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ISSN 1993-890X

LpR

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Secure Decisions in Uncertain Times

Essentially, we are all affected by the uncertain environment. Some more, some less. What can be deduced from the current situation and where are we heading during and after the Corona crisis?

Currently, there are many developments in the area of light in order for everyday life to be safe. On the other hand, we must not neglect environmental and sustainability challenges. These will likely become a central part of our orientation in the future. This issue of LpR has some very valuable articles devoted to this very topic, such as the Eco-Design regulations, the Repro-light project or the Lighting for Good initiative.

We should also consider the whole range of natural light. Spectral natural "authenticity" is good for mankind and also represents sustainable development. The new possibilities of data transmission via visible light also play a role here. We have consulted experts on this subject and will present the latest developments. But what about lighting design and the tools to enable the needed development steps? We look into "Light and Darkness", dive into Spectral Engineering and learn from the gaming industry.

What are the secure decisions?

Without question, we can state that we need a safe environment. The environment must be protected and everything we do must ensure "compatibility" for humans and animals, or let's say, nature. This is also about rethinking in terms of production and logistics. These are all challenging tasks and light can have a positive influence in so many areas. But we need this transformation at all levels. Only then will there be new, positive opportunities for all of us.

We hope you enjoy reading our carefully selected articles. Feedback from you is always appreciated.

Yours Sincerely,

Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting, LpS Digital & Global Lighting Directory
Photonics21, Member of the Board of Stakeholders
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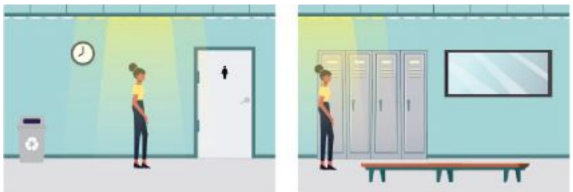
In Harnessing Luminaire Data
What Makes D4i and Bluetooth® Mesh a Perfect Couple for IoT Data Monetization?
Szymon SLUPIK, CTO at Silvair, Poland
Chair of the Bluetooth Mesh Working Group at Bluetooth SIG



ADVERTISING INDEX

Stephen A. MASON, Dr.

Dr. Mason graduated in Optometry from the University of New South Wales (UNSW) Australia in 1978. In private practice for more than thirty years, for the past decade, Dr. Mason has concentrated his interests on the development of LED light that offers beneficial effects for health and visual performance for the human eye and visuo-sensory system. Dr. Mason has been a visiting lecturer at UNSW and became a Fellow of the American Academy of Optometry in 1984. Dr. Mason spends the greater part of his time in studying and educating colleagues and stakeholders in the LED lighting community to raise awareness of the importance to the health of our eyes that we adopt best design attributes to illuminate the built environment.

Visual Performance and Cognition

An Overview

For lighting engineers, it seems that fluency in eye and brain function is becoming more important when deploying solutions for architectural lighting as we appreciate more the effect of light on cognition and visual performance.

Cognition

Many will recall the Philips 'SchoolVision' project, a hallmark in the research on the effects of light on cognition. Results for one location (Universitatsklimikum Hamburg-Eppendorf) enrolled 166 pupils and 18 teachers with psychological metrics measured over a twelve month period. By varying light volume and CCT correlated to task, the results showed a 35% increase in reading speed, 45% decrease in frequency of errors and 76% decrease in hyperactive behaviour.

Ferlazzo (2014) quoted in a review by Fabio (2015) revealed: "The study aimed at analyzing the influence of different CCT on cognitive functions, by comparing two lighting conditions with very different spectral compositions: warm CCT halogen lamps (2800 K) and neutral white LED (4000 K)… Results have shown that performance on executive functions and visuo-spatial abilities are modulated by exposure to a cooler light… participants have been significantly more accurate (higher number of hits and correct rejections) and faster response times have been registered under LED light than with halogen lamps".

It is accepted that the retinal ipRGC's are the primary zeitgeber controlling our circadian clocks. Stimulation of the ipRGC's whilst inhibiting release of melatonin from the brain ('waking us up') has the additional effect of promoting the activity of circulating dopamine- melatonin being an antagonist to dopamine. Retinal illuminance can have a profound bearing on circulating neuro-transmitters that effect mentation and the various parameters of cognition.

Dr. Octavio Perez, researcher and adjunct professor at Mt Sinai Hospital in New York, found luminance combined with strategic wavelengths influenced the relaxation and concentration of surgical teams in the OT. Further evidence for the influence of illumination on cognitive performance. Interestingly, highlighting the complexity of our sensory perception and this subject, some studies showed lighting scenarios that provided for best cognitive performance were not always those first favored for subjective visual comfort or may have required a period of adaption.

Visual Performance

The performance of the human visuo-sensory system hinges on the interaction of the optical characteristics of the human eye, the electro-physiology of the retina and its visual cortex (the brain).

Consider 'disability glare', a function of retinal stray-light caused by light scattering through the ocular media, moreso the short-blue wavelengths due to Rayleigh-type effect. Many 'white-light' LED light sources with higher CCT, have elevated wavelengths 430–450 nm and reduced wavelengths in the melanopic rich region of 470–490 nm. This compounds the problem, as the human eye relies on its sustained 'post-illumination pupillary response' (PIPR) being controlled by the ipRGC's with their maximum sensitivity at 480 nm. In short, the human eye is more likely to suffer from disability glare when exposed to white-bright LEDs with reduced wavelengths at 480 nm, the strategic wavelength needed to harmonize the pupillary response to the light volume. Furthermore, with ageing, retinal function, clarity of the crystalline lens, contrast sensitivity and dark adaptation all decline, compounded typically by a smaller and less responsive pupil. Lighting engineers need to consider a complex inter-play of factors in the design of projects to cater for a broad cross-section of the population, some of whom may possess compromised ophthalmic optics and neural processing.

The talented contributors to this LpR edition provide a window to the potential for novel solutions that can optimally influence cognition and visual performance. ■

S.M.

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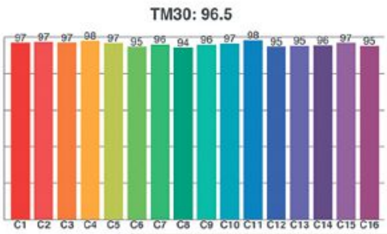

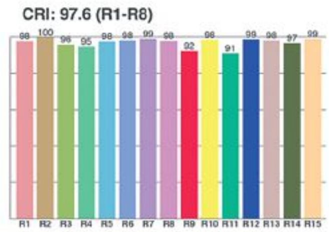

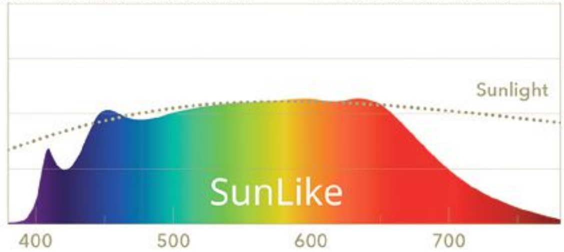

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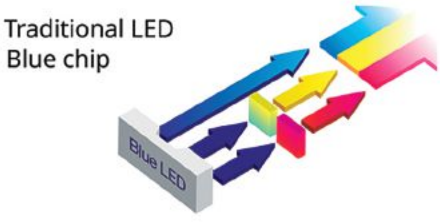

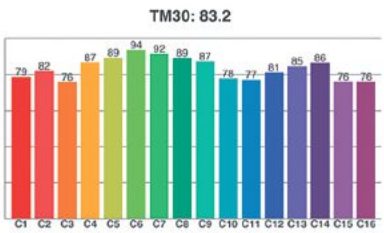

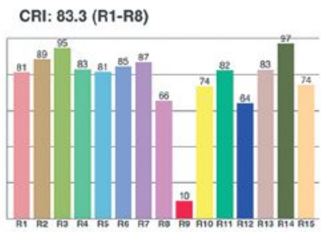

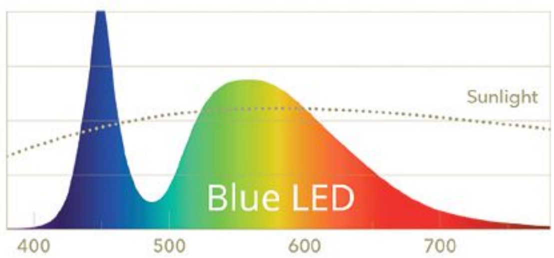

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APPOINTMENTS

Lighting — A Key Contributor to Healthy Buildings with Better Indoor Environmental Quality

By Ourania Georgoutsakou, Secretary General, LightingEurope

LightingEurope is supporting the call to scale up renovation across Europe and working hard to make sure it includes lighting. Renovation is at the heart of the European Green Deal and has been identified as a key driver for the European social and economic recovery post-COVID-19. There cannot and should not be any renovation of buildings in Europe without upgrading the lighting installations. Lighting is essential to making a building more energy efficient but also to ensure an adequate Indoor Environmental Quality (IEQ).

The EU's political commitment is backed up by financial support also. The Commission proposes to reinforce the EU 2021–2027 budget by making available an additional 750 Billion Euros under the new Next Generation EU financial instrument [1]. Given the relatively labour-intensive nature of renovation and the fact that it matches the "green, digital and resilient" ambition of the Commission recovery package, the document outlining the European Commission's proposals talks of regulatory and financial support to "at least double the annual renovation rate of existing building stock". A strategic communication on the Renovation Wave initiative and an action plan with concrete measures to deploy faster and deeper renovation is expected in the autumn.

The EU acknowledges the benefits of renovation: "cutting emissions, reducing energy consumption, and lowering household bills, safer healthier building and improving people's quality of life. It also acknowledges that an investment in renovation will create jobs and benefit the local economy." Some 75% of existing European buildings remain energy inefficient (and were constructed before legislation on building performance was in place). It is estimated that 80% of today's buildings will still be in use by 2050 and that only 1% (on average) of buildings currently undergo renovations each year.

Lighting contributes to Indoor Environmental Quality

Many perceive Lighting mainly as a driver for energy efficiency. This indeed remains one of the core values for the lighting industry, and the now mostly accomplished transition to LED technology has led to up to 90% savings for European consumers. The implementation of a comprehensive light management system will save 20 to 29 TWh per year as of 2030 (Lot 37 Ecodesign Lighting Systems [2]).

However, the benefits from lighting for the health, well-being, productivity, and safety of people are rarely seen as added value. At best, they come for free as part of the energy savings. These benefits received more attention in 2017, when three biologists were awarded the Nobel Prize for helping to explain how the human circadian rhythm works, including how light affects our daily biological cycle.

With the EU Renovation Wave initiative, the discussion must move beyond energy savings to also address healthier buildings, people's quality of life and a lower level of inconvenience. We spend 90% of our time indoors and the quality of our indoor environment has a direct and indirect impact on our health, well-being, and productivity.

But so far for most people quality is limited to heating & cooling and ventilation. The importance of good indoor air quality, for instance, is well known. The WHO relates ambient and household air pollution to a high number of premature deaths worldwide, and the term "air quality" is often used in discussions. We can also directly feel the effects of thermal comfort with heating or cooling.

We must look beyond air quality and address all aspects of Indoor Environmental Quality (IEQ): ventilation, cooling, heating, daylight, electric lighting, air-conditioning, dehumidification, plumbing and building automation and controls. The visual impact of lighting can be felt directly, i.e. we can see sufficiently to carry out our task and for orientation. The impact on our body and emotions from lighting is felt more indirectly but has meanwhile been proven in many studies [3]. With good quality lighting employees perform better, students score higher, and it improves the sleep, mood and behaviour of patients suffering from Alzheimer disease.

LightingEurope recommendations – No renovation without an upgrade of lighting installations

- Focus on non-residential buildings (public and commercial buildings), as already set out in the Energy Performance of Buildings Directive. We believe that public buildings should lead by example.
- Use LED lighting, in combination with controls and sensors. By switching from incandescent lamps to energy efficient LED lamps, it is estimated that Europeans have benefitted from up to 90% savings. Furthermore, these lighting systems, in addition to allowing for large energy savings, also offer significant benefits to the building users as regards their visual comfort, wellbeing, and productivity.
- Prioritise a full renovation of luminaires to include controls and sensors, with a minimum SRI level. "Just relamping" – simple replacement of a lamp – should be avoided. Replacing luminaires or introducing a whole new lighting design should be encouraged as this will lead to greater benefits in terms of energy savings and IEQ.
- The Smart Readiness Indicator (SRI) should be applied across the EU to maximise its energy savings potential and capture all the benefits it can bring to the wellbeing and performance of building occupants. Renovations should lead to a certain minimum SRI score.
- Introduce mandatory minimum requirements on IEQ. Criteria for lighting can be found in EN 12464-1 and should be referenced in the Renovation Wave Initiative.
- Access to public financing should be subject to the fulfilment of certain conditions. An obligation to include lighting renovation to obtain full subsidy should be introduced.
- Conditions to be fulfilled
  - Lighting should comply with EN 12464-1.
  - Use of controls and sensors, with minimum SRI level:
    - For lighting service 1a (occupancy control for indoor lighting), a minimum functionality level of 2 (automatic detection) should be required, as level 2 functionality is simple to implement and is based on established technologies that provide good additional levels of energy saving and user satisfaction as compared to level 1; and
    - For lighting service 2 (control artificial lighting power based on daylight levels), a minimum functionality level of 3 (automatic dimming) should be required, as level 3 functionality is simple to implement and is based on established technologies that provide

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good additional levels of energy saving and user satisfaction as compared to level 2.

For more information, please refer to our Position Paper on Healthy Buildings [4], Recommendations on the Renovation Wave Initiative [5] and our BetterLighting Campaign [3].

References

[1] https://ec.europa.eu/info/sites/info/files/communication-europe-moment-repair-prepare-next-generation.pdf

[2] http://ecodesign-lightingsystems.eu/introduction

[3] https://www.valueoflighting.eu/

[4] https://www.lightingeurope.org/images/publications/position-papers/LightingEurope_-_Position_Paper_on_Healthy_Buildings_-_20191122.pdf

[5] https://www.lightingeurope.org/images/publications/position-papers/LightingEurope_-_Recommendations_on_the_Renovation_Wave_Initiative_-_20200605.pdf

[6] https://www.lightingeurope.org

About LightingEurope: LightingEurope is the voice of the lighting industry, based in Brussels and representing 33 companies and national associations. Together these members account for over 1,000 European companies, a majority of which are small or medium-sized. They represent a total European workforce of over 100,000 people and an annual turnover exceeding 20 billion euro. LightingEurope is committed to promoting efficient lighting that benefits human comfort, safety and well-being, and the environment. More information is available at www.lightingeurope.org [6]. ■

Award Winning Nitika Agrawal Launches Light Dew

Nitika Agrawal

Lighting Designer **Nitika Agrawal** (NA) talks to **Trends in Lighting** (TiL) about her newly launched venture Light Dew. Following her experience in the lighting industry with AECOM, one of the biggest multinational building engineering and construction firms worldwide, and global lighting manufacturer, Zumtobel Group, Nitika Agrawal talks to us about the challenges and opportunities ahead with the launch of her own practice.

Trends in Lighting: Can you tell our readers about your journey into design and your achievements before creating Light Dew?

Nitika Agrawal: Early in my life, at the age of 5, I discovered my passion for art and design and would engage myself with complex hand drawings and artwork inspired by nature. During my summer holidays in India I would attend art workshops and learn tools like writing in calligraphy, oil painting or 3D model making with sola wood to enhance the way I communicate design. My mother introduced me to design and had been a great mentor and inspiration to me. I learnt to respond to empathy and people's emotions and translated it into my work, which helped me win awards at regional and German national levels, for example, a Unicef award, not for my design, but my poetry. Later in my life, I decided to translate my artistic and science skills into a profession that would resonate with my passion. I studied Architectural Engineering from TU Kaiserlautern in Germany, which I found too technical and less design oriented. I took a transfer to London and continued my studies in Interior Architecture and Design at London Metropolitan University with a focus on spatial design development and design thinking. As an interior architect, I always believed that light plays a vital role in the way we perceive spaces: "End to Darkness is where Light begins," which encouraged me to undertake a Master's of Science in Light and Lighting from the Bartlett at UCL. I never knew that a lighting industry existed as such and it just happened to me.

Soon after I finished my studies at the Bartlett, I started to work for AECOM as a lighting consultant, where I had the chance to work in a competitive environment and develop in depth lighting practice knowledge. I specialized in commercial, residential, hospitality, masterplan, street, heritage, and healthcare lighting. On an international level, I worked closely with architects and other building engineers that helped me to establish a broad knowledge of sustainability standards like BREEAM, LEED, SKA, ESTIDAMA, Well Standard, etc. essential for the improvement of human life quality and reduction of carbon footprint. In my spare time, I have worked on research and have presented my papers at various lighting conferences like PLDC, LFI and Lux Live, internationally. I developed confidence in my ability to design and communicate light when I first won the Spark's Luminaire Design Award for the design of Soleil, a children's healthcare fitting, in 2015. In 2017, I was awarded as one of "40 under 40" most talented lighting designers in the world at the Lighting Design Awards in London. In

2018, I received a WICE Award for being among the top 8 best construction and engineering consultants in Europe. I see the WICE Award as one of my greatest achievements to date, considering the consultant category is one of the toughest to win with over 200 applications. WICE has helped me to establish an image of a professional female role model in the lighting society and the society of building engineering. Moreover, it has given me recognition for my extracurricular activities like volunteering, promotion of STEM professions among architecture students, excellence in sports and education. The organization also prides itself on using diversity is one of their main selection criteria.

To gain an overall understanding of the lighting industry, I joined Zumtobel Group in Munich and managed lighting projects in Bavaria, Germany. I developed technical knowledge of lighting products and understood the collaboration between a lighting manufacturer and a lighting designer better.

Hewlett Packard Enterprise HQ London. Lighting Design lead Nitika Agrawal. Images and lighting design courtesy of AECOM. Contractor, Overbury

Trends in Lighting: What inspired you to make the leap and set up your own brand?
Nitika Agrawal: I have always had a dream to have my own practice. I just waited for the right time when I would feel confident enough to establish it.

Trends in Lighting: What is at the heart of the Light Dew brand?
Nitika Agrawal: Light Dew focuses on the emotional and psychological lighting requirements of the client. The lighting solution is a combination of aesthetics, design, function, sustainability and technical design resolution.

Trends in Lighting: Where do you draw the greatest inspiration from for your work?
Nitika Agrawal: "Lucis natura est et natura perfecta est!" – Light is nature and nature is flawless. I draw my inspiration for work from our mother nature.

Trends in Lighting: What do you think independent services can offer over and above larger corporations?
Nitika Agrawal: The flexibility to take projects of any size. Services can also be cheaper as they don't have large overhead costs. Flexible working hours and more flexible travel opportunities. I feel special attention and care to detail can be given to each project, because you are able to choose the projects you want to work on and decide on the workload. Working on projects you are passionate about achieves better results in overall design resolution.

Trends in Lighting: How is the current environment affecting lighting design?
Nitika Agrawal: Depending on which country we are talking about, Covid 19 has affected the lighting design industry in different ways. In general, some companies don't have enough work and had to make some of their employees redundant, some companies had decided to cut down the salaries of their employees, some had remained unaffected, some companies had even more work than before. As I have had a mixed feedback from lighting designers within my international network, it is difficult to draw a concrete conclusion.

Trends in Lighting: Can you share any tips from your lockdown experience and how you got through it?
Nitika Agrawal: I used my time during the lockdown to extend my knowledge in areas like business studies, software development and various lighting software tools. Many lighting conferences globally were held online, which allowed me to attend them without spending any time to travel to other countries. I used my time wisely to extend my knowledge by online self-studies and maintaining my social network, which allowed me to get through it.

Trends in Lighting: What advice would you give to a lighting designer considering setting up independently?
Nitika Agrawal: In general, before you set up your own independent lighting practice, you need to be confident in yourself and have an extended knowledge of lighting design and the lighting industry. You need to be prepared to answer any lighting related questions, your client may ask you, and provide the right solution. You have to be an extrovert to maintain a relationship with clients. You may have to work harder, most of the time on weekends too, to get the initial projects. You need to have a structured business plan and outline the risks involved and look at the financial investments. You have to be confident about your goals and have a clear vision for the growth of your company in the future.

About: Nitika Agrawal is an award-winning Lighting Designer with a diverse international background. One of her accolades includes being a 2018 finalist as WICE's best woman consultant in Europe. She is an experienced professional lighting design consultant formerly at AECOM, adept at delivering international projects, across the UK, Middle East, Russia, Africa, Germany and India. Her lighting expertise includes; Retail, Landscape, Masterplans, Hospitals, Roadways, Offices, Hospitality and Residential. Sustainable building, health and wellbeing is at the heart of her recently launched brand providing bespoke solutions, Light Dew. Her experience in sustainability accreditation including BREEAM, SKA, ASHRAE, LEED ensures projects achieve the highest ratings. One of her luminaire designs won a national Spark's charity award in 2017. She is known as an international speaker and has delivered numerous presentations across the globe. ■

HUMAN CENTRIC LIGHTING

Ledvance Extends Its BIOLUX HCL Range that Supports Circadian Rhythms

Ledvance have launched a new range of BIOLUX HCL products which are tailored to the specific demands of healthcare environments. The new products provide biologically optimized day-night lighting which reflects natural circadian rhythms to benefit both patients and medical staff, improving sleep regularity, concentration and mood.

BIOLUX HCL products from Ledvance provide biologically optimized day-night lighting that reflects natural circadian rhythms, to improve sleep, concentration and mood

Dieter Lang, Human Centric Lighting expert at Ledvance, commented, "It is common for hospital patients to suffer from a loss of circadian synchronization, especially in intensive care units, which are often without significant quantities of daylight. A stable circadian rhythm can support good sleep and, therefore, good recovery. The Ledvance BIOLUX HCL range follows the natural rhythm of day and night by providing brighter, bluer light during the day which reduces in brightness and blue content in the evening. As a result, a healthy day-night rhythm for the patients is supported."

Besides supporting the sleep rhythms of patients, the BIOLUX HCL range can improve the well-being and productivity of hospital staff, especially in rooms which are often without natural daylight such as X-Ray or MRI rooms. Furthermore, specific lighting, designed for night shifts, keeps staff active

and alert during the late hours without desynchronizing their body clocks.

The Ledvance BIOLUX HCL range consists of a control unit, panel and downlight which communicate wirelessly with each other. The products come with a 5 year guarantee when operated as part of a BIOLUX HCL system. The control unit, operated via a BIOLUX app, enables healthcare providers to select appropriate light modes for their facilities, with 5 pre-programed lighting modes available.

Ledvance BIOLUX products now come in environmentally friendly cardboard packaging with relevant product information immediately visible on the outside of the outer box. ■

Bridgelux – New Vesta Product Line Versions

Bridgelux announced commercial availability of new versions of its Vesta product line, adding full natural spectrum white point options to the industry's largest portfolio of tunable white solutions. Vesta Thrive, the winner of a 2020 LightFair Innovation Award, leverages patented Thrive technology to deliver the closest spectral match to natural light available in an easy to use tunable white solution. As

Vesta Thrive

part of the transition to human centric lighting, there is increasing demand for "natural" light sources. The evolution of the human species has conditioned us to thrive in daylight hours by the light of the sun, and after dusk, in the warm glow of fire. Vesta Thrive enables the development of luminaires that not only deliver natural full spectrum lighting, but also allow new opportunities to personalize lighting, tailoring our environment to individual preferences or task-oriented needs.

As announced last month, Bridgelux has developed a new metric to quantify the naturalness of light. Average Spectral Difference (ASD) averages the differences of the spectral peaks and valleys between a light source and a standardized natural light source of the same CCT. With extremely high CRI and TM-30 metrics and extremely low ASD values, Vesta Thrive is the closest match to natural light available in the market.

Bridgelux is continuing to expand its portfolio of human centric lighting solutions with additional Thrive COB and linear modules including V SeriesTM V8, V Series HD V4 and V6, and EB SeriesTM linear modules. Samples of these Thrive products are available now.

"Despite the global pandemic challenges, this remains an interesting and exciting time for lighting innovation".

TIM LESTER, CEO OF BRIDGELUX

"Bridgelux is a committed technology partner, ready to help our customers navigate the transition to human centric lighting. The combination of our Thrive and Vesta Series products constitutes a unique solution tailored for natural, human centric lighting. A total solution, also incorporating our Vesta Flex driver and controls products, enables rapid integration of this exciting new technology, accelerating the development of differentiated market leading products," said Tim Lester. ■

SOLID STATE LIGHTING

Amerlux's Cubebits Sets New Bar for Linear Downlights with Extraordinary Design

Amerlux, a leading design-and-manufacture lighting company, announced a groundbreaking set of recessed linear downlights that will re-shape industry views on lighting size. Cubebits brings a whole new definition to the term comfortable lighting by bringing breathtaking visuals to the space below with a single illumination beam. It offers a 1.5" aperture profile in 3-cell, 6-cell, 9-cell or 12-cell units as well as mounting into the Amerlux Linea Pendants and Gruv recessed 1.5 linear profiles. Cubebits is compatible with Grid, GB and wood millwork ceilings. Perfect for all retail, hospitality and commercial environments, the lighting is discreetly designed in a black and white specular finished louver that exudes bold confidence.

"The old story was: the smaller you went the more glare you'd get, if you wanted to deliver the right amount of light," said Amerlux President and CEO Chuck Campagna. "With our new Cubebits line, there is zero glare on the ceiling."

Campagna summed up the novelty of this cutting-edge solution: "You don't know where the light is coming from – it's a mystery."

Cubebits offers standard dimming capabilities with spot, flood and wide flood-beam distributions, a range of color temperatures (2700–4000 K) and 90 CRI. As designers and architects ponder a new world for retail, hospitality and commercial environments, Cubebits illustrates how they can push the boundaries with subtle flair and exceptional performance that has long been at the core of Amerlux's DNA. Reliable and long-lasting, Cubebits is rated to deliver outstanding light quality of up to 2208 lm for more than 70,000 hours without depreciation.

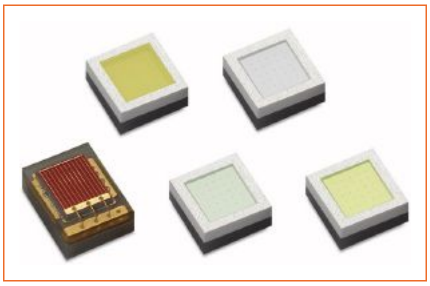
With Amerlux's Cubebits, ceilings won't be the same again for designers and architects

More information on the new Cubebits can be found at https://www.amerlux.com/Products/Interior/Downlights/Cubebits.

"Cubebits is a quiet and comfortable accent with the power to create attention and drama that designers and architects have long wished for," said Bill Plageman, vice president of marketing and product management for Amerlux. "It is poised to shake up the lighting world." ■

New LUXEON Rubix Color LEDs – High Power, Small Size and Unmatched Flexibility

Lumileds released the very small and very powerful LUXEON Rubix – a new color LED building block – designed to deliver maximum flux at drive currents up to 3A and unmatched design flexibility. With LUXEON Rubix, engineers are freed from the design constraints of pre-configured modules and can create custom arrays with smaller optics supporting smaller size luminaires.



3A capability, testing and binning at 85 °C, and a tiny 1414 package with uniform focal height puts LUXEON Rubix in a class of its own

"LUXEON Rubix introduces a size and power ratio that has never before existed for color LEDs."

LP LIEW, PRODUCT MARKETING MANAGER AT LUMILEDS

"Think of LUXEON Rubix as pixel-like – uniquely shaped arrays are possible, optics can be smaller, and exceptionally high light density allows solutions across a broad range of lighting segments to take new forms and increase their value," said LP Liew.

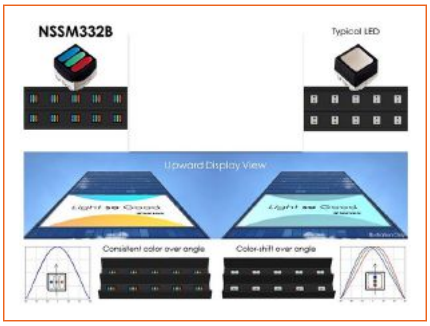
Each LUXEON Rubix delivers outstanding flux performance. Typical output for Red is 85 lm, Green is 310 lm, Blue is 112 lm and Royal Blue is 1635 mW. Typical output for white is 440 lm at 93 lm/W.

Complete product specifications are available in the datasheet and at the LUXEON Rubix web page: https://lumileds.com/products/color-leds/luxeon-rubix/

LUXEON Rubix is in-stock and available from your preferred Lumileds distributor. ■

NICHIA LEDs with Tinted Encapsulation Boost Contrast in Outdoor Video Displays

Building on over 25 years of LED manufacturing expertise dedicated to the video display market, Nichia announces NSSM332B – the newest addition to its surface-mount (SMD) LED portfolio.



NICHIA's new NSSM332B LED series enhances vividness of image detail

The NSSM332B is an innovative three-cavity, 2828 package design (dimensions: 2.8×2.8×2.5 mm) with tinted encapsulation to provide enhanced contrast to outdoor screens. The unique design takes full advantage of Nichia's latest die and packaging technology, and offers increased brightness and efficacy to complement the high-contrast properties. For an 8 mm pitch display at 7,000 Nit, the NSSM332B has an estimated power dissipation of only 26.6 mW, which is greater than 50% savings in energy, compared to a typical black package.

Developed as an optimum solution for a wide range of outdoor displays such as those used for advertising and live spectator events among other applications, the near perfect color over angle allows for exceptional video image from any viewpoint. Once integrated into HD display screens, the LEDs can create a more vibrant and captivating viewing experience by improving picture detail.

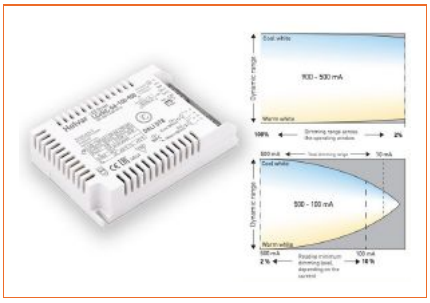
Scheduled to ship in September 2020, the NSSM332B exemplifies NICHIA's efforts to set a new standard of quality and further delivers on its brand promise of presenting 'Light so Good.' Mr. Tadahiro Takakura, General Manager of Display Business Planning in Nichia Corporation, said: "Outdoor display applications have unique requirements. With this new series of high-contrast, high-brightness surface-mount LED emitters, we're meeting the additional needs our customers have requested while still delivering proven efficiency, reliability and performance they have come to expect from all our solutions." ■

SMART & IOT

Helvar Introduces New Compact 45 W Tunable White Driver

Helvar is passionate about spreading the message of wellbeing through human-centric lighting solutions. This is why Helvar is very excited about announcing a new Tunable White LED driver with some fantastic features for professional lighting. Helvar's new 45 W DALI Type 8 compact driver comes with wide output current range, parameter setting option with NFC, and SELV60 rating, all great benefits for flexible luminaire design.

With accessory strain-reliefs you can install Helvar's new LC45iC-DA-100-900 driver also outside the luminaire, which is an excellent choice for pendants and LED panels. The driver supports our patented Switch-Control 2 functionality: an easy way to control both the light intensity and color temperature from a simple retrievable switch.



Helvar's new LC45iC-DA-100-900 45 W DALI Type 8 compact driver comes with a number of very useful features

And most importantly: flicker-free amplitude dimming down to 2% and wide dynamic dimming range guarantees excellent performance – that's a perfect match for lighting needs in spaces supporting wellbeing with lighting.

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We are with you all the way: match the driver with our iC Series LED modules and choose Helvar lighting control system to enjoy the ultimate customer experience only we can provide.

Are you looking for more information about what Tunable White or Human Centric Lighting is? To learn more about Tunable White, please visit: https://helvar.com/luminaire-components/tunable-white/ or find out more and order your samples from your closest Helvar representative.

Ledvance's New Portfolio Provides Smart Lighting for a Better Living Experience

An increasing number of customers are looking to integrate smart home functions in their residential area. With Professional Smart for Residential and the new Ledvance PARATHOM® portfolio, Ledvance supports professional users such as installers to achieve the full potential of connected lighting for their customers. The new Ledvance PARATHOM® portfolio for residential and garden areas can be controlled optionally by voice command or app and offers a suitable solution for a wide range of requirements. The portfolio impresses with a combination of quality, innovation, reliability and user-friendliness and is complemented by easy installation, good value for money and features such as color and color temperature change or dimming capabilities.

Ideal for indoor and outdoor environments, the Professional Smart for Residential and PARATHOM portfolio from Ledvance provides smart lighting that can be controlled by voice command or via app

Voice control via Alexa, Siri or Google Assistant: Professional Smart for Residential is available with either ZigBee or Bluetooth technology and, in addition the operation via app, allows convenient voice control with digital assistants such as Alexa from Amazon, Siri from Apple or Google Assistant.

System compatibility of PARATHOM® ZigBee: PARATHOM® ZigBee's smart lighting can be integrated into existing or preferred independent, compatible smart home systems, allowing control via app or smart speakers such as Amazon Echo or Google Nest. The compatible gateways include Philips Hue Bridge, Deutsche Telekom QIVICON, Schwaiger Gateway, Samsung SmartThings or SMART HOME by Hornbach. No external gateway is necessary if the device is controlled via Alexa with Amazon Echo Plus, Echo Show (2nd generation) or Echo Studio since these devices have already integrated a ZigBee gateway.

Thanks to the latest ZigBee 3.0 technology a high security standard is guaranteed and allows control on the go. In addition, the Professional Smart for Residential portfolio enables the easy creation of different light scenarios – dimmed, from warm to cool white and multicolor for choosing from 16 million colors. Complex functions such as wake-up light or home presence simulation complement the reliable, smart lighting solutions with ZigBee technology.

Easy setup of PARATHOM® Bluetooth: The PARATHOM® Bluetooth portfolio can be set up easily in less than one minute and no gateway is required. It allows lighting products to be controlled either via the Ledvance SMART+ app for Android and iOS, the Apple Home app or voice control via smart speakers such as Apple HomePod or Amazon Echo. The PARATHOM® Bluetooth portfolio from Ledvance can also be integrated into a Bluetooth mesh network. Users of the Ledvance SMART+ app therefore benefit from the new Bluetooth 5 standard. For example, if there are several Ledvance Bluetooth mesh devices, users can extend the control range of the smartphone to control the lights in another room, on the next floor or even in the garden – without getting up from the sofa.

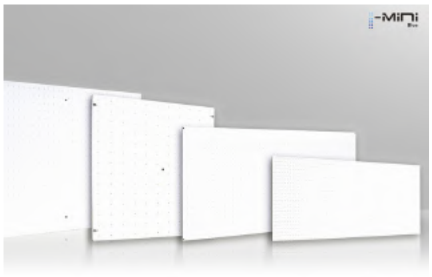
AUTOMOTIVE

Lextar Releases New I-Mini LED Modules Covering TV and Automotive Applications

Lextar unveils a full series of I-Mini Blue LED backlighting products adopting 3 key technologies including COB, DOB and mini lens array. Products can be applied to TV, monitor, laptop, automotive display and chartplotter; some of which have been mass produced and delivered to customers. This ensures Lextar's leading position in mini LED backlighting market.

Lextar has been the first to mass-produce Mini LED backlights since 2018. This time the company presents four new-generation I-Mini products, demonstrating its technology capabilities from LED chip, packaging, driver design to optical modules. Lextar's new I-Mini backlights adopt COB (Chip on Board) technology, directly implant its in-house flip-chip mini LED chips on the light board, which can realize ultra-thin panel design of

zero OD (Optical Distance). In addition, the DOB (Driver on Board) technology integrates the driver IC and microcontroller (MCU) on the light board for multi-zone control.



COB technology based I-Mini backlights directly implant Lextar's flip-chip mini LEDs

Lextar's new multi-channel driver IC increases the number of backlight control areas by 5 times to more than 1,000 zones, therefore the number of ICs can be reduced by 50%, and the display can achieve a high contrast ratio of 1,000,000:1. Moreover, with the latest mini lens array technology, I-Mini can achieve wide beam angle (> 160°) and high light extraction rate, increasing the panel brightness to 1600 nits, which is three times the brightness of the traditional panel. The three technologies of COB, DOB, and mini lens array show the advantages of Lextar's vertical integration, and unveil the key benefits of the new generation Mini LED products.

The most anticipated among all applications is Mini LED TVs, and Lextar is to be the first to launch 65-inch I-Mini LED TV backlight. By using around 20,000 mini LED chips and combining the three major technologies, Lextar releases a new I-Mini with more than 1,000 zones and a high dynamic contrast ratio (HDR) of 1600. In addition, Lextar also introduced I-Mini for 12.3-inch automotive display, with an ultra-high brightness of 1600 nits to enhance sunlight readability, and local dimming of over 360 zones to increase contrast. It has also adopted high tolerance material to push the lifetime up to 50,000 hours. I-Mini has demonstrated the advantages in terms of high brightness and reliability. The application will extend to land, marine and air displays in the near future.

"Ever since the mass production of Lextar's I-Mini backlighting products in 2018, Lextar has been the pioneer in this field. This time, Lextar extends the application to TV and automotive display to demonstrate its capability of mass production," said Mitch Lee, Vice President of Lextar Business Group.

"It is foreseeable that Mini LED market will grow rapidly in 2021–2022. Lextar is working with both panel and brand customers and will extend to more applications."

MITCH LEE, THE VICE PRESIDENT OF LEXTAR BUSINESS GROUP

Lextar has also released modified I-Minis for 17.3-inch laptop and 34-inch monitor. Its unique optical design reduces the number of mini LED chips by more than 20%, while still maintaining fine area control and ultra-thin design. This product will bring gamers and professional creators a brand new visual impact. ■

UV LIGHT

Nationstar's UV LED – A Pioneer in the DUV Sterilization Industry

Since 2016, NATIONSTAR has launched near-ultraviolet LED, deep-ultraviolet LED and modules, with wide wavelength range, high reliability and good feedback in the market. At present, we have established partnerships with many well-known manufacturers.

NATIONSTAR provides the right UV LEDs for numerous different applications

NATIONSTAR UV LED products include mosquito trap, nail beauty series, industrial curing series, sterilization, phototherapy and purification series, with wide wavelength range, wide range of power, strong compatibility, good heat dissipation performance and strong environmental durability.

Based on high reliability materials and excellent packaging technology, NATIONSTAR UV LED series products have lower thermal resistance, higher light output, and better air tightness. Taking silica gel 3535 series as an example, the thermal resistance of the device is greatly reduced with nano-packaging technology, which is reduced by more than 40% compared with that of conventional packaging products. The device has better heat dissipation and longer life. With more reasonable primary lens packaging, the optical power is increased by more than 6% compared with that of conventional products.

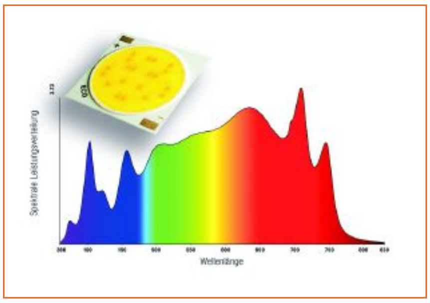
About NATIONSTAR: NATIONSTAR is a National level key high-tech enterprise with professional capability in manufacturing LEDs for display, LEDs for lighting, LEDs for plant lighting, UV LEDs, IR LEDs, Mini LEDs, etc. NATIONSTAR was founded in 1969 and started LED production in 1976. Its German subsidiary subsidiary were established in 2015. NATIONSTAR is one of the largest LED manufacturers in China and ranks 8th in the list of Packaged LED market shares in Q2 2018, according to the IHS Markit reports. In 2019□NATIONSTAR's sales amount is RMB 4.0 Billion. ■

HORTICULTURE

Broadband Neutral White LEDs Including Effective UV Component Modelled on the Sun for Rapid Plant Growth

With the plant LEDs GW3535U and GW1919U (COB) euroLighting offers new broadband LEDs with a special spectrum for stimulating plant growth (horticulture lighting). The advantage: the LEDs are not restricted to a specific plant species or growth phase, but can be used universally. Ready-to-use lamps with the new LEDs will also be available soon.

Modelled on sunlight, the plant LEDs reproduce the complete light spectrum and generate all wavelengths for each growth phase. This contrasts with LEDs, which only produce a violet spectrum of red and blue wavelengths. They cover the needs of the plant throughout its entire life cycle and thus contribute to a significant increase in growth and fruit yield.



