.

In the lecture entitled "Hermetic Polymer-Free White LEDs for Harsh Environments", Dr. Michael Kunzer, Group Leader LED Modules at the Fraunhofer Institute for Applied Solid State Physics, explained that LEDs in under controlled conditions could achieve lifetimes of several 10,000 h depending on junction temperature and current density. The conventional phosphor can degrade much faster under conditions such as elevated operation temperature, humidity, corrosive gas and air pollutant exposure. He showed that an entirely inorganic converter with a high thermal conductivity like a ceramic phosphor solves this problem. Furthermore, he described the developed process steps to produce polymer-free full ceramic LEDs with 4x3 W electrical power and a footprint of 4.2x4.2 mm^2 that offer a high efficacy of 125-140 lm/W. Dr. Kunzer pointed out that all light parameters are kept within the required tolerances and efficiency is especially high when compared to conventional hermetic LEDs in TO-can packages.

"VLC Luminaire - Visible Light Communication" was the topic presented by Prof. Guido Piai, who is Professor at the Interstate University of Applied Sciences, NTB, in Buchs, Switzerland. After explaining the background of the research and development, which is to provide a flexible, cost effective self-configuring solution for different lighting applications, Prof. Piai explained the basic principle of the solution for the required swarm behavior. He dipped deep into technical details showing block diagrams of the systems and protocols, the calibration, commands for the swarm behavior, and solving of communication conflicts. Finally, he showed test results of different applications proving reliable communication for distances of at least up to 20 meters. He admitted that one issue still remains: Extraneous LED luminaires or light sources, which are dimmed with PWM, and which use PWM frequencies near to the FSK frequencies of the VLC luminaires, can still disturb the system. Therefore, further tests and validations are needed, especially connected with real applications. In his conclusion, Professor Piai said that long-time tests are still pending.

Fraunhofer's second nominee, Dr. Peter W. Nolte from the Application Center for Inorganic Phosphors talked about "Temperature Profiling of Secondary LED Optics by Infrared Thermography", an approach to analyze the temperature profile of a secondary polymer optic in combination with a high-power LED module. Dr. Nolte explained why it is important to have an exact knowledge on the temperature profile within the secondary (polymer-) optic, the exact mechanisms and research method. He concluded that the results of the examined system suggest that while for the tested system the critical temperature was not reached, for smaller distances between LED and optic, unwanted effects must be expected and that, in particular, as LED power densities increase, the transmission properties of the optic need to be carefully matched with the LED emission spectrum.

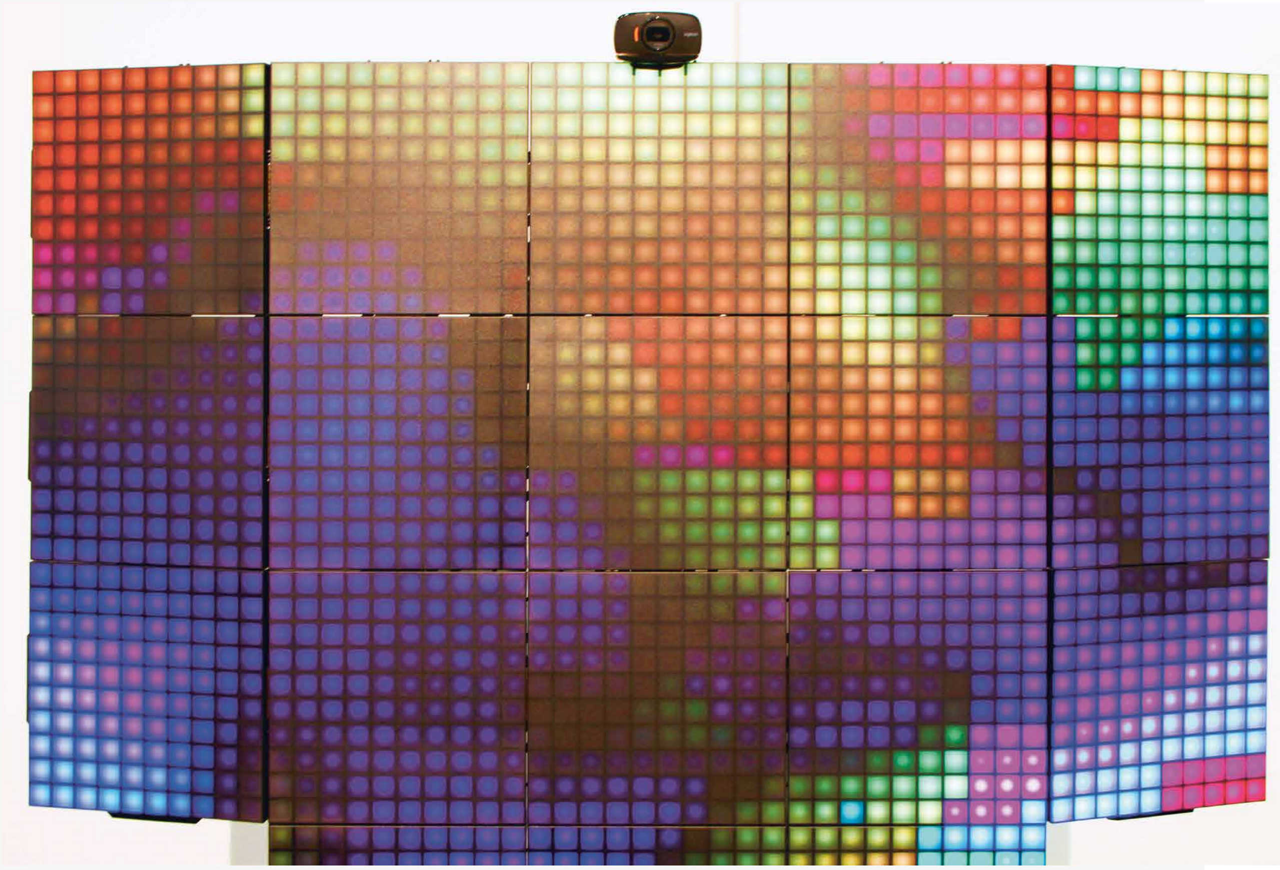
Best of TiL Lectures

Meanwhile about one third of the topics are dedicated to TiL. Numerous, well known specialists were invited to share their knowledge with the audience. The versatile program covered classical lighting designer topics, such as psychological effects and HCL, as well as forward-looking topics like LiFi, IoT, interactive navigation or smart applications. As the latter lectures might not be technical enough for LpR, the lectures of creative people could give valuable food for thought.

An exemplary example of one of these lectures is summarized below: Brad Koerner, founder of Koerner Design, addressed the topic of transition in his talk "From Architectural Lighting to Architectural Media". At the beginning he criticized that lighting has not changed much even though the technical opportunities are available. He asked for AX (Architectural Experience Design) in following UX in media design. He presented several examples of light integration in different materials from fabrics to LED modules directly embedded in walls and pointed out that, provided a thoroughly engineered product is used, lifetime should not be an issue. He appealed for providing meaningful interaction and implementation of other new technologies that go beyond unidirectional information transfer. As computing power today is no big thing anymore, he sees no impediment in introducing more sophisticated solutions. In regards to health and wellness, Mr. Koerner especially recognized the necessity to switch from "stiff" preset scenes to personalized solutions, ideally implementing AI. Such approaches could be applied in hospitality, retail, healthcare, offices, but also in outdoor public

Khatod was one of the companies shortlisted for the LpS Awards. They presented their solution for simplifying the production of IP rated luminaires; the NACTUS 6x2, Silicone Optical Systems

LEDs Chat, a company from France, was shortlisted for a TiL Award with MOZAÏK, self-configuring RGB tiles for media and artistic applications. The technology could also be interesting for automated lighting system commissioning



spaces. He presented some already executed examples and asked how the lighting future could look. For him, it is clear that it is necessary to combine sensing, light and material to provide true AX and to realize what Maya Angelou said: “I've learned that people will forget what you said, people will forget what you did, but people will never forget how you made them feel.”

Impressions from Workshops and Panel Discussions

Several interesting workshops and exciting panel discussions completed the event program. As a picture tells more than a thousand words, here are a few photos showing the activities in some of the workshops and panel discussions.

The workshops covered very different topics. Bartenbach demonstrated once more its excellence in the domain of visual perception and health. OLEDWorks focused on the capabilities of flexible OLEDs and how to apply them. EVONIK demonstrated its competence in PMMA plastics materials and processing. WIth a good part of fun and humor, Seoul Semiconductor's workshop offered a chance to experience the SunLike.

From the visitors attending the different panel debates, especially the ones at the Innovation

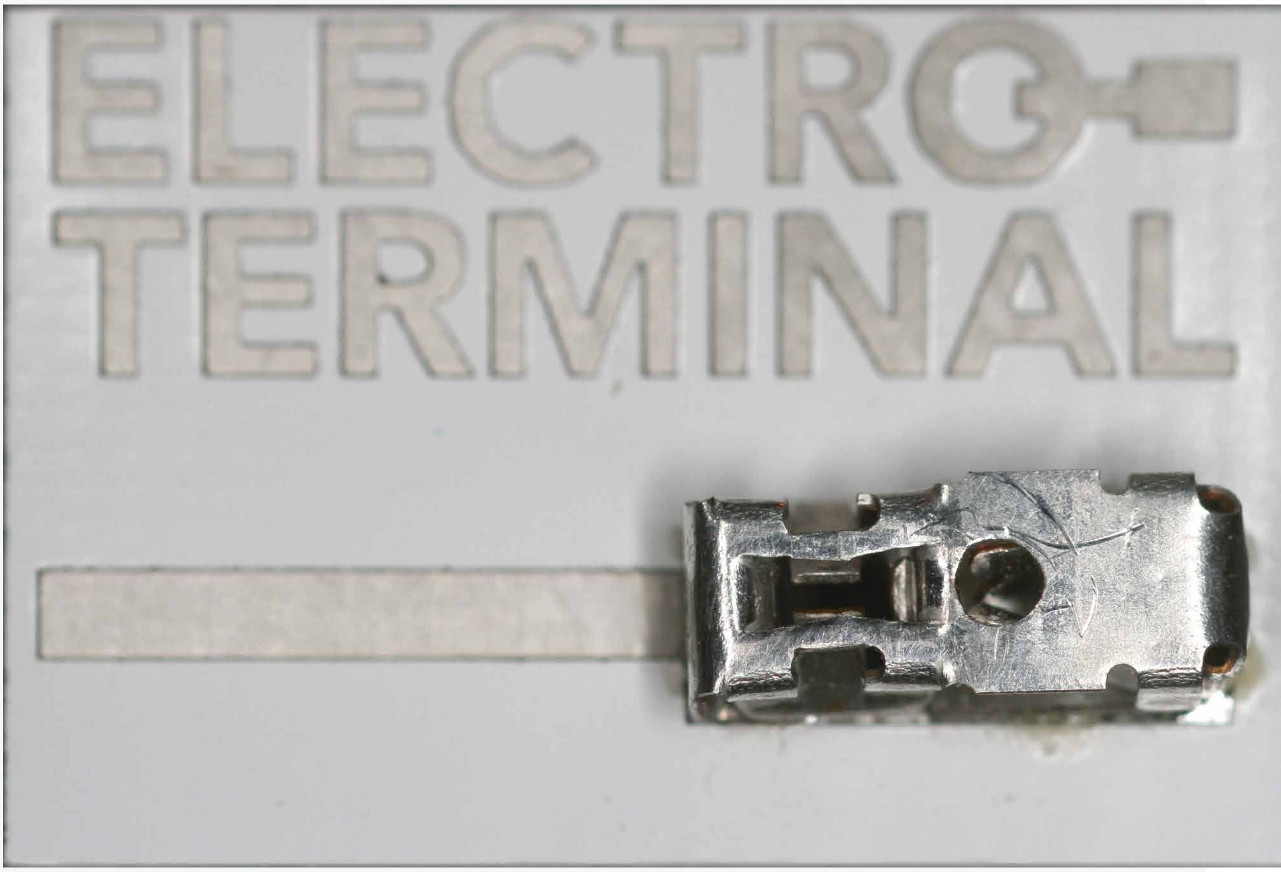
▲ Bartenbach’s workshop: Visual Perception and Health Demonstrations, was surprising and exciting. Previous demonstrations by Bartenbach at LpS were updated and extended by this year’s workshop