The spectrum of euroLighting's broadband LEDs for plant growth is based on the light of the sun. The GW1919U COB LEDs stimulate plant growth and provide a neutral white light

Their PPF value (Photosynthetic Photon Flux) is up to 31.2 µmol/s per COB and 1.7 µmol/s per LED. They emit a pleasant neutral white light with 4000 K and a CRI of over 97. It supports easy checking of plant health, protects the eyes and promotes well-being.

The additional UV component of the LEDs stimulates the formation of the active ingredients in medicinal plants as well as aroma and pigmentation.

Practical replacement:

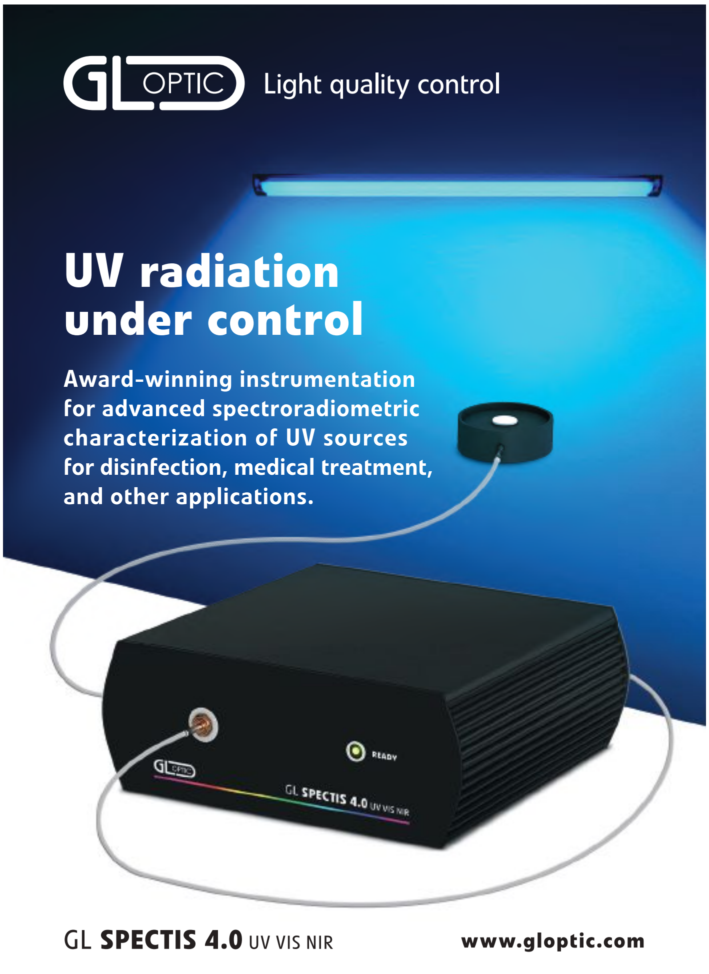
The GW3535U-LED replaces five to six conventional monochrome LEDs in one component (3.5×3.5 mm) and thus offers high space and cost savings as well as less effort in development.

Customized lighting solutions:

euroLighting offers not only LED components, but also customer-specific modules (AC or

DC) as well as finished luminaires and lighting solutions. These can be manufactured individually in terms of shape, size, spectrum and control, including, for example, special plant lights for horticulture, medicinal plants and much more.

About euroLighting: euroLighting GmbH, based in Nagold, Germany, concentrates its development and marketing activities in driverless AC technology. LED modules in this new AC technology are suitable for installation in all types of luminaires and do not require conventional power supply. A novelty are light-emitting diodes with sunlight similar spectrum. The product portfolio comprises different forms of modern LED illuminates, including street lamps, replacement for HQL lamps up to 150 W (≙ HQL 400 W), Retrofit modules as replacement for HQL and NAV lamps in lampheads, cylindrical construction forms as well as T8 LED tubes up to 1.5 m and LED-panel lamps as retrofit. All products are delivered in the newest AC technology. ■



EVENTS

Exhibitors at Guangzhou International Lighting Exhibition to Display the Latest Innovations Within the Lighting Industry

At this autumn's Guangzhou International Lighting Exhibition (GILE), exhibitors will unveil their latest products and R&D efforts at the China Import and Export Fair Complex, Guangzhou. Visitors will have access to the newest technologies in the lighting sector, across a wide range of products spanning the entire supply chain. What's more, earlier this month GILE and Guangzhou Alighting IOT & Technology cooperated in organising the first GILE online brand exhibition, offering a business matching platform for the industry ahead of the physical fair from September 30 – October 3.

Commenting on GILE's first step into online conventions, Ms Lucia Wong, Deputy General Manager of Messe Frankfurt (HK) Ltd explained: "The online exhibition held on the 9–10 June applied the latest technology to offer online consultations, business meetings, negotiations and matching as an all-in-one service, which provided a brand-new experience for exhibitors and buyers alike. Following the trend of digitalisation in an increasingly global market, GILE's online and offline content works in sync to empower the lighting industry."

This autumn, the fair will welcome exhibitors who continue to explore and present the latest lighting advancements and innovations. From smart to scenic lighting, IoT technologies, UVC sanitising lights and more, GILE provides a platform for industry professionals to keep up-to-date with market trends and information as the sector evolves.

Interconnectivity – compatibility becomes the big trend

Mutually compatible products have become a major trend in the lighting market. Shanghai Euchips Industrial Co Ltd is committed to product development and technology promotion of LED control systems. They will display their DALI dual-color temperature and full-color lighting products, as well as exhibits equipped with the latest DALI-2 technologies.

Zhejiang Umelink Intelligent Technology Co Ltd will primarily display NEMA interface related products, including a smart twist-lock optical and light controller equipped with 4G+Zigbee technologies, as well as a smart twist-lock optical controller equipped with the latest narrow band (NB) communications technologies. They will also display Zhaga compliant products, including smart lock-type controllers fitted with the latest NB-IoT technologies as well as other microwave sensor products.

Together, NEMA and Zhaga interfaces are widely used in smart city lamp posts. At GILE, Zhejiang Umelink Intelligent Technology Co Ltd will demonstrate the applications of NEMA and Zhaga interfaces and how to collect and manage data using computerised software, as well as how to control lamp post brightness through IoT networks.

Dedicated to developing healthy, human-centric and smart lighting, Alpha Lighting International Co Ltd will showcase zoom spotlights, wall-washer lighting, wireless charging, and magnetic and smart Bluetooth controls. Alpha will also demonstrate how to incorporate DALI and Bluetooth integrated LED lighting control systems into track and recessed lighting, bringing more lighting solutions into reality.

Scenic lighting – stimulated by the night-time economy and cultural tourism

Riding on the trend of the night-time economy and cultural tourism, scenic lighting is still a market with huge potential. With 17 years of experience in this sector, Zhongshan Gelinxing Lighting Co Ltd will bring their spotlights, wall-washer lights, strip lights and point lights to buyers looking to capture these trends. Guangdong Meteor Digital Lighting Co Ltd, which specializes in LED product development, manufacturing and sales, will also demonstrate their new high-power projection light for lighting the entire surface of tall buildings.

UVC sanitizing fluorescent lights – a new health and safety opportunity

The current pandemic has encouraged people to focus more on health, and healthy lighting has become a hot topic for discussion within the industry. This includes blue-light-reduction and blue-light-free technology, pure LED lights and full spectrum light technologies. Shenzhen Banq Technology Co Ltd, under BANQCN Technology Group, will display their ultra-thin, straight-down panel lights, no-spot COB LED strip lights and deep ultraviolet (UVC) lights. Their sanitizing products include sterilizing bulbs and desk lamps, plant lights (panel lights with lighting and sterilizing function) and UVC sterilizing fluorescent lights.

Sports and smart education lighting – a strong application potential

The application of sports and smart education lighting is another area with strong potential. Focusing on heat dissipation solutions of electrical products and application, Shenzhen Fluence Technology PLC will demonstrate its modular sports lighting which improves the installation and testing efficiency whilst lowering cost. Meanwhile, the multi-scenario application of smart education lighting can allow teachers to control indoor lighting efficiently by selecting the best output for varying situations such as teaching, self-study, projection and activity.

Talking about the industry outlook and upcoming show, Ms Wong said: "As the lighting sector is currently confronted with big changes, industry professionals will need to face these challenges and make the most of opportunities that are presented, which may require them to adjust their development strategy, technology development and design thinking. Since quality lighting can only be experienced in real-life, it is vital for the industry to meet in person to discuss and communicate. GILE will strive to empower the industry this year by combining online and offline content for the first time, to create a more diversified industry platform. We will also continue to encourage innovation and development within the industry and work to create more valuable opportunities for cross-industry cooperation."

The Guangzhou International Lighting Exhibition is a part of Messe Frankfurt's Light + Building Technology fairs headed by the biennial Light + Building event. The next edition will take place from 13–18 March 2022 in Frankfurt, Germany.

Messe Frankfurt also offers a series of other light and building technology events worldwide, including the Shanghai International Lighting Fair, Thailand Lighting Fair, BIEL Light + Building in Argentina, Light Middle East in the United Arab Emirates, Interlight Russia as well as Light India, the LED Expo New Delhi and the LED Expo Mumbai in India.

For more information on Light + Building shows worldwide, please visit www.brand.light-building.com. For more information regarding the lighting shows in China, please visit `https://light.cn.messefrankfurt.com/china/en.html` or email `mailto:light@china.messefrankfurt.com`.

Background information on Messe Frankfurt

Messe Frankfurt is the world's largest trade fair, congress and event organizer with its own exhibition grounds. With just under 2,600 employees at 29 locations, the company generates annual sales of around €736 million. We have close ties with our industry sectors and serve our customers' business interests efficiently within the framework of our Fairs & Events, Locations and Services business fields. One of the Group's key USPs is its closely knit global sales network, which extends throughout the world. Our comprehensive range of services – both onsite and online – ensures that customers worldwide enjoy consistently high quality and flexibility when planning, organizing and running their events. The wide range of services includes renting exhibition grounds, trade fair construction and marketing, personnel and food services. Headquartered in Frankfurt am Main, the company is owned by the City of Frankfurt (60 percent) and the State of Hesse (40 percent). For more information, please visit our website at: `https://www.messefrankfurt.com/frankfurt/en.html` ■

The 25th Guzhen Lighting Fair Set Date on Oct. 22–26, 2020

With China embracing the post-pandemic era and the industry recovers, lighting business is getting back on track. China's lighting capital-Guzhen, attracted a small upsurge in product purchases in the first half of this year. It is foreseeable that the accumulated industry energy will boost the launch of new products and make a big splash in this October. As a key wind vane of the lighting industry, Guzhen Lighting Fair is based on "China Lighting Capital" – Guzhen Town□the center of the lighting industry cluster with an annual output value of over RMB100 billion. Relying on the original lighting source, Guzhen serves as a bridge providing precise matching between hundreds of brands within the industry chain and tens of thousands of global buyers.

1 Main Venue + 7 Sub-venues to build the great GILF: Guzhen Convention and Exhibition Center, as the main venue, joins hands with the 7 sub-venues (Lihe Center, Huayi Plaza, Star Alliance, Lighting Era, Besun Plaza, Huayu Plaza and Streetlight City) to build the great GILF. The exhibition space of 8 venues reach over 1,500,000 sqm, presenting 2,500 high-quality exhibitors. The exhibition will be a one-stop lighting trading platform with full coverage of different exhibit categories, for direct procurement and convenient trade.

Online + Offline: Twin engines empowering the industry: Never has the Guzhen Lighting Fair shown any signs of recession even in the face of the COVID-19 epidemic: As early as March 18–20, the Guzhen Lighting Online Exhibition attracted 55,000 professionals came for online procurements. The new form of exhibition not only put the exhibition into the palm of the visitor's hand, but also vitalized the market. Draw from the experience of 24 physical events and the virtual one, the 25th Guzhen Lighting Fair will integrate online platform and offline fair, to achieve zero-impedance docking of supply and demand. Denggle.com, as the fair's B2B platform, allows users to make free inquiries, purchase announcements, make appointments with exhibitors, register for exhibition visits, get the e-catalogue, access the online procurement platform and other matching services. Nearly 20 high-level forums and new product launches will be held one after another during the fair, providing platforms for the lighting professionals to share information and ideas on the latest industry topics and solutions to the challenges.

Lead the trends to build an industry-wide chain: During the 25th Guzhen Lighting Fair, there will be about 840 well-known lighting enterprises participate in the event in main venue, tap directly into industry trends. Brands with strong engineering lighting capabilities will showcase the latest lighting products onsite, including decorative lighting, residential lighting, commercial lighting, outdoor lighting, etc. A Special Lamp Zone will be set up to exhibit lightings with specific functions, such as plant lighting, education lighting, car lights and off-grid lighting. Additionally, panel lights, fan lights, flood lights and solar streetlights can also be found. In sub-venue, Huayi Plaza is dedicated to European and American, modern, crystal, and customized lighting, among others. The Streetlight City has created a trading center with the collection of outdoor LED lighting, landscape lights and other types of outdoor lighting. Together with Lihe lighting expo center, Star Alliance Global Brand Lighting Center, Besun Lighting Plaza, Lighting Era Center, Huayu Plaza, the 8 venues bring together hundreds of thousands

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The latest C16 generation sets new standards in terms of flexibility, quality and efficiency!

- Reel2reel technology, PCB 25.2m long without PCB to PCB solder joints
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- >10'000lm/2m and still far away from the limit
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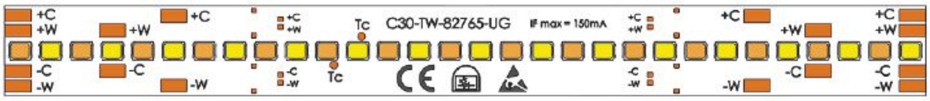
- Highest flexibility in practice. Safe production time and reduce your amount of different stock items!

New product release in Q4: tunable white version (PF25.2-C30)



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Cross-border integration: advocating a new healthy low-carbon concept:
Following the upgrading of the LED industry and the rapid development of intelligent cities and smart lighting, the exhibition has adapted to the new trends and designed a special Smart Lighting & Solution Zone. New products and technologies will be intensively unveiled to comprehensively promote the development of smart homes and provide one-stop smart system solutions for the industry. Using methods including cross-border integration and personalized customization, they will appear one after another in sectors including interior decoration lights, intelligent lighting and engineering customization.

The 25th China (Guzhen) International Lighting Fair Welcomes Global Manufacturers with Innovation

According to statistics from the China Association of Lighting Industry, in June 2020, the value of lighting exports from China were USD 4.578 billion, a year-on-year increase of 12.95%, achieving a positive monthly growth for the first time in the year. Among them, the LED lighting products exports were USD 3.185 billion, a year-on-year increase of 14.44%.

The lighting industry is ushering at dawn. The demand-side pressure of the overseas market will be more reflected in the third quarter and even the second half of the year, and is expected to unleash in October 2020.

The 25th China (Guzhen) International Lighting Fair in October will welcome global manufacturers with innovation: In the context of national favorable policies, economic recovery, active operation recovery of enterprises, and strong audience demand, the 25th China (Guzhen) International Lighting Fair (hereinafter referred to as the "GILF") will be held at Guzhen Convention and Exhibition Center, Zhongshan City, Guangdong Province, from October 22 to 26, 2020.

As the subsidiary of Informa, an international leading B2B information service group, and the subsidiary of Shanghai Sinoexpo Informa Markets International Exhibition Co., Ltd., a leading exhibition company in China and one of the large-scale lighting exhibitions held in the post-epidemic period, the 25th China (Guzhen) International Lighting Fair □GILF□will present a professional, excellent and safe lighting exhibition by virtue of its strong exhibition strength, professional exhibition service and innovative exhibition operation under the strict epidemic prevention and control.

The exhibition has 8 major venues, covering the exhibition space area of 1.5 million sqm, with a total of 2500 high-quality exhibitors participated, jointly creating a lighting feast with full coverage, direct procurement, convenient trade and price competitive products. At present, there are still more than 100 enterprises queuing up for booths. The number of exhibitors in the main venue is expected to exceed 840, surpassing that of the same period.

During the 25th GILF, all exhibits will be systematically and scientifically partitioned. Decorative lighting, residential lighting, outdoor lighting, commercial lighting, lighting accessories, equipment will be displayed based on zones. There will be special lamp zones exhibiting smart lighting & solutions, plant lighting, educational lighting, car lights, off-grid lighting, etc. that are with specific functions and demonstrate specific purpose in live mode. The exhibition will display products with advanced design, technology and ultra-high cost performance that indicate the new developing trend and new demand of the industry, aiming to trigger a breakthrough of the lighting industry. Meanwhile, a Smart Lighting & Solutions Area will be set up to display new products and new technologies in a centralized manner, with a view to promoting the development of smart homes in an all-round way, and providing one-stop intelligent system solutions for the lighting industry.

Under the model of cross-border integration, the GILF is in line with the global lighting market to introduce smart lighting projects and deliver brand-new lighting designs to buyers with the new concept of health and low carbon.

With the growing popularity of intelligent manufacturing around the world, the GILF aims to build a regional brand of "Guzhen Lighting" based on the innovation-driven industrial development strategy, thus creating a professional, market-oriented, branded and international lighting purchase feast. The Guzhen Lighting Manufacturing, Supply & Services Expo 2020 concurrently held in the main venue covers the upstream machinery, accessories and components, raw materials, and design, as well as downstream circulation, commerce & trade, services and other links of the industrial chain. It will also integrate the Internet of Things, 5G, AI and other technologies to promote the development of Industry 4.0 and achieve the transformation from manufacturing to intelligent, thus injecting new vitality into production.

Connecting global buyers online and offline, and leading the industry to seize new trends: The GILF plans a dedicated overseas online fair for overseas buyers who are unable to visit the exhibition due to the epidemic, and specifically builds a three-dimensional exhibition window for export enterprises to seamlessly connect with overseas buyers, thus promoting efficient and quick trading between the supply and requisitioning parties.

The organizer provides a factory show of the place origin for overseas buyers, allowing them to gain an in-depth understanding of the R&D, design, production, management, service and other aspects of the branded enterprises; it will also broadcast live at the enterprise booths during the fair, and arrange the persons in charge of exhibitors to personally introduce the hot new products on the spot. If buyers are interested in a product, they can submit a procurement requirement via the EZBUY on Denggle.com, and our EZBUY specialist will provide one on one service to match the corresponding exhibitors. In addition, overseas visitors can make appointments with exhibitors in advance through the online cloud exhibition platform of Denggle.com for a face-to-face exchange. The GILF also provides special travel allowances for loyal overseas buyers, who can enjoy more star-rated services at the exhibition site.

Moreover, by combining the features of EZBUY, Denggle.com and the offline exhibition, a "Denggle.com Diamond Member Zone" will be set up near the main entrance during the exhibition, so as to promote the member enterprises in diverse forms, such as on-site Mini booth, Denggle.com online shops, factory show and video display.

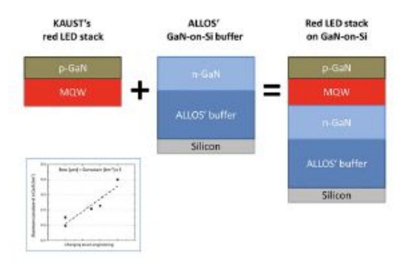
The epidemic will eventually dissipate, and the lighting industry will accelerate its recovery. With the joint efforts of lighting participants, the lighting capital Guzhen has experienced a small upsurge in new product purchases in the first half of the year. Looking into the future, we will witness a dramatical growth of the lighting industry in October 2020. Welcome to the GILF at Guzhen Town from October 22 to 26, 2020. ■

RESEARCH

ALLOS and KAUST Are Working on High Efficiency Nitride-Based Red LEDs on Si

ALLOS Semiconductors has engaged in a collaboration with Prof. Ohkawa and his team at King Abdullah University of Science and Technology (KAUST) for realizing high efficiency nitride-based red LEDs on large diameter silicon substrates. In the collaboration the teams are addressing fundamental issues like the large lattice mismatch and the quantum-confined Stark effect (QCSE) which are preventing the adoption of red nitride-based LEDs for practical industry usage. In particular, for the emerging field of micro LED displays there is a strong demand to enable red LEDs on large diameter wafers in addition to the established blue and green color LEDs in the nitride system in order to reduce manufacturing complexity and cost.

In this context, Prof. Ohkawa and team have developed an indium gallium nitride (InGaN)-based red LED stack with low forward voltage of less than 2.5 V and high efficiency by using local strain compensation and a



Established methods of integrating different LED stacks with high crystal quality and strain-engineering buffer technology are used. Inset: ALLOS' in-line process control enables ±5 µm bow range

modified MOCVD reactor design. The researchers have already grown red LEDs on sapphire- and Ga_2O_3-substrates [1] [2]. For potentially higher performance red LEDs by using strain-engineering on wafer-level – in particular for large wafer diameters – the team is now extending its work to silicon substrates by collaborating with ALLOS. This also enables huge advantages for mass production due to the scalability of up to 300 mm and thus processability in silicon process lines. For micro LED displays – in particular the monolithically integrated micro displays for e.g. augmented reality (AR) application – this is another important enabler.

The unique high crystal quality of ALLOS' gallium nitride on silicon (GaN-on-Si) technology with threading dislocation density (TDD) of $\sim 2 \times 108\,cm^{-2}$ is the pre-condition to achieve at least the same performance red LED as on sapphire. Furthermore, ALLOS' precise strain-engineering – which enables excellent emission uniformity for blue and green LED as well as flat bow wafer for 200 and 300 mm diameters – is used to optimize the growth conditions for red LED.

Both teams combine their unique technologies to handle strain and optimize crystal growth conditions for GaN-on-Si and red LEDs. To this end, the KAUST team will grow its red LED stack on top of ALLOS' GaN-on-Si-buffer layers, which will be fine-tuned during the collaboration to optimize the performance of KAUST's red LED stack.

Dr. Nishikawa co-founder and CTO of ALLOS, commented: "From personal experience I am aware how challenging it is to realize high efficiency red LED. From ALLOS' side we can provide our established blue and green high quality GaN-on-Si micro LED epiwafers of up to 300 mm diameter. Furthermore we see the opportunity that our unique strengths in strain-engineeringfi can contribute to improved red LED performance."

Commenting on the opportunity, Prof. Ohkawa said: "Our team has developed a high efficient red LED stack and continues to push the boundaries in this very challenging field. When talking to ALLOS, we of course were interested in the scalability up to 300 mm – but the capability to control the strain-engineering so precisely and in such a large process windows promises more progress for red LED performance."

For further information about ALLOS' technology, licensing options and how to cooperate with ALLOS in the exciting field of micro LEDs, please visit `https://www.allos-semiconductors.com`.

References

[1] "633-nm InGaN-based red LEDs grown on thick GaN underlying layers with reducing in-plane residual stress", D. Iida, Z. Zhuang, P. S. Kirilenko, M. Velazquez-Rizo, and K. Ohkawa, Applied Physics Letters 116, 162101 (2020). DOI: 10.1063/1.5142538

[2] "Demonstration of low forward voltage InGaN-based red LEDs on β-Ga_2O_3 substrates", D. Iida, Z. Zhuang, P. S. Kirilenko, M. Velazquez- Rizo, and K. Ohkawa, Applied Physics Express 13, 031001 (2020). DOI: 10.35848/1882-0786/ab7168

[3] "Metalorganic vapor-phase epitaxial growth simulation to realize high- quality and high-In-content InGaN alloys", K. Ohkawa, F. Ichinohe, T. Watanabe, K. Nakamura, D. Iida, Journal of Crystal Growth 512, pp.69-73 (2019). DOI: j.jcrysgro.2019.02.018

About Prof. Ohkawa at KAUST: Prof. Ohkawa is devoted to the development of nitride semiconductors for more than 20 years. He and his team at KAUST have successfully developed a specially strain compensated red LED stack and additionally have used their own MOCVD reactor design, which makes possible to realize high-quality and high In-content InGaN alloys by use of special features [3]. These technologies open a new way for high-performance nitride-based red LED for micro LED application. Now he and his team want to demonstrate their red LED technologies on large wafer diameters using ALLOS' GaN-on-Si technology.

About ALLOS Semiconductors: The ALLOS team looks back to 17 years of successful GaN-on-Si epiwafer technology development for up to 300 mm wafer diameter and today is focusing its world-leading technologies on enabling the next generation of revolutionary displays based on micro LEDs. The company can make its technology available through IP licensing and transferring the technology to its customers' MOCVD reactors. Additionally ALLOS is working with partners in advancing the technologies needed for micro LED mass production. ■

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Energy Efficiency	Interior Lighting Products	Resolution No. 10/2020	Chile	Resolution No. 10/2020 was approved by the Chilean Ministry of Energy on 31 July 2020 defining minimum energy efficiency standards for interior lighting products. The following products are affected: • Certain Tungsten filament incandescent lamps for home use and general lighting purposes, which have a nominal power between 25 W and 200 W; • Lamps with built-in ballast (CFL) for general lighting, with a rated power up to 60 W; a nominal voltage between 100 V and 250 V; • Double-ended fluorescent lamps for general lighting Exceptions to this requirement are lamps whose length exceeds 1200 mm and lamps whose nominal power is greater than 40 W; • Single-socket fluorescent lamp for general lighting; • Tungsten halogen lamps with single and double sockets; • Certain Tungsten halogen incandescent lamps (non-vehicular); • Certain LED lamps with built-in ballasts. The Ministry has outlined different stages for the efficiency of such products: • From 1 January 2021, lamps should have a minimum energy performance of 40 lm/W; • From 1 January 2023, lamps should have a minimum energy performance of 70 lm/W; • From 1 January 2025, lamps should have a minimum energy performance of 85 lm/W.
Energy Efficiency	LED Products for indoor lighting	GB 30255-2019	China	GB 30255-2019 was published on 4 April 2019 and applies to LED-lighting which is used in an indoor environment. It sets out minimum allowable values of energy efficiency and energy efficiency grades. The standard will repeal GB 30255-2013. It will enter into force on 1 November 2020.
Energy Efficiency	Luminaires for road and tunnel lighting	GB 37478-2019	China	GB 37478-2019 specifies requirements on energy grades, minimum allowable values of energy efficiency, colour rendering index and testing methods for LED luminaires for road and tunnel lighting. The standard applies to LED luminaires for road and tunnels with rated voltage of AC 220 V and frequency of 50 Hz, including LED control devices, but excluding interconnected control components that can be installed independently or other functional accessories that are not related to lighting. Although the draft of this standard was initially meant as a voluntary standard, this final approved version is mandatory. This standard will enter into force on 1 November 2020.
Safety	Domestic and imported lighting equipment using LED	QCVN 19: 2019/BKHCN	Vietnam	QCVN 19: 2019/BKHCN describes the requirements domestic and imported lighting equipment has to meet in terms of safety and electromagnetic interference from 1 June 2020 before being circulated on the market. This National Technical Regulation, published on 4 December 2019, affects all organisations and individuals who manufacture, import, distribute or trade LED equipment which is specified in the accompanying Annex: • LED light bulbs with built-in ballasts for general lighting work at voltages greater than 50 V; • LED common fixed lights; • LED mobile lights; • Double-sided LED bulbs designed to replace straight tube fluorescent lamps; • Commonly used LED luminaires.
Safety	Luminaires	IEC 60598-2-23:2020	World/Europe	Particular requirements – Extra-low-voltage lighting systems for ELV light sources was published. Main changes: • Title and scope were extended to include now luminaires with all kind of light sources including LED technology; • Normative references and the reference to transformer and control gear standards have been updated; • The short circuit test (23.7.6.1 and 23.7.6.2) was removed and reference is now made to the same test in Part 1. Note: the EN version is expected within this year.
EMC	Equipment for general lighting purposes	IEC TR 61547-1:2020	World/Europe	IEC TR 61547-1 Equipment for general lighting purposes – EMC immunity requirements – Part 1: Objective light flicker meter and voltage fluctuation immunity test method. Main changes: • Replacing IEC TR 61547-1:2017; • the scope of this document has been clarified to make a distinction between flicker testing without voltage fluctuations to measure the intrinsic performance of lighting equipment and flicker testing in which a specific set of voltage fluctuations are applied in order to measure the immunity of the lighting equipment to voltage fluctuations present on the mains; • the test procedure for flicker testing has been clarified. Note: this standard may also be refenced to support the light source requirement measurements of flicker of the ErP regulation
Performance	Lighting Equipment	IEC 63103:2020	World/Europe	Non-active mode power measurement. Key item: • specifies methods of measurement of electrical power consumption in non-active mode(s), as applicable for electrical lighting equipment including when having non-illumination components incorporated; • Range of supply voltage up to 1500 V DC or up to 1000 V AC; • Measurement method include also wired and wireless connected products; • This standard is to be referenced by endproduct standards with additional guidance of application and is not a stand-alone standard. Note: the EN version is expected within this year, this standard is expected to measure the part of requirements of the ErP regulation for light sources and external control gear.

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LIFI COMMUNICATION
Musa UNMEHOPA, Head of Ecosystems and Strategic Alliances for LiFi at Signify

Musa UNMEHOPA
Musa is Head of Ecosystems and Alliances for LiFi, at Signify. Prior to joining Philips Lighting in 2013, he worked for Bell Labs, Lucent Technologies, and Alcatel-Lucent. Musa has held senior leadership roles in various standards bodies, trade organizations and industry consortia, including chairman of the Technical Plenary of the Open Mobile Alliance, vice-chairman of the Board of the Zigbee Alliance, and Secretary General of the Zhaga Consortium. He also served on the boards of The Connected Lighting Alliance, the Emerge Alliance, and the Parlay Group, and is an advisor to several technology start-ups. Author of two technology books, Musa has been an invited keynote speaker and panelist at various industry events. His publications include numerous papers in technical journals and conferences. He holds two patents. Musa received a BSc. and MSc. degree in computer science from Twente University and MBA degrees from TIAS Business School and University of Bradford School of Management.

For over a decade, research in LiFi has been intensified with amazing results. When Musa Unmehopa, an authority in the lighting industry, took on the position of Head of Ecosystems and Strategic Alliances for LiFi at Signify, it was clear that LED professional would have to report what he has to say about the status of LiFi and his future plans. We have known him since he was appointed Secretary General at Zhaga at the beginning of 2014. Since then he was always in charge at Philips Lighting, now Signify, in some capacity, also representing the company in the Connected Lighting Alliance. In addition, his resumé marks him as a specialist in standardization and a technology advisor. This is where we would like to start our Q&A.

LED professional: Could you please tell us a little bit about yourself? How did you become involved in standardization? What can you tell us about your career at Philips Lighting -- now Signify?

Musa UNMEHOPA: I have been active in standardization for most of my working life. Having started my career in the telecommunications industry, developing 3G and 4G systems, I joined the standardization department of Philips Lighting in 2013. The company had recognized early on that the transition from conventional lighting to LED was not limited to light sources only. It opened up a world of opportunity to enhance lighting with communications capabilities. Philips Lighting, and now Signify, has been on the forefront of that transition and I was able to support the transition through leadership roles in the Zhaga Consortium, the Zigbee Alliance, and the Connected Lighting Alliance.

LED professional: The latest step on your career ladder is now the appointment as Head of Ecosystems and Strategic Alliances for LiFi. Why LiFi? What are the responsibilities, tasks and duties included in this position?

Musa UNMEHOPA: Our position as the industry leader in connected lighting, makes Signify the lighting company for the Internet of Things (IoT). The world of lighting and communications are converging. First, for example with Philips Hue, we were adding communications technology to lighting, in order to create a better lighting experience. Now, with LiFi, we are adding lighting technology to communications, in order to create a better communications experience. We bring a century of lighting expertise and a decade of connected lighting leadership to the communications industry. Lighting truly becomes a new intelligent language.

In order to realize the growth that we envision for LiFi, it is important to create a healthy ecosystem where all players in the value chain are represented and can thrive. LiFi is a communications technology, and any LiFi system deployment will consist of a network of interconnected nodes. The many nodes may have different functions and may be provided by different suppliers. This value chain includes luminaire manufacturers, LED component suppliers, mobile device manufacturers, chip vendors, communications service providers, network installers, etc. All these players need to come together to make LiFi a success.

Standardization plays an essential part in building this ecosystem, especially for applications with mass adoption in e.g. offices or the home. Network nodes from different suppliers must be able to interconnect and interoperate. Any successful communications technology today is based on a global connectivity standard. But connectivity alone is not enough. A strong certification program is needed to ensure true interoperability. Signify created this new role, Head of Ecosystems and Alliances for LiFi, to help build and lead the ecosystem that is needed to enable the growth of a strong LiFi market. Building key alliances with standards consortia, interest groups, trade associations, policy makers and government organizations will also be part of the role.

LED professional: There are certainly specific strategic goals that you want to achieve. Can you name and explain them? Is there already a roadmap that can be made public, or is there currently just an internal roadmap that allows you to give us a rough idea?

Musa UNMEHOPA: Our strategic ambition with LiFi is very clear. We want to unlock the extraordinary potential of light to address new high-growth markets, and to establish LiFi as a mainstream communications technology to connect millions of people and devices globally. To help achieve this strategic goal, Signify launched Trulifi in July of 2019. Trulifi is our own high-speed LiFi solution, to enable highly reliable, secure and fast wireless communication that leverages existing and future lighting infrastructure.

LED professional: In the meantime we have learned that "LiFi is not always LiFi" as there are huge differences between different approaches, for example, if high transmission rates are required or low baud rates are sufficient. Which key application does Signify see LiFi having the biggest advantages over conventional wireless solutions?

Indeed, "LiFi is not LiFi", just like "5G is not 5G". For LiFi there are many different use cases that can be applicable in many different market segments. Just like there are many different use cases for 5G, including mobile broadband, fixed wireless access, and many others. But there is one key aspect that all LiFi use cases have in common. If your environment is unfavourable for radio communication (electromagnetic interference, such as in industrial applications) or in situations where radio propagation is blocked (such as in a warehouse with a lot of metal structures) LiFi is the preferred solution. In places where exposure to radio waves is not desired or even harmful (hospitals, schools, volatile environments like mines or chemical plants) LiFi is not just the preferred option, it is the only option for wireless communication. Next to these applications, LiFi can help to offload conventional radio-based technologies and offers reliable, secure and high-speed network connectivity where it is needed.

In applications where low-latency must be guaranteed, such as for real-time controls of industrial robots, for hick-up free video calls, or for virtual reality applications, LiFi can offer that Quality of Service. The radio spectrum is heavily congested. When glitches occur in WiFi communications, these are often caused by bursts of RF interference from other users in neighboring areas. As light is guaranteed not to go through a wall, light communication will also not be hampered by communications by other users in the next room.

LED professional: What are the key applications from a user's perspective?

Musa UNMEHOPA: At Signify we take the perspective of market segments, each of which addresses different user communities and may support a number of use cases. The segments that we have identified for LiFi are Office, Hospitality, Digital Industry, Aerospace and Transportation, Public, Consumer and Devices. Each of these segments has specific use cases and requirements where LiFi could offer a solution. For example, in-flight connectivity in the aerospace industry is subject to strict regulations to ensure that the radios inside passengers' devices do not cause electromagnetic interference which may affect the navigation equipment of an aircraft. LiFi offers a solution that does not suffer from this problem, and in addition can reduce weight in the aircraft by eliminating the need for extensive copper wiring to each passenger seat. In the industry segment, we often see that wired solutions have disadvantages, because changing the factory layout is costly when you need to re-arrange the wiring to each of the machines. And factory workers may trip over cable bundles, causing a safety hazard. Wireless solutions based on RF technology also come with challenges, because factories are typically full of metallic surfaces and moving machines that can weaken, reflect, and block radio signals. LiFi offers uncomplicated and error-free transmission in these harsh industrial environments.

LED professional: For a successful breakthrough and broad application in the market, standardization is always a key element. Are there standardization activities?

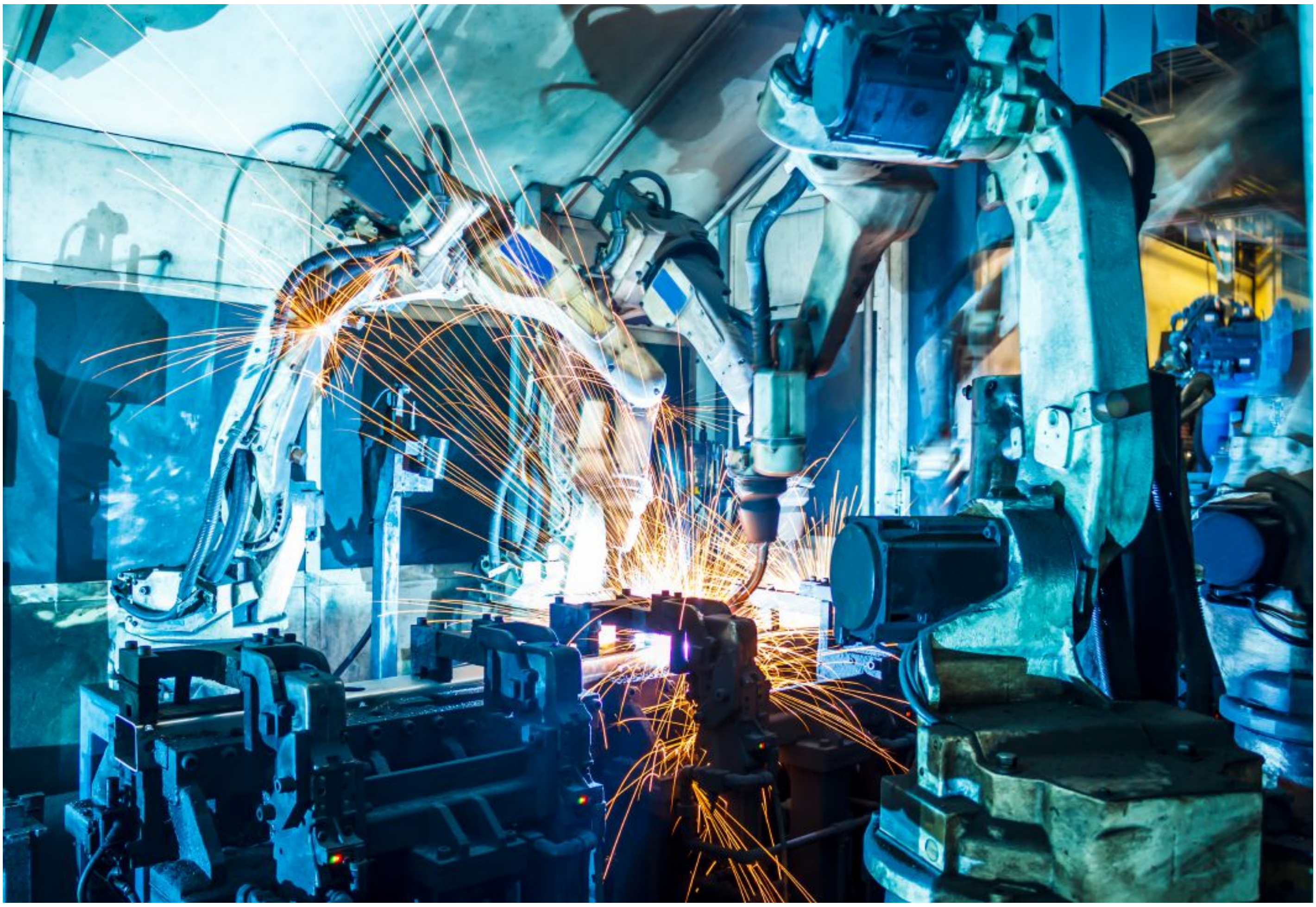

Figure 1: A potential LiFi use case – Robots welding in a harsh industrial environment (car factory) where RF communication is challenging

Figure 2: Access point and the LiFi endpoint, which are installed in the Philips stadium in Eindhoven

Musa UNMEHOPA: Standardization is key to innovation and an important condition for enabling growth. Compatibility and interoperability increase consumer confidence, lowering the barrier to mass market adoption and allowing for economies of scale in manufacturing and supply.

Today, there are a number of standardization activities across the industry which focus on the base protocol level, like how bits or packets are communicated over the optical wireless link. These activity streams may develop in a complementary manner and over time converge into a single system. Or they may evolve in parallel and co-exist in the market, where each is fit-for-purpose for a specific set of requirements and use cases. Our current, commercially available Trulifi rage is based on the ITU G.9991 standard, as the technology is mature, and chipsets are available on the market.

It is important to understand that standardization involves more than just specifying the basic communications protocol. Application functionality, for example, commissioning and system level behavior, like end to end security and network management, also need to be commonly understood. We must look at standardization in the broadest possible context. Besides specifying the technology, standardization also includes a testing and certification program, which verifies compliance with the standard specifications. But the program should also validate interoperability with other compliant implementations of the standard. And there needs to be a logo scheme which communicates this interoperability promise to manufacturers, system integrators, installers, and consumers, to help increase their confidence in adopting this exciting new technology. Signify will be active in all aspects of standardization. Where there are standardization activities already ongoing, we are contributing significantly to improve and enhance the technology. And in those areas where activities do not yet exist, Signify will commit resources to build and drive these areas forward in order to ensure the LiFi market reaches its full potential.

LED professional: **On the other side, there is IP. While often relevant for the success of a company, sometimes it also hinders a quick market introduction. What are your thoughts on that?**

Musa UNMEHOPA: I strongly believe in the ecosystem approach, which involves representatives of the entire value chain and stakeholder field. As with any communication networking technology, no one company can provide all parts of the entire system on their own. Alliance partners with shared interests and complementary skills will have to come together, to create and build a global market in which we can all compete effectively, to serve our customers in the best possible way. One of the benefits of international standardization is that these activities are conducted under transparent and widely accepted Intellectual Property Policies. Everyone participating in and contributing to the standardization effort agrees to grant access to their technology which ecosystem partners can use for compliant product implementations. This helps reduce uncertainty and remove roadblocks to broad market adoption.

LED professional: **As we delve more deeply into the technology and application related part of our discussion we have a couple of questions: Are luminaires really the best suited solution as LiFi access points? Are there no better, or at least equally well-suited, options that are serious competitors? Also, is Signify thinking about fully integrated systems where the light modulation is**

Figure 3: LiFi transceiver connects to an office luminaire

an integrated part of the illumination element or are they more focused on modules that could also, but not exclusively, be used in luminaires?

Musa UNMEHOPA: There are many reasons why using current and future lighting infrastructure provides such a compelling solution to offer LiFi connectivity. Wherever there are people, there is light. For decades, society has invested billions to illuminate every inch of where we live, work and play. This has resulted in an incredibly extensive and dense network of powered nodes, which can be leveraged to provide connectivity in addition to illumination. Line of sight is important for LiFi access points to deliver the communication signal to the end user, and the light points in the ceiling truly provide a winning proposition to host these LiFi access points. This is one of the premier reasons why we at Signify believe our company, as the number one lighting company in the world, is ideally positioned to be the driving force in enabling a huge market for LiFi.

Having said all that, we need to make meaningful choices driven by the use cases and requirements we want to address. For example, for the Office and Hospitality segments, we use Trulifi transceivers that are designed into luminaires. This choice makes sense, because of the lighting infrastructure that is already available in those environments. But for other market segments or other use cases, for example, real-time control of industrial robots, we may decide to use dedicated transceivers.

LED professional: **As previously noted, there are different kinds of LiFi. A common misunderstanding is that LiFi is always based on visible light, and especially white light. This approach is often also named Visible Light Communication, or VLC. But with VLC, we still have to distinguish how the white light is generated, because, for example, phosphor converted white light does not allow high data rates. What are the current preferred technologies? How can high data rates be achieved? Where are the current limits in the lab and under real live conditions? How fast will real live transmission rates improve over the next years?**

Musa UNMEHOPA: The design choices for LEDs, which are used for lighting applications, are optimized for efficiency and for power. These LEDs were not originally designed for fast modulation. The phosphor coating slows down the variation of light, which limits the data rates that can be achieved. Note that, while illumination LEDs are the current bottleneck in terms of speed, lab tests have shown bit rates above a gigabit per second. But these have not yet found their way to commercial applications. So while the reuse of illumination LEDs can be an attractive approach, for applications that require higher data speeds you may consider using Infrared LEDs.

LED professional: **While high data rates, which seems to be the key argument for introducing LiFi, can be realized, in the end it is still the slowest element in the chain that determines the speed. Does this mean that the luminaire of the future has to have a high-speed fiber connection,**

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or are there other approaches? Is it possible that luminaires will just be mainly used as a repeater or something in that direction?

Musa UNMEHOPA: It is not all about data rates. LiFi is more than "just" a fast, wireless communications technology. But the question is valid; you need to take a systems approach. Only focusing on the speed which can be achieved in the optical wireless link can be misleading, because the system is only as fast as the slowest link. The local area network that delivers the communications signal towards the LiFi access point in the ceiling, or even the backhaul link that connects the building to the Internet backbone, can be a bottleneck.

For in-building systems, fiber to the lamp could be an option in future. Our research lab is involved in the EU Innovation Action to explore this jointly with other partners and academia. Other options include Power over Ethernet or powerline communication (PLC). What will be the best solution is dependent on the use case, and on the existing IT infrastructure that is already installed in the building.

LED professional: **LiFi is based on the modulation of artificial light of a defined brightness. In comparison to daylight, the brightness is very low. Hence windows are a kind of disturbance variable that could be more than 10 times higher than the artificial light level. How can this noise be cancelled? Which mechanisms are currently known and used? How much does that reduce the transmission rates?**

Musa UNMEHOPA: This is, of course, true, but sunlight mostly has a constant or at most slowly varying intensity. LiFi systems, however, modulate the brightness of the light, above modulation speeds of 1 MHz. And the LiFi receiver is tuned to pick up this modulated signal. Nevertheless, sunlight does indeed cause some extra noise, which our LiFi system can easily accommodate. Note that in the infrared spectrum, the noise issue is significantly reduced, because infrared light from the sun is filtered by windows for the purpose of energy conservation and climate control.

LED professional: **Another aspect of the presence of windows concerns the marketing argument that LiFi is secure in regards to eavesdropping as light cannot pass through walls. Can you comment on that?**

Musa UNMEHOPA: Just like transmission rates, one needs to consider security at a system level and not just at the link level. While the fact that light does not pass through walls provides an additional level of physical security compared to other wireless technologies, you cannot rely on this alone for your network security. For example, we use cryptographic keys to protect LiFi communication, even if the eavesdropper is in the same room, or outside just next to the window. Having said that, keeing the light contained within a space adds an extra layer of protection, which is very much appreciated in specific applications.

LED professional: **During the day luminaires are often switched off and are also often dimmed. What are the consequences for data transmission?**

Musa UNMEHOPA: We talked before about the benefit of using infrared LEDs to achieve higher data rates. In case LiFi communicates via invisible infrared, the lighting can be dimmed or even switched off and the LiFi connectivity continues to operate. The quality of the light is not impacted in any way.

LED professional: **An additional issue could be that only indirect light reaches the receiver. Are there technologies and approaches to keep the system working?**

Musa UNMEHOPA: LiFi communication requires line of sight. However, when the direct line of sight is interrupted, communication is not necessarily lost. Just like with light for illumination, you do not sit in the dark when, for instance, a colleague approaches your desk and stands in between you and the light source. Indoor, we light spaces from multiple angles. Our LiFi systems work in a similar way, and continue to operate under conditions of indirect light. In addition, we provide a mechanism for automatic handovers. We support seamless handover between LiFi transceivers so that a user can be mobile and move from one LiFi-enabled luminaire to another. The LiFi endpoint will automatically connect to the closest transceiver with seamless handovers between the light points.

LED professional: **One argument against LiFi is often that it is currently a unidirectional communication as no means in the other direction are implemented.**

Musa UNMEHOPA: For Trulifi we use a bi-directional system, where the LiFi signal is transmitted in both directions. There may be some asymmetry in the up and down link, because LiFi access points in the ceiling are always connected to mains power, whereas LiFi endpoints may be optimized for power usage for example in battery-operated devices. The communication protocol itself is symmetric. Only our indoor navigation is one-way, as it uses lights as location beacons to do positioning.

LED professional: **In conclusion, would you summarize your view on LiFi in regards to the following points: What do you see as being the biggest obstacles on the way to mass application? Where are the biggest opportunities and chances? What are the prospects?**

Musa UNMEHOPA: LiFi provides a tremendous opportunity to launch a new communications paradigm, addressing use cases and applications where RF has limitations. We can do amazing things with light, and light truly can become a new intelligent language. And while the technology is still advancing and technical issues continue to be resolved, my focus is on building the ecosystem that needs to be in place to realize the market potential. Standardization, from technical specification of the base protocol, definition of system level behavior, all the way to an interoperability testing and certification program with logo scheme, will play a pivotal part. Signify is committed to lead, and to drive the success of LiFi towards broad market adoption.

LED professional: **Thank you!**

Musa UNMEHOPA: You are very welcome, it is always a pleasure to connect with your readers. Going forward, I hope to be able to share a lot more about ongoing developments in this exciting new domain. ■

Thrust Area Analysis of LiFi Communication Patents

One of the upcoming catchphrases of the past few years is LiFi – Light Fidelity. LiFi combines two rapidly growing technology fields: solid state lighting and communication. The basic idea sounds rather simple: Use modulated light instead of radio frequencies to transport data. Light is everywhere and LEDs allow us to switch light on and off at high frequencies that aren't perceived as flickering. Utilizing the high bandwidth light offers, transmission speed up to 100 Gb/s or even more can be achieved. But how will this technology develop, what are the most interesting aspects, and when will the right time to enter the market be? Although patent research will not substitute a crystal ball to predict the future, it can give us some valuable information to answer these questions.

Within the last 20 years about 8,000 patents have been applied for in the field of LiFi. We could read through all of them to learn the state of the art – but that would take months, even years. We could also do a patent analysis that would answer a lot of questions. But let's look a bit closer at the legal status of patents first. First of all, we have patent applications that will be published after up to 18 months. All published applications define the state of the art. Then the application will be examined – and that can last several years. If the patent is granted, the claimed features of the patent become a protected intellectual property right (IPR). So looking at published patent applications we learn about state of the art (considering there is a time delay between application and publishing). Looking at granted patents we learn which IPR have to be considered. In this case we have to look at the patents in detail. We do patent analysis to get information on the state of the art and therefore we use patent applications.

LiFi Innovation Intensity

Figure 1 shows the number of patent applications related to LiFi over the last 20 years. As there can be a time delay between application and publishing of up to 18 months, the numbers for 2019 and 2020 are not significant yet and not shown in the diagram. The application frequency starts at 100 to 150 applications per year at the beginning of the millennium and increases to a maximum of 409 in 2017. So the technology is not really young and considerable R&D has been done during the last two decades. Looking back into the 1990s (not shown in the diagram) we find significantly less patent applications. This suggests that development of LiFi mainly started with the development of powerful LEDs for lighting purposes.

From 2013 to 2016 innovation speed increased more and more and started to flatten in 2017. We are curious to see how it will continue; whether it will decrease after 2018. Looking at the total Know-How in a technology field we can plot the Know-How (expressed by the number of patent applications) over time. The shape of this curve (S-curve) gives an estimation of the technology life cycle: it starts flat (emergence phase), curves upwards (growth phase), flattens again (maturity phase) and becomes nearly horizontal (old age phase).

The technology S-curve can be derived by integrating innovation speed (number of patent applications per year) over time. It can be easily seen that the maximum of the innovation speed plot corresponds with the transition from growth phase (huge R&D effort) to maturity phase (market introduction and exploitation). It seems that this transition point was reached in 2017/2018 and that technology development will slow down and LiFi is now ready to enter broader markets over the coming years.

Thrust Area Analysis

Not everything contributes to the same degree to the innovation of LiFi. There are certain innovation drivers that can be components in a LiFi system, technologies or applications for LiFi. As we will see, street lighting is certainly a thrust area for LiFi, but military applications are not (yet).

"Visible light" as the communication channel, and "illumination" as the transmitter, are the main thrust areas for LiFi, as shown in **Figure 2**. They reached 95 and 105 patent applications in 2016. On the other hand, the number of patent applications has been decreasing since then. Apparently, illumination systems using visible light as a communication channel (commonly as a download channel) became standard technology for LiFi systems. With reduced R&D effort these systems will now intrude on the markets. Opposite patent activities for "infrared" are rapidly growing, although numbers are still less than for visual light. As the download channel becomes more and more standard, R&D on the upload channel (infrared is one possible solution) becomes intensified.

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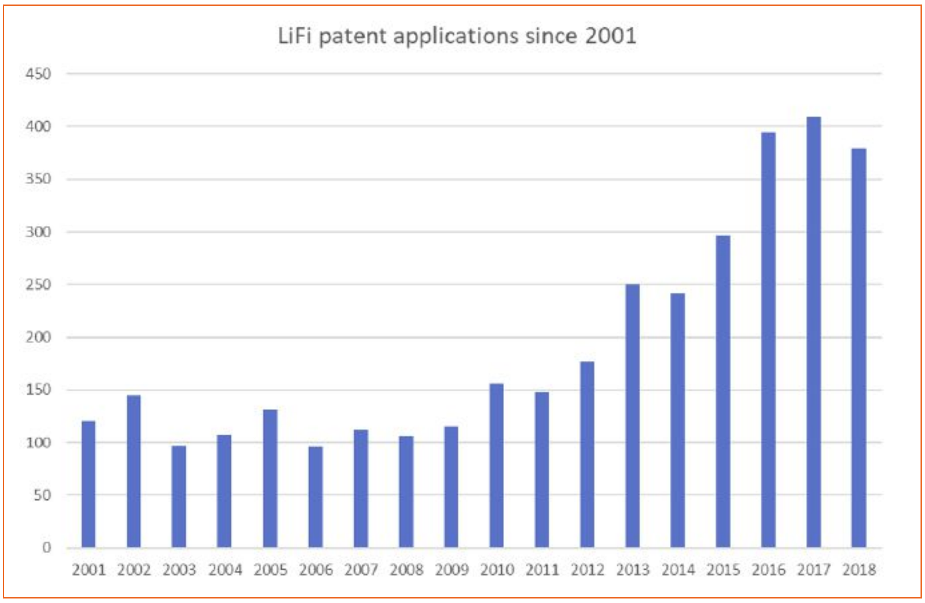

Figure 1: Number of LiFi related patent applications between 2001 and 2018. Numbers for 2019 and 2020 are not available yet as not all patent applications of these two years are published yet

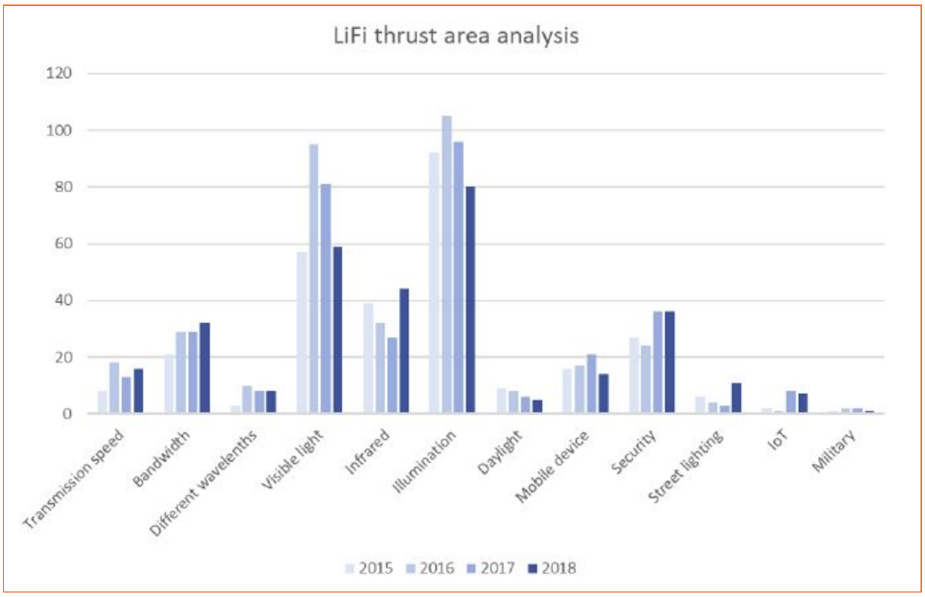

Figure 2: Analysis of several thrust areas for LiFi. One patent application can also belong to multiple thrust areas. The diagram shows the importance of the thrust areas, but also the development of this importance over the years 2015 to 2018

Using different wavelengths for upload and download is a basic approach for LiFi systems; nevertheless it doesn't seem to be a thrust area (less than 10 applications per year). A possible reason for that may be that a visible light/infrared solution is so obvious that activities for other two-wavelength-solutions are rare.

After defining the LiFi communication system, optimization of the communication path seems to still be an area for R&D activities, as can be seen when looking at the increasing numbers of patent applications in the areas of transmission speed and bandwidth.

On the application side, data security is a big driver. Thirty-six applications per year and innovation speed still seems to be growing. A similar increase can be seen in other applications like street lighting and IoT, but on a much lower level. Military applications were expected to be a thrust area (for data security reasons) but turned out not to be.

In general, we can see a shift from patent activities in technological thrust areas towards activities in application thrust areas. Other areas like communication with mobile devices or adverse influence of daylight, show little activity or uncertain trends and don't seem to be as important as thrust areas.

Conclusion

Patent analysis can be a helpful tool to define a suitable strategy for dealing with a certain technology. Technology s-curve analysis will help to find out whether to invest in R&D or to find the right time for market entry. Going into more detail with thrust area analysis, one can find appropriate activities for special areas in the technology field.

Using Patent analysis we found that LiFi technology is close to the S-curve inflection point right now. This means R&D activities will decrease in the next years and LiFi is ready to enter a broader market. We could identify Infrared, visible light and illumination as the main thrust areas for LiFi innovation. Further innovation will focus on transmission speed, high bandwidth and data security. On the application side, street lighting and IoT are the most promising areas. ■

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Dr. Sejkora received his Ph.D. from the University of Innsbruck after studying physics, IT and mathematics. He spent more than 20 years in the Research & Development department at Zumtobel Lighting and then went on to start his own company, "items" where, together with industrial partners, he has carried out more than 70 R&D and technology projects in the fields of LED lighting and lighting controls. He was Managing Director of the Kompetenzzentrum Licht GmbH from 2010 to 2015 and is currently the Research and Innovation Manager at Luger Research e.U.

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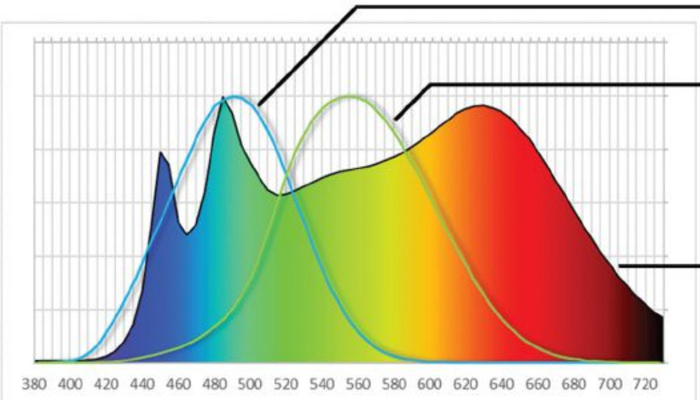

LUMINUS
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Lighting for Good

Over the last 200 years, recognition of repercussions from the industrial revolution has been slow to come. Now, 40–50 years after the alert given by the Meadows report, in 1972, people realize that something must be done. The initiators of Lighting for Good (LfG) are convinced of how essential it is to integrate ethics into daily business practices. It's a "must do something" situation. Something good, or something for good. The goal is to minimize waste, make fittings more efficient and to change the way individuals and companies think about lighting.

Lighting for Good is an ongoing initiative created collaboratively between Tiphaine Treins, principal of Temeloy Lighting and Nicolas Martin, Lighting Manager at LVMH, to create awareness of the waste created by the lighting industry and to propose solutions to create better and more sustainable lighting systems. The goal is to minimize waste, make fittings more efficient and to change the way individuals and companies think about lighting. They have been working with a wide range of suppliers who have been involved with LVMH who appreciate having a platform from which to generate change. Suppliers involved in this year's think tank are: Bluelite, Deltalight, Flos, FormaLighting, Luce5, Lucent, MoltoLuce, Nordic Power Converter, Orluna, Reggiani, Self Electronic, and Zumtobel.

Tiphaine Treins, founder and principal of Temeloy Advanced Lighting Design [2], is a leading edge lighting designer who routinely integrates state-of-the art technology with innovation, creativity and sustainability into her work. **Nicolas Martin**, Lighting Manager at LVMH [3], and involved in the luxury sector since 1998, is constantly focusing his efforts on the development of LED technology in the LVMH Maisons. Treins and Martin are collaborating on a 'think tank' and platform called Lighting for Good [1] with the object of establishing an 'eco gold standard' for suppliers of lighting fixtures.

Lighting for Good – History

The think tank is the core component of research and development work. The team meets on a regular basis and all decisions are made communally.

The program started in 2018 and it took one year to issue the charter. The charter lists all the criteria that needs to be addressed to reduce the environmental impact of the luminaire (lighting fittings and drivers).

From this work the team developed a scientific rating system to assess the environmental impact of lighting fittings. Four specific environmental impacts were looked at: **Health, Ecosystem, Mineral Resources, & Energy**.

The rating system for defining the qualities from poor to best is divided into seven categories: **Packaging, Durability, Efficacy, Quality of Light, Maintainability, Driver Efficacy and Materials**. The team has the support of the Montreal-based research group and center of expertise on sustainability and life cycle thinking – CIRAIG – an International Reference Center for Life Cycle Products, Services and Systems.

In June, LfG launched a website for suppliers and designers so that they can calculate the environmental impact of their fittings directly on the website, free of charge. The certification process for the supplier is also accessible on the website. The website also proposes a community platform accessible to all to discuss any manner of eco-design subjects. It's a place where lighting experts can share their knowledge or ask questions. Designers and suppliers can use the platform to comment on the charter and propose topics that they think need to be covered. The video channel of the website showcases some examples of eco-design development. The vision is to showcase eco-design solutions developed inside and outside the think tank.

In November, LfG will launch the rating system for exterior lighting and millwork. It will use the same rating system, fair/good/best, as the one used for the current system dedicated to one point ceiling fitting. The list of criteria will be adjusted to those different typologies. The ponderation of their impacts and methodology are worked out with CIRAIG.

Having an eco-friendly approach to lighting is all about innovation. The aim of Lighting for Good is to foster wide-spread participation in order to create an Eco-lighting revolution by sharing knowledge and collective intelligence.

Business Targets

- The need for new business models and the lifetime of luminaires reaching 100,000 hours means we must address the need for a new business model. We need to go from a linear model to a circular model. Some of the options that are being looked at are service-based. The aim is to define new business opportunities.
- It means we must think about "zero waste" and a circular model at the very inception of a design. It may be a long way off, but it needs to be looked at collectively. There might not be one single solution, but better options can be found.

Lighting for Good – Call to Action

"What is behind the word, "Good"? Is it ultimate "Good"? It is certainly not a futuristic utopia that only future generations will see. It's something that can be practiced today and tomorrow in any type of business. I envision three pillars to combat environmental problems and avoid a chaotic future: Trust, Standards, and Reliable Data", explained Nicolas Martin.

Trust

Nicolas Martin see Lighting for Good as a group of partners collaborating together with mutual trust. It is gratifying to see how competitors can share ideas and create something together, in the same virtual meeting room – with trust. The collaboration started seven years ago, with the first "LEDEXPO" event for the LVMH Maisons with all partners interacting respectfully and satisfactorily. Nicolas Martin took on the role of a trustworthy facilitator at LfG to stimulate the work group in the spirit of Truth and Trust.

Standards

Reduce – Reuse – Recycle has become a common catchphrase. So simple! The client shares the "Products" with other clients. A manufacturer receives an old spotlight, and refits it for other clients, so that in the future, only a small portion of lighting fixtures will be produced out of virgin materials.

In the past, some industrialists thought it prudent to make their products incompatible with the others. All of their customers would be held captive and have no choice about adopting the chosen system. It would mean recurrent sales. The same industries don't repair the products; they make them obsolete, and as fragile as possible. This is not good for the environment.

The good way—in the sense of "good for society"—to conduct business today, is to agree on common standards. If you have an open standard, you can share, not only the whole product, but also some subparts that can be replaced to make the product last longer, or to customize it to your needs.

This is what LfG does.

Some manufacturers object because of their branding. But within a given standard framework, a manufacturer can always show their uniqueness and capacity to innovate. Standards for USB and DVD ports does not mean the death of creativity. On the contrary, now is the time that creativity can excel.

Reliable Data

Lighting a space is 100% science and 100% art. One can leave the art to the retail/lighting designers. Lighting for Good has found a proposal for a standardized datasheet where every aspect is scrutinized. The environmental performance of the product is worked out and listed on the LfG scorecard as one comprehensive number. This makes it easy to buy.

It's possible that some manufacturers will exclude themselves from the group because they want to appear unique, showing only proprietary things, or because they want to do things the same way they have been doing for years. This type of supplier only wants to sell products, not services. These same people ask their clients to trust that they have the best products. Sometimes they create their own type of data sets that have no basis in science or reality. Unfortunately, this is not viable.

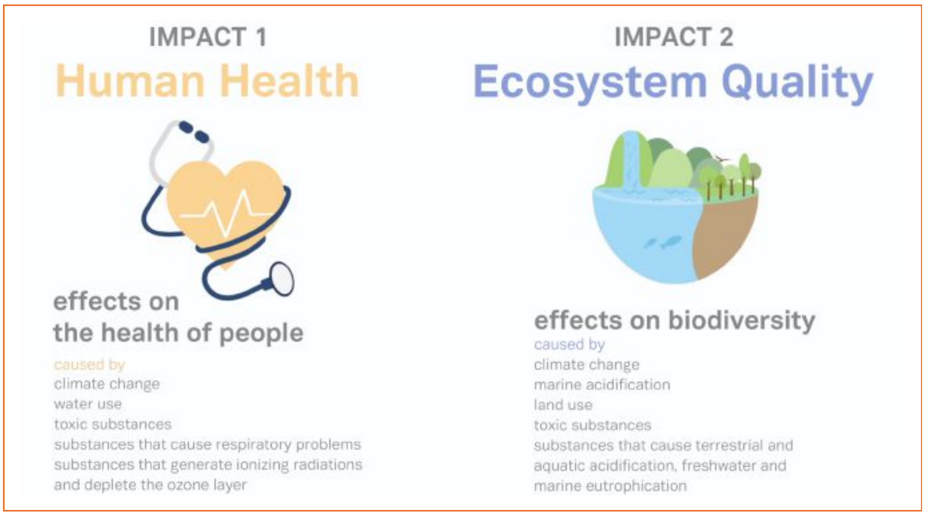

Figure 1: Impact factors 1 & 2 for human health and for ecosystem quality

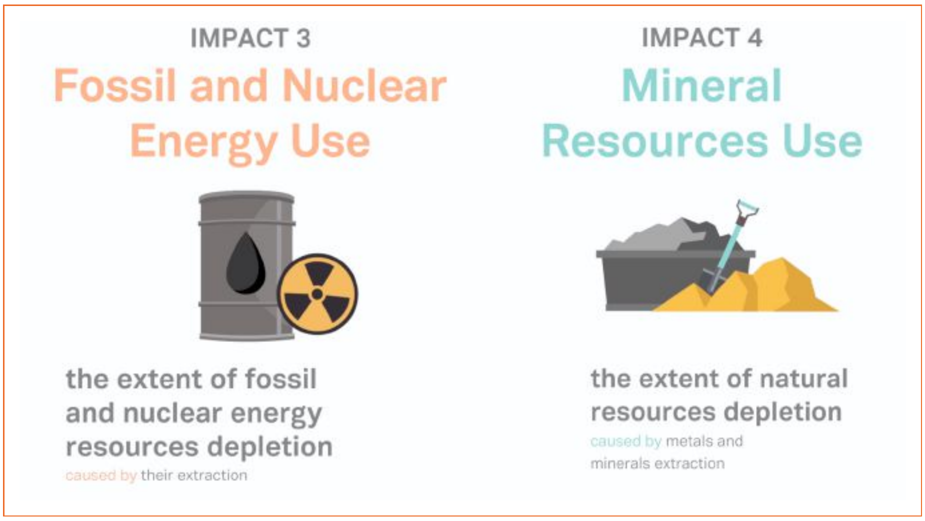

Figure 2: Impact factors 3 & 4 for fossil and nuclear energy use and for mineral resource use

"In conclusion, you are invited to join the "Lighting for Good" movement. Everyone is welcome to contribute to the research whether a designer, a manufacturer, or an end user / client. From collaboration to cooperation. From copyright to copyleft. When buying or selling fixtures ask for the Lighting for Good score. This is the best way to be good, in the lighting world today."

NICOLAS MARTIN, LIGHTING MANAGER AT LVMH

Lighing for Good – Collaborators' Statements

Figure 5: Bruno Napoli, Michael Monsonego, Andreas Stammler, and Mickey Madson (top/left-bottom/right)

"LFG Think Tank has succeeded in making competitors from all over the world work together in a good spirit with a single objective: to combine knowledge, experience and production capacity to create more efficient products. This initiative was already ahead of its time, starting the workshops at the end of 2018, and will be even more now in these very challenging time."
Bruno Napoli, Business Development Manager at Bluelite

"Our collaboration in this progressive think tank has made us better equipped to deal with the tectonic changes and collective responsibility that a post-covid world may bring. Throughout the two years of my participation, I have challenged my company's core behaviors as a manufacturer, mastered the productivity of remote meetings and trusted the process of information exchange for the benefit of our common goal."
Michael Monsonego, International Service Manager at Forma Lighting

"This unique collaboration shows what is possible when the main global manufacturers work together on a joint project. This can be a very good example for other branches of how one idea can bring generally advantaged lighting solutions to the global market. We all have to invest in sus-

Score card of your products

Every criteria has an environmental impact. We have qualified and given to each criteria an impact ratio. The environmental result of your fitting or driver determines if it can be awarded.

Your Details	
Company Name	
Contact Person	
Contact E-Mail	
Fitting & Driver reference	

Mandatory Criteria			Yes	No
Packaging	A	Certified cardboard (100%FSC, FSC Mix, or FSC Recycled)		
	B	Wrapping		
	C	Recycling compatible glue		
	D	Biochemicals for printing		

Criteria		Score of 1	Score of 2	Score of 3	Score of 4	Score of 5	Environmental Impact Score (0-5)	Ratio	Amount
1. Durability	1.1. Lumen maintenance	30 000H	50 000H	100 000H	150 000H	200 000H		0.7	
2. Luminaire Efficacy	2.1. Efficacy of the LED module	60lm/W	90lm/W	100lm/W	110lm/W	120lm/W		6.5	
	2.2. Candelas per lumen of the optics	5cd/lm	10cd/lm	15cd/lm	20cd/lm	30cd/lm		1.7	
	2.3. Dimming level with +80% efficacy	at 80% output	at 60% output	at 40% output	at 20% output	at 1% output		1.4	
	2.4. Standby power	>1W		<1W		=0W		0.3	
	2.5. Kglm/kgs of the luminaire	>0.5	>1	>2	>3	>4		0.7	
3. Quality of Light	3.1. Colour deviation	5 steps	4 steps	3 steps	2 steps	1 step		0.7	
	3.2. Colour rendition index	tm30-15 Rf=90	tm30-15 Rf=92	tm30-15 Rf=94	tm30-15 Rf=96	tm30-15 Rf=98		1.9	
4. Maintainability	4.1. LED module replacement	Needs Tools (1)		Toolless (3)		Toolless Reversible (5)		0.5	
	4.2. Standardized sizes for light engine	yes (1) no (0)						2.0	
	4.3. Interchangeable optical system	yes (1) no(0)						1.5	
	4.4. Quick electrical connector	yes (1) no (0)						2.0	
	4.5. Demountable plaster kit	yes (1) no (0)						2.0	
	4.6. ISO lumen after maintenance	yes (1) no (0)						12.1	
5. Driver's Efficacy	5.1. Total Harmonic Distortion (THD)	>10W = <20%		>100W = <10%		>300W = <5%		0.1	
	5.2. DC/DC without capacitor	yes (1) no (0)						2.2	
	5.3. Thermal protection of drivers	yes (1) no (0)						2.2	
6. Materials	6.1. Recycled luminaire materials	>10%	>20%	>30%	>40%	>50%		0.3	
	6.2. Recycled drivers materials	>1%	>5%	>10%	>15%	>20%		0.4	
								TOTAL	

13 ¦ CHARTER

Figure 3: Lighting for Good scorecard with criteria and score levels

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tainable lighting solutions. That's our responsibility."
Adreas Stammler, Int. Key Account Manager, Molto Luce

"The Lighting for Good think tank is a good opportunity for companies across the value chain of the lighting industry, to discuss and explore opportunities for more eco-friendly solutions. This type of collaboration is needed, to create the innovations required to significantly reduce our climate footprint. Furthermore, the think tank has come up with clear measurable parameters that can be used to evaluate different products. Climate awareness is expected to increase post-COVID19, so the timing of this initiative is perfect."
Mickey Madsen, Founder and CEO of Nordic Power Converter

"COVID has been a mechanism to focus Lucent on designing and creating a simpler product for the future, ones that can be installed with ease and also ensure the longevity to the maximum with current technology. We feel like the rest of the think tank, that LFG should be the new blueprint that all lighting should be judged upon when fixtures are considered on projects."
James Morris-Jones, International Sales Director at Lucent

"Lighting For Good focuses on sustainable products with a long lifespan, timeless design and high efficiency, both in use of energy and of materials: high-performant, recyclable, with interchangeable components."
Koen Dequae, Quality and Standards Manager at Deltalight

Lighting for Good – Awards

In 2019, the Lighting for Good awards was created in order to enhance creativity around eco-design and lighting fittings. The goal was to have an event that will provide the possibility of putting into motion, on a very practical level, the research and the solutions that have been developed. Another goal was to challenge existing solutions. After two years, it has been shown that it has been a powerful drive to innovate and create more eco-friendly luminaires.

Through this process, most of the suppliers involved have discovered that eco-design is not more expensive, but on the contrary, it can help to reduce cost. The awards are divided into five categories:
Best Efficacy, Best Material, Best Maintenance, Best Packaging, and Best of Best.

This year, there are 11 shortlisted suppliers: **Deltalight, Flos, FormaLighting, Luce5, Lucent, MoltoLuce, Nordic Power Converter, Orluna, Reggiani, Self Electronic, and Zumtobel**.

The results will be announced on the 5th of November during the LVMH store awards. The names of the winners will also be published in LED professional Review (LpR) November/December issue. ■

References

[1] https://lightingforgood.org
[2] https://www.temeloy.com
[3] https://www.lvmh.com

AUTHOR: Nicolas MARTIN
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Figure 4: Lighting for Good Award winners 2019, at the Magic room, in the LVMH tower of New York

Figure 6: Lighting for Good Award Trophy (3D-printed)

New Requirements for Energy Efficiency and Labelling of Lighting

The regulations on the energy efficiency of lamps and light sources previously applicable in the European Union have been fundamentally revised and restructured. Manufacturers, marketers, and distributors will have to consider the new energy label and the ecodesign requirements for light sources. This article presents the new regulations and the challenges they pose.

The Commission Regulation (EU) 2019/2020 on the ecodesign requirements is intended to significantly reduce the consumption of energy and resources in Europe. Since the last revision in 2012, illuminants have been classified in energy classes A++ to E to provide consumers with a transparent basis for making decisions on the purchase of particularly energy-efficient products. However, with the progressive development of LED technology, the illuminant market has changed fundamentally. To take account of the increased energy efficiency, both the calculation basis and the classification are now being adjusted. Light sources are then classified in classes A to G. The basis for this is Regulation (EU) 2019/2015 on energy labelling. Like the Ecodesign Directive, it will apply from September 1, 2021 and replace Regulation (EU) 874/2012. The energy label will then only be mandatory for light sources. The labelling obligation for containing products such as luminaires ceased to apply on December 25, 2019.

Figure 1: Energy label – Arrow

Common Rules for All Types of Light Sources

Various regulations exist to date on both the energy label and the eco-design requirements. Regulation 244/2009/EC, adopted in 2010, led to the intended phase-out of the classic incandescent lamp, as it was no longer able to meet the significantly increased energy efficiency requirements. Regulation 245/2009/EC relates primarily to office lighting. LED technologies are only mentioned in the margins. It was Regulation (EU) 1194/2012 that closed this gap and defined the environmentally friendly design of LED lights in detail. The new Ecodesign Directive (EU) 2019/2020 now brings these regulations together and for the first time takes all relevant lighting technologies into account.

This also applies to the new regulations concerning the energy label in Regulation (EU) 2019/2015, which also applies to all light sources regardless of the technology used. These include light-emitting diodes (LED or OLED), fluorescent tubes, halogen and incandescent light sources. Light sources are defined in Article 2 of Regulation (EU) 2019/2020 as electrically operated products that have different optical properties and “are intended to emit or […] to be possibly tuned to emit” light. Single LED chips and LED dies are therefore not considered light sources.

Among other things, light sources in potentially explosive environments, for emergency use, in radiological and nuclear medicine installations as well as in vehicles are also excluded from the regulation. Nevertheless, the manufacturers of those light sources must prove by test reports that their products are suitable for use in the respective environment.

New Calculation to Determine the Energy Class

The formula for determining the energy efficiency class of a light source is simplified. It is derived from the so-called total mains light output ratio (lm/W), which is the luminous flux divided by the power in the switched-on state multiplied by a type-specific factor (**Table 1**).

Light Source Type	Factor F_{TM}
Non-directional (NDLS) operating on mains (MLS)	1,000
Non-directional (NDLS) not operating on mains (NMLS)	0,926
Directional (DLS) operating on mains (MLS)	1,176
Directional (DLS) not operating on mains (NMLS)	1,089

Table 1: Factors F_{TM} by light source type

Energy Efficiency Class	Total Mains Efficacy $\eta_{\text{TM}} \sim (lm/W)$
A	$210 \leq \eta_{\text{TM}}$
B	$185 \leq \eta_{\text{TM}} < 210$
C	$160 \leq \eta_{\text{TM}} < 185$
D	$135 \leq \eta_{\text{TM}} < 160$
E	$110 \leq \eta_{\text{TM}} < 135$
F	$85 \leq \eta_{\text{TM}} < 110$
G	$\eta_{\text{TM}} < 85$

Table 2: Energy efficiency classes of light sources

To achieve the lowest energy efficiency class (G), a value of more than 85 lumens per watt must be met. The other classes are graded in steps of 25 lumens per watt, with the highest efficiency class (A) being awarded starting at a value of 210 lumens per watt (**Table 2**).

The "plus classes" A+ and A++ introduced in 2012 will consequently be omitted. When the regulation comes into effect in September 2021, it is expected that none of the light sources then available on the market will achieve efficiency class A and only a few will achieve class B. Furthermore, some of the light sources available today will not meet the requirements. This is an additional motivation for manufacturers to further increase the energy efficiency of their products.

Detailed Consumer Information

Regulation (EU) 2019/2015 also defines how the energy label is to be displayed on the packaging and what information it must contain (**Figure 2**).

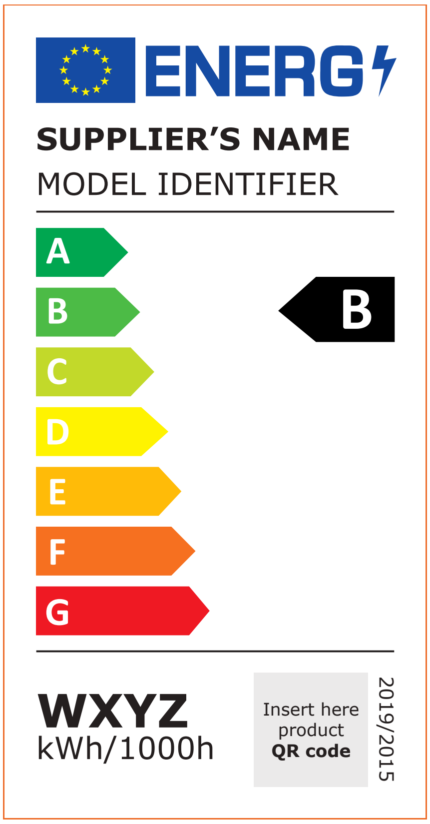

Figure 2: Energy label

The label should be located on the side facing the customer and must not be smaller than a specified minimum size. If the label cannot be placed on the front, at least an arrow indicating the energy class must be printed there (**Figure 1**).

The packaging of the light source must also contain information on its lifespan, power when switched on, color rendering index (CRI) and standby power. The luminous flux in lumens (lm), the correlated color temperature (CCT in kelvin (K)) and, in the case of directional light sources, the beam angle in degrees shall be indicated directly on the light source, provided that it does not excessively affect its light emission. If a luminaire or other containing product is sold which already contains the light source, the luminaire itself does not need to be labelled, a textual statement such as "This product contains a light source of energy efficiency class E" is sufficient. All necessary information is defined in Annex V of the regulation.