◀ The OLEDWorks “BendOLED lighting, Bring Your Bended Design to Light” workshop gave insights into the use of flexible OLEDs

▼ “PMMA - See, Feel, Experience” was EVONIK’s motto for their workshop. They brought numerous samples from accelerated lifetime testing of PMMA products with them to demonstrate the difference between standard PMMA and high grade, high quality PMMA material

◀ Perfect light distribution and appearance without glare - independent of the position. These are the attributes of Bartenbach's Lightdisk. This downlight optics for tunable white solutions was also shortlisted for the TiL Award

▶ Electro Terminal brought several new products with them. One of them was the Microcon SMD Pure - a tiny, versatile PCB connector without housing



▲ **Seoul Semiconductor combined information, fun and hands-on experience for all participants of their workshop "The Closest LED Light to the Sun"**

◀ **Audiences at the various panel discussions on topics from HCL to Lighting Design and Innovation, used the chance to ask panelists some thought provoking, and sometimes critical, questions**

▼ **The CEO debate on Day Three was one of the highlights of the panel discussions. Visitors seized the opportunity to ask about strategies for better, healthier, human centric and environmentally friendly illumination**

Panel and even more at the CEO Debate got some surprising, direct and open answers on their questions.

Get Together Evening - Combining Business with Pleasure

The Get Together evening on day two started with a sunset-cruise on Lake Constance. This year the event was held in the Eilguthalle in Lindau to better accommodate the Award Ceremony for all seven Awards. This heritage-protected building where tradesmen once moved their goods from the trains to the barges, proved to be the perfect location for catering, entertainment and the award ceremony. The evening ended with the ferry bringing everyone who wasn't staying in Lindau, back to Bregenz.

For nominees, the award winning companies and the winning researcher, the presentation of the awards was the highlight of this event. The ceremony started with the Scientific Award, handed over to Dr. Octavio Perez by Dr. Guenther Sejkora, for his research at the Mount Sinai Hospital. The jury concluded that: "The paper is based on a clear definition of a research question, hypothesis and objective of the research. Methodology of the screening study is described in detail and both subjective and objective parameters have been measured. Although ED lighting is a very special application, the paper gives interesting results."

▲ Two happy winners of the LpS Award

Arno Grabher-Meyer presented the three LpS Awards for the “Best Lighting Technology”, the “Best Application Technology” and the “Best Sustainability Technology”. The Optisolis Ultra High CRI White LED development made Nichia successful in the category “Best Lighting Technology“. In their argumentation the jury honoured the Optisolis because “this new product alters the misrepresentation that LEDs either do not render colors of artwork properly or damage the color pigments of precious paintings”. Lumitronix in Cooperation with Toshiba Materials and Seoul Semiconductor succeeded in the category “Best Application Technology” with the Circadian Light Module & Controller because “The consequent implementation of the TRI-R technology to mimic the diurnal changes of the sunlight spectrum brings illumination one step closer to the ultimate HCL. The compact, programmable PowerController V2 with its configurability that allows the control of the light using different input options adds additional value to the module”. In the third category, GL Optic’s new approach for a Modern Lighting Audit tool convinced the jurors as ”For modern buildings it is increasingly important to proof the realization in audits, either to receive certifications like the Green Building Certificate, LEED Certification, CEE or Title 24, just to name a few, or to proof the correct execution of the planning for the building contractor or building owner. GL OPTIC’s GL Modern Lighting Audit tool dramatically simplifies the necessary audit”.

Rogier van der Heide had the privilege to give the TiL Awards for the “Best Lighting Application”, the “Best Connected Lighting Solution” and the “Best Non-Architectural LED Lighting” in the mentioned order to TRILUX for their Bicult LED that “opens up new ways for flexible desktop and room-lighting in office applications. Integrating sophisticated light distribution, circadian lighting and connected lighting techniques, it is pointing in the direction of future lighting”. Silvair’s Commissioning Tools are the worthy winner of the second TiL award as “They allow time efficient commissioning of Bluetooth Mesh based lighting installations without the need for trained personnel. The user can focus on lighting specific configuration and doesn’t have to bother with network setup and configuration which is all done automatically”. The last award to be assigned went to Bilton for their Linear LED Strip based on a High-Frequency Design. The product was convincing because “The combination of contactless power coupling and individual control of multiple LED groups allows the use of this technology in different applications. The specifications suggest that the diverse application possibilities can trigger new creative solutions”.

The companies that made it in the second round, being nominated for the awards, received documents and an honorable mention. Before the dancefloor was cleared for dancing, a group photo was taken with the available nominees and winners.

Insights and Outlook

Once again the event took a huge step forward in bringing together technology and application. The overall quality of the lectures was very high; with some being outstanding because of the brilliant workup or the important topic. While there is probably still a long way to go to merge the heterogeneous audiences of technicians and lighting designers, a first, very successful step, was taken at the LpS and TiL 2018. The experiences from 2017 and this year have already triggered new ideas for 2019. But that is another story! ■

Standardized Programming of Lighting Components Using NFC Technology

NFC programming of LED drivers is rapidly gaining popularity as a fast, feature-rich, flexible and easy method to set the operating characteristics of LED drivers inside luminaires. Arnulf Rupp, Chair of MD-SIG, describes how the MD-SIG specification for NFC programming of lighting components makes it easy for luminaire manufacturers to use NFC programming in a production line where multiple brand drivers are used one after the other

The Module-Driver Interface Special Interest Group (MD-SIG) is a global lighting-industry consortium. MD-SIG is a sister organization of the Zhaga Consortium and aims to meet the growing demand in the market for harmonization by introducing a standardized, multi-vendor electrical interface for LED drivers and LED modules.

MD-SIG is harmonizing existing setting methods and power-interface definitions for LED drivers, and introducing new setting and programming methods. The consortium has already released specifications for critical definitions and for an analogue method of current setting, and has now added a specification for digital Near Field Communication (NFC) programming.

Introduction

NFC is a set of communication protocols that enable two electronic devices, one of which is usually a portable device such as a smartphone, to establish communication by bringing them within 4 cm of each other. NFC is best known for its use in wireless payment systems. Increasingly, NFC is being used in the lighting industry, e.g. for identification, control, or configuration of components such as drivers.

Figure 1: Increasingly, NFC is being used in the lighting industry, e.g. for the configuration of LED drivers

MD-SIG members include leading global vendors of LED drivers, and some of these companies have already introduced to the market different approaches to NFC programming of LED drivers. However, these approaches brought to market are proprietary solutions based on different NFC protocols requiring software and hardware which is specific per driver brand. This makes it complex for luminaire manufacturers to use these programming methods in a production line where multiple brand drivers are used one after the other.

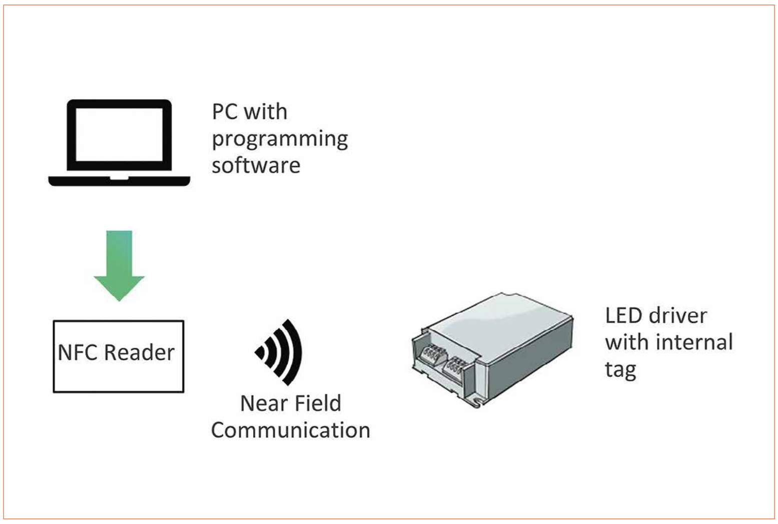


Figure 2: NFC programming of drivers - system overview

To counter this complexity, these MD-SIG companies have agreed to harmonize their programming methods, and developed the NFC specification for lighting components. The specification is based on the ISO/IEC 15693 standard for NFC, and was approved by MD-SIG in March 2018.

By issuing this specification, MD-SIG aims to harmonize NFC programming methods resulting in a single industry choice for NFC programming of luminaire components. All NFC programmable devices that comply to this standard can be programmed by any of the Qualified NFC Readers defined in this standard. At the same time, this standard leaves a wide space open for vendor differentiation by means of both driver features as well as programming software.

NFC Programming of Drivers

Manufacturers of LED luminaires currently use a variety of programming methods to set the operating characteristics of LED drivers inside luminaires. NFC programming is a new and promising method to do so. It is faster than traditional methods of LED driver programming, more feature-rich and flexible than resistor-setting techniques, and has a reduced training requirement for production-line staff. This technology could also offer new in-field services in the future e.g. installation and maintenance of street-lighting luminaires.

NFC allows the manufacturer to wirelessly set the LED driver operating parameters, such as operating current, constant lumen output and dimming levels. This can be done on a manufacturing line without the need to apply mains voltage to the driver, reducing effort in the production line to protect the workers from mains voltage.

The NFC system is depicted in figure 2. It comprises an NFC reader and an NFC tag integrated into a driver. The NFC reader is a hardware device for exchanging data with an NFC Tag. The NFC tag is an IC that can be used as data store which can be read, and under some circumstances written to, by an NFC Reader. The tag is a passive device and activated by the energy contained within the signal emitted by the NFC reader. In contrast to what the term suggests, an NFC Reader can both read from and write to an NFC Tag.

In the NFC programming system, the NFC reader is connected to a host PC, and receives its instructions from this PC. The NFC reader wirelessly transfers the programming data to an NFC tag inside the LED driver. The parameters are programmed using an NFC reader in combination with software that is specific to the LED driver vendor. This software typically runs on a standard host PC. After such a programming phase, the LED driver operating parameters are at the desired settings.