If an energy label is mandatory for a product and it is to be launched on the European market, manufacturers, importers, and distributors must register it in the EPREL database since 2019. Until next year this only applies to lamps and only a small amount of data is recorded. In future, data from light sources will also have to be registered, even if they are part of a containing product. Information required includes the type of light source, energy class and energy consumption. For LEDs and OLEDs, a lifetime factor must additionally be specified.

Ecodesign Requirements and Endurance Testing

Among the requirements of the new ecodesign regulation are that both the type-specific maximum permissible power consumption and the standby power of maximum 0.5 watts are not exceeded. Other new requirements include color rendering, flicker and other stroboscopic effects of mains-powered LEDs and OLEDs.

A change that is most relevant for manufacturers results from the new rules for mandatory endurance tests. The luminous flux at the start of the test is measured as a reference value. The lamp is then switched on in 1200 complete and uninterrupted cycles of 2.5 hours each. The pauses between the cycles are 30 minutes. This results in a total test time of 3600 hours with 3000 operating hours. Finally, the luminous flux of all non-failed specimens is measured again, and the lumen maintenance is calculated from this. This factor must not fall below a defined value depending on the lifetime declared for the product.

Compared to the current regulation, which demands an endurance test of 6000 operating hours, the test period has become significantly shorter. However, in future at least nine instead of eight out of ten light sources must be operable after completion of the endurance test. In addition, light sources that can detect measurements are not permitted on the EU market today.

Automated Testing

Although the required test time is significantly reduced with the new regulations, endurance tests usually still demand an enormous amount of manual effort. TÜV SÜD has therefore collaborated with its project partner Opsira, which specializes in optical systems technology, to develop a fully automated robotic goniometer. To meet TÜV SÜD's requirements, Opsira equipped an industrial robot with a DAkkS-calibrated photometer and a spectrometer and also programmed the software for the specific application.

The testing robot is now a part of the extensive, constantly growing testing facility in Garching. There the robot can independently manage up to 8000 lighting units for endurance tests. The individual units are approached independently and at definable intervals throughout the day (and night). This enables more measurements to be performed within the same amount of time. Time-consuming, manual work steps are no longer necessary. Data on the luminous flux and the light spectrum of the products as well as the lighting uniformity are recorded and can be evaluated at any time. This provides manufacturers with an above-average amount of data in a very short time, which they can use to optimise and fully describe their products – and at the same time meet the new (EU) 2019/2020 requirements for endurance tests. ■

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Future Scenarios of the Lighting Industry: Towards a More Sustainable and Innovative Market

The world is in the midst of a major transformative moment, and sustainability, among other aspects, has become one of the biggest challenges for society today. Some specific lighting features, such as new materials and efficiency, are already becoming very important. However, there are some other features that should be addressed. The question is not just whether and how sustainability will change the current products, but rather, what implications will be observed in the lighting value chain and what impact they will have on the current market.

As part of the European Commission's Horizon 2020 work programme, the aim of the Repro-light project is to start the transformation of existing luminaire solutions towards the next generation. The project takes into consideration sustainability, modularity, customization, intelligent systems and users comfort. Based on the technology that has been developed within this project, some future scenarios for the lighting industry have been identified. This article outlines six specific future scenarios. Three scenarios for Continuous Line Luminaire for industry context and another three scenarios for new desktop concept called Personal Table Light (PTL) for office context. The potential future scenarios have been developed according to type of luminaire, usage context, sustainable features, lighting features, lighting intelligent level, and personalization features. Using a storytelling tool and defining a specific Product-Service System (PSS) map for each scenario, the research work focuses on the implications that each potential scenario would have on the value chain of the industry. Moreover, it shows all the different stakeholders involved in service delivery and their mutual connections in a single frame. The obtained scenarios highlight the impact in the near future that the sustainable and innovative approaches will have on a luminaire company structure and the whole value chain perspective. Due to the creation of new advanced services in the near future, mainly related to sustainability and customer satisfaction, new stakeholders will join the PSS and some others will disappear.

Introduction

Scenarios are a "rich and detailed portrait of a plausible future word". Scenarios help to get a grip on the future by visualizing it and making it as realistic as possible [1]. Furthermore, they help focus thinking on the most important factors driving change in any product or service. By considering the interactions between these factors, it can improve the understanding of how change works, and what we can do to guide it. In the REPRO-LIGHT project scenarios have been used to help us to share the product vision and visualize the potential values and opportunities that the REPRO-LIGHT luminaire can bring to the user, client, company and environment. In addition, these scenarios have been used to identify the implications that each potential scenario might have on the current luminaire value chain. To this end, key scenario factors were identified and prioritized. Then, combining factors scenarios were defined. Afterwards, scenarios have been visualised base on storytelling technique and entirely described with a Product Services System (PSS) map [2]. The PSS is a synthetic graphical representation that shows in one single frame all the different actors involved in a product-service delivery, and their mutual links (e.g. flows of materials, energy, information, money, documents, etc.). Thus, a PSS clarifies how the different stakeholders and roles are connected one to the other, showing the values they exchange. The PSS is considered an excellent vehicle to enhance competitiveness and to foster sustainability simultaneously [3], so it perfectly fits in the general approach of Repro-light project and its objectives.

REPRO-LIGHT Luminaire Key Factors

The key lighting factors are light features that have been used to create scenarios. To define them, an exhaustive list of features that characterize the REPRO-LIGHT luminaires was developed. Next, features which referred to the same idea were removed, and the remaining features were grouped and discussed with luminaire experts from Bartenbach and Trilux companies. As a result, 7 groups of key factors and their corresponding sub-factors were defined and are described below.

Type of product

Two types of products were selected for scenario building. They are described below:

- CLL: Continuous Light Luminaire is a continuous line lighting system for industrial or office environments.
- PTL: Personalized table light is workplace lighting in the form of personal table light.

Level of luminaire

Two types of lighting levels were selected for scenario building. They are described below:

- Standard: Luminaire that allows manual adjustment of light features to increase user comfort.
- Premium: Smart luminaire that adjust light features to user needs and environment in order to increase comfort and efficiency. The premium luminaire also allows the aesthetic personalization of the light housing.

Usage context

Three types of usage contexts were selected for scenario building. They are described below:

- Factory: Refers to an industrial site where workers manufacture goods or operate machines.
- Office: Refers to a room or other area where an organization's employees perform administrative work.
- Retail: Refers to the space where consumers buy goods and services.

Light features

Three types of light features were selected for scenario building. They are described below:

- Brightness: An attribute of visual perception in which a source appears to be radiating or reflecting light. In other words, brightness is the perception elicited by the luminance of a visual target. It is not necessarily proportional to luminance.
- Color: The characteristic of visual perception described through colour categories.
- Distribution: The way light is distributed throughout the workspace.

Light intelligence criteria

Four types of light intelligence criteria were selected for scenario building. They are described below:

- Person detection: Refers to the system that is able to detect the presence of people in a specific area and function accordingly.
- Ambient light detection: Refers to the system that is able to detect the features of the ambient light and function accordingly.
- Fatigue detection: Refers to the system that is able to detect worker fatigue level and function accordingly.
- Task detection: Refers to the system that can detect the type of task the worker is performing and function accordingly.

Sustainability aspects

Three types of sustainability aspects were selected for scenario building. They are described below:

- Maximum energy efficiency: Refers to the refurbishment of the luminaire for re-use in a similar application.
- Maximum material efficiency: Refers to the refurbishment of the luminaire for re-use in another application with lower light demands.
- Renewable energy grid: Refers to the refurbishment of the luminaire with an increase of the drive current.

Aesthetic criteria

Refers to the option to personalize the housing of the luminaire as well as the furniture or system where the luminaire is going to be installed.

Results

Combining the different factors and subfactors, six scenarios have been generated: three potential scenarios for the Continuous Line Luminaire (CLL) product, and another three future potential scenarios for the Personal Table Light (PTL) product. **Table 1** shows the selection of factors and subfactors that result in the construction of the six abovementioned scenarios. The first column of the table sets out the key factors and subfactors, the second column the first scenario, the third column the second scenario and so on until all scenarios are presented. The "×" in the table indicates which of the subfactors are considered in each of the scenarios.

Scenario 1: This scenario represents REPRO-LIGHT standard Continuous Line Luminaire in a factory environment. The scenario presents how the installation and refurbishment of the luminaire in companies can achieve maximum energy efficiency.

Scenario 2: This scenario focuses on REPRO-LIGHT premium Continuous Line Luminaire in a factory environment. The scenario presents how intelligent luminaire adapts brightness based on person detection technology.

Scenario 3: This scenario is focused on REPRO-LIGHT premium Continuous Line Luminaire in an office environment. The scenario presents how intelligent luminaire adapts brightness and colour based on person and ambient light detection technology

Scenario 4: This scenario is focused on REPRO-LIGHT standard PTL luminaire in an office environment. The scenario presents how a worker can manage the luminaire features (brightness, color and distribution) according to their task and level of physical and mental fatigue.

Table 1: Factors and sub-factor of each scenario

	CLL			PTL		
	1	2	3	4	5	6
LEVEL OF LUMINAIRE						
Standard	×			×		
Premium		×	×		×	×
USAGE CONTEXT						
Factory	×	×				
Office			×	×	×	×
Retail						
LIGHT FEATURES						
Brightness		×	×	×	×	×
Colour			×	×	×	×
Distribution				×	×	×
INTELLENGE CRITERIA						
Person detection		×	×	×	×	×
Ambient light detection		×	×	×	×	×
Fatigue detection					×	×
Task detection					×	×
SUSTAINABILITY ASPECTS						
Maximum energy efficiency	×			×	×	×
Maximum material efficiency		×				
Renewable energy grid			×			
AESTHETIC CRITERIA						×

Scenario 5: This scenario focuses on REPRO-LIGHT premium PTL luminaire in an office environment. The scenario presents how an intelligent luminaire system adapts features (brightness, colour and distribution) to the specific task of the worker and their level of physical and mental fatigue.

Scenario 6: This scenario focuses on REPRO-LIGHT premium PTL luminaire in an office environment. The scenario presents how a luminaire housing as well as the furniture systems can be personalized to fulfill the aesthetic requirements of the company.

As mentioned before, for each specific scenario a storytelling and a PSS have been describe. Storytelling is a narrative of the complete path followed by a character in the chosen context and it shows the value-in-use by a sequence of realistic service moments. It presents the experiences of the customers and helps to better understand what the experience of the intended user is like [4]. To build the storytelling firs it has be considered what the beginning of the story is and how it will develop and end. Later, key moments of the experience have been defined and finally, visuals to illustrate the story were design. **Figure 1** shows part of the storytelling of scenario 2. The storytelling of scenario 2 describes the actions of Ana, a factory worker, throughout a working day. The storytelling describes how an intelligent Continuous Line luminaire system interacts with Ana from the moment she arrives at the factory until she leaves.

In parallel, a Product Service System (PSS) was build for each scenario. As mentioned

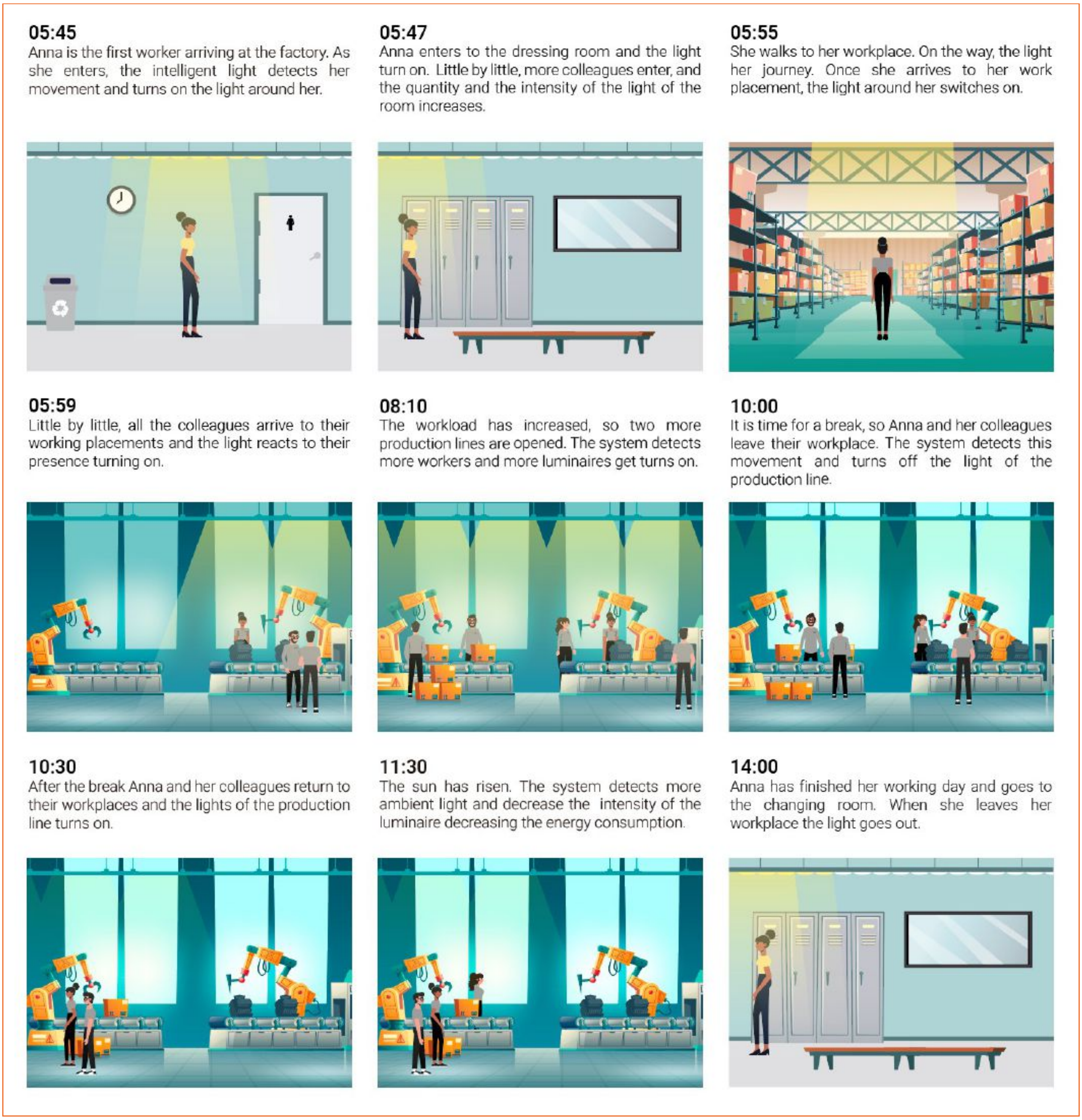

Figure 1: Storytelling of Continues Line Luminaire - Scenario 2

before, the PSS resumed in a synthetic representation of the whole product-service delivery and the links between all stakeholders. In this specific case, the PSS map illustrates how the different participants are connected to each other, highlighting the values they exchange. It also helps to understand the dynamics of the services, identify gaps and opportunities [5]. To build the Repro-light PSS maps (i) first the boundaries of the whole system were defined, (ii) later every stakeholder involve in the services was identify and, finally, (iii) the mutual links were described.

The set up process starts with suppliers who provide luminaire parts to the manufacturer. In this scenario in addition to luminaire parts, the suppliers also provide software solutions to manufacturers. Manufactures are the stakeholders who manage the development and manufacturing of the luminaire products and software's and are those who provides services and materials directly to their customer or through sales agents (wholesaler). In addition, these processes may also involve other stakeholders such as installers. Finally, the users are the stakeholders that interact, direct or indirectly, with luminaires through customers.

Closing the system general flow, customers are those who contact installers, wholesalers or the manufacturer to request maintenance or end of life. These processes are managed by installers, which means that they are in charge of deinstallation and

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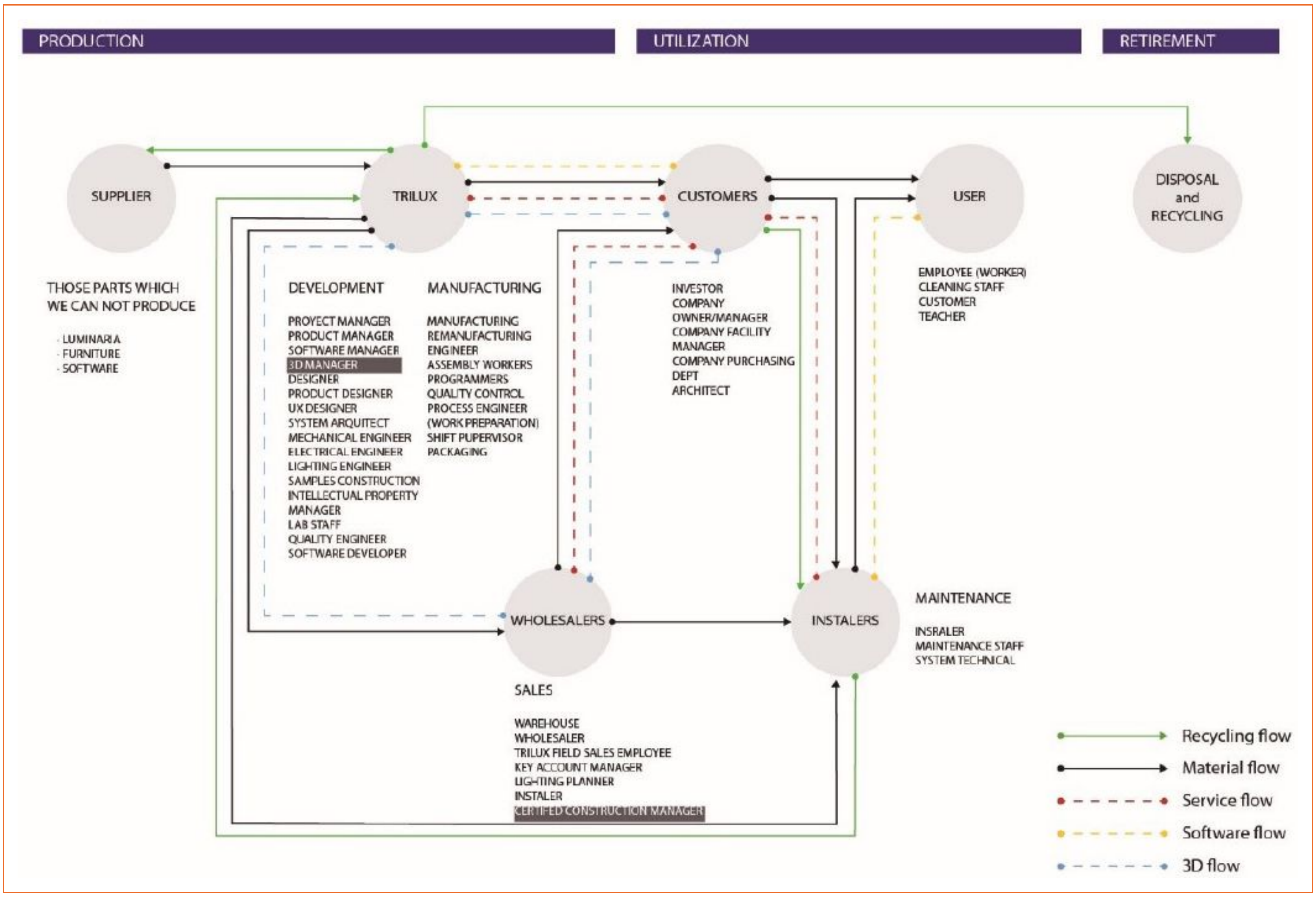

Figure 2: PSS of Continues Line Luminaire - Scenario 2

sending the luminaire back to the manufacturer. The manufacturer, will either reuse parts and components, send reusable parts and components to the supplier, or send parts to be recycled or disposed of.

Conclusions

The development of scenarios has begun with the analysis and identification of key factors that lead the future of intelligent and sustainable lighting. Combining factors, the REPRO-LIGHT project builds six potential future scenarios that visualize the future of intelligent and sustainable lighting. The future scenarios have been developed according to type of luminaire, usage context, sustainable features, lighting features, lighting intelligent level, and personalization features. Using a storytelling tool and defining a specific Product-Service System (PSS) map for each scenario, the research defines the implications that each potential scenario might have on the luminaire value chain.

The conclusions were obtained from the REPRO-LIGHT project. This analysis shows that the level of intelligence embedded in lighting systems is one of the most relevant axes that will drive innovation in the future of lighting. Intelligent lighting, besides providing comfortable environments for workers and users, encourages efficiency and environmentally friendly lighting. In this regard, systems that measure ambient light, identify the number and position of people and track their gestures and facial expressions need to be developed. The intelligent lighting systems require new stakeholders such as software suppliers, electronic engineers, software developers, UX designers and system technicians. In addition, new interaction flows ,such as software service flow is observed. The second predominant factor in the lighting sector is comfort. These systems seek to adapt the qualities and characteristics of the lighting to the needs of the environment. In this sense, research is moving towards the ability of lighting to adjust the color, distribution, brightness, and intensity of light.

The third predominant factor is sustainability. The lighting sector is not exempt from the understanding that nature and the environment are not endless sources, and that their protection and rational use is necessary. Therefore, understanding the life cycle of lighting systems and developing solutions that allow for a lower consumption of resources and a greater use of these will be a fundamental axis. Sustainable lighting requires stakeholders with knowledge in remanufacturing processes, techniques and technologies.

Finally, the customization of the lighting systems. Thanks to new technologies such as 3D printing, the manufacture of customizable lighting begins to be a reality. 3D printing enables the customization of products, being able to create products adapted to the needs of customers, technologically feasible and economically viable. Customizable lightning needs stakeholders such us product designers, 3D suppliers, 3D managers and certified construction manager. In addition, new interaction flows such as 3D flow appear in the PSS. ■

Acknowledgment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No768780. The authors thank all members in the Repro-light consortium, especially Sebastian Knoche from ITZ and Judith Gross from Bartenbach for

REPRO-LIGHT

Initiating Transformation in the European Lighting Industry

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

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their valuable part in producing the results presented in this manuscript.

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Mondragon University is a non-profit co-operative private university in the Basque Country, officially established and recognised in 1997, whose primary aim is the transformation of society through the comprehensive education of persons and the generation and transfer of knowledge. It is part of Mondragon Corporation with whom it shares the values and principles which have made it possible to be active agents in the development of a more just and sustainable society. Its main campus is in Mondragón, Gipuzkoa.

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Full Spectrum LED Study 1.0

The recently introduced full spectrum LEDs are designed for electric lighting appliances to produce natural light quality also for indoor spaces. They allow an almost comprehensive reproduction of the visible wavelengths of light. The new light sources enable the lighting industry to approach daylight spectra more closely than before, at significantly lower costs and less complexity than in the past.

Despite possible benefits of the new technology, full spectrum LEDs are not yet on a par with standard LED solutions on the market. This is probably due to the fact that they are more costly in comparison to the standard LEDs while a supposed positive effect on human beings has not yet been evaluated scientifically. Even though there is plenty of research in the field of light perception in general, there has been almost no basic research to date to investigate the impact of full spectrum LEDs on human beings. To address this lack of knowledge, the Fraunhofer Institute for Building Physics IBP (Fraunhofer IBP) in Stuttgart, Germany, conducted a study in order to evaluate the impact of full spectrum LEDs on human visual perception and task performance.

Status Quo LED Spectra

Since LEDs were introduced in the lighting industry (around 2008), their efficiency and product life span have been continuously developed and improved. In addition to these parameters, in recent years, color temperature and its control (circadian light), as well as color rendering have become increasingly important. Most recently, since 2018, the range of products in the LED segment has been considerably extended by products with light spectra that are close to natural sunlight. Numerous discussions with market participants suggested that there are many aspects reflecting the benefits of this technology, like a higher Color Rendering Index (CRI), but also a better representation of saturation and higher fidelity and gamut indexes (Rf, Rg – TM30-15). The new LED generation has not yet been able to prove its full effectiveness in the market due to higher production costs and lower lifetime and efficacy compared to standard LEDs. Depending on the product, LEDs only have a minor share in the final price of the luminaire. It is often less than USD 1. This implies a large potential for a substantial increase in product quality and the associated added value for manufacturers and end users of luminaires. The positive impact of sunlight on human beings is beyond debate [1], the impact of the full spectrum LED technology is to be evaluated. For this purpose, the Fraunhofer IBP carried out a study with test subjects in a room environment (laboratory) in which the new technology was installed on a large scale.

Methods

83 test participants performed both cognitive tests and practical tasks, and evaluated their perception subjectively in a laboratory environment in order to compare the perception and the effects of four different LEDs. The LEDs that were compared were two full spectrum LEDs and two standard LEDs (CRI 80, 4000 K (standard 1), and a mixture of CRI 80 2700 K and 6500 K at 4000 K (standard 2)). The illuminance at table height was 750 lux on average.

Full Spectrum LEDs and Daylight

The spectral composition of daylight has shaped our perception for millions of years. Full spectrum LEDs try to mimic this spectrum and to achieve similar effects to natural light. Of course, the spectrum is only one of the parameters that needs to be taken into account when comparing daylight to artificial light sources. Besides the huge intensities that sunlight can provide, also the variation in color temperature throughout the day and the variations caused by reflections and refractions of clouds also need to be taken into account (**Figure 3**). The tested LEDs are available in various color temperatures which basically allow for the implementation of "human centric lighting" or "daylight mimicking" applications. Latitude and climate (cloud cover parameters) also affect the intensity and the spectral composition over time which lead to big differences in daylight perception at a technical and cultural level. In comparison, the often discussed effects of façade glazing on the spectrum are not of importance (for standard window glass).

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The introduction of full spectrum LEDs allows them to come closer to natural light in interiors. From a holistic point of view, it is one of a few parameters that concern the effects of natural light.

Test Facility “HiPIE-Lab”

The High Performance Indoor Environment (HiPIE)-Lab is an innovative and adaptable state-of-the-art test environment for user studies at the Fraunhofer IBP in Stuttgart (**Figure 1**). The lab is built as a room-in-room system of approximately 45 m^2 and allows perfect control of air flow, temperature, acoustics, light and humidity. It is also equipped with two windows, an artificial sun, a flexible luminous ceiling and a modern 360° sound system for virtual sound scenarios.

Figure 1: HiPIE-Lab at the Fraunhofer IBP | © IBP

Installation of LEDs and Calibration

After specifying the LED type, the LED boards were designed and produced according to the specifications. A DMX system was chosen and designed to allow flexible and real-time control of several lighting conditions. It also offers possibilities to synchronize the complex 360° audio system to the lighting control to allow more evaluations on a multimodal level.

Figure 2: Installation and wiring on the lab ceiling. Remaining fields are illuminated by fluorescent light sources (stock) | © IBP

The ceiling of the lab consists of 81 light panels, each with a size of 600×600 mm. To ensure sufficient illuminance, 16 to 20 panels were used for each LED type (**Figure 4** and **Figure 2**).

Calibration

In all scenes, the color temperature was 4000 K and the illumination level 750 lux (average value), measured with a PRC Krochmann Radio Lux 111 (Class A) luxmeter according to DIN EN 13032. The color temperature and the spectrum were measured with a GL Spectis 1.0 Touch Spectrometer. The parameters are shown for all four LED conditions (**Figure 5**, **Figure 6**, **Figure 7**, **Figure 8**).

Study Procedure

The participants were individually invited to the Fraunhofer IBP in Stuttgart. In order to avoid data bias, the study was limited to participants with normal or corrected to normal eyesight. Prior to the main tests, each participant’s eyesight was tested with Landolt’s test for visual acuity [2], the Ishihara test for color perception [3][4] and the SpotChecks Contrast Sensitivity test [5]. The participants completed the eyesight tests in a room lit according to the standard testing scenarios of the respective test. Participants were asked to wear their glasses or contact lenses in case they usually wear any.

The main part of the study took place in the HiPIE-Lab. Participants were tested individually and each participant was assigned to one out of four LED conditions (full spectrum LED 1, full spectrum LED 2, standard LED 1, standard LED 2). Conditions were assigned randomly, however balanced by time of day over the course of the study. Only paper pencil tests were used in order to avoid effects of screen or display use on visual perception.

First, participants filled out a short questionnaire about demographics and general information (gender, age, educational level, occupation and general usage of screens) and rated their first impression concerning glare on the de Boer glare rating scale [6]. Next, a ten-minute adaption phase with eyes open and an auditory presentation of irrelevant content followed in order so that the participants could adapt to the lighting conditions.

Afterwards, the method of Visual Analogue Scales (VAS) was explained to the participants in writing. VAS is a graphical rating scale whose endpoints define extreme values of a certain characteristic. Participants can indicate their current perception, feeling or mood by marking a representative spot on the scale. In this study, the scale was exactly 10 cm long, so the marked spots were converted into numbers be-

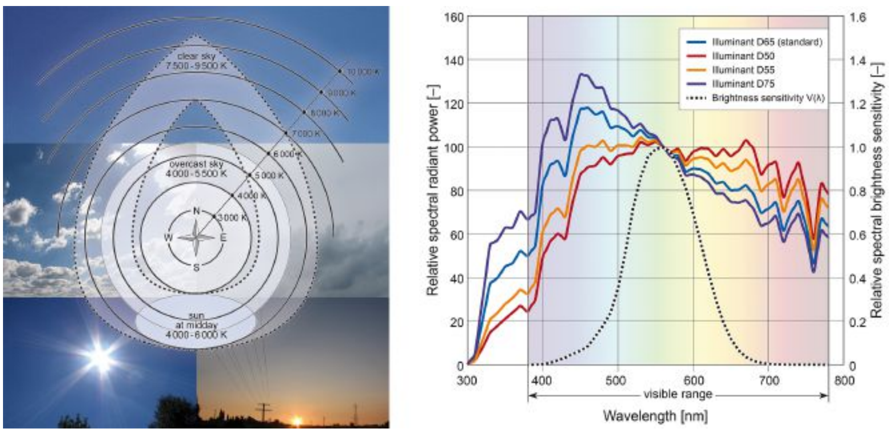

Figure 3: Assignment of sky states to color temperatures (left) and relative spectral radiant power of selected illuminants series D (daylight) (right) | © IBP

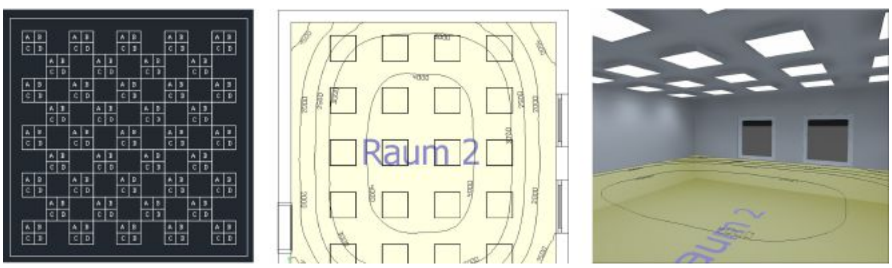

Figure 4: Schematic illustration of the lab ceiling and distribution of the LED type (left) and lighting calculation (middle, right) | © IBP

tween 1 and 10 for analyses. The higher the rating, the more positive was the evaluation on the respective characteristic. After the instructions, participants completed the Karolinska Sleepiness Scale (test point 1: pre), which measures the level of sleepiness in the last ten minutes [7].

Following, the participants performed the attention test "Frankfurter Aufmerksamkeits-Inventar 2" (FAIR-2) in order to evaluate whether the performance varied under the different lighting conditions [8]. The "FAIR-2" is a standard psychological test in paper pencil form which demands accurate and fast differentiation of visually similar symbols. After the instructor had explained the procedure of the test, a short training was performed, followed by the main test. This main test consists of two pages with target and distraction items with the target items to be identified within a time limit of three minutes per page. Four different aspects can be evaluated with this test: understanding of instructions, performance speed, quality (accuracy) and consistency.

After the test, participants filled out further VAS concerning the general room lighting (comfort, pleasantness, attractiveness, workplace suitability). Next, three objects (a printed text, a can of Coke and a Nivea Cream) were placed in front of the par-

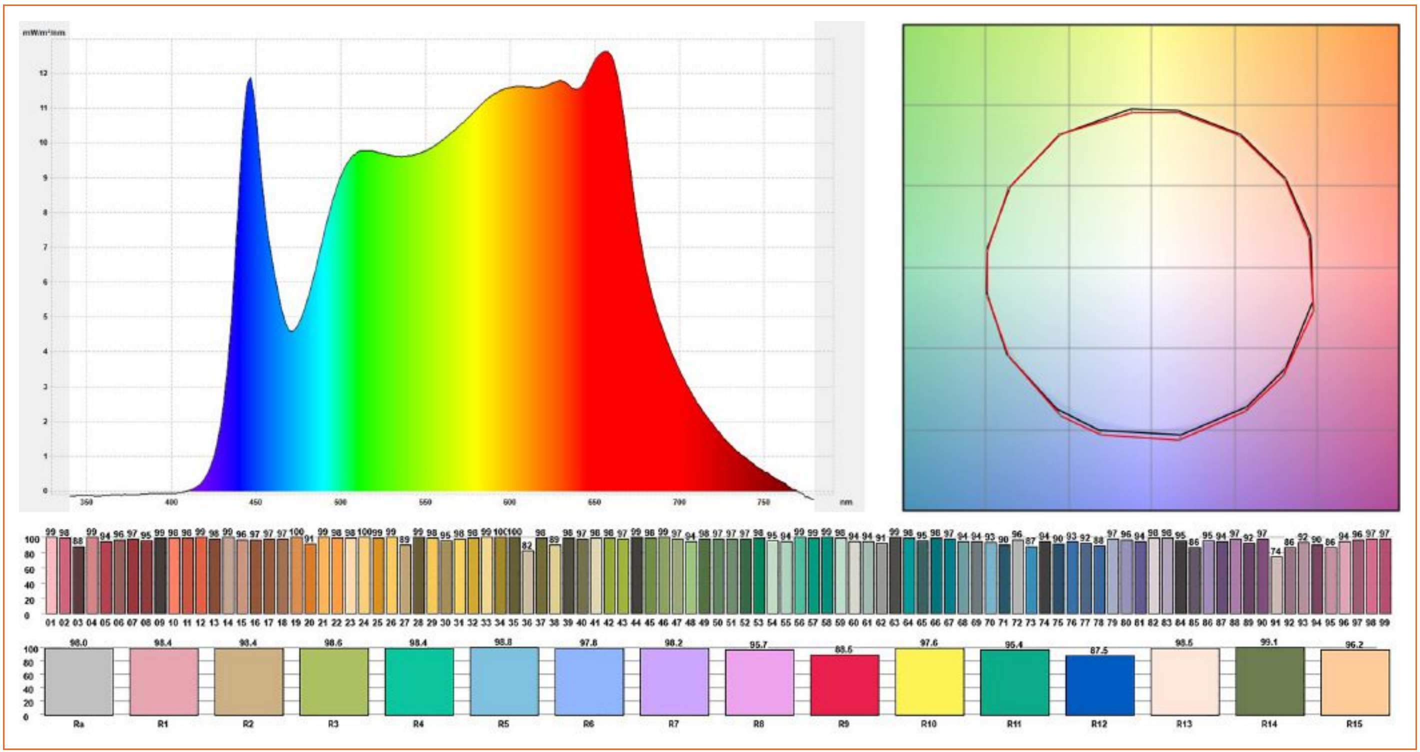

Figure 5: On-site measurements: spectrum, color vector graphic, TM-30-15 fidelity index and CRI of scene 1 (full spectrum LED) | © IBP

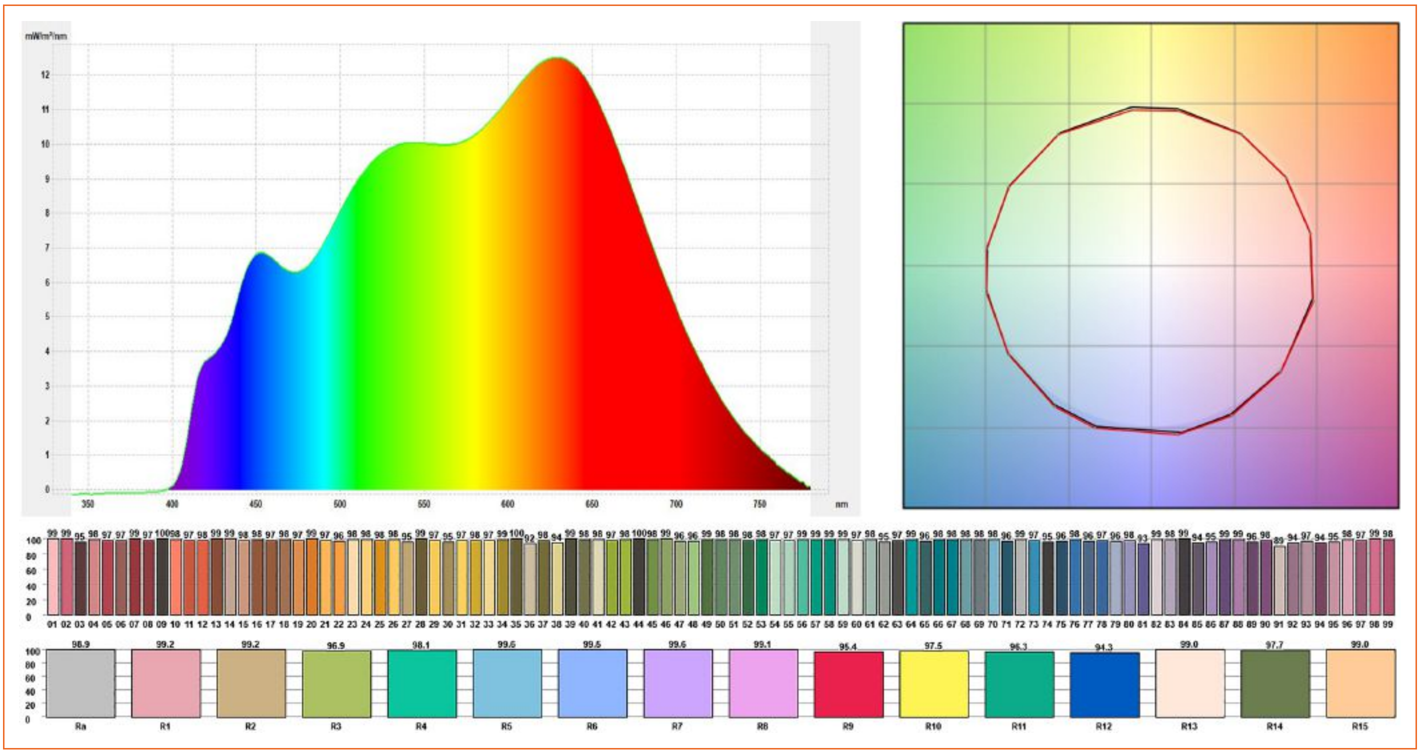

Figure 6: On-site measurements: spectrum, color vector graphic, TM-30-15 fidelity index and CRI of scene 2 (full spectrum LED) | © IBP

ticipant (**Figure 9**) and further VASs were assessed in relation to the visual perception of the objects based on an adapted version of [9] (naturalness of the objects and their color and colorfulness). These objects were selected because it can be assumed that they and their appearance are generally known to all participants. Besides these objects, the perception of the wooden desk surface as well as the participant's own hands were also evaluated. Furthermore, the participants rated the general viewing / visual conditions (bright – dim, comfortable – uncomfortable, pleasant – unpleasant, interesting – boring).

In order to increase the field relevance of this study, two practical tasks were included: Gloss sorting and fabric evaluation (**Figure 10**). First, participants had to sort seven NCS Gloss Scale cards (ISO 21813) according to their gloss as fast as possible. Second, participants received 16 pieces of fabric (three different types). Eight of these pieces were intentionally damaged or soiled and the participants' task was to identify these pieces. Both tasks were timed.

The study was closed with a further completion of the Karolinska Sleepiness Scale (test point 2: post). The study took about one hour in total, with approximately ten minutes spent on the eyesight tests. One

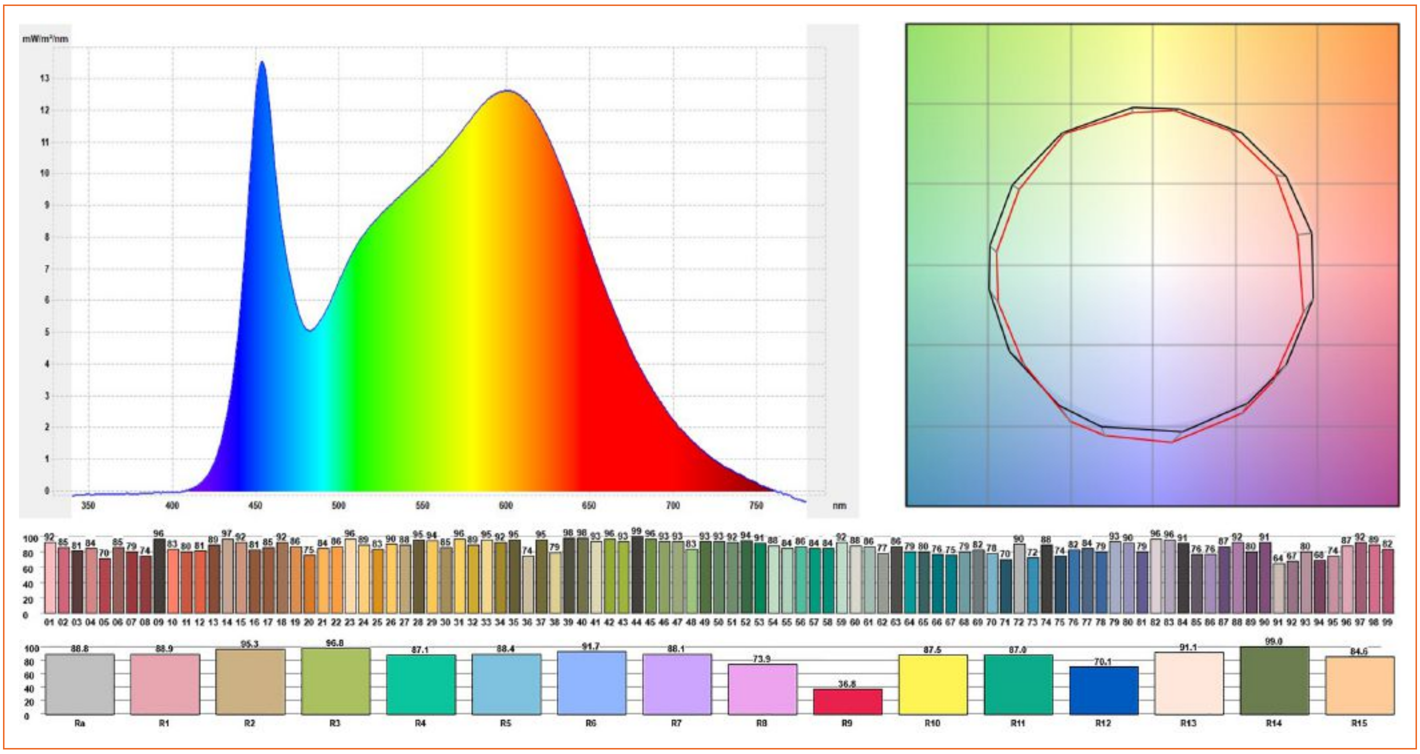

Figure 7: On-site measurements: spectrum, color vector graphic, TM-30-15 fidelity index and CRI of scene 3 (Standard LED 1) | © IBP

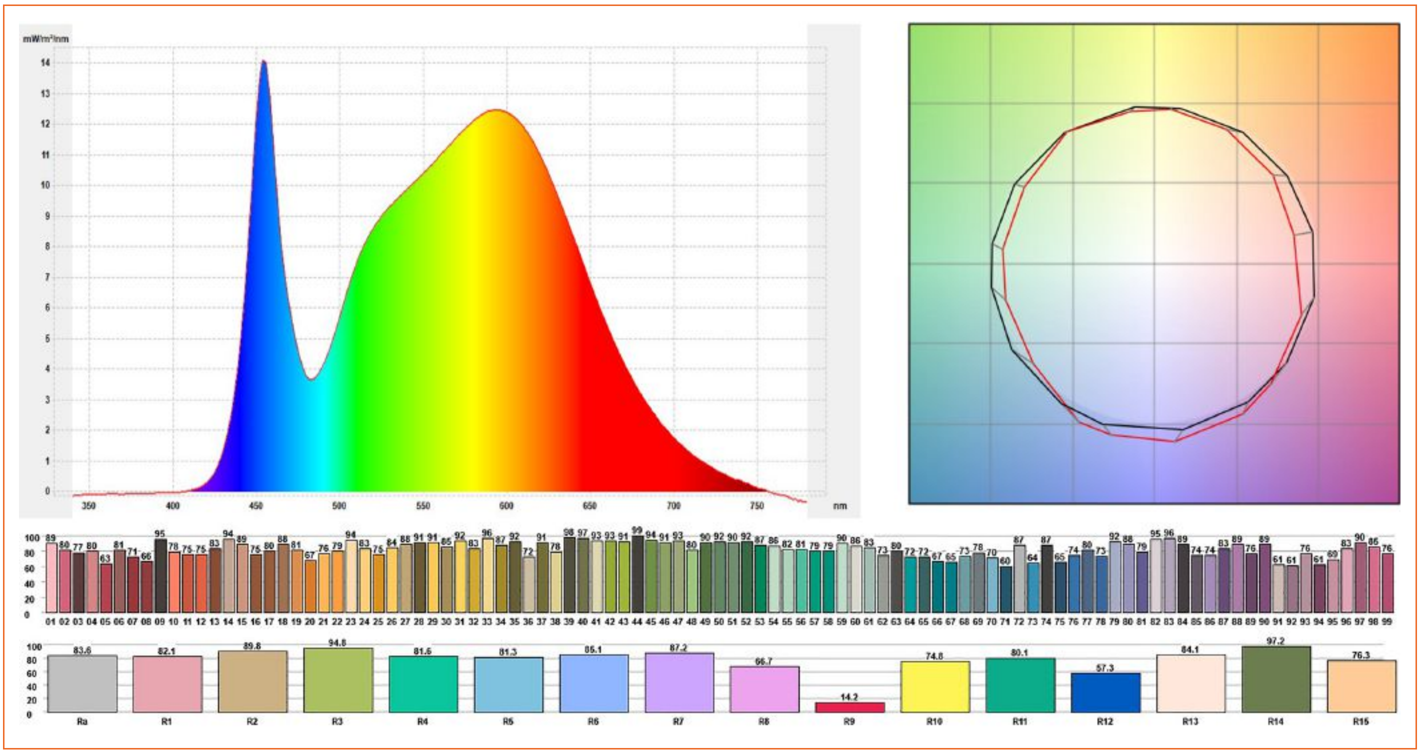

Figure 8: On-site measured files: spectrum, color vector graphic, TM-30-15 fidelity index and CRI of scene 4 (Standard LED 2) | © IBP

Figure 9: Rating of different objects and viewing conditions via paper pencil tasks | © IBP

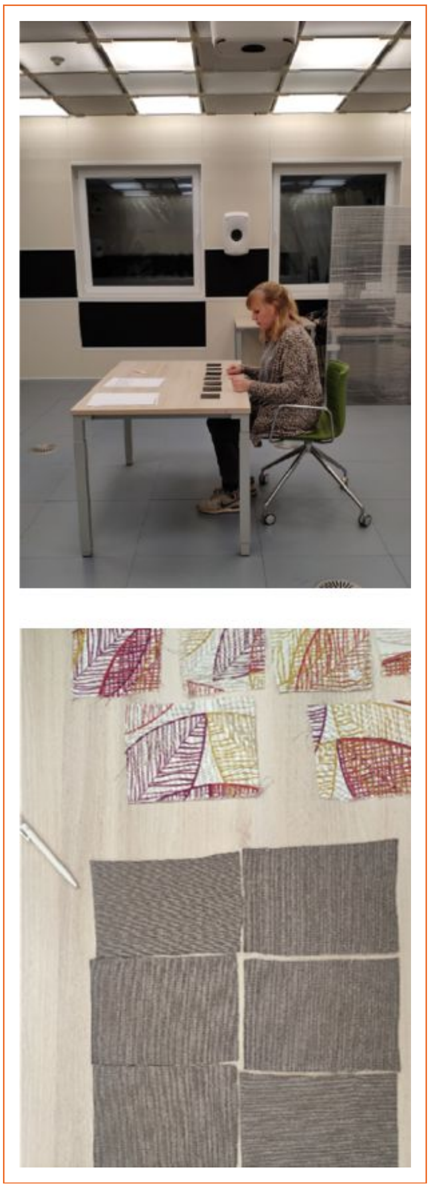

Figure 10: Participant performing the gloss sorting test (top) and fabrics which the participants had to sort (bottom) | © IBP

participant was tested at a time and participants received a monetary compensation of 20 euros.

Results

A total of 83 participants took part in the study. The data of two participants had to be excluded due to severe outliers in at least one of the eyesight tests and of one participant due to misunderstanding of the FAIR-2 instructions. The mean age was 24.37 years ($SD = 3.49$) and 69% of the participants were female. 83% of the participants were students.

In the following, the results of the statistical data analyses are presented. Since the aim of the study was to evaluate fundamental effects of full spectrum LED technology on human beings and not to compare individual full spectrum LED technologies, the results of this study are published without reference to specific manufacturers. The results are presented anonymously and always with reference to the full spectrum LED technology with the greatest efficiency. In addition, as a non-profit research institution, the Fraunhofer Gesellschaft is not permitted to favor certain manufacturers from industry through reporting. The four scenarios are named Full Spectrum LED 1 ($n = 19$), Full Spectrum LED 2 ($n = 21$), Standard LED 1 ($n = 19$), Standard LED 2 ($n = 21$). In addition to descriptive statistics (e.g. means), inferential statistics (significance tests, e.g. analysis of variance) are carried out in order to evaluate whether a detected difference between two groups is a real or random difference. The significance level was set at 5% and analyses with a significance level lower than this are defined as statistically significant. Furthermore, effect sizes are calculated in order to indicate whether an effect is relevant in practical terms.

In total, 19 different items were evaluated in this study. For each of them, comparisons between all four LED conditions were analyzed. In all analyses, it was controlled for the individual level of display usage and contrast sensitivity.

Subjective Evaluations

The subjective evaluation of glare on the de Boer scale did not differ depending on the LED condition. Concerning the general room impression, a statistically significant difference was found between one of the full spectrum LEDs ($m1 = 5.7$) and the Standard LED 2 ($m2 = 4.04$) for the item “Overall, the lighting in the room is… very uncomfortable – very comfortable” (**Figure 11**).

The effect size is large ($\eta^2 p = 0.104$). Further, a statistically significant difference was found between one of the full spectrum LEDs ($m1 = 6.5$) and the Standard LED 2 ($m2 = 4.44$) for the item “Under the lighting, the overall desk area appears to be … very unpleasant – very pleasant”. The effect size is large ($\eta^2 p = 0.137$). In the section concerning colours, a statistically significant difference was found between one of the full spectrum LEDs ($m1 = 6.62$) and the Standard LED 2 ($m2 = 4.15$) for the item “The colour of the objects on the desk looks… very unnatural – very natural“ (large effect size of $\eta^2 p = 0.14$; **Figure 12**) and for the item “In this lighting, the colour of my hands look… very unnatural – very natural” ($m1 = 7.53$; $m2 = 5.61$; medium effect size of $\eta^2 p = 0.085$).

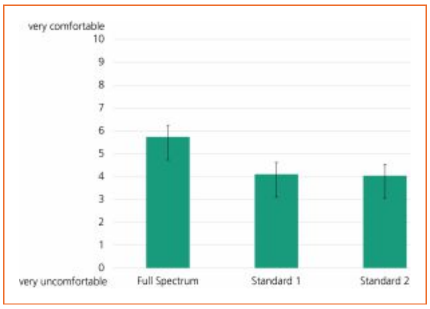

Figure 11: Bar charts of the rating of the item “Overall, the lighting in the room is… very uncomfortable – very comfortable” show means and standard errors of means

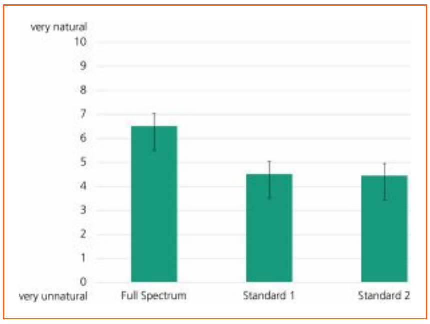

Figure 12: Bar charts of the rating of the item “The color of the objects on the desk looks… very unnatural – very natural” show means and standard errors of means

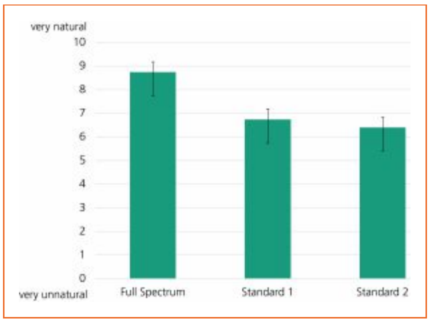

Figure 13: Bar charts of the rating of the item “How would you rate the naturalness of the following objects? … your hand” show means and standard errors of means

Concerning the naturalness of the hands themselves, a statistically significant difference was found between one of the full spectrum LEDs and both of the standard LEDs ($m1 = 8.74$; $m2 = 6.73$; $m3 = 6.4$; large effect size of $\eta^2 p = 0.173$; **Figure 13**). All other subjective evaluations did not differ in a statistically significant way between the LED conditions.

Performance Tests

For the FAIR-2 test, the four different test scores mentioned above were calculated. Also for the gloss card sorting, several scores were analyzed: Total correctness (all correct versus at least one error), percental correctness (e.g. points for each card put on the correct spot, points for each irregularity found), time needed to complete the task. For the fabric sorting task, both the time stopped and the amount of detected damages were counted. For none of these performance tests statistically significant group differences were found. Thus, the LED conditions had no effect on the performance in these three tests.

Effects on Sleepiness

Pre- and post-sleepiness scores were compared in order to evaluate whether the course of sleepiness varied throughout the study depending on LED condition. All groups got activated during the test session (feel more awake, more alert and less relaxed at the end of the test session compared to the beginning). This is probably due to the stimulating nature of a test session. However, no statistically significant difference was found between the LED conditions concerning the course of sleepiness or alertness/relaxation.

Summary and Conclusion

In this study, two full spectrum LEDs and two standard LEDs were compared by having participants of a study subjectively evaluate items on lighting conditions, naturalness and colors, and complete different performance tests. Statistically significant differences were found between at least one of the full spectrum LEDs and one of the standard LEDs for comfort of the overall lighting in the room, pleasant appearance of the desk area, naturalness of the color of the objects on the desk in general and of the participants' hands, and overall naturalness of the participants' hands. For all comparisons that were statistically significant, at least one of the full spectrum LEDs revealed "better" effects than the standard LEDs (e. g. higher naturalness, higher ratings of comfort).

No statistically significant effect of the LED condition was found for performance tests (attention, gloss and fabric sorting). Furthermore, in all LED conditions, the participants felt more alert at the end of the test compared to the beginning, with a similar effect in all LED conditions. Throughout the study, there was no case in which the standard LEDs outperformed the full spectrum LEDs in a statistically significant way. It can be summarized that the study is in favor of full spectrum LEDs, however, the effects are specific.

The results obtained from this study give insights into the question whether, based on the new technology of full spectrum LEDs, practically relevant effects can be identified with regard to the impacts on human beings and human perception of full spectrum. This first investigation focused on basic research and was purposely designed to be independent of the context of usage. For the future, the findings can be used as a basis for follow-up projects aiming at specific contexts (e.g. offices, retail, gastronomy, health and care services) within the scope of a field study. ■

Acknowledgements

The project and this publication were supported by Nichia (Japan), Seoul Semiconductor (Korea) and Toshiba Materials (Japan). We also thank Lumitronix (Germany) for equipping the laboratory.

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Average Spectral Difference – New Metric to Evaluate the Naturalness of Artificial Light Sources

Lighting has more effect on people than just enabling us to see – it can also impact and affect our mood and health. Advanced spectral engineering methodologies enable spectral manipulation to enhance or reduce emission at specific wavelengths. This technology can be used to augment or suppress specific targeted wavelengths in the emission spectra, or to reduce spectral spikes and valleys to improve the spectral consistency to that of natural light, both of which may affect human physiology. While there are differing schools of thought in the lighting industry, delivering natural light is of primary interest to many human centric lighting advocates. This raises the question: how do we objectively quantify naturalness? Standard lighting quality metrics such as CRI and TM-30 do not fully address this naturalness question. This article presents a new metric, Average Spectral Difference (ASD), which provides a quantitative measurement of how closely a light source matches the spectra of natural light.

Characteristics of Natural Light Sources

In recent years, the lighting industry has begun to explore ways to improve the quality, as much as the quantity, of light produced by LED light sources. More broadly, lighting designers, specifiers, and end-users are exploring the concept of human-centric lighting (HCL). HCL has many definitions, but it is broadly agreed that it encompasses the effects of lighting on the physical and emotional health and well-being of people.

While there are many factors that can be considered in developing a human centric light source such as color temperature, color rendering, glare, flicker, and more, the spectral power distribution (SPD) of the source is a fundamentally important factor to consider. There are two main areas of research and development for spectral enhancement of LEDs tailored for use in HCL applications: exaggeration or naturalness.

The first area focuses on influencing human behavior. Several studies have shown that enhancing or retarding certain wavelengths can affect human physiology. Through increasing intensity in the blue to cyan wavelength ranges, melatonin secretion can be suppressed, increasing alertness. Conversely, through reducing emission in these wavelength ranges, the opposite effect can be achieved, increasing restfulness and relaxation. While various scientific studies have been conducted to support this interaction with light at specific wavelengths and human physiology, the long-term effects of this artificial influence on humans remains unknown.

The second area focuses on replicating the spectra of natural light, under which humans have evolved for hundreds of thousands of years. There is a strong presumption among lighting experts and HCL advocates that the more natural a light source is, the better for the observer. Mimicking the spectra of natural light sources offers advantages in bringing natural lighting to interior environments where humans spend most of their time, and lighting specifiers for both residential and commercial spaces such as offices, schools, care homes, and hospitals might also presume that the safest option is to avoid exposing people to non-natural augmented lighting.

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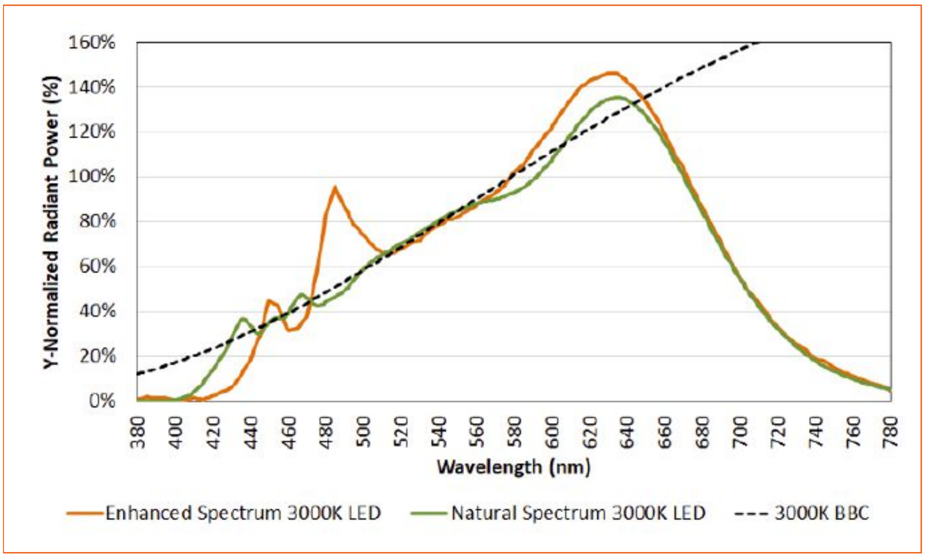

Figure 1: Spectral engineering examples of 3000 K LEDs targeted for human centric lighting

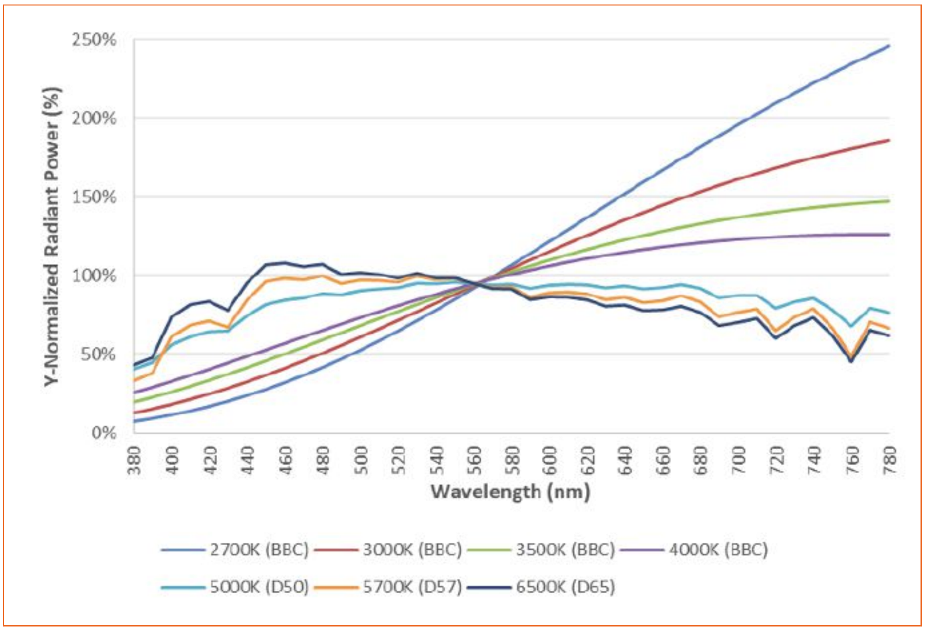

Figure 2: The standardized reference SPDs of natural light

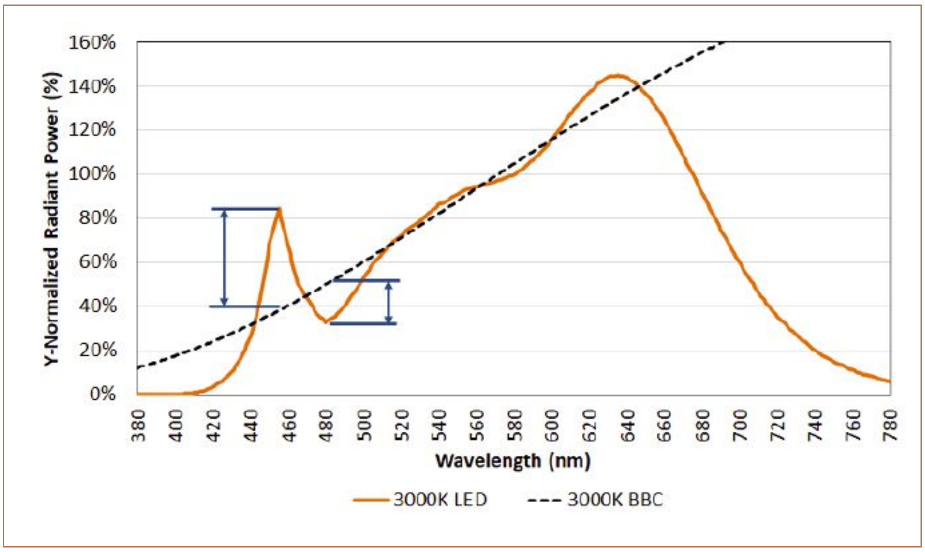

Figure 3: SPD of a typical 98 CRI 3000 K LED with IES TM-30 R_f of 94 and R_g of 102, still exhibiting a spectral spike at 450 nm and valley at 480 nm

Figure 1 shows spectral power distribution curves for two 3000 K LED light sources against the 3000 K Black Body Curve (BBC). The enhanced spectrum pertains to the first area of R&D where the SPD is selectively exaggerated to nudge human physiology into a "wakefulness" state, whereas the natural light SPD is indicative of the second area of R&D in which the spectrum is engineered to match natural light. By looking at these SPDs, we can qualitatively see that the natural light curve matches the BBC much more closely than the enhanced spectrum curve, however arriving at a quantitative comparison has eluded industry experts, until now.

Evolution has conditioned humans to function in daylight hours by the light of the sun, and after dusk, in the warm glow of fire. Thus, we define natural light sources as those of sunlight and firelight. Conveniently, these natural light sources have standardized spectral definitions, ubiquitous in the lighting industry. The most widely used scientific method for defining a light source is the SPD, typically plotted on a graph of the type shown in **Figure 1**.

Likewise, **Figure 2** plots the standardized spectral definitions of natural light. They represent the exact balance of wavelengths to which evolution has conditioned the human body to respond, and under which humans have evolved and thrived.

SPDs can be plotted for any visible light source. If an artificial light source with a color temperature of 6500 K, for example, has a spectral power distribution closely matching the D65 curve in **Figure 2**, it will have a higher Color Rendering Index (CRI) value compared to a light source that does not match the standardized spectral reference as closely.

Color quality metrics such as CRI and TM-30 provide important information about the extent to which a light source matches the lighting effect of a natural reference source such as daylight (at cooler color temperatures of $\geq$5000 K) or the black body curve (at warmer color temperatures of $\leq$4000 K). However, two different light sources with the similar CRI, TM-30 R_f, and TM-30 R_g values may appear differently when viewed side by side, or may have vastly different physiological impacts, because they have significantly different SPDs. Thus, these metrics alone are insufficient to define the naturalness of light. **Figure 3** compares a 3000 K LED with near perfect CRI of 98, to the standardized definition of a 3000 K natural light source (i.e. the black body curve). The comparison shows that simply having high CRI and TM-30 values does not necessarily mean that the source is a close match to the spectra of natural light, as indicated by the highlighted spectral peak and valley.

Average Spectral Difference: A Definitive Measure of Naturalness

To quantify the relative difference in naturalness between SPDs, we must first consider the spectral range in which the comparison is made. Although the spectral range of human vision stretches from 380 nm to 780 nm, the subset of this range that corresponds to the photopic response curve, or V(λ), is ideal for this calculation. V(λ) is the luminous efficiency function describing the average spectral sensitivity of human visual perception of brightness. The wavelength range of 425 nm to 690 nm was chosen to remove the tails of the V(λ) gaussian distribution below 1% of the peak value at 555 nm. While the V(λ) curve stretches from 380 nm to 780 nm, the rationale for reducing the total range is rooted in maximizing the usefulness of the comparison between light sources. As the ASD acronym reads, the metric uses an "average" of the spectral differences between two SPDs across a range of spectra. Since nearly all LED light sources have low emission at the low and high ends of the visible spectrum, averaging the spectral differences over the entire range results in a less meaningful comparison as the data is skewed by the lack of emission at the tails of the distribution. The range proposed covers 99.9% of the total area under the photopic response curve, shown in **Figure 4**.

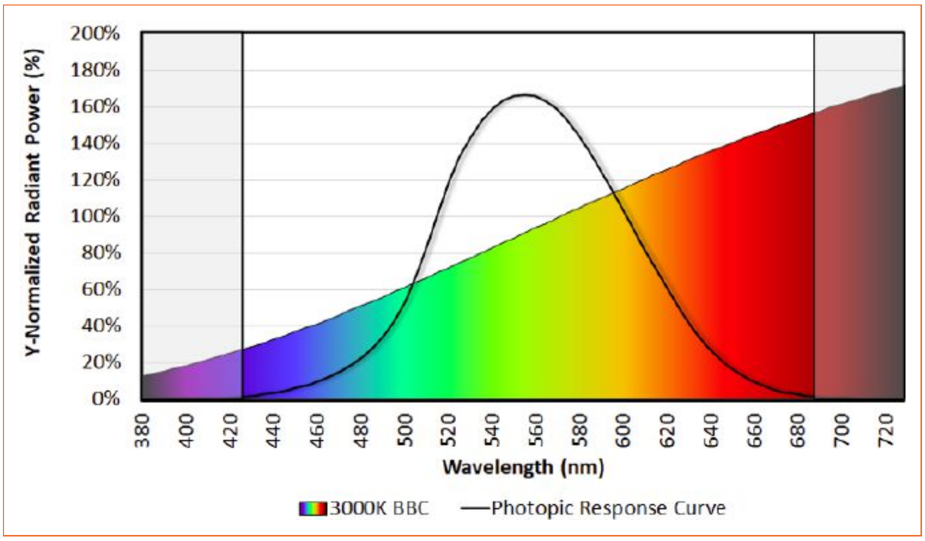

Figure 4: Photopic response curve, V(λ), against the 3000 K blackbody curve with shaded boxes indicating the cut off range for ASD calculations

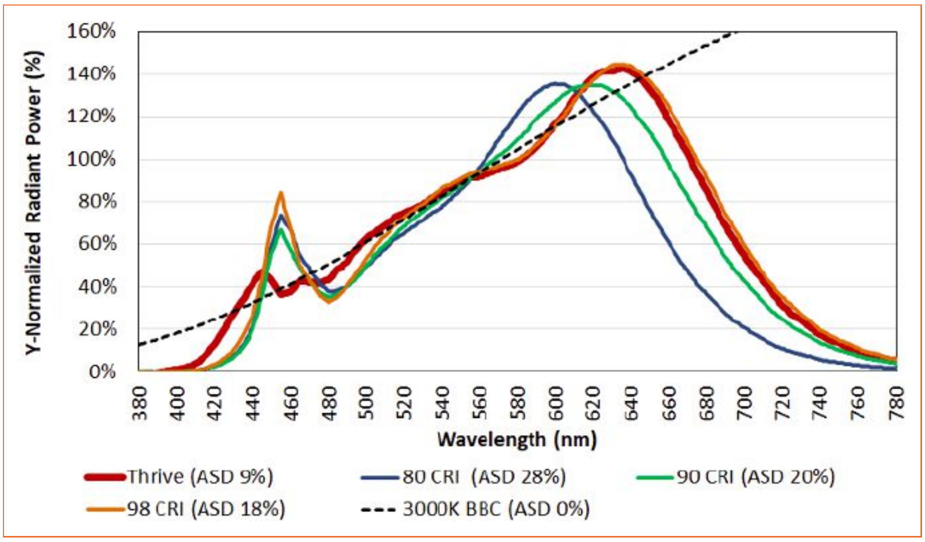

Figure 5: SPDs of 80 CRI, 90 CRI, 98 CRI, and Thrive LEDs in comparison with the blackbody curve

Evalutation Metric		3000 K BBC	3000 K Thrive	3000 K 80 CRI	3000 K 90 CRI	3000 K 98 CRI
ASD		0%	9%	28%	20%	18%
CRI	R_a	100	98	83	92	98
TM-30	R_f	100	98	84	91	94
	R_g	100	101	93	97	102

Table 1: Typical ASD, CRI, and TM-30 values for 3000K light sources

To arrive at a quantitative value for depicting the naturalness of the light source, the SPDs of each source are first Y-normalized so that they are comparable in the visible spectrum. The spectrum is then divided into 266 1 nm wide segments between the visible light wavelengths of 425 nm and 690 nm. The difference in radiometric power between the artificial light source and its reference light at each nanometer segment is measured and expressed as a percentage deviation. The absolute values of all 266 values are then averaged to produce a single value. This calculation can be expressed as an Average Spectral Difference, or ASD. Lighting professionals can compare this single value to assess the relative naturalness of different light sources under consideration.

The equation for calculating the ASD value is:

$$ASD = \frac{\sum_{\lambda=425}^{690} \left| \frac{\phi_{ref}-\phi}{\phi_{ref}} \right|_{\lambda}}{266} \quad (1)$$

The ASD value, expressed as a percentage, always compares a test source to a reference source at the same CCT. The reference source used in this calculation is the blackbody curve (BBC) for light sources of 4000 K and below, and the daylight spectrum (standard illuminants such as D50, D57, and D65) for light sources of 5000 K and above. These natural light reference spectrums are equivalent to those used by the IES for calculating TM-30 color quality metrics.

A comparison of the 3000 K LED SPDs in **Figure 5** shows the superior qualitative naturalness of the Bridgelux Thrive™ source compared to other Bridgelux standard LED sources at 80 CRI, 90 CRI, and 98 CRI. By using the newly defined ASD metric, the quantitative difference is stark. While the best of the three standard LEDs is the 98 CRI product, with an ASD of 18%, the Thrive LED has an ASD of just 9%, cutting the deviation from natural light in half.

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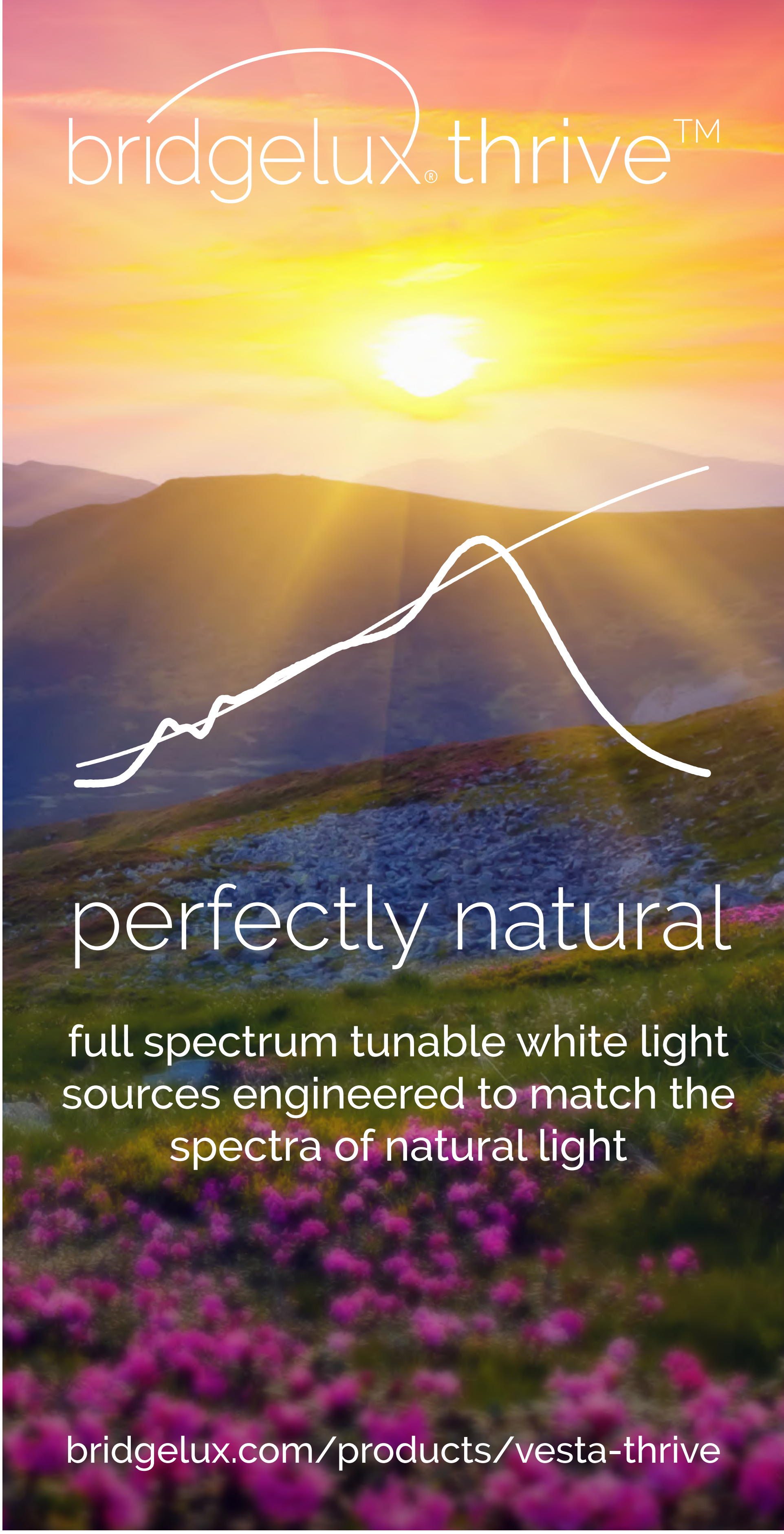
It might seem counterintuitive that the 98 CRI product would have a similar, and not significantly lower, ASD value in comparison to the 90 CRI product, however, the 98 CRI product has been spectrally engineered to deliver a high CRI, not to deliver a closer match to natural light. This validates the premise that CRI alone is not an accurate measurement of naturalness.

While high CRI and TM-30 values can be produced by a light source that has a poor (high) ASD value, a light source with a good (low) ASD value will always correspond to high CRI and TM-30 ratings due to the naturalness of the light. **Table** 1 exemplifies this by showing that the two sources with the lowest ASD values (natural light as defined by the black body curve and Thrive) have near perfect CRI, where the 98 CRI product also has a near perfect CRI but a much worse (higher) ASD.

When comparing the quality of light between two sources, it is important to understand the limits of human vision. The limit of perceptible distinction of color fidelity between two sources can be specified and is typically referred to as the just-noticeable difference. Research conducted at the California Lighting Technology Center (CLTC) at the University of California at Davis produced an interesting finding about human perception of artificial light sources using the TM-30 framework. The CLTC research suggested that if an illuminated reference color sample has $R_f \geq 92$, the average observer may not be able to distinguish between that source and the reference source, natural light. Thus, for a human observer, light sources with TM-30 R_f values ≥ 92 are essentially equivalent to reference natural light sources with R_f of 100.

Figure 6 compares the individual color sample fidelity scores of the 3000 K Thrive LED and the 3000 K 98 CRI LED. For the 3000 K Thrive LED, 97 of the 99 TM-30 color sample fidelity values are ≥ 92 with the two values below 92 still greater than 90. For the 3000 K 98 CRI LED, only 74 of the 99 color sample fidelity values are ≥ 92, with 13 of the 25 values below 92 also below 90.

While the data reported throughout this article is based on 3000 K light sources, the same comparison can of course be made for other CCTs with similar results. **Table** 2 shows the comparison of existing color quality metrics vs. ASD for Bridgelux Thrive and other Bridgelux high CRI light sources at commonly used CCTs. While there are minor differences in the CRI and TM-30 metrics, the differences in the ASD values



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between these sources are significantly higher, as this metric has been developed specifically to provide a quantitative measurement of naturalness. This data further indicates that high CRI or TM-30 values do not necessarily correlate to low ASD values, but in all cases a low ASD value corresponds to high CRI and TM-30 values.

The natural lighting spectrum delivered by the Bridgelux Thrive products can also be used to implement advanced forms of tunable human-centric lighting solutions. Tunable white lighting gives the end user flexibility and control to further personalize their environment beyond the historical limitation of only adjusting intensity through dimming. Since the CCT and SPD of sunlight changes throughout the day, having a natural spectra light source that is also SPD and CCT tunable enables spectral alignment between it and sunlight throughout the day. This approach maximizes harmony between the indoor lit environment and inhabitant circadian rhythm. Other use cases for natural tunable white sources include function-oriented lighting and personalization per individual preference.

The award winning Bridgelux Vesta Thrive products deliver full, natural spectra in an easy to use two channel tunable white solution. The Vesta Thrive spectra delivers low ASD values across the tuning range, delivering a significantly closer match to natural light than other two channel tunable white lighting options. The ASD values for a 2700–6500 K Vesta Thrive COB range from 8% to 11%.

Conclusions

The lighting industry is ready to move on from fundamental comparisons of raw lumen output and power consumption to the profound differences in the naturalness of light from one source to another. To date, quality of light metrics have been narrowly confined to color fidelity and color gamut, comparing the rendering and saturation of color with a reference light source. Users are becoming increasingly mindful of the effect of LED light on human health and well-being, driving the demand for natural lighting products which mimic the spectral power distribution of natural light sources. ASD is a comprehensive and scientifically credible metric, independent of human observation or preference variables, that marks a significant improvement on existing lighting metrics that aim to quantify the naturalness of a light source.