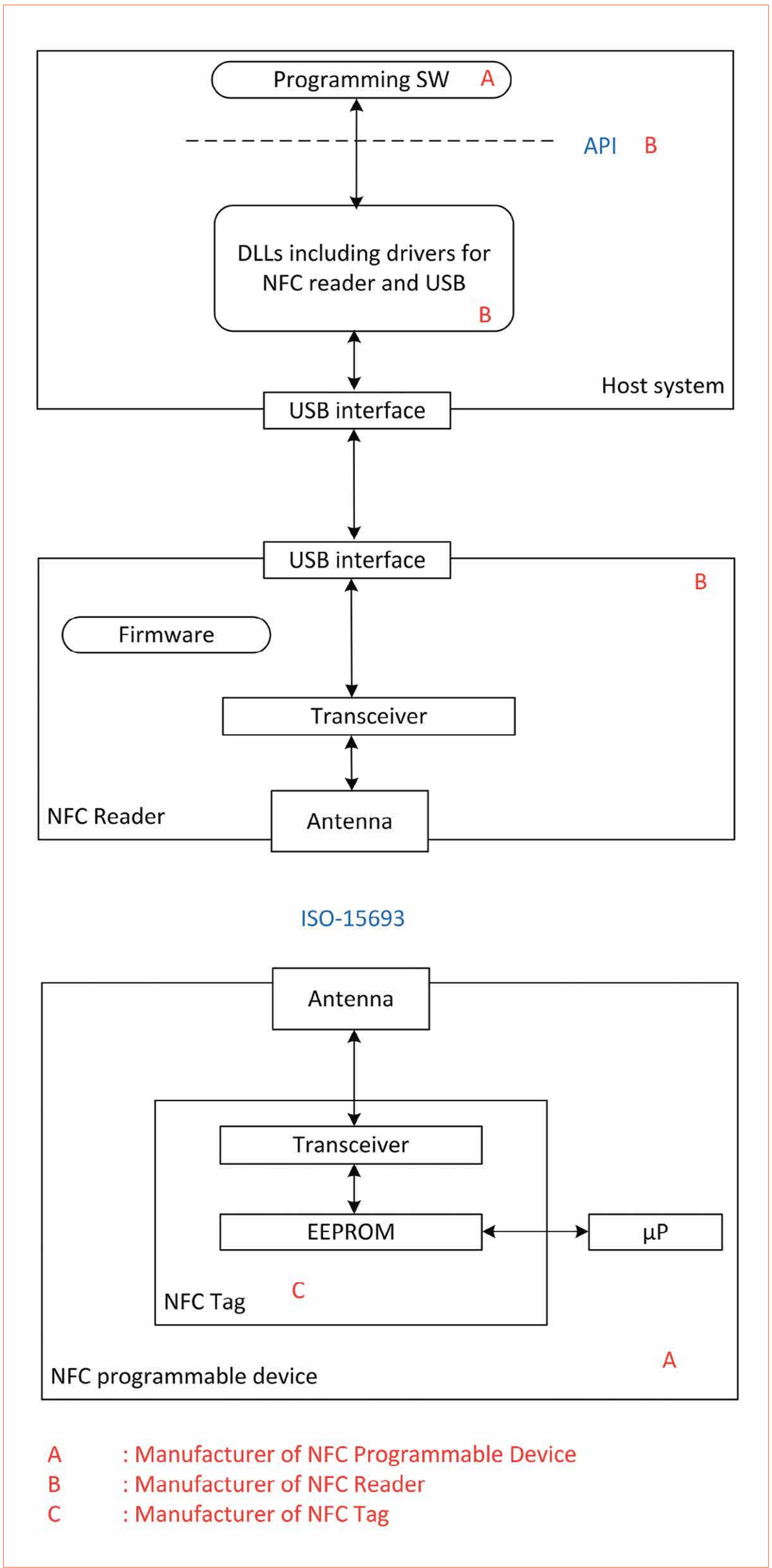
MD-SIG NFC Specification: System Overview

The MD-SIG NFC specification for lighting components follows the general approach to NFC driver programming outlined above and depicted in figure 2, but makes it more specific by defining a number of the interfaces. The major interfaces being the one used by the programming software to access the system features and the interface between the NFC reader and the NFC programmable device.

A block diagram of the NFC programming system is depicted in figure 3. The device to be programmed is labeled “NFC Programmable Device” at the bottom of this diagram. This can be any electronic device. The target application is the programming of LED drivers; sensors and network transceivers would also be in scope.

The NFC Programmable Device features an NFC Tag and associated antenna. The antenna is mounted in the device in such a way that it can be used for NFC data transfer without opening the device. The NFC Tag holds an NFC transceiver interfacing to the

Figure 3:
NFC Programming system - overview



antenna and an EEPROM for storage of data. The NFC Tag also features an interface that allows the microprocessor of the NFC Programmable Device to access the data in the EEPROM.

The hardware required for NFC communication with the NFC Tag is implemented in the NFC Reader. This device holds an antenna and a transceiver for NFC communication, an interface to the host system and a memory component storing the Firmware of the NFC Reader.

The rest of the system is implemented in software running on a host system, typically a PC. Software libraries (DLLs) and drivers allow for control of the NFC Reader. The DLLs provide an Application Programming Interface (API) which is used by the Programming Software. This Programming Software holds the user interface for NFC programming.

Figure 3 is the basic block diagram of the NFC programming system. The standard is more flexible and allows variations for some of the details. E.g., the USB interface between host system and NFC Reader is just an example. In practice it can be any common computer interface like TCP/IP. Similarly, the NFC antenna of both the NFC reader and the NFC programmable device may be implemented internally or externally, as a separate device.

MD-SIG NFC Specification: Separation of Concerns

It is good to point out various providers come into play to implement an NFC programming system. This is also depicted in figure 3.

To implement an NFC programming system requires hardware and software from:

- The manufacturer of the NFC programmable device
- The manufacturer of the NFC reader
- The manufacturer of the NFC tag

For a good understanding of the MD-SIG NFC specification for lighting components it is important to realize that the different components in the NFC programming system are provided and are under control of different providers. Manufacturer A supplies and has control over the NFC Programmable Device and the Programming SW for programming NFC Programmable Devices of brand A. Manufacturer B supplies and has control over the NFC Reader hardware, the NFC Reader firmware, the NFC Reader software libraries including drivers for the NFC Reader, and the Application Programming Interface (API).

Manufacturer C supplies and has control over the NFC Tag,

The MD-SIG NFC specification defines interfaces to provide for the appropriate separation of concerns between these different providers. By adhering to the standard interface specification, they can develop their products in relative isolation; yet, the products can be used together to implement an NFC programming system.

MD-SIG NFC Specification: Additional Details

The LEDset NFC specification describes the appropriate interfaces between the components in the NFC system and features a list of mandatory requirements and recommendation for the LED driver interface (or another NFC programmable device), the interface to the NFC reader and the programming software.

The interface between the programming software and the NFC reader is specified through a list of supported software commands. These commands are supported by all qualified readers through the provided software libraries, and ensure that the programming SW of a specific brand is compatible with all Qualified NFC Readers. Next, the specification has a number of recommendations to ease the co-existence of multiple NFC programming software packages on one host PC.

The communication protocol between NFC reader and LED driver is specified to ISO/IEC 15693. A minimum set of ISO/IEC 15693 commands is selected to be supported by LED driver and NFC reader. It is also required that NFC Reader manufacturer shall support download of firmware in the NFC Reader by the Programming SW. There is no requirement for a minimum programming distance between NFC Reader antenna and the NFC Programmable Device. Information on programming distance should be provided in the datasheet of the device.

MD-SIG NFC Specification: Market Update

MD-SIG has published a list of compliant NFC products. These comprise qualified NFC readers and qualified NFC tags, to be used in the drivers. The MD-SIG website maintains a list of qualified readers. The MD-SIG NFC specification comprises a list of tags that have been qualified. A number of driver manufacturers have already introduced compliant drivers and programming software to the market.

Conclusion

The MD-SIG has created a specification for NFC programming of LED drivers, which makes it easy for luminaire manufacturers to use NFC programming in a production line where multiple brand drivers are used one after the other. LEDset NFC compliant equipment and software enables luminaire makers to streamline their production and to use LED drivers from different vendors using the same programming hardware. Drivers and software complying with this standard are on the market already from leading driver manufacturers.

Members of MD-SIG have access to the NFC programming specification [1], which describes the system setup and the requirements that are mandatory to achieve compliance of the programming software, the NFC reader, and the LED drivers and other luminaire components.

References:

[1] More information can be obtained from a.rupp@osram.com or secgen@zhagastandard.org

Bluetooth Mesh Protocol as Applied to Lighting

Little more than one year ago, Bluetooth SIG released the Bluetooth Mesh standardization. Meanwhile, it has become widely adopted and is also one of the favorite systems for lighting controls. Russ Sharer, Vice President of Global Marketing and Business Development for Fulham, starts with an explanation of the Bluetooth Mesh protocol as applied to lighting control and defining its key elements. In a second portion of the article, he answers questions that lighting control evaluators could be asking their vendor.

Every so often, a technology comes along that captures the attention of lighting professionals. Some become widely deployed, others remain just outside mass deployment, and some just die. Lately, using Bluetooth mesh for lighting control has become a much-hyped technology. But why?

Bluetooth mesh offers an open wireless communications standard that is scalable. It's also extensible to provide control and energy management for other systems, which makes LED lighting controls more valuable and the foundation for building automation.

Bluetooth Mesh - The Right Balance of Reliability and Ease of Use

Lighting, after decades of very little modification, is on the cusp of significant change. From the time Edison (or Swan or Davy or whoever) invented the lightbulb, the industry slowly evolved over a century. People's first, and usually, only thought was lighting for illumination. But now lighting has entered the conversation over energy usage and optimization, human and plant health, productivity, and much more. Lighting is also at the center of the largest potential discussion of them all - the interconnection of devices, sensors and machines into an Internet of Things (IoT). Overhyped far ahead of its reality, regardless, IoT is having an impact on how lighting is being connected and controlled, since lighting has emerged as the best endoskeleton for device interconnection. But this communication requires a common language.

Today, lighting controls come in many different options and can do many different things. They can be wired or wireless. They can be a multitude of different protocols, both standardized or proprietary. The inclusion of sensors adds even more value, and creating apps make it all come together. While there are many options available, one option appears to be taking the lead in terms of ease of use, functionality and availability: Bluetooth mesh.

Over the last three years, I have had many conversations with lighting industry professionals, and those discussions explain why Bluetooth mesh will be the most successful technology used for lighting control ever.