Existing quality metrics do not address the naturalness of light sources, and as such there has been significant interest in understanding and utilizing ASD as a new quantitative metric. Work will continue, together with industry partners, to define appropriate industry standard metrics to quantify spectral matching to natural light to enable straightforward comparisons between artificial light sources. As our industry evolves with an increased focus on human centric lighting, Bridgelux will continue to develop innovative products that transform the lit environment to mimic the naturalness of sunlight. ■

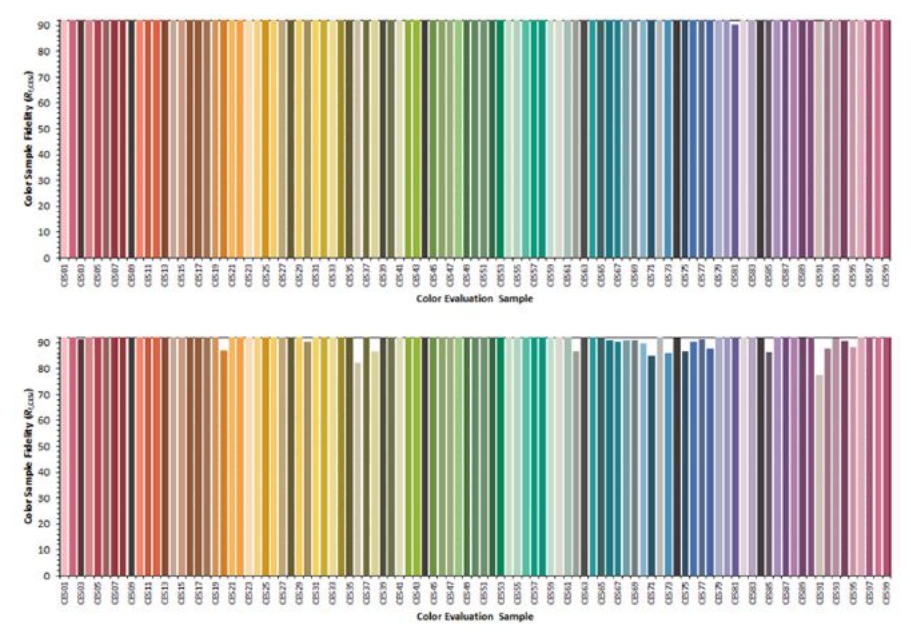

Figure 6: TM-30 Individual sample fidelity scores of a 3000 K Thrive LED (top) and a 3000 K 98 CRI LED (bottom)

CCT	Bridgelux Product	ASD	CRI R_a	TM-30 R_f	TM-30 R_g
2700 K	Thrive	10%	98	96	99
	> 95 CRI	19%	97	94	101
3000 K	Thrive	9%	98	98	101
	> 95 CRI	18%	98	94	102
4000 K	Thrive	8%	98	97	100
	> 95 CRI	18%	96	90	97
5000 K	Thrive	9%	98	97	100
	> 95 CRI	15%	96	93	100
6500 K	Thrive	8%	98	96	99
	> 95 CRI	16%	96	91	98

Table 2: Typical ASD, CRI, and TM-30 values for Bridgelux LEDs of various CCTs

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Facing the Challenges of Spectral Engineering with a New Software Tool

The world of lighting is facing three technological challenges that will be the key factors in the near future: control systems, circular economy and spectral engineering. In the market, there are very advanced solutions at the control level related to different protocols such as DALI, DMX or Bluetooth/Wifi, but there are still no such advanced solutions related to circular economy or spectral engineering. In fact, spectral engineering is becoming one of the biggest technological challenges to solve for light source manufacturing companies.

The raising of Human Centric Lighting (HCL), which consists in the affectation of the visual and non-visual part of the light in people, has caused the luminaries to have to provide dynamic scenes, emitted by LEDs of different color or hue. When using luminaires with more than one channel, the classic light characterization parameters, such as the Correlated Color Temperature (CCT) or the Color Rendering Index (CRI), are no longer useful for accurately defining light. In a multichannel LED system, it is possible to generate light with reasonable values of CCT and CRI but absurd in other values, such as color saturation or distance to the planckian (blackbody) locus. Likewise, it is necessary to obtain more parameters for the characterization of LEDs (such as those derived from the TM-30 method or those associated with melanopic sensitivity) in order to make comparisons between LEDs of different brands from the beginning. Thus, when manufacturers of light sources have the need to comply with standards (i.e. WELL standard) or specifications (i.e. IES TM-30 annex E), it will no longer be found that the information of commercial LEDs is limited and not homogeneous. In addition, for scenarios where dynamic scenes are required, a luminaire manufacturer has to perform the calculations of color mixing of the different LEDs, a complex task and impossible to accomplish by hand with precision due to the large number of combinations that can be generated. This means that, for the optimal generation of custom spectra, a spectral engineering tool like the presented in this paper is necessary. It consists of a software that allows the user to generate a PCB containing different commercial LEDs and create and manage new dynamic light scenes, enabling precise spectral modulation and calculating colorimetric, non-visual and energetic parameters. With this tool, it is also possible to apply concepts of the circular economy since it is possible to reuse luminaires for different uses, extending their useful life and opening new business models for companies that manufacture light sources.

Spectral Engineering

We can define spectral engineering as the activity of applying scientific knowledge to the design, building and control of machines, roads, bridges, electrical equipment, etc. When applying this definition to light, two different questions arise: is it possible to apply the scientific knowledge to design or build new lighting conditions? Do we have the right tools to analyze, create and manage new advanced Lighting Emitting Diode (LED) fixtures?

The first question has an easy answer: yes, it is possible to apply the scientific knowledge in so many different scopes, including these three popular applications: colorimetry, Human Centric Lighting (HCL) and horticulture. Spectral engineering has an important role in creating state-of-the-art devices and environments so that they comply with the most demanding benefits, such as creating a fixture with a super high Color Rendering Index (CRI), a room with a very low melanopic flux or a greenhouse designed for an optimal tomato growth.

The second question is a little more complex to answer. Nowadays, most of the lighting companies are using spreadsheets for creating new light recipes or scenarios for their multichannel fixtures. Usually, the technician starts moving a slider or introducing an input value into a cell manually and the spectral power distribution of the light composed by different channels, changes. Finding a perfect solution is very hard, since all the colorimetric, non-visual or energy parameters change at the same time while moving a value of one channel. Other really big and specialized companies can have a programming team in charge of programming specific routines or software in order to achieve their own goals, but a lot of economic resources have to be consumed.

The photopic vision is the vision relating to or denoting vision in daylight or other bright light, believed to involve chiefly the cones of the retina [1]. Also, we can define the melanopic vision as the vision related to the human body's neuroendocrine response carried out by the intrinsically photosensitive Retinal Ganglion Cells (ipRGCs). The melanopic vision is connected to the circadian response in humans and the Melanopic Spectral Efficiency (MSE) function has a peak around 490 nm, situated on the blue region of the visible range [2]. So, if we divide the melanopic vision by the photopic vision we get the Melanopic/Photopic ratio (M/P ratio).

M/P ratio is often wrongly related to the Correlated Color Temperature (CCT), and it has a direct relation to the Equivalent Melanopic Lux (EML), which is broadly used, for example, in the WELL Standard [3]. EML is the multiplication of the classical illuminance in lux by the M/P ratio.

$$EML = E \times MP \qquad (1)$$

where

E is the illuminance (in lx), and
MP is the M/P ratio.

To see the relationship between the M/P ratio and the CCT we will use a huge database of commercial LEDs we have analyzed where we have filtered the white ones (about 700 different devices). In **Figure 1** we can see the representation of these LEDs in the CIE 1931 colorimetric diagram (left) and the position of every LED on the M/P ratio vs CCT chart (right). If there was a direct relationship between these two parameters, this point cloud would be a straight line.

It is very easy to find out that there are a lot of LEDs with similar M/P ratios but a very different CCT and vice versa, as shown in **Figure 2**.

For example, in **Figure 3** we have two different commercial LEDs with a difference of 1500 K but with no M/P ratio variation. As the maximum of the MSE is situated at 490 nm, the amount of radiation around

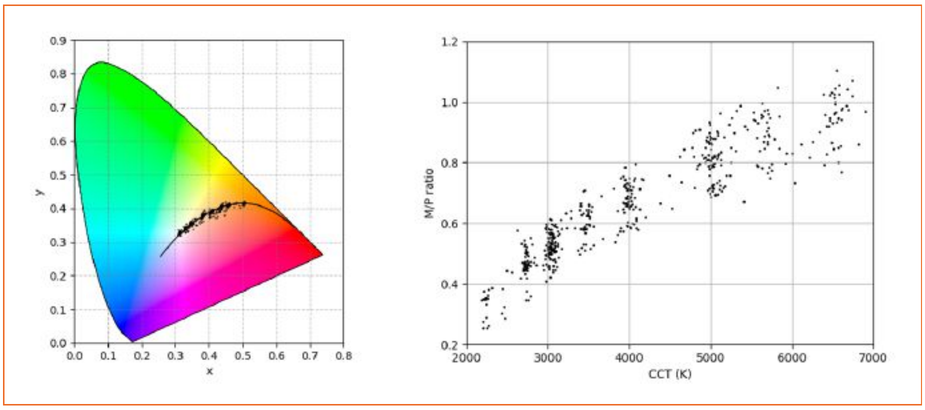

Figure 1: White LEDs of the database represented on the CIE 1931 colorimetric diagram (left) and in the M/P ratio vs CCT chart (right)

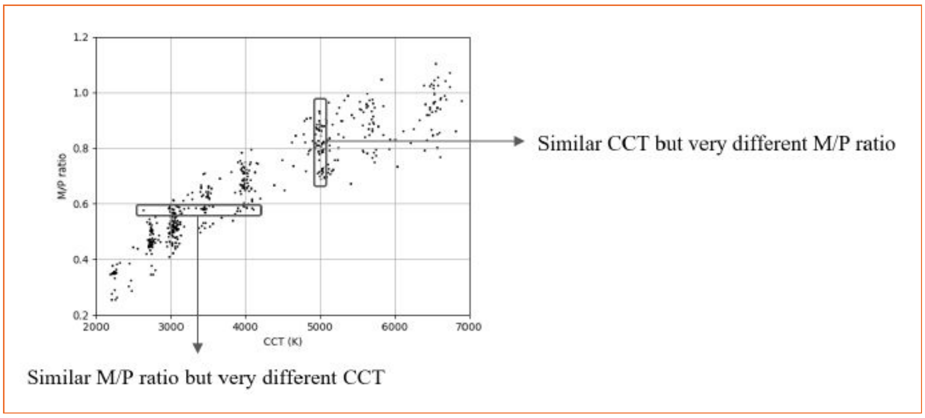

Figure 2: M/P ratio vs CCT chart and comparison between white LEDs with similar M/P ratio but different CCT and vice versa

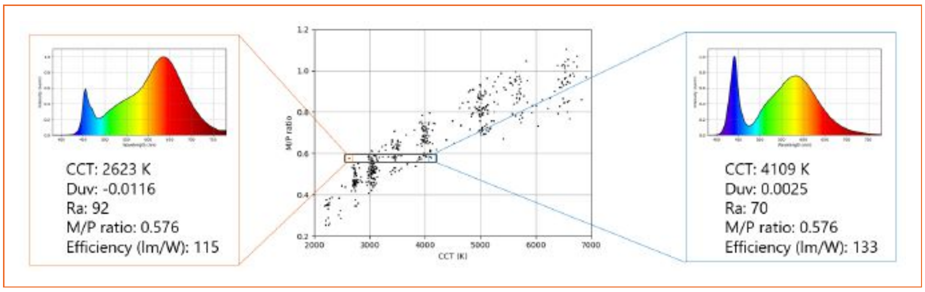

Figure 3: Comparison between two LEDs with the same M/P ratio but very different CCT

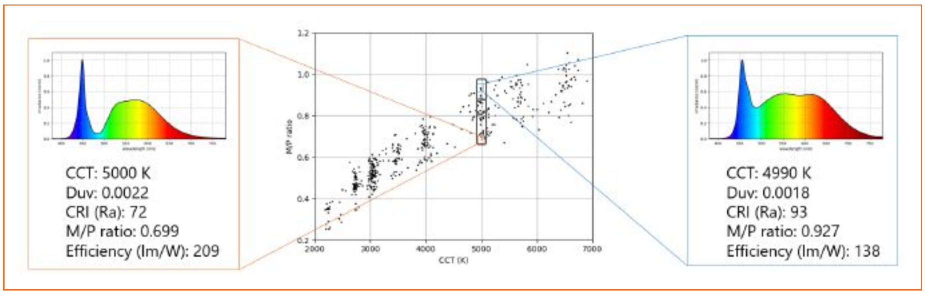

Figure 4: Comparison between two LEDs with very similar CCT but different M/P ratio

this value is crucial when calculating this parameter.

Another interesting example can be shown in **Figure 4**: Two LEDs with practically identical CCTs but with a huge variation of M/P ratio.

What happens if we add the CRI as a new variable in the same M/P ratio vs CCT chart? We can say that, when comparing phosphor-converted white LEDs and variations of this technology, the relationship between these three parameters seems more defined, as shown in **Figure 5**. White LEDs have similar shapes: a blue/violet peak and then a spectral distribution of radiation along the visible range. LEDs with high CRI usually have more radiation around 490 nm, avoiding the cyan gap and affecting the M/P ratio value. However, as discussed later, the relationship between these three parameters is not generally applicable.

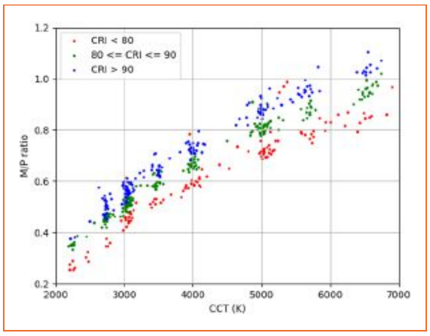

Figure 5: Relationship between M/P ratio, CCT and CRI applied to 700 commercial white LEDs

Case Scenario: PCB Showroom

Nowadays, in the market, it is possible to find a lot of lighting systems working with more than two channels. **Figure 6** shows the spectral power distribution of the LEDs of the fixtures we have installed on the showroom in the Barcelona Science Park and two different spectral recipes. The fixtures are composed by five different LEDs: red, green, blue, warm white and cool white. We can create different light scenes taking into account a lot of different colorimetric, non-visual or power parameters.

One of the most interesting possibilities of the system is the production of metamers. The metamerism is the perceived matching of colors with different nonmatching spectral power distributions. Colors that match this way are called metamers. If two light sources with different spectra are directly observed, it is possible to perceive the exact same color if they are metamers. However, they can deliver different light properties, such as CRI or M/P ratio and they can have different energy efficiency. An example of a metamer can be seen on **Figure 7**.

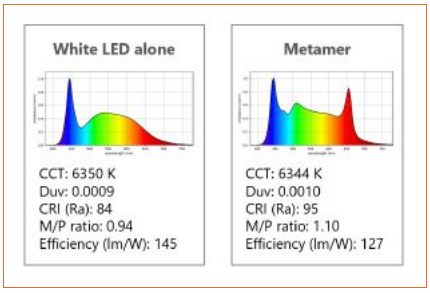

Figure 7: Two metamers. The first one (left) is a white LED and the second one (right) is a specific combination of a five channel LED fixture mimicking the CCT and distance to the planckian locus (Duv) of the first one. However, the difference in the CRI, M/P ratio and energy efficiency of the two metamers is very noticeable

If we take a look on the capabilities of the system when comparing to the commercial white LEDs, in **Figure 8** we can see that it is possible to achieve very high M/P ratio values. We can have CRI 80 combinations with a M/P ratio above 1 in CCTs greater than 4000 K. Moreover, if we focus on the CRI values, we can see that it is possible to achieve CRI 95 values from 2400 K to beyond 7000 K. The white LEDs working alone have both CRI 84, so there is a substantial improvement resulting from a controlled mixing of the light.

The results of a multichannel system are closely related to the global LEDs chosen. In this case, the choice is related to certain colorimetric parameters and the efficiency of the white LEDs, that was very high some years ago.

If we select LEDs taking into account the M/P ratio, we can have a system that can achieve practically any M/P ratio available on the market. As shown in **Figure 9**, at 3000 K we can have CRI 80 combinations with an M/P ratio that can go from 0.4 to 0.8. If we look at the CRI vs CCT chart, we can have values of CRI 95 from 2000 K to 7000 K and beyond. This means that we have the technology to achieve practically any value available on the market and this technology, on a multichannel system, depends more on the global selection of LEDs than the individual selection of white LEDs of the fixture we are creating.

Furthermore, the relationship between CCT, M/P ratio and CRI is not applicable in multichannel systems. This is because these systems can deliver a lot of different spectral shapes as opposed to commercial white LEDs, that generally have similar shapes. The CCT can be modulated through several ways and the peaks of the monochromatic LEDs are crucial on the determination of the M/P ratio. A violet, blue, cyan or green LED can increase the CCT, but each one is going to have different impact on the M/P ratio.

Using a multichannel system enables us having full control over the light properties and going beyond the possibilities offered by the market. However, shaping the spectrum that matches our interests can be really challenging, because all the light parameters are interconnected. If we increase, for example, the intensity of the red channel, it will have consequences on the decreasing of the CCT and M/P ratio but also varying the CRI, R9, energy efficiency, distance to the planckian locus, etc.

We need tools to create and manage new light scenarios, because the use of spreadsheets and derivates represent a bottleneck for the development of this technology.

Kumux

Kumux is the first advanced spectral engineering tool that allows the user to generate a PCB containing different commercial LEDs and create and manage new dynamic light scenes/recipes, enabling precise spectral modulation and calculating colorimetric, non-visual and energy-related parameters all at once.

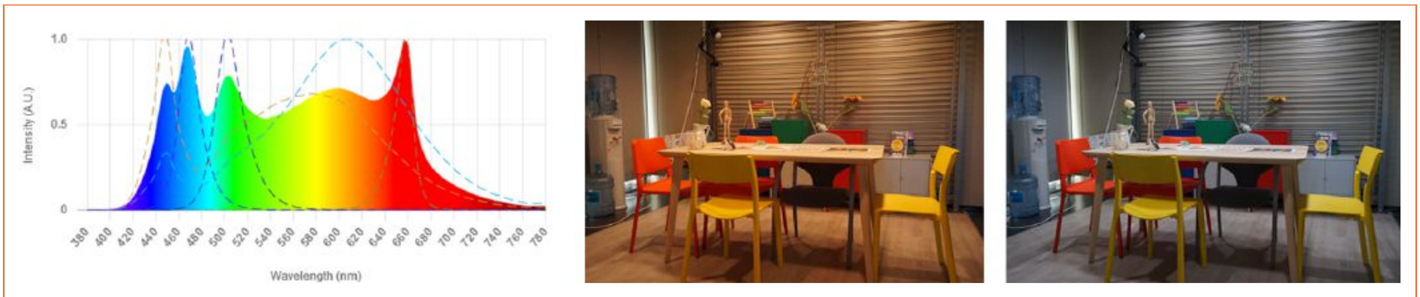

Figure 6: Spectral power distribution of the 5 LEDs of the fixtures installed on Barcelona Science Park and two different spectral recipes

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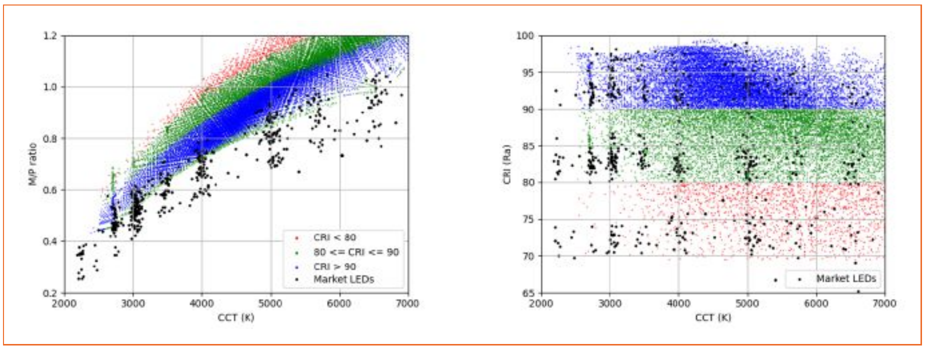

Figure 8: Achievable values of the multichannel fixtures installed on the Barcelona Science Park for M/P ratio (left) and CRI (right) in function of CCT

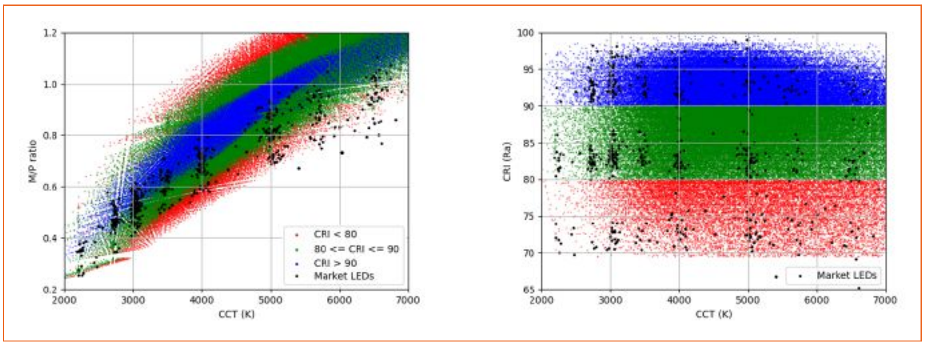

Figure 9: Achievable values of a multichannel LED system in order to get the maximum flexibility in M/P ratio

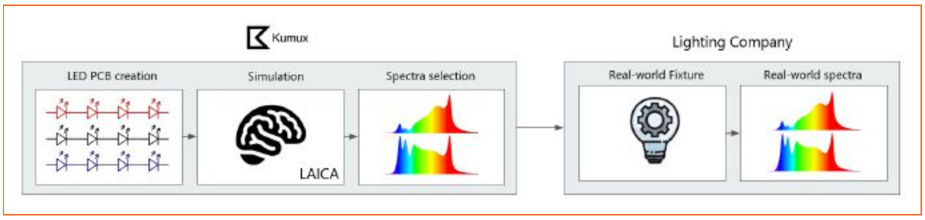

Figure 10: Kumux flow. From the creation of a LEDs PCB to the fixture emitting specific spectra

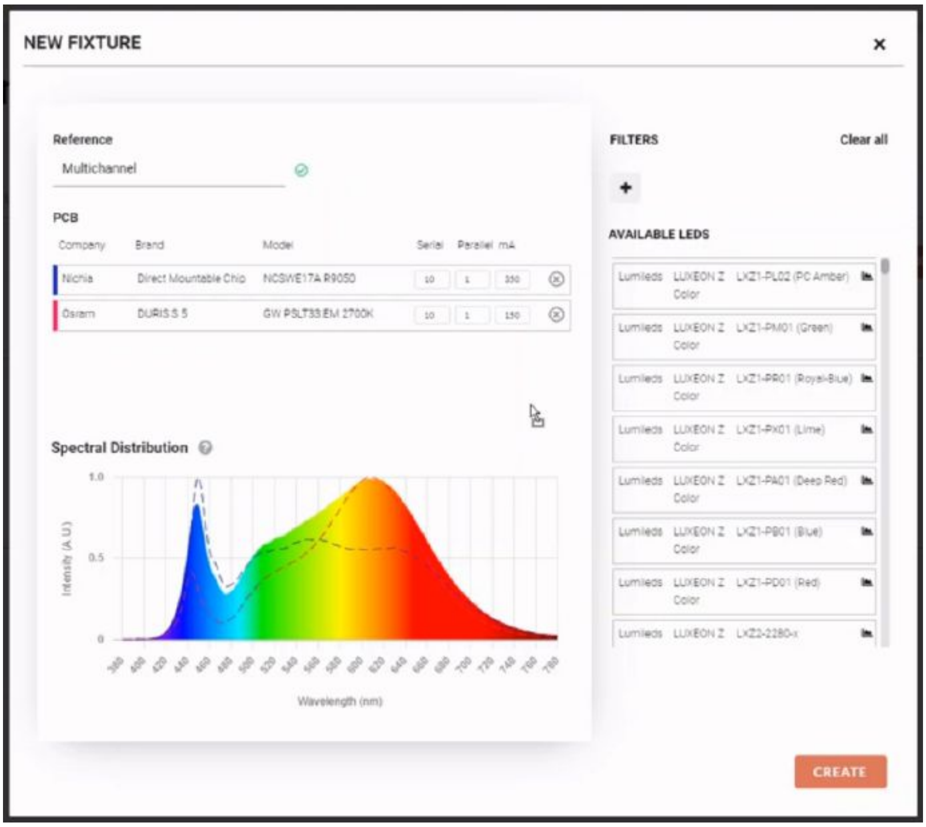

Figure 11: Process of dragging and dropping LEDs from the database to the PCB

The process follows the flow shown in **Figure 10**: Creating a LEDs PCB, running the simulation algorithm and selecting the spectra that fits a particular interest. Then, the results can be exported so the electrical current values of the different channels can be embedded into any control system with the purpose of recreating the simulated spectra.

The creation process of a LEDs PCB consists in dragging and dropping the LEDs and setting the number of LEDs in series, parallel and the driver current for each channel. It is possible to select any of the 700 LEDs of the database we have seen before, plus the color LEDs (around 1000 LEDs in total). The information of each LED is presented in a standardized format and the possibility of searching LED using the filters is also possible. As the information on the PCB is updated, a spectral power distribution chart corresponding to the maximum intensity of the different channels is also updated (**Figure 11**).

Another interesting option is the possibility of adding custom LEDs. Adding custom LEDs is a necessary step in order to reduce at the minimum the error between the theoretical data and the reality. This error has three different components: binning, thermal variation and the effect of the diffuser in the fixture. The lighting manufacturers know these three problems that affect the final shape of the spectrum. If we make the calculations with these errors corrected, the results of the simulation will match perfectly with the reality.

Once the LEDs PCB is created, we can start the simulation process in order to find all the possibilities of the fixture we are creating. The problem to solve is similar to find a needle in a haystack, because it is possible to generate billions and billions of combinations by mixing the light of the LEDs at different intensities. The question is: which combinations are the most suitable? At Kumux, we have developed our own algorithms in collaboration with the Barcelona Supercomputing Center. They are composed by several different routines and they all work at the cloud, integrated to the software platform. Out of the billions of possible combinations, the result is the most relevant few thousand of combinations taking into account the colorimetric, non-visual and power values of the different parameters.

In order to find a specific spectrum, the filtering process is started (**Figure 12**). The user finds a screen with charts and sliders where the different combinations can be selected. Using the sliders, it is possible to set the range of any parameter and all the other parameters and charts change as well, since they are all interconnected. All the scenes can be exported to a file that includes the electrical current values of the different channels of the fixture created. Then, the reproduction of these scenes in the reality can be easily done.

Conclusions

An introduction to spectral engineering has been made through some basic definitions and the visualization of a database containing around 700 white LEDs.

There is a relationship between the M/P ratio, CCT and CRI, but it is only applicable to phosphor-converted white LEDs in a generalized way, although there are specific cases that may have distant values. The Barcelona Science Park showroom contains a multichannel LED system that allows reaching M/P ratio levels unreachable for the white LED market, although it is an optimized system for certain colorimetric parameters and it has a high energy efficiency. There are other systems that allow us to go much further in terms of modulating the M/P ratio based on the CCT. The showroom is also capable to reproduce metamers.

Finally, the developed spectral engineering software (Kumux) has been introduced. It allows the creation of a LEDs PCB, the addition of custom LEDs, the calculation of all the possibilities of the PCB and the choice of the recipe that best suits the needs. ■

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Figure 12: Filtering process and finding a particular recipe

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Transient Infrared Thermography for Thermal Conduction Path Analysis of LED Modules

A common way to qualify the thermal conduction path of LED modules is to measure the operational temperature of the LEDs at specific reference points. While thermocouples are widely used for this purpose, infrared thermography offers a contact-free and efficient method to obtain the required temperature information. In contrast to thermocouples, thermographic imaging allows to measure the temperature distribution over a relatively large area. Though the static thermographic images are used to detect hot spots and temperature gradients, they are less helpful for the analysis of the thermal conduction path between LED and the heat sink or the lamp housing.

In this work, the potential of transient temperature measurements by infrared thermography is evaluated. For illustration, different sets of LED modules are investigated with the modules operated on a temperature-controlled heat sink. After the thermal equilibrium is reached, the power supply is switched off and the cooling curve is recorded by a high-speed thermography camera. Subsequently, these images are numerically analyzed to reveal the single components of the thermal conduction path. This technique allows the analysis of slight changes in the thermal path within the LED-solder-PCB stack. Hence, inhomogeneous or defective soldering leading to insufficient thermal contact between the LED and the board can be detected.

Theoretical Background

Heat Conduction

The conversation of energy represents the essential point of the description of heat conduction. Every change in heat energy in a region has to be either generated via a heat source or caused by a net heat flow through one of its boundaries. If such energy inflows $\dot{E}_+$ and energy outflows $\dot{E}_-$ as well as sources of energy $\dot{E}_\mathrm{s}$ are balanced against each other, the resulting change in energy $\dot{E}$ is given as [1]

$$\dot{E} = \dot{E}_+ - \dot{E}_- + \dot{E}_\mathrm{s}\,. \tag{1}$$

Together with Fourier's law of heat conduction, the heat equation can be readily derived from **Equation (1)**, i.e.,

$$\nabla^2 T(x,t) - \frac{1}{\alpha}\frac{\partial T(x,t)}{\partial t} = -\frac{q(x,t)}{k}\,. \tag{2}$$

The source term $\dot{E}_\mathrm{s}$ enters as a source density $q(x,t)$. Additionally, the parameter α, which denotes the thermal diffusivity, is introduced. Here, the thermal conductivity, k, is assumed to be isotropic and homogeneous. Thermal conductivity and thermal diffusivity are linked to each other via the mass density, ρ, and the specific heat capacity, c_p, i.e.,

$$\alpha = \frac{k}{\rho \cdot c_\mathrm{p}}\,. \tag{3}$$

This is the general formulation of the heat equation. It can be used to solve for the temperature field of a given system and a set of boundary conditions and sources. Vice versa, the source distribution can be derived from its temperature field. In this work, transient heat conduction is of special interest.

Transient Problems in Composite Media

Transient problems arise when a system is heated with a constant source distribution for a period of time, until it reaches an equilibrium temperature distribution via heat flow over the boundaries. Then the heating power is turned off and the temperature field relaxes back to its equilibrium state. The behavior of the temperature field while relaxing back to equilibrium gives insights about the thermal properties of the system.

As thermal systems in practice are rarely homogeneous, samples consisting of different media are considered. A natural step to construct a more complex medium is to look at two materials with different thermal properties in contact with each other with a certain contact resistance. This scheme can be generalized to a layered material, which consist of many homogeneous subsystems which are in close contact to each other. If the size of the subsystem is further reduced, a better approximation to arbitrary media is achieved.

The Electro-thermal Analogy

A common simplification when dealing with small thermal subsystems is to assume that the temperature is constant inside them, so that a single temperature can be assigned to the system. While the temperature inside such a subsystem is homogeneous, neighboring systems can have different temperatures and this is reflected by a thermal resistance between both systems. This approximation can be made more exact by the reduction of the system size. A system simplified in such a way is called a lumped capacity model.

This kind of approximation is popular because the problem can be restated as a network problem. The goal is to construct an electric circuit that resembles the behavior of the thermal system. A method used to construct this equivalent network is called identification by deconvolution [2]. The amount of energy stored in a subsystem can be identified with a thermal capacity value, C_{th}, and the magnitude of the temperature drop to an adjacent system is quantified by a thermal resistance value, R_{th}. Thus, a time constant

$$\tau = R_{\text{th}} \cdot C_{\text{th}} \tag{4}$$

can be attributed to each subsystem.

The electric analogy of this behavior is a low-pass or RC-circuit. Depending on the geometry and partitioning of the system, various kinds of networks can be constructed. Here, the focus is set on a one-dimensional model that is heated on one side by a single heat source. Hence, the network becomes a chain of RC-circuits as depicted in **Figure 1**.

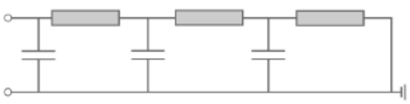

Figure 1: Cauer network for electro-thermal analogy

The voltage applied on the left side of the circuit corresponds to a temperature difference of the source relative to the surrounding thermal reservoir, that is represented by the ground potential in electric terms.

In practice, the thermal properties of the individual layers and boundaries are often unknown. Hence, their respective resistances and capacities that have to be prescribed to each RC-circuit are also unknown. It is, however, possible to reconstruct the thermal properties using a transient measurement of the step response of the temperature to a change of the heating power. In this work, the temperature response is measured by an infrared camera.

Experimental Setup

Thermography Setup

The thermography setup is comprised of an infrared camera (InfraTec ImageIR 8380S), which uses an indium antimonide focal plane array snapshot detector. The geometric resolution is 640 ×512 px. As the camera is sensitive for the mid-infrared spectral range (2.0–5.7 µm), it has a noise equivalent temperature difference of below 25 mK at temperatures close to room temperature and it runs at a maximum sampling rate of 200 Hz. The housing of the equipment minimizes the influence of reflections from external sources and shields the sample from unwanted convection losses. The camera is operated in a top-down configuration and is facing the top side of the LEDs. A sequence of images is taken that shows the surface temperature of the entire LED board. The camera is connected to a computer for frame synchronization and data post-processing.

The LED Array

The LED array under investigation is a commercially available one and comprises of 16 LEDs. The diodes are arranged in a 4 × 4 geometry and are soldered on a printed circuit board. The entire array is mounted on a temperature controlled heat sink. Each of the 16 LEDs comprises a stack of phosphor on top, a semiconductor chip beneath and a solder connection to the PCB. The PCB is mounted to the heat sink with clips without additional heat transfer paste. The infrared emissivity of the phosphor, i.e. the surface of the LEDs, is considered to be close to unity.

Electrically, the LED array comprises of four strings, which are connected in parallel. Each string consists of four LEDs and one resistor. The array is operated at 0.5 A and 5 V. Thermal losses in the semiconductor as well as the light conversion process in the phosphor (stokes shift) represent heat sources. Additionally, a considerable amount of energy is lost in the above-mentioned resistors on the bottom side of the array. The power supply is controlled digitally by a computer and synchronized with the camera to guarantee an exact knowledge of the time after turning off the LED array.

Experimental Details

Measurement Procedure

As mentioned above, the LED array is operated at 0.5 A and 5 V. Once the thermal equilibrium is reached, the thermografic measurements are started. After a while, the LED array is powered off and the temperature is measured for approximately 100 s. For the period shortly before and after power off, the image recording is kept at a high rate to guarantee a fine temporal resolution of the shutdown process. Later the sampling rate is reduced logarithmically to keep the overall amount of data manageable. These measurements are repeated for three different LED arrays of the same production.

Evaluation Procedure

The measurement provides a sequence of thermografic images, which are further analyzed by deconvolution [2]. **Figure 2** shows such an image just before the power supply is switched off.

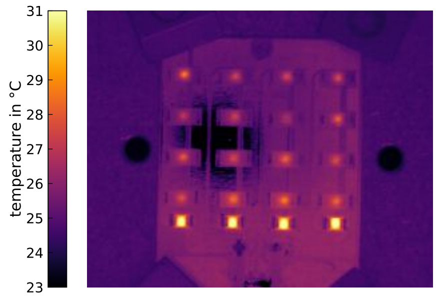

Figure 2: Image of one of the LED arrays immediately before turning off the power. The LEDs are arranged in a 4 × 4 geometry, and with a row of resistors at the bottom

From these images, the temperature signal $T(t)$ for each LED is extracted by averaging over a small area of pixels around the hot spot. This signal is used to construct the dynamic thermal impedance Z_{th} via **Equation (5)**. Here, P is the difference in power deposition inside the LED, when turning off the electric supply.

$$Z_{\text{th}} = \frac{T_0 - T(t)}{P} \tag{5}$$

The reference temperature T_0 is taken to be the phosphor temperature immediately before the power step. The derivative of

$$a(z) = Z_{\text{th}}\big(t = \exp(z)\big) \tag{6}$$

in logarithmic time $z = \ln(t)$ is related to the time constant spectrum $R_{\text{th}}(z)$ by the convolution [2]

$$\frac{\mathrm{d}}{\mathrm{d}z} a(z) = R_{\text{th}}(z) \otimes w_z(z). \tag{7}$$

The time constant is linked to the thermal resistance R_{th} and the thermal capacitance C_{th} via **Equation (4)**. The function $w_z(z)$ is defined as

$$w_z(z) = \exp\big(z - \exp(z)\big). \tag{8}$$

To calculate the time constant spectrum $R_{\text{th}}(z)$, a deconvolution has to be done, which is performed in the Fourier space via fast Fourier transformation (FFT). The frequency spectrum is filtered via a Blackman-Nutall filter, which belongs to the class of the cosine sum windows. Filtering is necessary to reduce the influence of high frequency noise components that are otherwise strongly amplified by the deconvolution process.

Experimental Results

Imaging the LED Array

Figure 2 shows one of the LED arrays immediately before turning off the power. It shows the four by four geometry of the LEDs and the electrical connection between them. The brightest areas, hence hottest are observed at the resistors located at the bottom of the board close to the power supply. The LEDs show peak temperatures between 26.7 °C and 28.9 °C, while the resistor temperatures at the surface exceed 32 °C.

The large black spot visible inside the array is a reflection from the camera, also known as the Narcissus effect. Overall, a small temperature gradient is visible on the base plate with increasing temperature closer to the resistors and the power supply.

To extract a single temperature curve for each LED, a small circular area is drawn around the corresponding hot spots over which the average value is determined. **Table 1** shows the temperature differences for each LED of the array from the beginning to the end of the measurement. The top left LED in **Figure 2** is labelled A.1, while the bottom right LED is labelled D.4. It is noticeable that the LEDs of the C and D rows show higher temperatures than those of the A and B rows. However, LEDs A.1 and B.4 show higher initial temperatures than their neighboring LEDs.

LED	1	2	3	4
A	4.6	3.4	3.5	3.6
B	3.0	3.5	3.0	4.1
C	4.0	3.8	4.1	3.6
D	3.8	4.6	4.7	4.2

Table 1: Temperature differences for each LED array from start to end of the measurement in K

Time-dependent absolute temperature values for the top row (A) are depicted in **Figure 3**. The x-axis shows the time t relative to the start of the measurement. It is scaled logarithmically so that it resembles $z = \ln(t)$.

Calculating the Time Constant Spectrum

To calculate the time constant spectrum as defined by **Equation (7)**, the temperature curve of **Figure 3** is used. First, the thermal impedance has to be calculated using **Equation (5)**. To do this, the power step in every LED has to be known. As a simplification, light emission and non-uniformities of the electric resistance between the LEDs junctions are neglected, which is equivalent to the assumption of an identical power step for each of the LEDs. Since a relative comparison is of interest only, the value of the power step is assumed to be unity. The starting temperatures T_0 for each LED can be taken from **Figure 2**. The dynamic thermal impedance is shown in **Figure 4** on a logarithmic time scale.

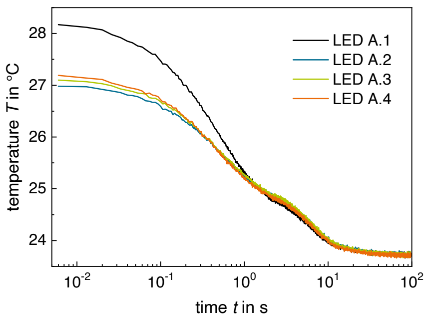

Figure 3: Temperature evolution of the top row of the LEDs depicted in **Figure 2**

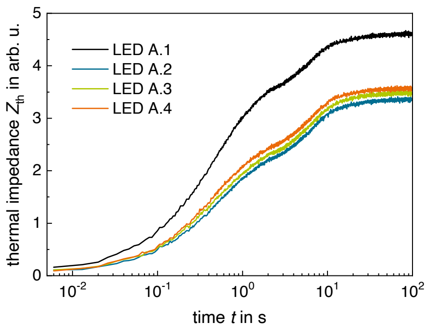

Figure 4: Thermal impedance for the top row of LEDs shown in **Figure 2**

From the derivative of the impedance in logarithmic time as defined in **Equation (6)**, the time constant spectrum is calculated via fast Fourier transformation and spectral filtering. The result is displayed in **Figure 5**.

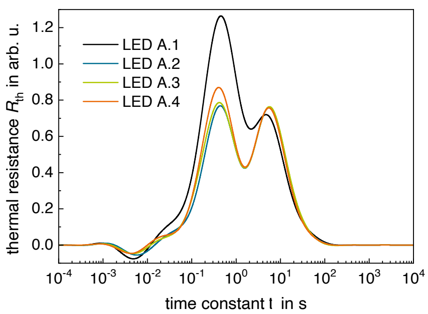

Figure 5: Time constant spectrum for the top row of the LEDs shown in **Figure 2**

From a physical point of view, the time constant spectrum has to be positive. However, because of the high noise amplification of the deconvolution process and the properties of the filter functions some negative values might occur. As they are non-physical, they are set to zero to include them in the evaluation.