What Bluetooth Mesh Makes Different

Bluetooth is a wireless specification developed by Ericsson late in the last century and now controlled by the Bluetooth Special Interest Group (SIG). Everything relating to the Bluetooth mesh standard is now developed by the Bluetooth SIG, in conjunction with its over 33,000 members in 150 countries. The Bluetooth SIG develops the specifications and operates programs to ensure products comply with said specifications. Bluetooth mesh specifies all levels of the communication to ensure an interoperable environment. By the Bluetooth SIG being so forward looking, it has created an eco-system of various industries, running on the same platform. Nowhere else can you find lighting products, various types of sensors, HVAC devices, building automation devices, etc., using the same technology, allowing the potential

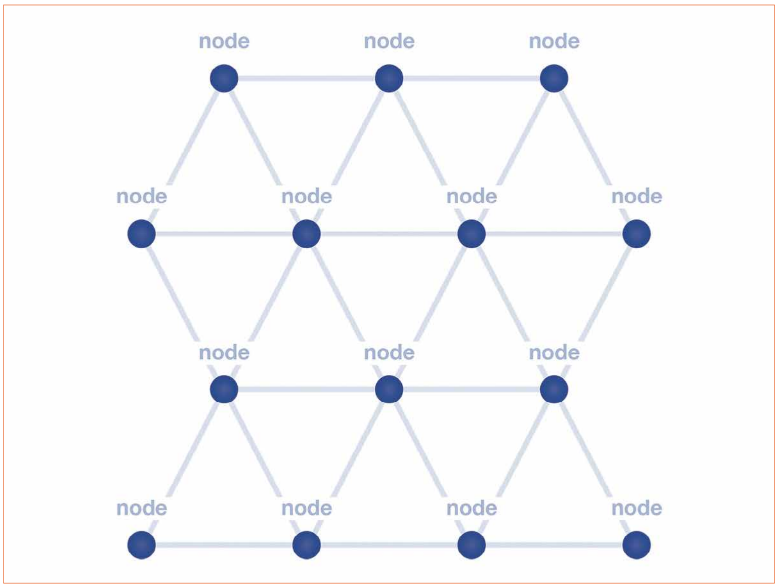


Figure 1: Scheme of a BT mesh connection structure as defined by Bluetooth SIG

Figure 2: Basic BT message communication format

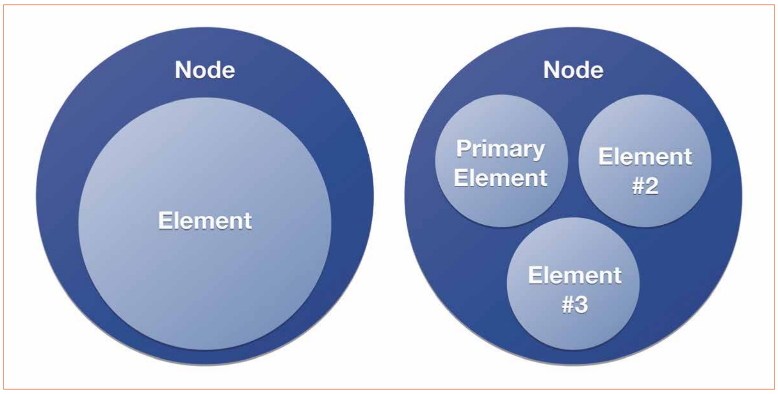


Figure 3: Basic BT node structure - nodes have at least one element, the primary element, and may have one or more additional secondary elements

of a fully converged, interoperable building. Not to mention that all mobile phones, tablets and PCs this year, will ship with integrated Bluetooth capability, making the system even more prevalent.

Bluetooth was originally specified with a connection structure of Point-to-Point (1:1), then after a few years added Broadcast (1:m). Point-to-point is the most familiar topology, where a single device communicates to another single device, such as a phone sending music to a wireless headset. Yet whatever the connection mechanism, any Bluetooth device can talk to any other.

Bluetooth devices are commonly referred to as nodes once they are provisioned. Provisioning is a secure process that typically involves an application on a handheld, smart device issuing the unprovisioned device a series of security keys that allow it to become part of the Bluetooth network. Once provisioned, nodes have state values that reflect their condition and are shared with the network. This could simply be ON or OFF or a value, such as 50 percent brightness. These state values can be queried by another node or changed through messages.

In July 2017, the Bluetooth SIG added the mesh connection structure, giving each node multiple paths to the nodes closest to it (Figure 1). Mesh (m:m) networks allow nodes to have two-way communication between each other, sending and receiving messages throughout the network. Nodes communicate with each other by sending and receiving messages formatted in multiple byte frames (Figure 2). There are two types of messages on a Bluetooth mesh network: access messages and control messages. Application level communication involves access messages. Access messages act upon state values; changing them, retrieving them or delivering them to other nodes in the network. Changing a state value would typically change some physical aspect of the device, like switching it on or off. Control Messages are messages that concern the operation of the Bluetooth mesh network, such as managing relationships of nodes or determining the distance between nodes.

Wireless mesh networks have been around for a while, but Bluetooth mesh is unique and beneficial because it does not need a router or a gateway to collect and distribute commands or data. Instead the network relies on each of the nodes relaying messages from the source node to the destination. Additionally, because messages are transmitted using flooding and are broadcast through multiple nodes, there is no single point of failure; if a single node fails, the messages will simply broadcast to its intended node though different nodes. Flooding means there are generally multiple paths that a message can make it to a node. If a node goes down, the message will still arrive at its destination.

Bluetooth Mesh Networks Are Scalable

Each node in a Bluetooth network is an addressable entity, called an element. Each node has at least one element, the primary element, and may have one or more additional secondary elements (Figure 3). The number and structure of elements does not change throughout the lifetime of a node, as long as it is part of a network, i.e., a switch will always be a switch, a sensor a sensor and a luminaire a luminaire.

Additionally, Bluetooth mesh uses a system of various address types to identify individual elements or sets of elements. There are three primary addresses in a Bluetooth network and a fourth special address type.

Bluetooth network address types:

- Unicast address: uniquely identifies a single element, assigned to devices during the provisioning process
- Group address: a multicast address that represents one or more elements. Group addresses are typically used for multiple nodes in a specific space, such as a room or part of a room
- Virtual address: a way to label a group of like nodes to communicate mesh messages with the full group with the same virtual address, regardless of location, instead of addressing specific unique addresses
- Unassigned address: a special address type used to indicate that an element has not yet been configured or does not have a unicast address assigned to it

The primary element is addressed using the first unicast address assigned to the node during provisioning. Each additional secondary element is addressed using the subsequent addresses. These unicast element addresses allow nodes to identify which element within a node is transmitting or receiving a message.

The maximum frame in which a message can be encased is 215 bytes, and when it communicates over Bluetooth 4.2 radio will transmit at 1 megabits per second at distances of up to 60 meters.

The latest Bluetooth 5 spec allows low-energy transmissions to sacrifice data rate for more range, up to four times the range of Bluetooth 4.2 Low Energy, for a maximum of around 100 meters. That's a theoretical maximum, although it's still going to be a huge improvement over older versions of Bluetooth.

Another attribute that varies the transmission distance is the Class of Bluetooth radio. Most of us who have used Bluetooth with our mobile phones realizes that the connection decays and breaks after 4-5 meters. That's because phones and the kinds of devices it attaches to use a Bluetooth Class 1 radio - mostly due to its low power usage. For lighting control, most devices will use a Class 3 radio - extending the transmission distance to over 100 meters.

In addition to the ability to extend range at the expense of bandwidth, Bluetooth 5 adds a new interface to double bandwidth at the expense of power. This new physical layer (PHY) supports speeds of up to 2 megabits per second and higher with transmission power of +20dB in low energy mode.

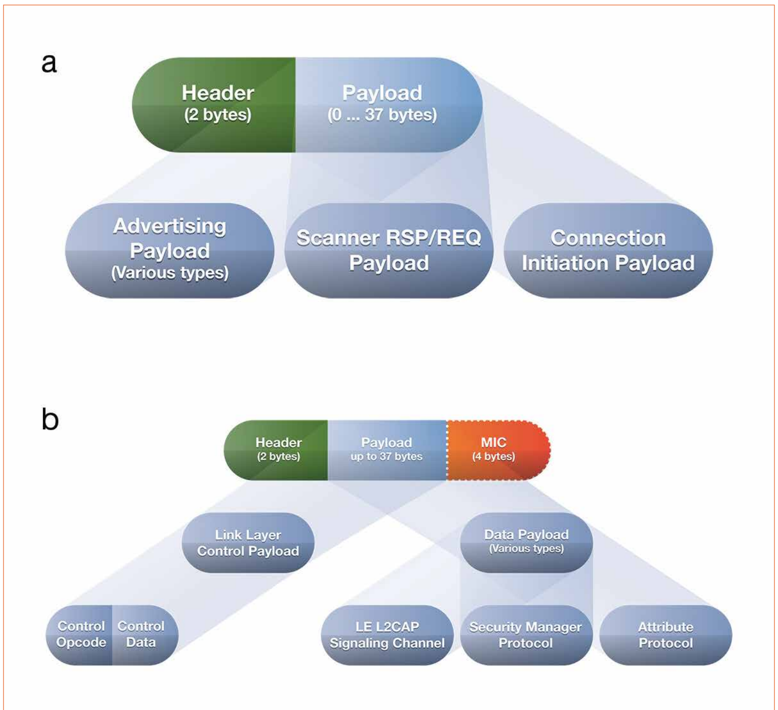
In other words, the new Bluetooth version offers two interfaces for low energy operation: one to transmit less data over much longer distances, and one to transmit twice the data over a shorter range.

This is great news for devices that need to transmit bursts of large amounts of data (like a firmware update) or for data-hungry applications like audio or video. And, most importantly, Bluetooth 5 is backwards compatible with the older version.

The Bluetooth frame addressing size is 4 bytes. When you do the math, the theoretical maximum number of nodes in a Bluetooth mesh network is 32,767. In real world networks, a network will likely consist of thousands of nodes, and for lighting expect group sizes that more closely align with today's number of lights on an electrical circuit - say 50 to 200. Each circuit can therefore become a sub-network of the overall Bluetooth network.

When considering Bluetooth mesh scalability there are practical limitations for indoor use that can limit the network size. The distance between nodes also is dependent on the material between nodes, such as walls or floors. The more material and the denser the material, the shorter the range becomes. Other variables that will affect distance include the output power of the transmitter, the sensitivity of the receiver and the antennas. In a typical, commercial office trial,

Figure 4: **More detailed structure of the BT data transfer structure**



no problem could be recognized with nodes communicating with each other through several walls at a distance of 30-40 meters.

SIG-Qualified Bluetooth Mesh Ensures Interoperability

The Bluetooth SIG has published specifications detailing the mesh protocol and specifying each layer of the mesh stack. When vendors implement software in accordance with these standards, their products can be mixed and matched, with the proper security, on any Bluetooth mesh network.

To help ensure compliance and compatibility, the SIG has programs in place to test products to these specifications ensuring interoperability between vendor's products. Note that there are other proprietary Bluetooth products available on the market as well as other wireless mesh protocols available. While these products and protocols may follow part of the SIG specification, they do not necessarily comply totally, so other vendor's Bluetooth devices will not communicate with these proprietary products. Additionally, without following the Bluetooth SIG specification, you compromise the strict reliability, scalability and security expectations that Bluetooth mesh delivers.

It also should be noted that it is possible to adhere to the mesh standard, but still not interoperate with lighting control. To be a totally interoperable node on the mesh requires that the lighting models be implemented as well.

Messages, states and elements are put together with models, which are messages that change the state of a node (Figure 5). Models define and implement the message types, state values and associated behaviors that govern a particular aspect of a node. A node can implement one or more models, and the functionality of any node is determined by the combination of models it implements.

While the mesh specification defines lots of different models, there are three basic types of models: client, server and control. Server models contain state, while client models do not; clients only interact with servers by sending and receiving messages. Control Models are a combination of both clients and servers. In all cases, models publish and subscribe to a variety of defined message types, which act upon or report server state values.

All Bluetooth SIG-qualified products, including mesh implementations, are listed on the Bluetooth SIG website.

Flooded Mesh Is Efficient and Robust

A flooded mesh or managed flood approach is the easiest way to enable simple, reliable and scalable mesh networks. The managed flood messaging approach of Bluetooth mesh, with its publish/subscribe group-messaging model, supports extremely efficient messaging for high-performance, large-scale networks.

In a lighting control system, it is important that the correct nodes receive their messages and act accordingly, so Bluetooth uses a publish/subscribe model of communication. Nodes that generate messages publish or send messages, and nodes that receive the messages subscribe or accept messages. At provisioning time, nodes are configured with destination addresses to which they will publish messages or messages to which they will subscribe.

Nodes only respond to messages published from addresses to which they have subscribed, and all others are ignored. When a node publishes a message to a group address, it does not need to know the individual addresses of the nodes that will receive the message. This means that if the set of nodes which have subscribed to that address changes, for example when a new light is added in a particular room, there is no impact at all on the light switch; it will continue to publish ON/OFF messages to all the lights in the assigned group.

In a mesh network, a large percentage of messages will be multicast to group addresses and virtual addresses. If nodes in the same room need to receive a message, the message will not need

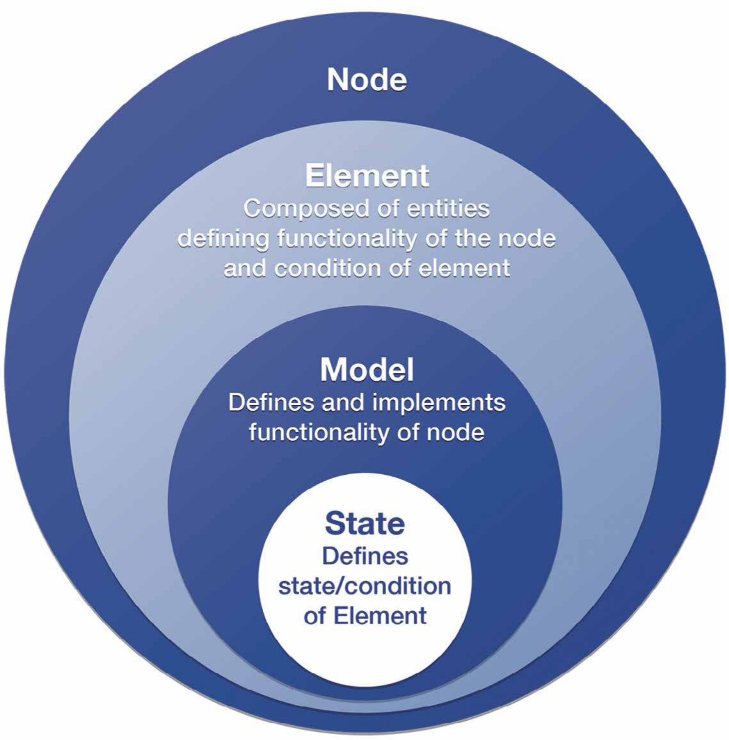


Figure 5: Messages, states and elements are put together with models, which are messages that change the state of a node

to look for specific addresses where it needs to send the message; it will flood the message out and the nodes that are assigned to that group will subscribe to the message. A flood approach is the most efficient method for multicast messages.

There are a number of optional characteristics that a node may possess, giving it additional, distinct capabilities within a Bluetooth mesh network. One of these unique characteristics, which is a significant feature of Bluetooth mesh for lighting control, is an energy optimization mechanism called friendship. Some nodes, like sensors, operate using very low energy powered by a small battery that must last for years, or using energy harvesting technology with no batteries. These nodes are referred to as low power nodes or LPN. Other nodes, such as those connected to mains power, have a plentiful supply of power. An LPN will form a partnership with one of the nodes with abundant power; these nodes become friend nodes. A friend node allows an LPN to conserve its limited power by storing a cache of all incoming messages and relaying messages on behalf of the LPN. The friend node stores those messages addressed to the LPN and delivers them when the LPN wakes and requests the messages. Additionally, the friend node delivers security updates to the LPN.

Some people feel that a flooding approach is a waste of bandwidth and creates unnecessary noise because a single message, in theory, could be sent through almost every node in a network. Frequently the argument is heard that the message could continue on forever, hopping from node to node indefinitely. Bluetooth mesh limits the number of hops with a field called TTL (Time to Live); TTL limits the number of hops to no more than 127 hops, although practically, the TTL is set to a significantly smaller number. Bluetooth mesh adds extra intelligence to the system to maximize the efficiency of the hops by requiring all mains-powered nodes to send status updates, called heartbeats, at regular intervals. Heartbeats allow the network to learn its topology, and therefore learns the number of hops to reach each node. This allows each node to set the TTL to the most efficient value. Additionally, every node contains a message cache that looks for duplicate messages to discard to eliminate unnecessary processing further up the network. Bluetooth is optimized for small amounts of data, such as single commands or reports; it is not intended for data-streaming or high-bandwidth applications.

For applications such as lighting control, flooded mesh is easier and more efficient to deploy and manage than routed mesh. Routed networks are much more complicated because each node needs to be assigned a function, such as a routing node, central hub or coordinator. Then a routing table and algorithms are used to tell messages which path, or which nodes, a message should take. This creates a chance for significant network interruptions and creates potential for a single point of failure. It also increases the cost of each node in the system.

Bluetooth Mesh Is Designed To Be Secure

Bluetooth mesh was designed with security as its highest priority. First, security in Bluetooth mesh is mandatory. Nodes, the network and individual applications cannot be compromised in any way because of a multitude of fundamental security measures. Bluetooth is concerned with more than just securing individual nodes or connections between nodes, it is concerned with securing the entire network.

Security with Bluetooth mesh starts with the nodes but doesn't end there. Nodes are provisioned using 256-bit elliptic curves and out-of-the-box authentication. Messages also are secured using AES CCM authentication and encryption with 128-bit keys; each message has a minimum of 64 bits of authentication, with the possibility to have up to 1088 bits of authentication for the longest messages. Not only are all messages encrypted and authenticated, but encryption and authentication also take place at the network and application layers.

To further enhance authentication and encryption, Bluetooth mesh separates network security, application security and device security, addressing each independently using application keys, device keys and network keys. Additionally, these security keys can be changed during the life of the mesh network via a key refresh procedure. There also is isolation in Bluetooth mesh networks so they can be divided into subnets, each cryptographically distinct and secure from the others.

All of these Bluetooth mesh features prevent any kind of security attack that is currently known to man. Brute-force attacks are prevented by using 128-bit keys with a minimum of 64-bit authentication on every message. Replay attacks are stopped by using a new sequence of numbers on every message sent and checking those on every message received. Man-in-the-middle attacks are avoided using ECDH cryptography during provisioning with out-of-band authentication. Trashcan attacks are prevented using a key-refresh procedure, allowing keys in all remaining devices and blacklisting the removed/broken devices; in other words, should someone disassemble a thrown-out device it can't reveal any security information. Physically insecure device attacks are eliminated by permitting devices in an insecure location to have separate keys to those in a secure location; for example, this stops someone from accessing a Bluetooth luminaire and sending a message to unlock a door. Visitor attacks are prevented by giving guests and visitors temporary and limited access to the network using a separate set of keys; these guest keys have a limited lifetime. Also, Bluetooth mesh uses a message obfuscation procedure. Since there are no identifying values, such as the source or destination address, an attacker cannot know where a message was sent, thus protecting the user's identity. Each time a message is relayed, this obfuscated information is changed, removing the ability to track message flow.

Why Bluetooth Mesh Is the Preferred Wireless Addressing Standard

There are wireless alternatives to Bluetooth mesh. Zigbee, for example, is a mature wireless competitor for lighting control with a variety of products available on the market today. While there are some benefits to the use of ZigBee, there are concerns that have prevented its wider adoption, including system cost, security and reliability. First, a Zigbee network is dependent on a gateway to form and administer the wireless network. The theoretical maximum number of notes per network is 240; anything with more nodes will need another gateway and will have to be treated as a separate network. Speed is a concern in Zigbee, which can transmit ~250 kb/sec versus 1,000 kb/sec with Bluetooth mesh. The maximum node limitations and the slower speed greatly limits the scalability of Zigbee in large projects, especially if the network controls more than just lights. Furthermore, Zigbee does not specify the full stack, so there are interoperability issues. In other words, not all Zigbee products can easily communicate with each other.

Thread is another wireless mesh network protocol based on IPv6. Like Zigbee, Thread does not specify the full stack (in Bluetooth terminology models) so there is little interoperability between vendor's applications. At provisioning time, Thread takes a two-step approach: one step to set up network and a second step to add logic, such as creating rules and zones; with Bluetooth, all of this takes place in a single step. Thread also needs a gateway or hub for the devices to communicate. All of this limits the scalability of a Thread network.

Taken together, along with the fact that the use of Bluetooth in so many consumer products makes the cost of silicon very low, Bluetooth mesh clearly offers a simple to use, scalable, interoperable and robust low-power communications structure on which to build lighting control systems. Unlike any other wireless technology, including Wi-Fi which has significantly higher power usage levels, Bluetooth and its mesh communications topology and lighting models will deliver the promise of lighting control at a reasonable price point, which can be extended for other IoT applications. ■

Enriching Horticultural Lighting for Faster Growth and Better Crops

Horticulture lighting is no new lighting application, but it gained momentum with the introduction and evolution of LED lighting, and it is meanwhile one of the fastest growing markets in lighting. Dr. Richard Blakey, Application Engineer at Würth Elektronik eiSos, explains how LED-based horticultural lighting can deliver even bigger advantages for commercial growers by introducing additional wavelengths that increase photosynthetic response - like Würth Elektronik's new members of the WL-SMDC SMD Mono-Color Ceramic LED Waterclear family that is used as a reference in the article.

LED lighting technology presents a strong case for commercial growers to upgrade from traditional horticultural lighting, often utilizing high-pressure sodium (HPS) lamps. LED-based alternatives consume less power, and so can significantly reduce utility costs. Radiated heat is greatly reduced, which gives growers more control over the climate inside greenhouses and prevents burning and drying of the plants. This also allows lamps to be placed nearer the plants, which not only enhances utilization of greenhouse space but also gives flexibility to use extra lights for filling-in shaded areas.

As if these advantages were not enough to have growers of any types of crops, from flowers to food, chomping at the bit to join the LED-lighting revolution, there is the added advantage of the superior controllability that allows LED light to be tuned for maximum emissions at Photosynthetically Active Radiation (PAR) wavelengths. Moreover, as LED technologies continue to move forward and our understanding of plant biology and responses to light to various wavelengths continues to evolve, the characteristics of the emitted flux can be engineered even more precisely to potentially optimize the appearance, market value, and growth rate of plants and further boost returns for growers.

Improving Spectral Content

Red and blue wavelengths are known to encourage photosynthetic activity, and are easy to generate using LEDs. Early LED light engines for horticulture have tended to concentrate on these wavelengths. However, several other wavelengths are known to encourage plant growth. Future generations of lighting products that include the right quantities of these additional wavelengths could further accelerate growth and improve plant quality.

To understand how, we will first look at the multiple aspects of plant growth that are connected with exposure to light.

Then we will assess how individual wavelengths stimulate these responses, to understand how a wider range of wavelengths besides plain red and blue are needed to maximize plant growth, quality, and health.