To compute the parameters of the corresponding Cauer network (**Figure 1**) from the time constant spectrum, some additional calculation has to be done that involves a discretisation. However, this approach is not further pursued since the time constant spectrum can be interpreted directly for the sake of comparison.

Analysing the Time Constant Spectrum

In **Figure 5**, the time constant spectra for the four LEDs of the top row are shown. Two peaks are clearly visible in thermal resistance. The first peak lies at approximately 0.5 s and a second maximum is found close to 5 s. In the thermal impedance spectrum (**Figure 4**), these features are also visible at the corresponding time values. While the second peak has the same height for all diodes shown, the LED A.1 has a larger value for the first maximum than the LEDs A.2 to A.4. When comparing these peak intensities to the corresponding temperature differences in **Table 1** a monotonous correlation is found. Increasing peak intensities in the first peak correspond to increasing temperature differences.

The cooling behavior can also be interpreted physically. As the camera is observing the LED stack from the top, the temperature measured can be identified with the phosphor temperature. Because of that the fastest cooling dynamics belong to the connection of the phosphor to the semiconductor chip and the solder connection of the entire chip to the PCB. On a slower time scale, the relaxation of the temperature is limited by the connection of the PCB to the heat sink. For these reasons, the first peak in **Figure 5** is interpreted as a cooling dynamic belonging to each individual LED and thus summing together the influences of the phosphor, the semiconductor and the soldering quality. The second peak is interpreted as the influence of the surrounding PCB dynamics on the LED temperature. This includes local temperature trends on the PCB owing to locations of other heat sources and heat sinks as well as structure and type of the material used for the board.

Conclusion

All temperature sources in the PCB can be identified and compared quantitatively at the same time. Global temperature trends on the PCB are visible and show that the resistors at the bottom side of the board have a significant effect on the LED temperatures.

Nevertheless, the relative performance of the individual cooling paths of the LEDs to the PCB can be assessed on the basis of time evolution, taking into account their ambient temperature level. It is shown that LED phosphor temperatures can be correlated with the intensity of the peak associated with the semiconductor chip. The accuracy can be increased further by including differences in the magnitude of the power step.

Analyzing the entire LED array via infrared thermography enables a comprehensive examination of the thermal behavior of the component. ■

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Peter W. Nolte obtained his master of science in physics from the University of Paderborn, Germany, in 2007. Subsequently, he started to work in the field of photonic crystals and silicon photonics at the Martin Luther University of Halle-Wittenberg, Germany, where he defended his PhD thesis in 2015. In 2014, he moved to the Fraunhofer Application Center for Inorganic Phosphors in Soest, which is a branch lab of the Fraunhofer Institute for Microstructure of Materials and Systems IMWS in Halle (Saale). He currently leads a research team, focusing on the reliability of light emitting diodes and phosphors.

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Fraunhofer Application Center for Inorganic Phosphors: Light emitting diodes (LEDs) are the future of lighting technology. Modern high-power LEDs offer numerous advantages in terms of efficiency, compactness, lifetime, and environmental protection as compared to conventional incandescent and energy-saving lamps. New challenges consist not only of improving the LED chips, but also in the phosphor and encapsulation materials. In addition to the efficiency of the LEDs and the phosphor, reliability and colour stability are also important aspects. The thermal management of LEDs and LED modules is of crucial importance. Rising demands in intelligent lighting systems, especially in those which are particularly adapted to the respective needs of the user or application, are triggering great amount of interest in starting new research projects. In the field of phosphors, our range of services consists of the design and development of phosphors and phosphor systems, and their performance evaluation with the aim of improving their efficiency, reliability, and colour stability. In order to do so, comprehensive optical and spectroscopic analyses, thermal and microstructural characterizations are applied at the Fraunhofer Application Center in Soest as well as investigations into the long-term stability of light-emitting diodes and lighting elements. The output of our research activities have led to phosphor-doped glasses and glass ceramics for lighting and lighting technology as well as medical diagnostics. Further research fields include the characterization of optics for light-emitting diodes as well as the microstructuring of optics and phosphors.

Range of services: The Fraunhofer Application Center in Soest provides tailor-made services as per customer requirements. The aim is to support the competitiveness and the future of the lighting and its associated industry as well as related areas. The optimization of materials, components, and systems are aimed to contribute to the success of the project partners. The focus remains the collaboration of both parties in the concept and applications.

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Choosing the Right Inductor Technologies for Automotive LED Lighting

In terms of cost, volume, weight and overall functionality, the electronic content in vehicles continues to increase significantly. A consequence of these trends is the demand it places on the power systems. There is a general trend toward 48 V systems in vehicles, partly to support the adoption of mild hybrid drivetrains but also to better meet the increased demand for power across the entire vehicle. However, the 12 V circuit remains primarily responsible for the majority of the body electronics and this is likely to continue.

A portion of the increased demand on the 12 V system is attributed to the introduction and wider use of LED lighting, both internally and externally. While LED technology is, by its nature, more power efficient than other forms of lighting, it has its own power-related requirements. Part of that relates to the quality of the power provided, which needs to be highly stable and regulated. The quality of the 12 V bus can vary considerably within a system where the instantaneous current flow can suffer from massive fluctuations in load demand, based on the driving conditions.

The most recent examples of how LED lighting is changing the automotive sector include high performance LED headlights and smart adaptive lighting systems. In addition to providing a constant light output, these solutions are capable of modulating their output based on external conditions. These increasingly sophisticated automotive LED lighting systems require equally advanced electronic circuitry to control the headlight's intensity, angle and focus. These systems must also continue to deliver the reliability that automotive manufacturers demand. A critical element in all of these systems are the inductive components used in the power supplies, as this article will explain.

New Automotive LED Lighting Applications

The way LEDs are now used in vehicles is evolving rapidly, thanks to their flexibility, low power and low profile. They enable entirely new user experiences, both inside and outside the vehicle. Initially, LED technology displaced conventional filament bulbs in turn signals, but has quickly progressed to brake lights. Indeed, there are few cars now that do not feature a high-level rear brake light, a development that was almost entirely enabled by LED technology.

Figure 1: LED lighting is changing the automotive industry

The development of high voltage LED lighting means it can now be applied to forward-facing lights too. LED-based headlights are quickly overtaking the use of older technologies such as halogen. The wider use of daylight running lights, or DRL, is also thanks to LED technology.

In addition, it is becoming more common for vehicle manufacturers to offer configurable interior lighting, based on LED technology, that allows the car owner to customize their environment. All of these new features need control systems; these are much more complex than the simple "on/off" circuits that were used in older style lighting circuits. The move to more sophisticated configurations, featuring multiple LED strings or even matrices of LEDs, comes with their own demands.

The Power Demands of LED Lighting in Automotive Applications

As the junction inside an LED is effectively formed on a semiconductor substrate, each LED will experience a forward-voltage drop; depending on its construction and light frequency this could be as much as 4 V. In addition, the temperature of the substrate can also influence the voltage drop, meaning it is subject to change in operation. While the voltage drop may vary, the current needs to remain constant to produce a stable light level. This means control systems must take into consideration the topology used, the stability of the power supply, the operating temperature and the possible changes in load due to demand.

Another important consideration here is the role that lighting, in general, now plays in the integration of advanced driver assistance systems (ADAS) in a vehicle. Many of these systems now employ image sensors to monitor the surrounding environment. Initially, image sensors were used in parking cameras, which have now totally displaced other types of proximity parking sensors in new models. More recently, adaptive systems, such as cruise control, lane departure and collision avoidance, use image sensor data to make decisions. These systems work best in conditions where the light is constant and stable, and as such operate in collaboration with high-intensity LED lighting to deliver dependable performance.

The increased use of ADAS, many of which have considerable power requirements, also puts greater demand on the power systems. Consequently, the power circuits developed for automotive applications typically operate over a much wider voltage range than the system's battery voltage might seem to indicate. A complex power management strategy is necessary in order to accommodate the increased disruption that rapidly switching circuits can introduce in a closed system, such as a vehicle.

With so many challenges involved, it is worth considering why the industry still feels that the adoption of LED technology is justified. The longer-term benefits of LED technology are well documented across all of the sectors and application areas where they are now used. These include a significantly longer working life with a higher light output for a given power. This efficacy translates directly into better power efficiency, which is becoming more important due to the reasons outlined earlier.

Another reason is the increased functionality made possible by LED technology. One such advancement is the adaptive driving beam, or ADB. With ADB, the headlights remain in high beam mode until the car senses that it needs to dim them, due perhaps to another vehicle approaching, at which point the light is either dimmed or steered away from the oncoming automobile. The benefits of using high beams all of the time are clear, but the technology requirements needed to operationalize these benefits are quite complex. Typically, ADB functionality will rely on multiple sensors to monitor the road, oncoming traffic and the attitude of the car (is it going uphill, for example, or rounding a bend). The required processing needed to handle the data is significant, even if the output of that processing is simply dimming the light output temporarily.

LED Driver Technology

Modern light fittings, such as headlights, can comprise many individual functions, including high and low beams, daylight running lights and turn signals. Each of these functions will be based on either individual LEDs or LED strings. The light emitted from each LED will be a function of the voltage across the junction and the current flowing through it; modulating the current will result in varying the light output. While it is entirely feasible to use linear regulators to modify the light intensity, a switching solution is more efficient. When using a switching topology, the size and value of the passive components can directly impact the end solution's efficacy.

Because there are various forward-voltage drops involved, a supply circuit may be needed for each function. For example, if only one LED is used, the supply circuit would have a single converter and a driver that would step-down the voltage. In the case of a long string with multiple LEDs connected in series, multiple converters may be used with multiple drivers to step the battery voltage up or down. In some cases, the design decision may be to use a step up/step down driver, also known as buck-boost. There are various topologies used to implement a buck-boost power supply, including flyback, the H-Bridge and SEPIC (single-ended primary-inductor converter).

Because of the large number of individual LEDs now involved, It is increasingly common to use an integrated driver for LED strings, as opposed to discrete circuits, particularly in ADB headlights. These drivers allow a string of LEDs to be connected together but controlled independently (**Figure 2**). In this scenario, the approach taken would be to boost the battery voltage to a level of around 60 V, and supply each LED through its own, controllable, buck converter to modulate each LED's output. In this configuration, each buck converter would require an inductor with a relatively high value of around 100 µH and would be complemented by a smoothing capacitor rated at around 100 V, with a capacitance of between 1 µF and 10 µF.

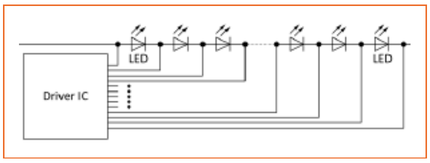

Figure 2: An example of an integrated LED string driver

From **Figure 2** it is clear that the type of LED configuration will influence the type of power supply used. Similarly, the type of power supply implemented dictates the requirements of the inductors. In a switching circuit the inductor is intrinsic to the operation; the inductor stores and releases energy at a rate based on the switching frequency. In general, the higher the switching frequency, the more frequently the energy is transferred. This tends to allow smaller inductors to be used in switching circuits operating at higher frequencies. However, higher switching frequencies can also have an impact on the amount of interference generated. Inductors are, of course, also an integral component in electromagnetic filters, so they are important for multiple reasons.

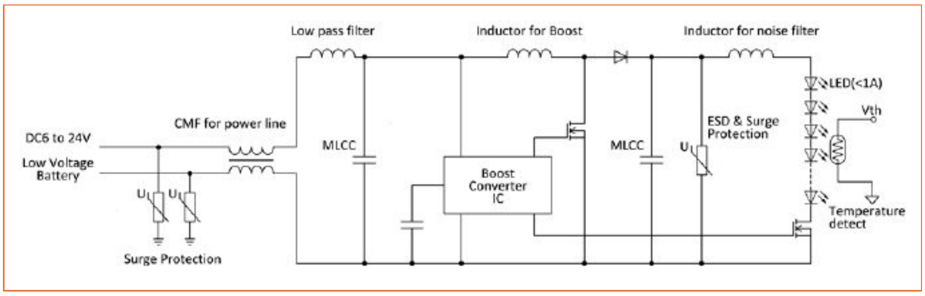

Figure 3: A typical boost converter circuit for LED lighting

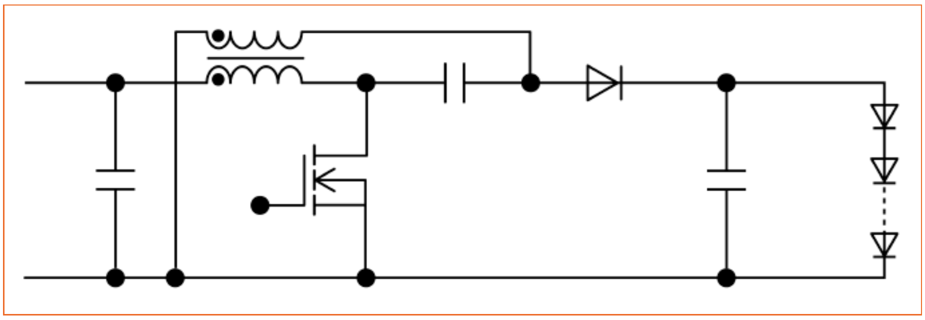

Figure 4: An example of a SEPIC switching circuit for an LED string using dual coil

Figure 3 provides an example of a boost converter circuit for a headlamp application based on an LED string connected in series. The circuit diagram identifies the inductors used for filtering and power conversion. This circuit would be able to supply around 30 W at 30 V to the LED string and would operate at between 200 kHz and 400 kHz.

Other applications with lower power requirements, such as DRL or interior lighting, could be served by a buck-boost converter, typically based on the SEPIC topology. **Figure 4** shows a SEPIC circuit based on a dual-coil inductor, such as the B82477D series from TDK.

Key Features of Inductors for Automotive LED Applications

Power inductors are generally manufactured using either wire-wound, multilayer or thin-film construction. The core's material will either be ferrite or other magnetic metal; the high magnetic flux density offered by metallic magnetic cores makes them suitable for the higher currents used in automotive LED applications. Like LEDs in the lighting application, inductors exhibit losses that can change dynamically, based on the operating conditions. These losses tend to result in an increased core temperature, which will also affect the inductance value. Because of this, choosing the right inductor for an application is crucial to the overall circuit performance and efficiency.

In the case of **Figure 4**, the voltages applied to L1 and L2 are the same, based on a dual coil device with a winding ratio of 1:1. In this configuration, the load on the inductor is twice the load of a single coil, in which case an inductor with a low core loss and high DC superimposition would be selected.

By their nature, an inductor creates and collapses a magnetic field, formed by a conductor wound around the core. Depending on its construction, the magnetic flux generated will be either a closed magnetic path or an open magnetic path. Based on this description, the inductor will be termed as either a non-shielded or shielded type, which relates to how much leakage flux occurs.

A non-shielded, or open magnetic path inductor, will typically exhibit greater leakage flux; this energy can provoke noise and interference in nearby wound devices, adjacent components and PCB tracks. However, many manufacturers now utilize a resin coating to encapsulate the inductor's winding that contains a magnetic material. This can result in an inductor which functionally performs similarly to a closed magnetic path design, although a "fully shielded" type will offer an improved leakage figure. Beyond this, the metallic integral molding type, which uses encapsulation formed from soft magnetic metal powder, exhibits the lowest flux leakage performance.

In more demanding applications, such as automotive LED lighting, a ferrite ring core shield is often chosen, due to its superior performance. The CLF-NI-D series from TDK is one example of the power inductors available for automotive applications. These inductors feature wires wound around a ferrite core, then enclosed by a solid ring core. The series covers inductance values from 1.0 µH to 470 µH and can operate at temperatures up to 150 °C. Automotive grade power inductors are mechanically more robust, support extreme shock, vibration, and wide temperature performance over commercial grade. Actual circuit condition demands combined with physical location within the vehicle influence which inductor is the right choice type, including technology and construction.

Conclusion

The automotive industry is going through a period of exceptional change, with the increased adoption of electric drivetrains and the electrification of other mechanical functions. A car is already a highly challenging environment for sensitive electrical systems, a situation that is expected to continue as the electronic content within vehicles increases.

As lighting transitions to fully LED-based, it will function as significantly more than merely simple illumination. It will be integrally vital, linked with advanced driver assistance systems, (ADAS), applications such as forward-looking collision avoidance, lane departure and parking. These LED systems will be responsible for creating the proper environment, enabling advanced image sensors to function optimally. Even minor fluctuations in light output could lead to a negative effect on these systems.

Beyond ADAS, LED lighting is now a differentiator for many automotive manufacturers. Consumers are starting to demand LED lighting, which puts them in the driver's seat. Consequently, manufacturers must implement LED lighting in the very best way possible, which ultimately comes down to the stability of the power supply. Inductors are integral to achieve that user experience.

Automotive LED lighting is just one application where the choice of inductor is critical. TDK has been manufacturing ferrite materials since 1935 and over that time has built up an enviable level of expertise in its use, in all applicable areas. It now offers several product lines qualified to AEC-Q200 and suitable for LED lighting, including the CLF-NI-D, SPM, VLS7040DX-D and the B82477D inductor series.

Engineers looking to develop LED lighting solutions should not underestimate the importance of choosing the right inductor technology. ■

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Bill Gisseler is a senior applications engineer at TDK Corporation of America (Lincolnshire, IL) with over 23 years' experience in magnetics and emc component applications. He serves as chair of the EIA Inductive Devices subcommittee. Bill has experience directing manufacturing operations of SAW filters, RF isolators, and FET switch products.

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Combination of an Advanced Thermo-Transfer Technology and a Novel High Impact Light Source to Improve MR16 Products

MR16 is has been, and still is a popular form factor, not just in residential applications but in many traditional lighting systems. Since the switch to LED technology many MR16 products suffer from poor quality, poor efficacy, poor luminous flux and poor overall light quality. A novel thermo-transfer technology combined with new high impact light source promises to change this situation. Bertrand Ouellet, Owner of LUBO Lighting, manufacturer and provider of architectural and landscaping exterior lighting fixtures explains how the combination of these two technologies especially resolve heat dissipation issues and results in an advanced high-performance lighting system that features lumen, longevity, and sustainability. He describes and explains the basic idea, the technologies and applications based on LUBO Lighting's Cameleon spot light.

The approach of the novel MR16 is based on two complementary heatsink contact technologies: the patented thermo-transfer technology allows efficient heat dissipation in a retrofit fixture with small ecological footprint as well as the recently launched product collection of novel MR16 bulbs in three variations 336 lm, 680 lm **and** 1500 lm**, conceived specifically for MR16 format applications. This article describes the functioning of this new lighting system and its components.**

LED Lighting Retrofit Fixture with Advanced Heat Dissipating Features

Heat dissipation is critical when a LED is placed inside a sealed lighting fixture such as an outdoor lamp. This is a major concern in the lighting industry because lumen efficiency cannot reach its full potential without a direct link with heat dissipation. This heat sink technology assures the heat transfer inside an enclosed lighting fixture (**Figure 1**). It is compatible with standard MR16 light bulbs, but can be optimized with a highly performant light bulb collection, that have been specifically created to maximize thermal transfer of the lighting fixture to create high-impact lumen power (up to 1500 lm) on a very small footprint.

High Impact Light Source to Improve MR16 Lights

Inspired by the concept of the circular economy, this patented advanced thermo-transfer technology assures performance, functionality and efficiency. This technology is merged in the aluminum hollow body of the lighting fixture in **Figure 1**.

This fixture is a minimalist size format for standard MR16 outer diameter 2.25" × length 2.95" (inner diameter 2"). The lighting fixture is a 12 V accent and dimmable flood light. It is available with adjustable rear center swivel allowing lock rotation under 240° TILT and 360° rotation. This lighting fixture comes with various mounting applications, lenses, louvers and color dichroic filters to create different lighting effects. The construction of the fixture is made with 6063-T5 Aluminum and appropriately finished by an anodizing process (coating thickness 15 to 25 microns) for optimal usage and contact with the bulbs (thermo-transfer technology). This coating works best for different environments and is adapted for rigorous climates. For optimal dissipating material, the aluminum thermal-conductivity is 201–218 W/mK with a hardware SS. The fixture can be installed in various applications such as stakes, canopies for trees, houses, electric boxes and more. The lead wires are tinned copper wires (ULECC 18 AWG). Certified for landscape lighting, UL 1838 and low voltage.

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TEST	WATTS	BULB TEMPERATURE IN FREE AIR (℃)	INSIDE LUBO ENCLOSED FIXTURE WITH CONTACT(℃)	INSIDE COMPETITOR ENCLOSED FIXTURE(℃)	TEMPERATURE DROP BETWEEN C AND D (℃)	REDUCTION (%)
	A	B	C	D	E	F
1	7	62	47.6	75.8	-28.2	23.2
2	6.5	66.5	54.6	80.4	-25.8	17.8
3	8	83.2	62.4	111.8	-49.4	25
4	4	64.5	40.6	72	-31.4	37.1
5	7	58.5	40.9	73.7	-32.8	30.1
6	8	65.3	45.5	84.5	-39	30.3
7	8.5	82.5	51.3	95.4	-44.1	37.8
8	9	87.5	53.9	108.5	-54.6	38.4
9	7	69.5	50.4	81.2	-30.8	27.5
10	6.5	55.8	44	86	-42	21.1
11	6	55	41.6	86	-44.4	24.4
12	7	73	56	85.2	-29.2	23.2
13	6	65.5	41	81.5	-40.5	37.4
14	6.5	57.5	48.3	69.5	-21.2	20.8
15	8	82.8	45.1	106	-60.9	45.5

Table 1: Temperature comparison of different conventional MR16 fixtures with the presented new system

Spot Fixture Components

For a better understanding of the working principle of the IP protected system, the exploded drawing in **Figure 2** shows the relevant components of the referenced spot light (numbers 1 to 8 show the most relevant parts of the mechanical assembly for the thermo-transfer technology).

Figure 1: A patented advanced thermo-transfer technology assures performance, functionality and efficiency

1. Optional glare shield (45° angle, short or long)

Made with AL-6063-T5 also acts like critical mass for the thermo-transfer. The fixture includes an optional 45° angle shield, possibility of 9 cm long and adjustable. Attach to housing with Thumb Screw with

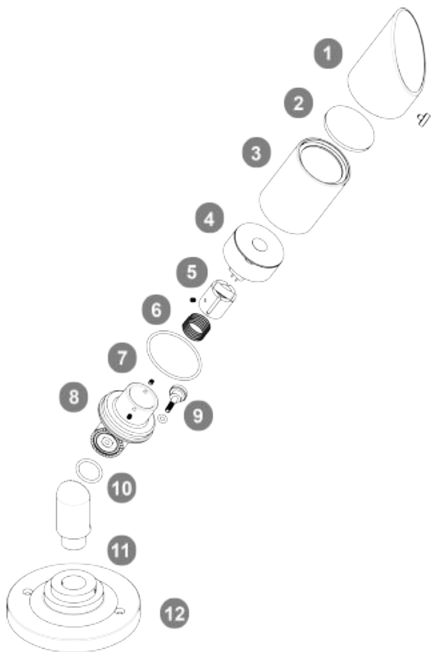


Figure 2: Exploded drawing of the luminaire

Polymer tip for safer contact. Screen is removable, fixed over the body (housing) using different height for better glare control.

2. Lens

Exterior lens (AR low iron 2S) heat strengthen. For 10% more lumen transmittance, 99.9% transmittance.

3. Housing Fixture

Made by CNC process with AL-6063-T5 thermo-transfer conductivity (201–218 W/mK. The closure is with a bayonet lock mechanism. For better glare control, the housing is removable ready for one or two internal accessories such as various lenses, louvers, colors or dichroic filters.

4. New MR16 (but fits also all standard MR16's)

Possibility of 3 variations of the new bulb collection and all standard MR16's. – Inside each novel lightbulb is a COB LED from Nichia. Heat transfer shape is made of anodized aluminum 6063-T5.

5. Sleeve

The sleeve has two cavities: one for the socket holding fixed with an Allen screw. The other cavity is to secure the MR16's bi-pin when closing the fixture.

6. Spring

Assures best bulb heat sink contact with the housing. It pushes up any light bulb (novel bulb or standard MR16).

7. O-ring

Silicone O-ring sealed with half-closed cavity that stabilizes side unit housing and stable side unit.

8. Stable side unit

Stabilize and secure the direction with Knuckle Teeth. Secure the contact with the housing using bayonet lock mechanism.

9. Thumb Screw

Stainless steel, to adjust direction.

10. O-ring

Silicone gasket provides seal for knuckle to prevent water intrusion or dust.

11. Mobile side

Adjustable rear center swivel with lock rotation under 240° TILT and 360° rotation. Provides durable mounting for luminaire.

12. Mounting accessories

Many options available for modularity: Canopy: 3", 5", for trees, electric boxes, spikes and more. The driver for the bulb (1500L) is located behind the canopy.

System Components for ECO Design

The newest bulb collections heat sink is complementary to the lighting fixtures heat sink (**Figure 2** number 1 to 8). This combined technology has been developed in collaboration with OPTECH (Institute of Photonics and Optics). The system has been developed for upmost versatility with advanced combined technology. The fixture with advanced heat sink (**Figure 1**) is also compatible with all standard MR16 light bulbs. Although, the standard MR16's must have top flat aluminum rings for optimal contact with the inside housing flat contact for better heat transfer. This is the first heat sink development with eco design concept for multiple type of MR16 light bulbs.

With the same anodize minimalist lighting fixture that allows all standard MR16's and also the novel bulbs to function at high performance. With the versatility of applications, the bulbs can reach a high number of lumens with just one minimalist fixture (**Figure 3**). This lighting fixture uses a minimum of raw material (three times less aluminum) and only weighs, with the bulb, included 13.8 oz. Raw material has a huge impact on the amount of CO_2 on the planet. This is why minimal aluminum use is preferable for maximum efficacy.

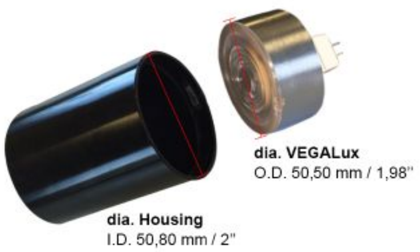


Figure 3: Minimalistic configuration of the new approach that still provides high performance

Although, the standard MR16's must have top flat aluminum rings for optimal contact with the inside housing flat contact for better heat transfer. This is the first heat sink development with eco design concept which gives us a possibility of using almost any standard MR16 on the market with secure efficiency performance. The aluminum fixture (**Figure 1**), used for integrated advanced thermo-transfer in addition to the high impact light source is a very small retrofit fixture designed for COB LED Performance. It only weighs 13.8 oz with the bulb included and it is made with precision by CNC.

This fixture closes with a bayonet mechanism (**Figure 3**) which reduces friction on half inch movement, instead of three to four turn screwing treads which could destabilizes the bulbs bi-pins placement. It is sealed with half-closed cavity that fixes in place the silicone O-ring for best outdoor protection against water and dust. Keeping the retrofit system alive is to secure the future generation of contributing to circular economy by finding any bulb replacement and other components (driver, diode, etc).

The sleeve has two cavities: one for the socket (fixed with Allen screw), and one to secure the base of any MR16 bulb (Bi-Pins). The bulb is secure in one of the sleeves cavities (**Figure 2**: Number 5) while closing the bayonet mechanism of the lamp because the MR16 Bi-Pins are fixed inside different duro-plastics for stability. The spring under the sleeve, pushes any standard MR16 bulbs or a novel bulb (**Figure 2**: Number 4) for efficient contact with the housing of the fixture transferring the heat outside the enclosed lighting fixture.

This technology guaranties a healthy life for any MR16 light bulbs because of the heatsink efficiency. Laboratory test results show that a manufactured light bulb temperature inside an enclosed fixture (See Heat Dissipation Chart). drops to an average of 29,30% compared to a room temperature of a lightbulb (**Figure 4**). This temperature drop is a gain for the thermo-transfer technology that allows novel high-performance bulbs to reach more lumen. From the results of the heat dissipation chart, only 70.7% of the thermo-transfer is used and the novel high impact light source allows to use the full potential of the heat dissipation technology.

Three Bulb Variations and More

The novel MR16 bulb series includes 3 variations with 4 optic lenses each with 336 lm, 680 lm and 1500 lm (outside driver with PWM dimming process) light sources. As more lumens means more heat evacuation and reduction of lifespan for bulbs, for more precise heat sink contact between the fixture with patented thermo-transfer, the novel MR16's are made with precision machined CNC process. The bulbs outer diameter of 1.998" is designed to fit the lighting fixture with an inner diameter of 2.000" (**Figure 3**) which enables the retrofit heat sink contact with more efficiency. The light source is able to reach 1509 lumen with more than 60.000H life at LM70.

Technology Overview:

- Using an external driver, the lamps can reach 1509 lm which means a gain of 33,6% more lumen output. With integrated driver, the bulbs can provide 1060 lm.
- For optimal compatibility the choice of aluminum 6063-T5 allows an optimal thermal conductivity 201–218 W/mK (compared with A380 96 W/mK almost two time more thermal conductivity) for the bulb heatsink and mostly for the housing.
- For a better heat dissipation contact the choice of treatment surfaces must be an anodized: the bulbs heat sink and all the aluminum fixture (**Figure 1**).
- CNC process manufacturing gives optimum and precise contact between elements.
- 10% more lumen transmittance, 99.9% transmittance.
- Precise thermal mass and shape, not more nor less, for secure thermal dissipation efficiency.

Comparison of the New Technology to a Conventional MR16 Product with Comparable Light Output

A side-by-side measurement of luminaires with the new IP protected technology with the conventional MR16 technology was made to prove the advantages of the new technology. The results shown in **Table 1** impressively demonstrate how much better the thermal behavior of the new concept is.

The Novel MR16 Bulb with 1500 lm and External Driver

The standard driver is design with PFC which contributes to energy efficiency. Slight flicker may be recognized with the camera of a smartphone. Less flicker may be recognized with 12 V AC or 12 V DC transformers. Connection to electronic 12 V transformer with dimmers often cause unsmooth dimming, flicker or other compatibility issue. But this novel MR16 collection can even work with most 12 V electronic halogen-transformers. The optic lens is able to snap in and out of the lightbulbs body (**Figure 4**) at three specific cavities already fixed by CNC. All lenses have the same shape to reduce inventory.

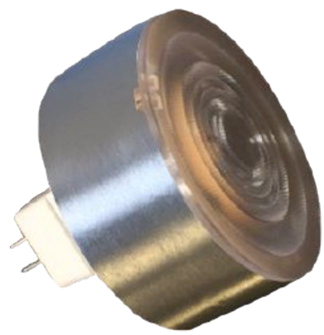
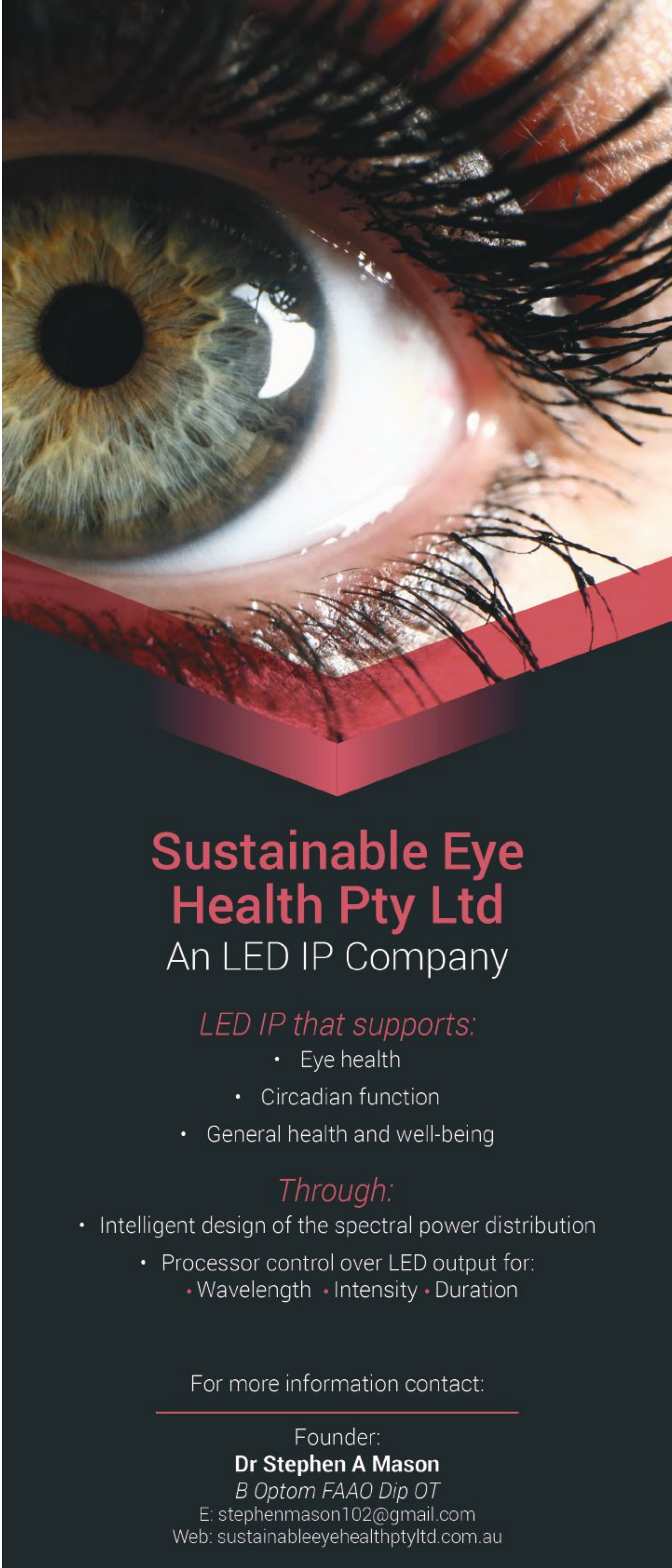


Figure 4: The VEGALux 1500 lm lamp has the same dimensions as a standard MR16

Conclusions

This bulb collection has now completed the first stage of development by achieving the highest number of lumen inside an enclosed fixture. It is important to mention that the MR16 bulb is used as a model for the first prototype to represent this technology. It is possible to apply this technology in different formats. The innovative MR16 lighting system can evolve to a second stage of development: optimization of performance. The second stage will also include versions designed to use line voltage (110 V/277 V outdoor and indoor). It is also planned to make them available in different formats, such as MR11, MR16 and PAR20 with line Voltage or 12 V. The high efficiency light bulb system comes close to perfection as the new generation of COB LED may reach CRI 97 for a better ecological footprint, to enrich lives and the environment. This high-quality light is an excellent step forward for healthier live and environment. ■

AUTHOR: Bertrand OUELLET
Mr. Quellet is Founder and Owner of small business LUBO Lighting and has been focusing on designing state-of-the-art lighting solutions with small environmental footprint, allowing lighting designers and architects to enhance and showcase their work since 1995. He has been optical researcher for a project development for two years with OPTECH (Institute of Photonics and Optics) to created a new MR16 light bulb to be integrated inside an enclosed lighting fixture by leveraging LUBO Lighting's heat dissipation technology. Patent 2017: Technology for outdoor sealed lighting fixtures. A heat dissipation allowing energy saving and allowing an extended life for the LED bulbs. He realized architectural and landscape lighting concepts in Long Island, New York, as well as throughout Quebec from 2002 to 2012.



The Poetics of Darkness

Darkness: The partial or total absence of light. Also defined as tenebrosity, evil, wickedness, sin, devilry, hell, unhappiness, distress, ignorance, among others. Very few words with positive connotations are used to describe darkness; also light, good, and day are suggested as antonyms for darkness itself [9].

This paper offers a critical reflection on how we as human beings think and conceive darkness, with the intent of expanding the conversation and ultimately reframe our approach towards darkness within the creative process. As lighting designers ourselves, we experience that darkness is rarely discussed or even addressed in the design process. However, we consider that lighting design is directly related with the effective use of darkness and contrast. In fact, to understand how to work with light is to comprehend and acknowledge its inherent relationship with darkness and shadow [4].

Darkness has a unique presence in the way we understand our surroundings. Its ephemeral quality helps us define the character of architectural spaces, and the relationship between the elements that integrate it; influencing the experience we live in space and as a result making it memorable. If darkness holds such a relevant role, why do we as designers tend to minimize its potential?

Precedents and Context

What is darkness? How do we understand darkness? Throughout history the idea of darkness has been established and shaped by implied associations based on our culture and origin [12]. These notions are deeply rooted in our collective consciousness through negative concepts that we have accepted as universal truths. For instance, have you ever used darkness as a synonym for evil? Have you ever used it to describe something unknown? Or perhaps darkness has impacted your feeling of safety within a space? Similarly, we can recognize false concepts related to how darkness might impact our experience of space, such as: the impression of limiting legibility while concealing features, hinder orientation or create confusion within the built environment as a result of limited visibility [2].

Another factor that determines our understanding of darkness and light relates to language. As hinted previously, light and related terms are often used to describe positive qualities of objects, spaces or people. Whereas darkness is commonly used in a negative context to describe experiences and emotions. Referring to this diagram by Claudia Dutson (**Figure** 1), we can see how language is divided when talking about darkness and light. Having an ample and rich vocabulary of positive terms to refer to light, and on the contrary very few positive words to describe darkness; making evident the negative value attached to it [2]. This association of language and the clear separation in our vocabulary, conditions the way we understand darkness today.

It is important to note our understanding of darkness has evolved with time. In the past, we had a less conflictive relationship with darkness. Our ancestors used to live around the sun cycle during the day and twilight at night, using the eyes innate ability to adapt to perform activities under dim light, in other words embracing darkness [8]. Although today, our lifestyles and needs have changed, we must not forget that such ability to adjust to different light intensities is still embedded in our system [1]. The wide range of brightness levels the eye can experience is illustrated by William Lam in **Figure** 2, demonstrating its ability to adapt to multiple light conditions going from low luminance levels in a dark night to ten thousand times more light in a bright sunny day. Recognizing this property of our visual system is critical to introduce darkness in a space.

The eye holds a dominant role in our culture. Historically, light and sight have been interrelated and understood as equivalent. Light refers to the action of seeing and darkness to the impossibility of seeing and the sense of touch. As an example, the Greek's theory of light was centered on human vision and many of their successors followed this idea that light itself emanated from the eye as a metaphor to see the world [12]. As a result of this thought, the inherent link between light and darkness began to disappear. Consequently, the Western culture has been dominated by the model of ocularcentrism, focusing on the visual system as the primordial instrument to understand our world. This philosophy has conditioned our architecture and contemporary city, suppressing the multi-sensory essence of our environments and causing an imbalance in our cognitive system [10]. Focusing only in the sense of sight and reducing the rest of the senses creates a gap between us and the world that surrounds us.