Then finally we will analyze the other important factor that constitutes the light recipe: the intensity of each wavelength incident on the plant's surface. The intensity must be optimized to ensure the desired qualities in the end product: ensuring the best possible appearance among plants for decorative purposes; better taste, texture and nutritional content of food crops; and higher-yielding plants such as Aloe Vera, as cultivated for the production of latex.

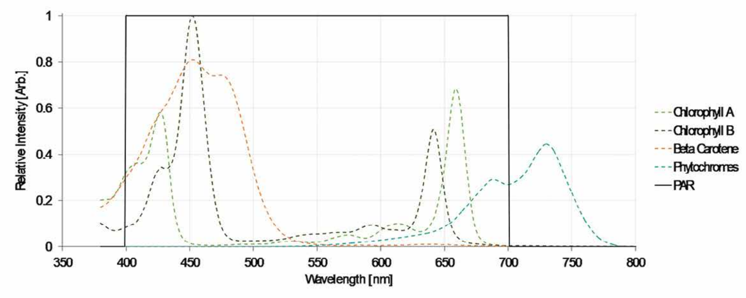


Figure 2: Characteristic absorption spectra of different pigments used for photosynthesis [1]

Understanding Plants to Create Better Lighting

Photosynthesis is the process that converts water and carbon dioxide into complex carbohydrates (i.e. sugars) and oxygen using energy from light. However, although the energy radiated by the sun that reaches the earth's surface consists of the entire spectrum of visible light (and more), plants utilize light within a limited range of wavelengths for photosynthesis.

The wavelengths used are related to the absorption characteristics of the different pigments present within organelles called chloroplasts that are responsible for different functions of photosynthesis. Most of these pigments absorb light in the wavelengths that correspond to the colors blue and red. This explains why most leaves appear green, as these wavelengths are not absorbed, and why carrots appear orange, as they contain very little chlorophyll. The most common pigments are chlorophyll A, chlorophyll B and the carotenoids.

The range of wavelengths absorbed by plants is referred to as photosynthetically active radiation (PAR). It corresponds to wavelengths in the 400-700 nm range. Chlorophyll A is the primary photo-pigment accounting for around 75% of photosynthetic activity and has absorption peaks at approximately 435 nm and about 675 nm. Chlorophyll B, once thought to be an accessory photo-pigment, extends the range of wavelengths that can be used for photosynthesis with absorption peaks in the region of 460 nm and about 640 nm.

Energy from these wavelengths is captured by chlorophyll B and then passed to chlorophyll A through electron spin resonance. All higher plants have these two pigments, which accounts for their green color.

Carotenoids have a comparatively much wider wavelength absorption range than the chlorophylls with an absorption range from about 400-510 nm. In addition to their accessory light-harvesting function, more recent research has revealed further roles of carotenoids: for example, their absorption wavelengths overlap with those of the chlorophylls as they protect the chlorophylls from photo-oxidation when light intensity is high in the short-wavelength high-energy ranges [2].

In addition, plants have a variety of photoreceptors that are critical to plant development yet have absorbance wavelengths mostly outside the PAR region. These include phytochromes, which regulate processes like chlorophyll synthesis.

Several other responses are linked to the intensity and spectral content of light reaching a plant's surface. These include responses to growing in the shade, circadian rhythm, circannual rhythm and weather variations, and can have a strong influence on photosynthesis rate, photomorphogenesis (plant anatomy), phototropism (direction of growth) and photonasty (non-directional changes such as flower opening). All are dependent on a wide variety of photoreceptors and can be particular to specific orders, families and genus of plants [3].

Improving our understanding of the numerous ways in which light influences plant development can highlight opportunities to further improve artificial lighting, aiming to orchestrate and optimize growth for bigger and better crops and greater commercial performance.

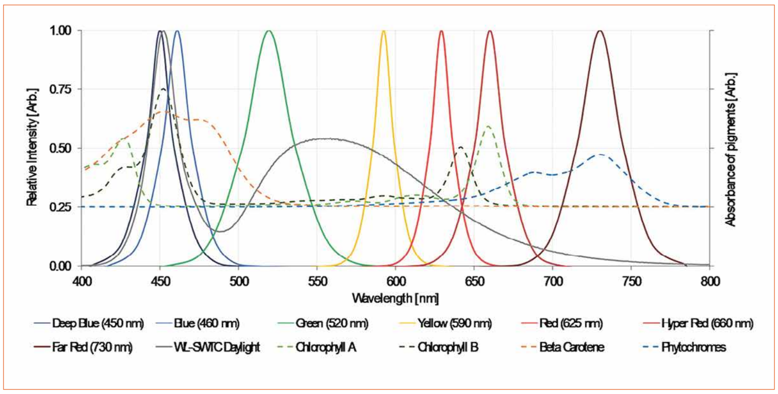
Richer Spectral Palette

To identify ways to improve horticultural LED lighting, let us first acknowledge that red light in the 630–660 nm range is the main driver of photosynthesis. It is not only essential for the growth of stems but also regulates flowering, dormancy and seed germination. Blue light from 400-520nm is another major driver of photosynthesis. It is also linked to the regulation of chlorophyll concentration, lateral bud growth and leaf thickness. However, over exposure can inhibit growth, so blue light must be carefully controlled and mixed with other wavelengths.

In addition to the red and blue wavelengths, it is becoming apparent that green, far-red, deep blue, and ultraviolet wavelengths are also needed to stimulate the wider variety of beneficial responses.

Green light (500–600 nm) was once disregarded as being unimportant to plant development, but recent investigations have revealed that plants in the shade of others are influenced by green wavelengths as part of the "shade-avoidance response" that encourages faster growth. Artificially inducing this response has obvious value for commercial growers.

Figure 2:
Plant responses to illumination within and outside the PAR range



Introducing far-red, which is in the infrared range of the spectrum at 720–740 nm, also enhances the shade-avoidance response resulting in greater stem length. In addition, it is known to enhance germination and can reduce the flowering time of plants.

Ultraviolet in the 280–400 nm range is still highly experimental in the cultivation of plants. Studies suggest it can provide protection against fungal growth, for plants such as lettuce and tomato that are resistant to its mutagenic properties. In addition, UV may encourage the generation of certain protective secondary metabolites, molecules like anti-oxidants and phenols, which are important for human nutrition.

Superimposing photosynthetic responses on LED-emitter wavelengths as a unified image shows how artificial lighting can be tuned to provide optimized wavelengths for plant growth. Many articles have presented simplified diagrams linking red and blue wavelengths with a subset of photosynthetic responses. Figure 2 presents a more complete overview, showing how additional wavelengths can drive other essential responses.

With a richer spectral palette available, luminaire designers can pay extra attention to the differing needs of various types of plants. This includes optimizing the light recipe not only for specific species and even cultivars (sub-species) of plants, but also to better meet the needs of growers cultivating certain types of crops, such as flowers, decorative pot plants, culinary plants, or plants grown to yield natural products for use in industrial processes.

In addition to faster growing, which is always desired to reduce the time to revenue, plant characteristics can be adjusted to satisfy differing market expectations. For example, the most desirable salad vegetables have thin, light leaves for improved texture when eating. On the other hand, one of the most desirable qualities in aloe vera plants is to have thick leaves to produce a high quantity of latex. Regarding flowering, decorative plants need to maintain their flowers for as long a duration as possible. Conversely, when growing pineapples, inhibiting the flowering process enhances control of the harvest period.

To help designers create more sophisticated horticultural lighting products, especially wavelengths of 450 nm (deep blue), 660 nm (hyper red) and 730 nm (far red) are required. These wavelengths enable a diverse range of combinations that can be tailored to the needs of the target cultivar.

Completing the Light Recipe

Of course, spectral content is just one aspect of the light recipe. The intensity of each usable wavelength present is also critical.

Unlike LED lighting for streets or buildings, which is tuned to the response of the human eye and can be measured in terms of the luminous flux in lumens (lm), horticultural lighting is quantified in terms of photosynthetic photon flux (PPF) expressed in µmol/s.

A Reference for Presentation of Research Results in the Plant Sciences defines PPF as the total amount of photosynthetically active photons that are produced by a light source each second [4]. This is the most appropriate metric, because photosynthesis is a biochemical process quantified by the number of sugar molecules generated per number of photons, even though photons of different wavelengths have different energy levels. The conversion from electrical power to PPF is performed using the Plank-Einstein relation and Avogadro's number and is the sum of all photons generated in the wavelength range.

From the PPF, two further metrics can be derived that are important when designing for horticultural lighting applications. Photon efficacy, expressed in µmol/J, quantifies how efficient the LED is at creating PPF per joule of electrical energy used. This is often quoted in datasheets for horticultural lighting products as a figure of merit.

In addition, photosynthetic photon flux density (PPFD, µmol/m^2/s) quantifies the total amount of photosynthetically active photons that reach the target area per second. This parameter is highly reliant upon the distance and angle from the source, and is usually measured using a quantum meter selective to PAR wavelengths. Figure 3 illustrates how the PPF for a given light source relates to PPFD in a lighting application.

Note that the PPF and PPFD metrics are based on PAR – that is, the overall quantity of radiation present in the photosynthetically active region, from 400 nm to 700 nm. Although this has provided a sound basis to guide the early development of LED horticultural lighting, it is not adequate as a sole index for assessing future generations of products.

Firstly, it gives equal weight to all wavelengths within the PAR range, whereas all wavelengths are not equally important for photosynthesis. Moreover, as this article has observed, wavelengths outside the PAR region are now being found to have an appreciable impact on plant growth and development.

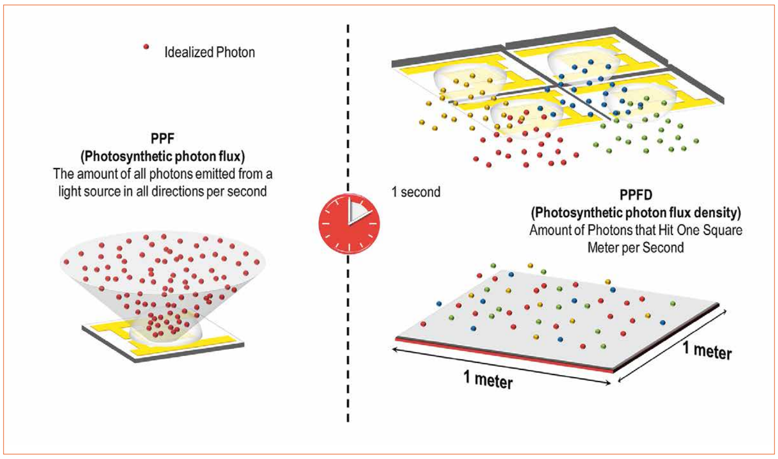


Figure 3: PPF is a product-related parameter that influences the PPFD in the target application

Optimizing the Implementation

Clearly there is scope to refine the metrics used to describe horticultural lighting products. This is needed now, due to the far more precise control over the lighting recipes made possible by ongoing advancements in LED technology. Work by bodies such as the American Society of Agricultural and Biological Engineering (ASABE) is aiming to standardize methods of measuring and testing energy consumption and performance characteristics of horticultural lighting. The ASABE has already published several standards and guidelines, which should help identify and coordinate the use of LEDs for plant growth.

The development of marketable LED horticultural luminaires is in its infancy, although some pilot schemes are beginning to yield guidance about product selection, return on investment, and effects on crop performance.

Guidelines are emerging to help prospective buyers evaluate lighting systems, and astute installers and product designers can learn from the findings to deliver better results for customers. A report by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute [5], for Lighting Energy Alliance members and Natural Resources Canada found that up to four times as many LED luminaires were needed to deliver the same Photosynthetic Photon Flux Density (PPFD) as traditional HPS lamps. So LED product designers need to be careful to ensure their luminaires indeed consume less power across an entire installation. In addition, when a large number of luminaires are installed to maintain PPFD, greater shading occurs reducing the amount of natural daylight reaching the plant's surface, necessitating a greater output from the luminaire. This can destroy the greater efficacy of LED luminaires. However, this issue will be mitigated and eventually eliminated as the performance of LEDs continues to improve.

In addition, different types of plants are known to respond differently to differing light recipes. This could enable designers to offer easily selectable presets – say in a menu of a smartphone or tablet app - that are optimized for specific crops, although the performance benefits of this are debatable.

It is very early to cite reliable data on the ultimate effects on yields. One LED manufacturer has suggested that crop yields could increase nearly 10 % by "topping-up" existing HPS lighting with tuned LED lighting, based on trials with a small sample of fruit and flower growers.

Conclusion

Although the energy savings and improved climate control made possible by LED-lighting technology are valuable benefits for growers, the opportunity to accelerate plant growth and enhance product quality to meet specific market needs is perhaps the most exciting opportunity. Acquiring the best possible understanding of plant responses to various wavelengths, and then leveraging high-quality LEDs covering all the valuable wavelength ranges, enables lighting designers to bring new products to market that will deliver even bigger and better returns for growers.

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48 VDC Integrated Drivers Offer New Options

In the telecommunication and IT businesses, especially, 48 VDC grids have become quite popular. This growing global trend to facilitate direct current (DC) power supply in building "microgrids" presents new opportunities for solid state lighting designers. TE's Lighting Industry Manager, Ron Weber, and Global Product Manager, Scott Hamilton, describe how LED lighting fixture designers can now design luminaires around a 48 VDC constant voltage input, available to take advantage of the benefits of a low voltage DC distribution grid in a building.

DC building power distribution simply has too many benefits to be ignored – nearly 95% efficiency, resiliency in outages, increased safety from shock, compatibility and ease of integration with data and communications wiring, and renewable generation and storage systems…the list goes on. All that adds up to cost savings and convenience in electrical delivery, installation and maintenance, as well as fixture and controls' bill of material (BOM) cost.

Figure 1: Integrated 48 VDC drivers offer new design options and may provide additional impetus to the transformation to DC grids

Why 48 VDC?

Very likely, the dawn of the 48 VDC age for LED illumination has a lot to do with the work of telecommunications engineering concerns who have, for decades, invested in an entire ecosystem of 48 VDC components, power supplies and cabling. More recently, this resource investment greatly accelerated and advanced as cloud computing and high performance data centers engineers started to standardize around low voltage DC distribution. These systems were first driven by the need to connect to battery back-up systems that operate at 48 VDC. The electrical and mechanical engineering work that has gone into the telecom grade power regulation and distribution components and systems to date seems certain to benefit the lighting and building electrical engineers now taking them up.

Of course, this does require a change in the building electrical when compared to a conventional AC system. DC power servers need to be added to the building electrical design layout and arrayed so one or more servers can efficiently serve an entire office building floor of luminaires. That's a small price to pay given the safety and service cost benefits that come with the easier installation and maintenance of the low voltage system and any lighting fixtures that connect to it.

For a lighting designer working on a new luminaire platform, cost and complexity can be driven out and new functionality and system flexibility can be brought in when low voltage DC (LVDC) at the 48 V level is the starting point. Eye-catching design and aesthetics are often at the forefront of a new fixture designer's requirements.
With 48 VDC, the fixture designer is freed from the AC to DC conversion engineering task.

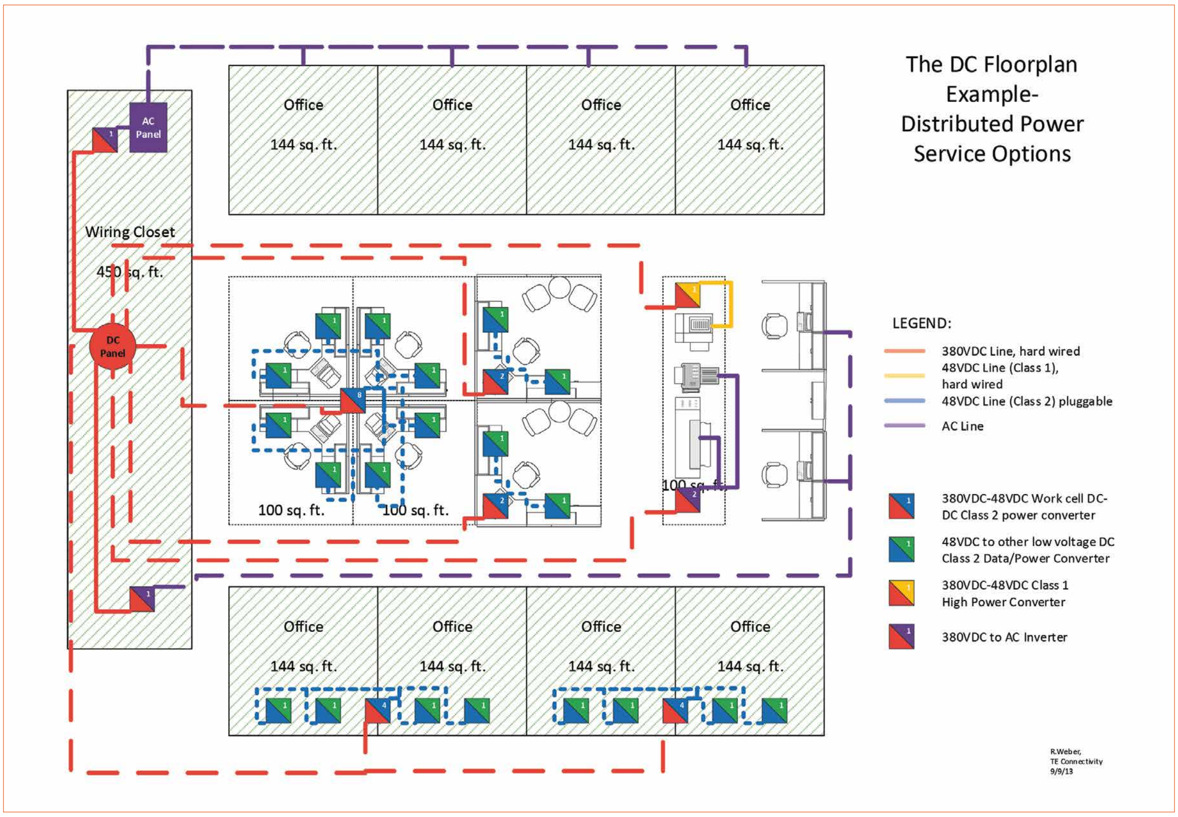

Figure 2: 48 VDC grids require a change in the building electrical system. This is what the new structure could look like

Standards Arise to Support Improvements

The advent of the chip-on-board (COB) package and its inherent low voltage DC power requirement provided a near ideal match to the low voltage DC power distribution system. Of course the early versions weren't without issues, the most important of which is that packages initially came to market with little standardization. Designing with these was no easy or simple task and resulted in a fixture design being beholden to a specific COB LED. This introduced complexity into the design process and in turn, resulted in longer and more expensive product development cycles.

Time has a great habit of sorting out complexities. The LED lighting ecosystem has benefitted in recent years from the standardization efforts jointly driven by luminaire designers, engineers and LED manufacturers. One example of this is under the umbrella of the Zhaga organization. Specifically, the development of Zhaga Book 12 that defines chip-on-board (COB) LED Holders and arrays was a great step in standardizing footprints and LED holders. This, in turn, provided fixture designers with dramatically greater flexibility in light engine design by allowing different COBs from different manufacturers to be interchangeably used in a single fixture design. Customers could now specify preferences and they could be easily accommodated by the fixture manufacturer. The designers were no longer shackled to using a specific manufacturer's LED.

During the early stages of COB development and market introduction, the lack of standardization of these packages tempered connectivity solutions. Those of us with some longevity in the LED industry no doubt recall the early "starboards" that initially entered the market and started the path toward COBs. Customers often resorted to hand soldering to these earlier board-based LEDs. That posed a whole other list of challenges since soldering to a device that by its nature is designed to pull heat away is a task left to highly skilled solder technicians.

For connector companies such as TE Connectivity, developing COB holders during that time was a challenge due to the wide array of non-standardized COB products out there.

To address this lack of standardization, the first "scalable" holder was marketed that could be adjusted during assembly. While not optimal, it did offer a solderless termination to a wide range of COB packages.

With Zhaga book 12 well codified, the ecosystem has coalesced around standardizing the size and distance between mounting screws, establishing standard light emitting surfaces and establishing preferred COB sizes. The establishment of standard COB sizes included electrical and mechanical "givens" like contact pad location and configuration. That paved the way for the standardized solderless LED holders that were so needed by lighting designers.

The availability of standardized COB holders formed a crucial element to simplify and flexibly integrate COB LEDs into their fixtures. Of course, the issue of driver integration into the fixture still remained a challenge.

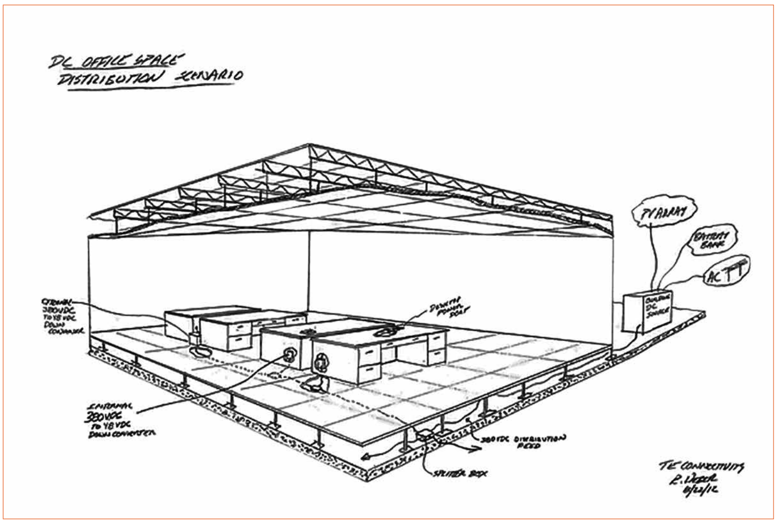

Figure 3:
Quick sketch of a possible 48 VDC grid office solution

However, the holder standardization offered a unique platform upon which to base new solutions that could eliminate this challenge.

The advent of a 48 VDC distribution system and the standardization of COB holders offered up a "perfect storm" of sorts. Unshackled from the need to incorporate bulky AC/DC conversion components, the next step in the evolution of COB holders started to gel. The empty space under a Zhaga-compliant COB holder offered an ideal location to integrate a compact constant low voltage input / constant current output DC/DC convertor. The resulting integrated driver COB holder provides luminaire designers with an option that lets them eliminate unattractive "squirted plastic and bent metal" bricks that they have been required to integrate into their fixtures for many years. Interestingly the more compact fixture designs that result from using integrated driver COB holders and the space freed up is allowing for more innovation around fixture connectivity. The added space simplifies integrating wired or wireless data connectivity modules in their lighting systems and is vital for manufacturers' future product plans and roadmaps. The more work luminaire engineering and manufacturing teams can do to support connectivity integration, the better.

In Practice - Track Lighting

Let's look at a conventional track lighting system design. On a conventional LED track lighting head, a heat sink is likely necessary which is integrated into a base that clips into the track. A COB is mounted to the heat sink and an optic that the designer has chosen is attached to the front. Next comes the challenge of integrating an AC/DC driver into the fixture. In order to house the LED driver, a separate, unsightly rectangular enclosure is most likely hanging off the lighting head.

Not only can that make the track light heads very unsightly, it adds a level of complexity to the manufacturing assembly. With a 48 VDC system that has integrated the LED driver into the Zhaga-compliant holder, the external driver box is eliminated. A track head fixture simply becomes the heat sink, COB and integrated driver holder, the track attachment base, and optic. The simplicity of this design is clear.

The aesthetic benefit of using an integrated driver COB holder is not the only consideration. By using an integrated driver COB holder, the manufacturing process is dramatically simplified because it's solderless. It also eliminates the connection between the driver and the COB thereby offering additional assembly efficiencies. Design phase choices like these can make or break a product's success in the market, because added assembly or manufacturing expense drive up the product sales price.

Product line customization is possible since you can switch the COB without any other industrial design change. If the customer wants a different color temperature or a different light output, the COB LED is fully modularized and changeable. This would certainly not be possible when the manufacturer is hand-soldering the COBs.

48 VDC without Compromise on Controllability and Flicker

The benefits of 48 VDC power in a building microgrid are clear, and the LEDs in such luminaires clearly benefit in terms of thermal characteristics, efficiency and longevity. But it is clear, too, that luminaire makers should not be asked to sacrifice on light controllability. This is a first "must have" from a fixture designer's point of view. In Europe, that means digitally addressable light interface (DALI) compliance. In North America, 1 to 10 V dimming is a must.

To simplify connectivity of power and dimming, four wires are needed for an integrated driver COB holder - two for current and two for dimming.

Given the miniaturization of lighting fixtures and a trend away from the 18AWG wires traditionally used in lighting fixtures, finer wire (such as 20, 22 or even 24AWG) can be used in these newer LED fixtures. Fine wires do pose handling challenges in manufacturing but this is easily solved by connectorizing the interface to the COB holder. That's where a fine pitch connector such as TE Connectivity's mini CT connector comes in. Properly done, this single plug and play connection of the four wires is keyed and polarized, so the assembler cannot terminate the wires to the luminaire together in any way but the correct one and no manual wire crimping errors are introduced.

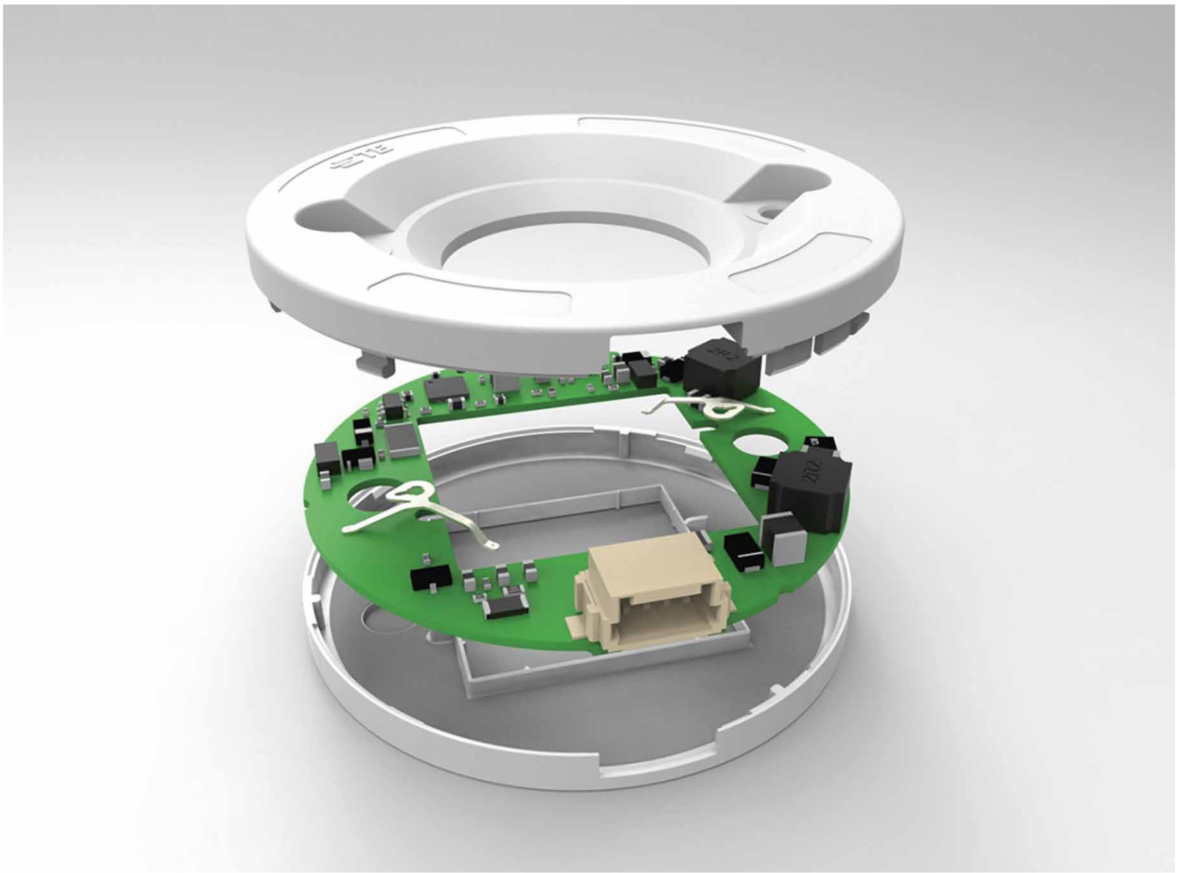

Figure 4:
The integration of 48 VDC drivers in LED holders or compact moldules must not compromise qualitiy aspects like durability and low flicker, even under dimming conditions

The second "must have" is high performance on flicker. The end customer demands a fixture that must deliver very low flicker. There can be no "weak link" in the luminaire components causing flicker since changes in illumination quality are perceptible (and often highly annoying) to the human eye. It's one of those fundamental defects that illumination engineers have sought to overcome since the very first meetings of the Illuminating Engineering Society (IES) in 1906 and 1907 [1]. These "problems involved between the production of light and the physiological effect produced by the light on the eye" are at the heart of the LED professional's engineering task.

Clearly, the quality of the LED driver circuit regulating voltage to the LED array is important, as flicker from LED sources is a direct result of variations in the current being delivered. Well-engineered and tested COB holders with integrated drivers would deliver less than 2 percent flicker at minimum dim, which as is well known, the industry considers zero flicker.

Engineering Alignment Benefits LED Lighting

Now is a fascinating time for the LED lighting professional. Standards have been sufficiently defined so component suppliers can deliver interchangeability, modularity in platforms, and attractive pricing and options for light sources and optics. 48 VDC constant current infrastructure is at hand. Integration at the holder and driver level brings design and assembly benefits. As exciting as the industry was ten years ago when LEDs first came to market as incandescent and fluorescent replacements, the promise today of new levels of illumination quality, luminaire sophistication and greater than 95% energy efficiency is just as exciting, if not more so.

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Cover-page

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Main Image: Matthias Rhomberg, LED professional

Scientific Award, LpS Award and TiL Award trophies at the Awards Ceremony and Get Together Evening at the Eilguthalle in Lindau

Next LpR

HEALTH & WELL-BEING
Issue 71 - Jan/Feb 2019

TECH-TALKS BREGENZ

Octavio Perez, Adjunct Researcher at Mount Sinai Hospital NYC
Dr. Octavio L. Perez is a passionate professional, a researcher and a scholar who contributes to exploring, developing and bringing to the real world the benefits of light and lighting for human wellbeing and wellness, and ultimately health. He won the LpS Scientific Award 2018 and LED professional interviewed him about his work, HCL and the role of LED lighting. ■

RESEARCH

"Best Papers" at LpS 2017: Implications for Human-Centric Lighting Design in Tropical Nursing Homes
Light synchronizes our physiological and psychological rhythms to the 24-hour rhythm of the ambient changes. For the elderly, adequate environments to compensate for increasing frailty and sensory loss are crucial. A pilot study aimed to explore HCL design strategies in nursing homes in Singapore. Pre-/post implementation user surveys together with quantitative evaluations were conducted. ■

Flex LED Based Smart Light System for Healing Chronic Wounds
Chronic wounds are notoriously challenging to treat, because they do not follow the typical healing process or time-frame. The resulting burden is significant, affecting over 40 million patients. Blue light is known for its anti-microbial and anti-inflammatory effects in the initial stages of the healing process. A smart, wearable system for blue-light treatment of chronic wounds has been developed and, for the first time, it has been demonstrated that blue-light illumination can offer much more than just antibacterial effects. ■

TECHNOLOGIES

Healthy Light - LED Technology for Health- and Care-Applications
The right light at any time during the day or night is absolutely essential for health & wellbeing, especially in health and care applications. The article demonstrates why mimicking real daylight conditions with extended daylight curves, a direct and an indirect component (CCT 1.800–16.000 K), besides full spectrum and high color-rendering, are essential. It discusses the benefits for the medical staff, the patients and residents that can be derived from special colors. ■

SPECIAL TOPIC

Melanopic Green - The Other Side of Blue
Numerous medical studies have shown that exposure to blue light at night suppresses the production of melatonin and so disrupts our circadian rhythms. It is therefore only common sense that we should specify warm white (3000 K) light sources wherever possible, also for street lighting. The article discusses if it is sufficient to only look at the CDT or if other wavelengths and aspects should be considered. ■

subject to change

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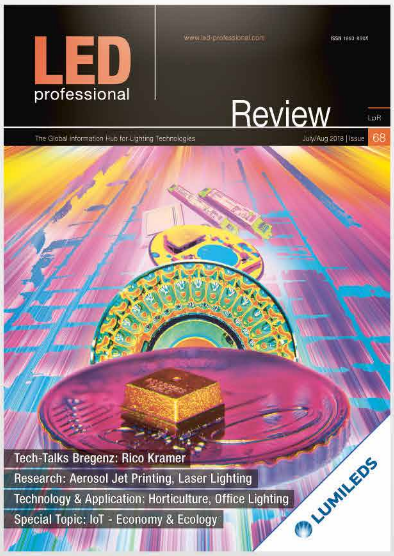

CONTRIBUTE

to the LED professional Review

EDITORIAL CALENDAR 2019

ISSUE N°	IN THE SPOTLIGHT*/**	ABSTR. DUE	ARTICLE DUE	ONLINE PUB.	PRINT PUB.
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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