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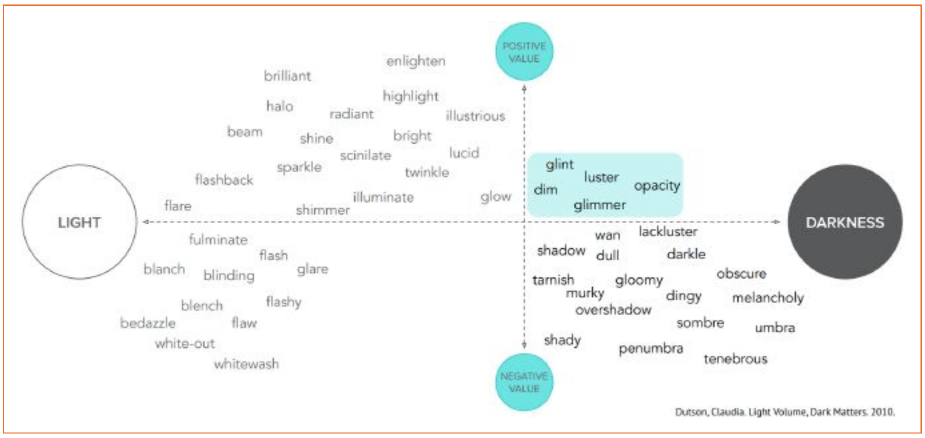

Figure 1: The language is divided when talking about darkness and light by Claudia Dutson

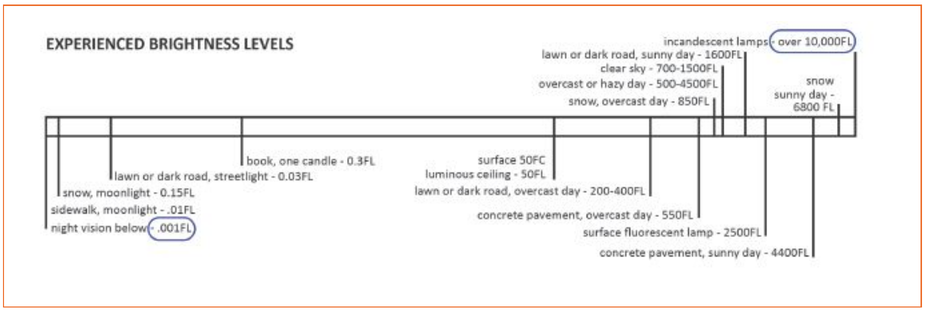

Figure 2: Range of brightness levels by William M.C. Lam

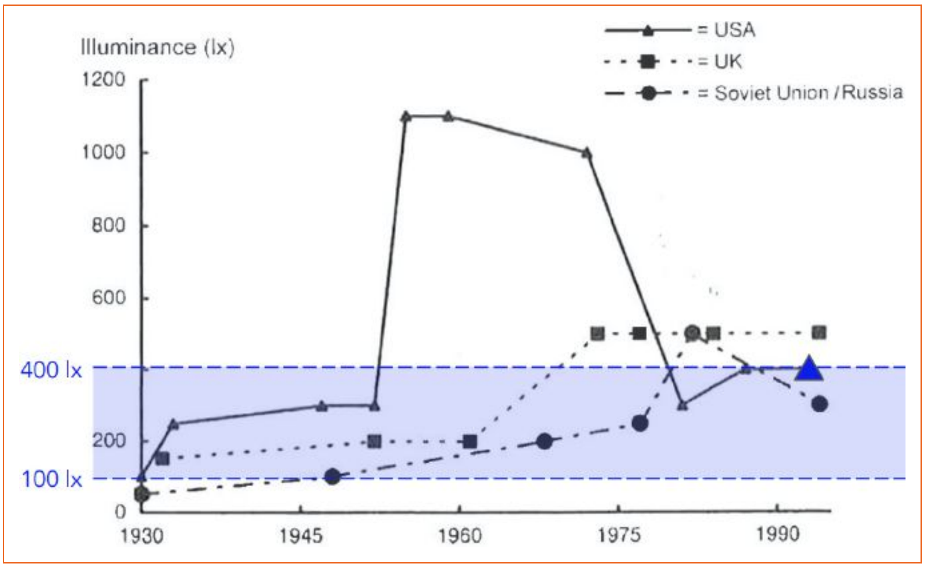

Figure 3: Illuminations recommended for general offices in the US, UK, and the Soviet Union/Russia since 1930 (after Mills and Borg, 1999) by Boyce, Peter R. Human Factors in Lighting. CRC Press: 2nd Edition. 2003

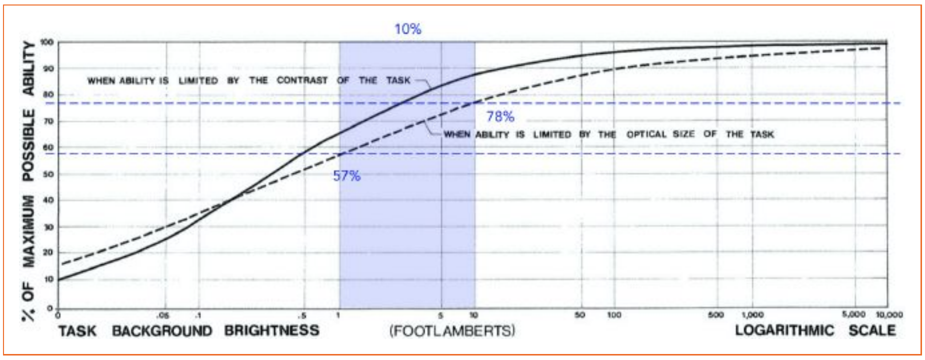

Figure 4: Relationship between brightness and productivity by William M.C. Lam

Current Practice

Today in particular, we focus on the sense of sight through fields such as electric lighting, constantly reinforced by technological innovations that promote brighter sources in the effort of providing "better" luminaires. As a result, we inhabit over illuminated cities designed to appeal to the sense of sight and neglecting the use of the other senses.

It is worth mentioning as well, that in our current practice as lighting designers, the recommendations and standards contribute to reinforce this tendency pro light and unfortunately against darkness. As an example, **Figure 3** compares lighting recommendations for an office space in Russia, the United Kingdom and the United States between the years of 1930 to 1960, demonstrating an increase in light levels through the years. If 100 lux were considered sufficient in 1930, why today 300 lux or more are required to perform the same type of activity? Although architecture and the way we perform tasks have evolved, the eye adaptation ability remains current but nonetheless neglected **[1]**.

We acknowledge that certain tasks require specific light levels within interior spaces. Nonetheless, research has demonstrated that increasing the amount of light within a space is not synonymous with better productivity **[6]**.

Looking at **Figure 4**, we can observe the relationship between brightness and productivity. The vertical axis indicates the percentage of people's effectiveness to perform specific tasks, the horizontal axis shows the amount of luminance the eye perceives from the work surface. There is a 57% ability to perform a task at very low light levels, when light levels increase a 10%, our ability to perform the same task increases considerably by 21%. However, from this point forward the percentage increase of productivity and light levels is not proportional. At this point if light levels are raised 10%, people's performance would increase only 3%. It is evident that although performance increase is substantial at the beginning, beyond that threshold higher luminance does not impact performance meaningfully enough to support higher light levels. We take this as a clear indication that design solutions driven only by quantitative parameters might limit creativity and exploration during the design process **[7]**.

Lighting recommendations are an integral part of our practice however to enable creative exploration, it is essential to be aware that quality lighting design goes beyond providing light for the sake of seeing, beyond producing spaces that appeal mainly to our sight. Approaching design from this quantitative perspective, frames lighting design as a visual product only, disconnecting it from the inherent temporality and depth that darkness and shadows bring into space [11].

Proposal

This leads to our main question: how to recover the poetic value of darkness in lighting design? We aim to demonstrate the potential of under-lighting and its multiple benefits, encouraging others to consider the poetic experience of darkness that will spark the multisensory participation of the observer.

First we propose to recalibrate our design process, recognizing that darkness and light have equal value as creative tools. To understand this further, we can refer back to (**Figure 1**).

Starting by considering light and darkness as equal in value, and looking at these words from this perspective we selected those that could talk about qualities for both, for example: halo, twinkle, glow, dim, luster, opacity, penumbra and umbra. Then, what if we remove the notions of positive and negative, and start thinking of these as relative values, not good, nor bad but complementary to each other. With this notion as base, we propose to consider darkness as a vast spectrum with multiple nuances and intensities. When we recognize darkness as a relative condition with the same creative value as light, we start to dissipate the preexisting negative notions around it, and welcome the possibility of exploring it as part of our creative process [4].

Moreover, to reiterate the idea of relative values, our intention is to convey that each of these qualities of light and darkness (**Figure 5**) could represent infinite possibilities in the built environment. Making evident that the presence of darkness is not absolute, on the contrary it allows unlimited ways of expression when interacting with light [2]. All together considering darkness as a spectrum begins to reveal other features in spaces that ultimately will establish a new rhythm of perception and experience.

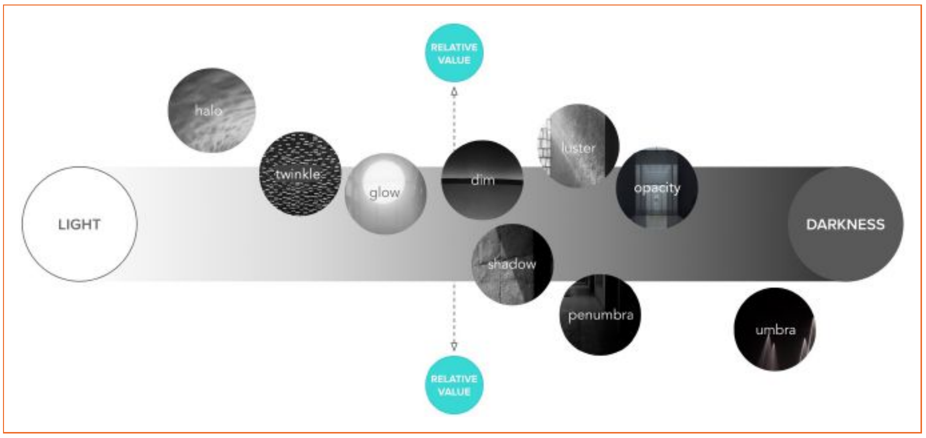

Figure 5: Darkness as a spectrum, infinite possibilities in the built environment by Castro and Llamas

Application

Every project is an opportunity to put in practice this concept and see light and darkness through this lens. We consider that one effective and practical way of introducing the application of the light to dark spectrum is through understanding contrast and contrast ratios. Various moods could be triggered depending on the ratio of darkness to brightness, ranging from a subtle to a strong impression.

Using as a reference the following chart from the IES handbook (**Figure 6**), helps to provide a better understanding of the relative value of darkness. A classic example of this condition is (**Figure 7**) where two equal squares appear to be a different shade due to a brighter or darker background.

CONTRAST & FOCAL POINTS				EXAMPLE APPLICATIONS
	Role	Reflectance	Illuminance Ratio	
Strong	Dominant	>50%	~20:1 focal-point-to-task	House of Worship
		<50%	~40:1 focal-point-to-task	Retail
	Dramatic	>50%	~10:1 focal-point-to-task	Corporate & Hospitality Lobbies
		<50%	~20:1 focal-point-to-task	Retail
Moderate	Feature	>50%	~5:1 focal-point-to-task	Hospitality Retail
		<50%	~10:1 focal-point-to-task	Transition Spaces
Soft	Visual Edge	>50%	~2:1 focal-point-to-task	Conference rooms Residential
		<50%	~5:1 focal-point-to-task	Reception
Subtle	Visual Relief	>50%	~1:1 focal-point-to-task	Office
		<50%	~2:1 focal-point-to-task	Residential

Figure 6: Contrast and contrast ratio by IES Handbook

Figure 7: Two equal squares appear to be a different shade due to a brighter or darker background

When introducing this concept, it is important to recognize that each space and program will have different constraints and requirements. As one would assume, an office space requires higher light levels than a breakout room. From here it is possible to identify the best suited ratios for each type of application: a dramatic contrast ratio would work best in retail or hospitality, a moderate contrast ratio could enhance transitional spaces, whereas a corporate environment would benefit from a subtle contrast ratio [5].

Having determined that darkness as a spectrum is as valuable as light itself in the creative process, we aim to reestablish the relevance of the multi-sensory experience in space. Supported through case studies, we seek to demonstrate how beneficial the intentional use of darkness can be within architecture.

As previously described, our understanding of darkness is linked to our collective consciousness. In the past, the available sources gave spaces a unique lighting quality; surrounded by dynamic shadows and a warmer dim light. Today, this memory is still present, as proof we continue to enjoy candlelit spaces as well as moments by a fireplace [8].

Thomas Wilfred in his work Clavilux used light, color and movement to create depth, and emphasize different saturation intensities. In this particular case, darkness acts as a background to the pieces. Darkness enhances the ephemeral and dynamic qualities of light, allowing us to appreciate it at its fullest capacity. This experience at its core, resembles the experience of contemplating a candle and its flame (**Figure 8**).

Figure 8: Clavilux by Thomas Wilfred

In a similar manner, Anthony MaCall with his series Solid Light Works uses darkness to reveal a series of ethereal volumes. In this case, light and dark have a presence of equal value, both are shaping our perception and creating a very unique rhythm in the way we experience the space. Spectators tend to gather around these sculptures of light, in an act of collective synchronicity comparable to the experience of gathering around a bonfire (**Figure 9**).

Darkness could also be used to provide spatial shelter, addressing the most relat-

Figure 9: Series Solid Light Works by Anthony MaCall

able misconception: darkness is unsafe and high light levels the opposite. Instead we propose the use of darkness to allow anonymity within a space, letting users enjoy moments of privacy and tranquility to support stillness and serenity in certain spaces without the use of physical boundaries [8]. This idea counteracts the belief of lack of security in low light, and provides a positive aspect to the use of darkness.

At the MIT Chapel by Saarinen, the use of darkness draws attention to detail. The intentional use of under illumination embraces the visitors and supports eye adaptation from the soft glow at the perimeter to the focal point at the skylight. Creating in between a threshold area of dim light for contemplation and shelter (**Figure 10**).

Figure 10: MIT Chapel by Eero Saarinen

Even though the luminaires are meant to provide light for visibility and safety in public spaces, glare usually obscures and hinders sight. At the Highline by L'Observatoire International, the use of darkness successfully prevents this effect. Dim light is strategically located to reduce glare and supports eye adaptation allowing visitors to move through space and appreciate the context, reconciling darkness with safety (**Figure 11**).

Another benefit is the intentional use of darkness as a source of visual information.

Figure 11: Highline by L'Observatoire International

On the one hand, shadows communicate direction, time and location inherently contributing to spatial legibility and orientation [8]. On the other hand, darkness and contrast can also present symbolic information related to the use or intention of space. Directly or indirectly, the application of darkness within a space can expand on the meaning and purpose of such space.

"My favorite lesson from this research was realizing that we all like and need a level of darkness in our environment. As lighting designers, the tools are already at hand, it's up to us to maximize darkness potential by reconciling and reframing the way we express and think about it."

MONICA LLAMAS

"For its ephemeral characteristics and inherent relativity to one's perception the Poetics of Darkness is a complex topic, yet it offers a challenge to redefine our sensibility to our environment, opening the possibility of addressing larger collective issues."

FLORENCIA CASTRO

In the Chapel of the Capuchinas in Mexico City, the interaction of color, materiality and shadow broaden the understanding of space. The side aperture projects an ever dynamic shadow on the colorful wall, moving and changing as time passes or daylight conditions varies, bringing to the interior the element of time and reinforcing the spiritual character of the space. All at once these components reveal to the visitor the symbolic content of space (**Figure 12**).

In the same manner, Le Corbusier at Palais des Filateurs in Western India, plays with contrast to reveal the materiality and depth of the architectural massing. In this case shadow helps us to understand the texture, the character of the materials and the orientation of the building. In addition these moments of light and dark bring forth the tactility of the concrete walls, one could easily imagine how warm or cool these would feel under direct light or surrounded by penumbra. These elements in conjunction allow us to experience multiple scenarios throughout the day (**Figure 13**).

Lastly, the layering of darkness and light can help establish hierarchy and emphasize spatial depth; modifying our sensory experience. This strategy proposes a new perceptual rhythm that could suggest multiple narratives within a space [2].

At the Salk Institute by Louis Kahn the play of light and shadow modifies the space throughout the day offering unexpected experiences to the visitors every time they approach [3]. Here darkness becomes appealing, dissipating the misconception of fear to the unknown (**Figure 14**).

Richard Kelly, at the General Motors Technical Center presents light and darkness as two pure volumes that define perceptual boundaries within the space. Darkness around the volume of light helps define the depth of space and frames the user's attention (**Figure 15**).

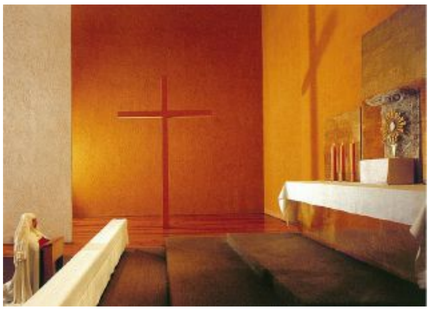

Figure 12: Chapel of the Capuchinas by Luis Barragan

Figure 13: Palais des Filateurs by Le Corbusier

Figure 14: Salk Institute by Louis Kahn

Figure 15: General Motors Technical Center by Richard Kelly

Conclusion

With these case studies our goal is to demonstrate that the potential of underlighting as a design strategy although unique is possible, but unfortunately seen as inadequate for architecture. From here, we hope designers are able to reflect further on what is considered as acceptable light levels to welcome the possibility of darkness and embracing the benefits of its application (**Figure 16**). In particular, understanding that darkness can be multifaceted and can be used to define different elements as well as multiple experiences. More important, darkness enables a new rhythm of perception in space.

To conclude, we consider that the virtues of darkness can be classified in two aspects, one that refers to the quality of space and another one that relates to the practical and quantitative aspect of design. In the qualitative aspect, it is important to recognize the value of darkness for what it reveals and not for what it conceals. From the field of perception and experience, darkness slowly reveals what at first glance is not seen, that is, unlike light that allows us to see everything at once. The application of darkness as a spectrum, contributes to spatial richness, stimulating all the senses and inviting us to participate in the experience. All together, it allows to reestablish the inherent intangible essence, giving access to the poetic field in architecture.

In the quantitative aspect, we conclude that there is a need to re-evaluate the standards and recommendations for the practice of lighting design; to recalibrate how we validate lighting design, thinking beyond the amount of light in space. Although there are valid recommendations dedicated to the understanding of perception, in our daily practice we continue to give priority to the amount of light applied to each surface. Finally, the intentional application of darkness implies an automatic benefit in saving energy consumption, proposing to reduce the number of luminaires in space, turning each project into a sustainable design solution (**Figure 17**). ■

AUTHOR: Monica LLAMAS

As an architect and lighting designer, Monica has great sensibility to space and light needs. She solves complex design problems through critical analysis of space and the people who inhabit it. With over 5 years of design experience in Guatemala and New York, Monica continues to skillfully and creatively communicate new approaches to lighting design within multidisciplinary teams. Currently Monica is part of the Office for Visual Interaction team collaborat-

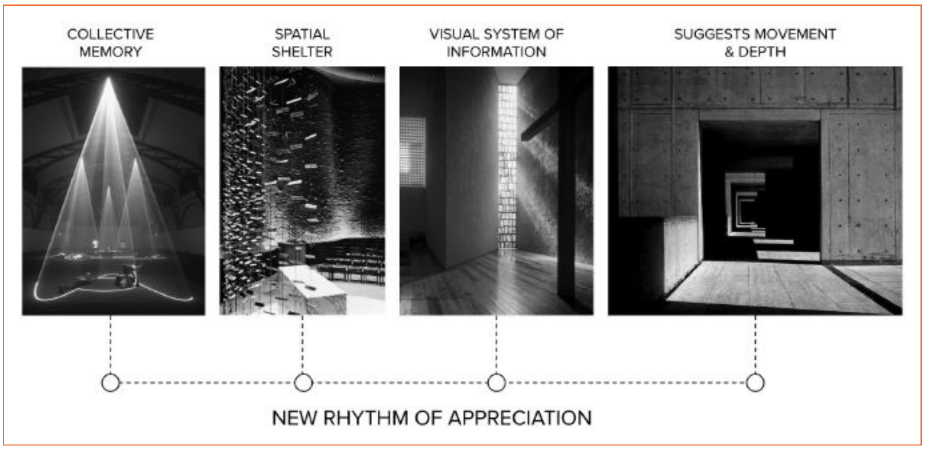

Figure 16: Benefits of the intentional use of darkness by Castro and Llamas

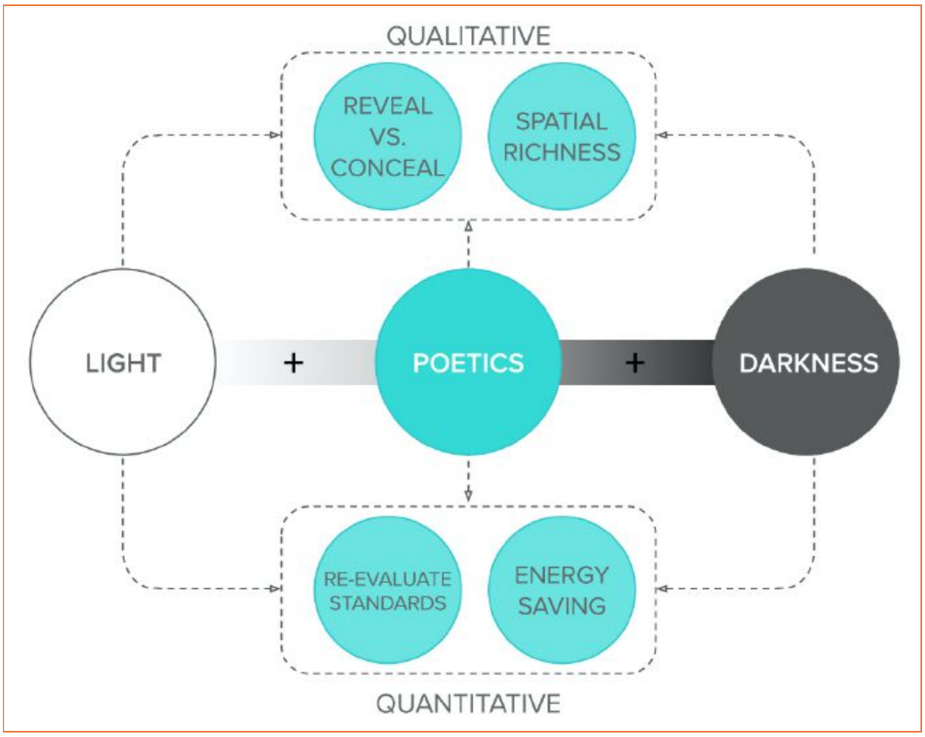

Figure 17: Qualitative and quantitative aspects by Castro and Llamas

ing as a full time Senior Lighting Designer, she also continues to be an advocate for emerging designers and promoting the exchange of ideas. She spreads the voices of young professionals through her participation at LEDucation and LightFair International and has been recognized for her exceptional abilities with a 40 Under 40 Award from Lighting Magazine. Monica holds a Bachelor of Architecture degree from Universidad Francisco Marroquín (Guatemala, GT) and a MFA Lighting Design degree from Parsons The New School for Design (New York, NY).

AUTHOR: Florencia CASTRO

Trained as an architect, Florencia recognizes the power of light and shadow to heighten the experience of the built environment. Her approach casts lighting design as a creative yet technical challenge; a complementary practice between daylight and electric light. Today, she collaborates as a senior lighting designer with Flux Studio, a design firm based in New York City, focused on a transdisciplinary practice and commitment to light and its relationship to our perception of space. Her extracurricular contribution to the profession focuses on promoting dialogue and critical thinking about light and design. For her work in the lighting community Florencia has been named one of the 40 most promising up-and-coming designers, 40Under40 by Lighting Magazine 2020. Florencia holds a Bachelor of Architecture from Universidad de las Americas Puebla (Puebla, MX) as well as a Master of Lighting Design degree from Parsons The New School for Design (New York,NY).

Authors: Monica (top), Florenica (bottom)

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Gaming in the Lighting Sector A Game Changer?

Platform-driven business models are closing gaps between suppliers and consumers. The companies that have grown the most over the past decade are based on this idea. Looking at other branches, this has gone hand in hand with a series of tools and configurators that support the end user in decision-making, and increase variants in the portfolio at interesting cost ratios. Ideas like parametric design, and recent developments in the gaming industry offer new opportunities for easy creation of excellent lighting solutions for end users, designers, suppliers and system integrators.

A Thought Experiment

The first magic item in the Harry Potter novels is a Deluminator [1]. This shouldn't surprise any light Passionists. Based on current practice, the ability to connect to any luminaire remotely and switch them on and off is truly magical. However, this might not be a good idea in real life, especially with lights that provide our perceived security.

In virtual space, the idea of a Deluminator is a real asset. Light and lighting effects can be experienced directly. Lighting designers might add a series of functions, like the play on surfaces, color temperature, light distribution, heights, daylight, sensors, etc. – the list quickly tends to be of considerable length.

Other industries took the step into the virtual world earlier. The car configurator is a classic example. Not only can you create your car online, you can also immerse in the design via VR [2]. Later in the sales process, the final configuration becomes the foundation of the contract, and controls automatisms in manufacturing processes and installed software options in the car. For our thought experiment, we are therefore expanding our Deluminator with the components of our lighting solution – the real sensors and luminaires, which are configured via the parameters of their virtual relatives (**Figure 2**).

The Reality

Realistic lighting in virtual spaces is a standard for many computer games and virtual film sequences. This was secondary to Pacman and Tetris – classics of the gaming industry in the beginning. But nowadays, the physical principles of real perception have been implemented in virtual worlds. James Cameron's classic Avatar from 2009 was certainly a door opener for the industry. A fantastic world, with a series of impossible elements, embedded in a majority of familiar looking objects. With the rising expectation and competition, the borders have been moved a lot in recent years. The film "Rebirth" produced by Quixel [4] or insights into "Control" [5], a computer game that won several awards in 2019, clearly demonstrate that the complex subject of lighting can be presented in high quality today. When focusing the interaction on lighting instead of other gameplay, very good results are achievable with standard PC performances today, although a high-quality GPU will always add considerable quality.

Over the past few weeks, FutureACT has developed and analyzed affordable business models. The following four are deemed to be highly relevant for the upcoming months.

The Showroom

With a virtual showroom that accommodates several variants and styles, wholesalers, contractors and installers can make decision-making processes faster, more efficient and more valuable at affordable costs. The combination of lights, buttons, sensors, blinds, electrical devices and remote-control options allows the user quick decisions and priority setting. Especially solutions for smart homes and IoT applications profit from a virtual showroom. An empty room with the option for the user to create their individual variant is a win. The connection to ERP systems is doable (**Figure 1**).

The Configurator

Specific product configurators are massive sales support for manufacturers. Sample streets, parking lots and industrial environments have proven to be great applications to start with. The rapid variation of lighting distributions, heights, bracket dimensions and further options like daylight, season, trees, etc., result in a good foundation for demonstrating features and benefits (**Figure 2**).

The Specific Project

For larger and more complex projects – easily identified when there is a sample budget – an interactive model is suitable for design support. In the early stages, basic variants of luminaires, brightness levels and materials will be made controllable. During the decision-making process, decisive parameters are removed and advanced parameters are released. Thus, the model develops in the process until all decisions have been made. The resulting "game" can be used at any time – together with a feedback interface – whenever participation is advantageous – i.e. in municipal projects. A simple touchscreen is completely sufficient for this (**Figure 3**).

The GUI Project

Control algorithms and personalized user interfaces can be developed and decided in the virtual world. Afterwards, the solution is linked to reality via appropriate hardware interfaces. Thus, the virtual GUI might become the real control center. This is particularly suitable for smart home and pilot applications as well as for research and development projects. For project sizes in which decentralization plays an important role, the central intelligence has to be distributed appropriately.

The Starting Point

Being able to discuss the above options is primarily possible due to the progress of the platforms in the gaming industry that makes the options financially feasible. Examples of this are the Unreal Engine [6], Unity [7] or the Cryengine [8]. Interactive, three-dimensional worlds can be created on these editors. These platforms also offer free programmability and access to physical principles, materials, user interface and

Figure 1: This is a demonstration for an application specific configurator. With the click of a mouse, you can change road classifications, pole and bracket dimensions or apply various lighting strategies in real time, like the Smartnodes light bubble

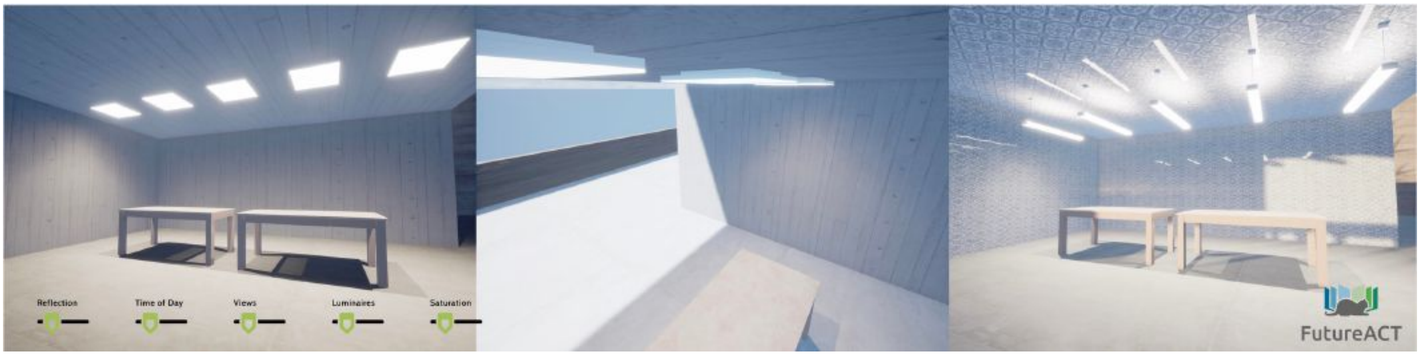

Figure 2: An example of a simplified lighting configurator. Simplified architecture and control over a series of parameters allows a quick check of product related aspects

Figure 3: This project combines KNX controls, automatic blinds and a human centric lighting approach using the change of color, brightness and direction- all dependent on time, and offers results and configuration opportunities in real-time

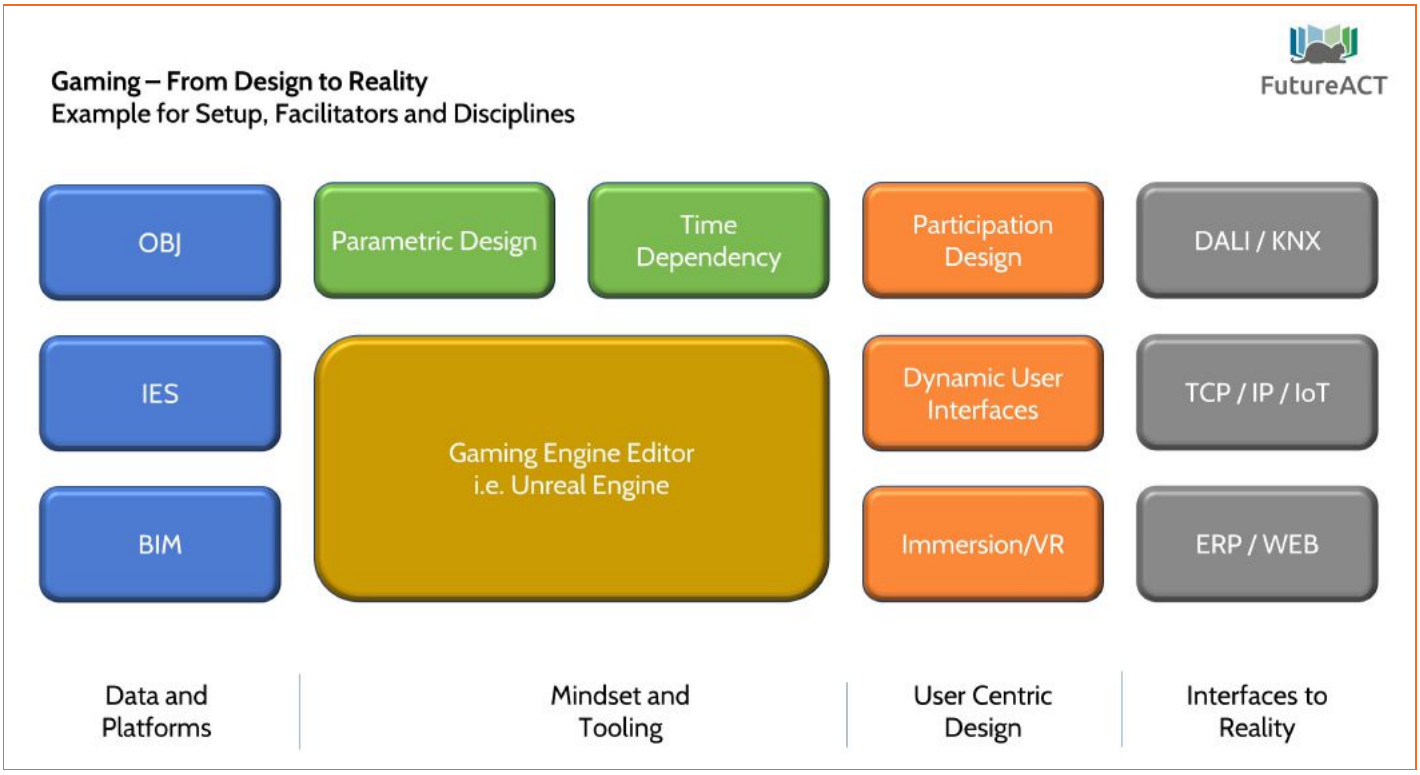

Figure 4: Progress is not only down to pure computer power. There are a variety of ideas that make gaming for construction and engineering intersting and affordable

control options. Immersive virtual reality is just as possible as simple web solutions using pixel streaming.

Objects can be easily integrated into these worlds. Classic formats, such as DWG, IFC, 3DS, OBJ or FBX are available for import. This also includes the option of integrating intelligent objects (e.g. BIM Building Information Modeling [9]), city models (e.g. Open Street Map [10]) and skeletal 3D objects (e.g. people in motion / Mixamo [11]). For this purpose, several web platforms have been set up and made accessible. This simplies access for the various construction and design industries. For lighting designers and suppliers, the possibility of integrating IES lighting distributions based on luminous flux is of immense importance.

Using the above options, virtual worlds can be created. With little effort they can get very close to photorealism. An interesting opportunity is to model the luminaire image and light distribution separately and and link them to each other. For the variety of transparent, semi-transparent and metallic surfaces surrounding luminaires, we finally can combine a photorealistic visual perception of the luminaire with the distribution of lighting in the space (**Figure 4**).

The decisive factor for the lighting sector for now is to create simple interaction interfaces. The open editor approach of the gaming engines using classic programming languages – primarily C or C ++ – is supportive. Graphic software design options [12] make it easy to get started and allow for quick adaptation in new projects. Over the past few months, FutureACT has developed a whole arsenal of menus for the lighting and installation industry that can be put together for individual applications based on the Lego principle. This also includes simple interfaces to other programs and programming languages. TCP / IP, DALI, KNX and Bluetooth have already been successfully implemented.

The Beneficiaries

To be a real game changer, the question of the beneficiaries arises. The likelihood of a game changer is only big if every participant involved in the sales funnel benefits from the development. Thus, the central question is: Who would profit from an optimized Deluminator?

- Decision-makers see variants side by side at the push of a button, can determine their own perspective and modify parameters. This supports the assessment of the value of lighting and its consequences. Thus, decisions are made faster. Real benefits are kept in in mind. This reduces errors later.
- Design teams can present samples for the same budget on a much bigger scale without producing waste. Above all, this helps when testing algorithms and networked functions in smart future applications.
- Lighting suppliers show their features in real user benefits. This helps for internal training of own employees and creates greater market proximity. An invaluable advantage for training centers, marketing and sales.
- Control providers map interventions and sensors live and literally make complexity tangible. This is especially true, when real sensors and touch panels control the virtual application.
- System integrators parameterize the technology in a much earlier project phase. This simplifies project funding. In addition, the graphic interface from the design phase might become the visualization and control surface of the project. Since decision-makers and users are already used to the interface, misunderstandings are reduced.
- Wholesalers can bundle single products to advanced solutions. This supports their customers with increased services and creates added-value.
- Especially retail chains program and test adjustments beforehand in virtual space and parameterize their numerous locations remotely. This makes seasonal adjustments and sales or space optimization easy. The individual retailers get an insight into the upcoming experiences in advance and prepare themselves perfectly.

- The customer pre-configures his solution – like any car configurator today. As a result, the initial consultation is qualitatively better, more efficient and revolves primarily around user needs and questions. For the solution provider, this foundation offers a great opportunity to optimize their follow-up-processes and increase competitiveness.

Outlook

The time is ripe for the use of gaming approaches in the lighting industry. The lighting industry can use the tools of the gaming industry with relatively little effort. First projects demonstrate success. The number of beneficiaries is huge, and the barriers are relatively low. The architecture **[13]** and automotive industries are good role models and serve as a reference for management decisions. With the LED, which is electronically controllable, the industry foundation is excellent. The huge task of networking lighting into IoT applications will serve as a catalyst. The upcoming years will offer the possibility of differentiation for early adopters. In the long run, gaming will change the industry and become a hygiene factor. ■

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About FutureACT
The aim of FutureACT is to facilitate decision-making, improve environment and use resources more efficiently. Excellence is reached by using the benefits of digitization and user-centric design – from easier participation processes to high empathy in the solution design. As a result the company develops solutions, that are profitable and, at the same time, ethically and socially respected, With their recent projects "menschlichT"(2019) and "ParaTimeDesigner"(2020) – the office demonstrated a new of thinking.

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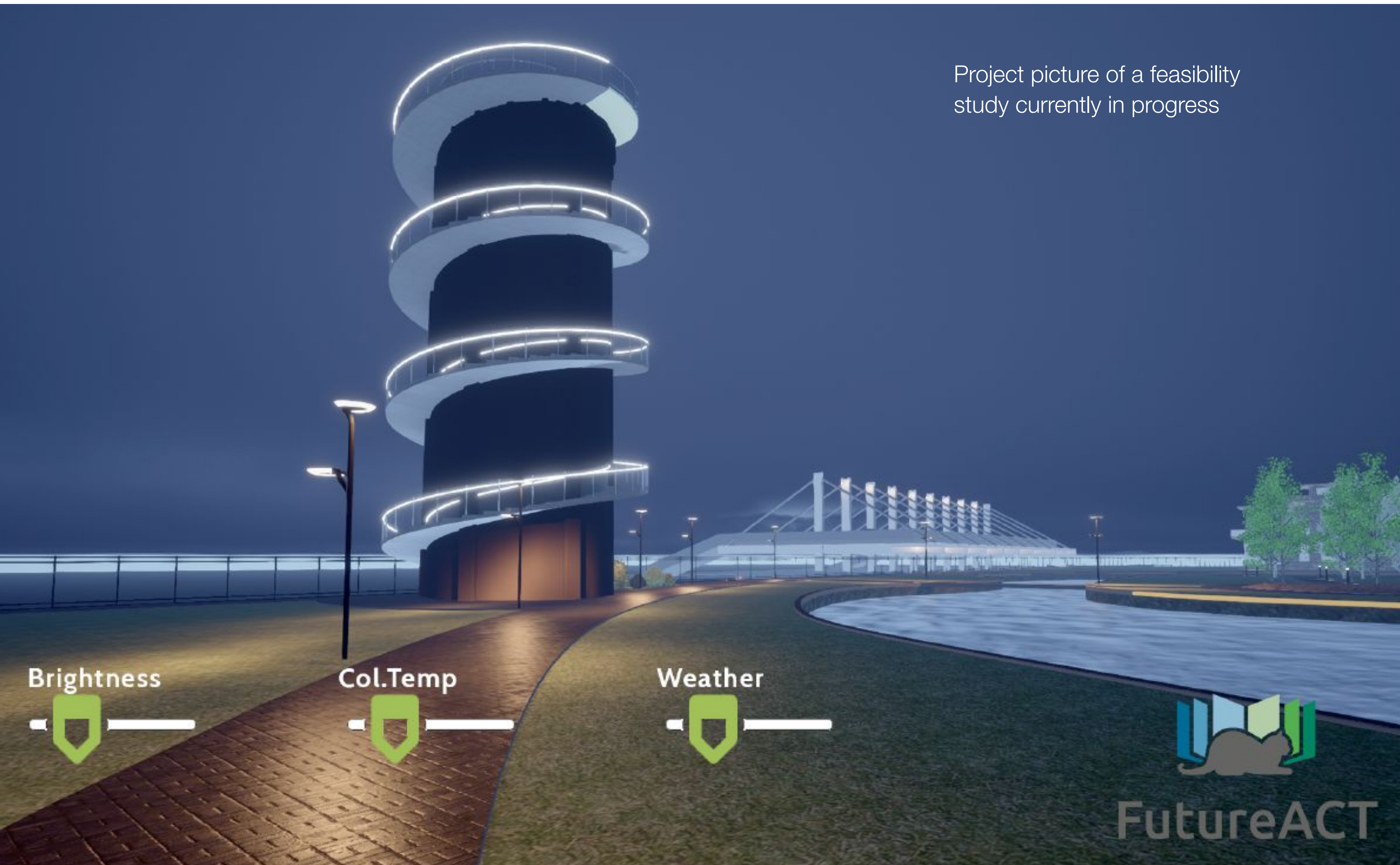
Wolfgang Bernecker is currently CEO and founder of FutureACT e.U, a management consultancy with the focus on lighting and digital solutions for the early adopter market. He combines his education as an engineer – specializing in communications engineering – with his experience in design and business. In the past he worked as lighting designer, took over a series of strategic positions in the Zumtobel Group and managed two technology museums. He founded FutureACT 2019. As a "Smart Designer" and "Project Facilitator", he is characterized by his holistic approach.



Project picture of a feasibility study currently in progress

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OCTOBER 19, 2020

DIGITAL PUBLICATION
NOVEMBER 15, 2020

PRINT PUBLICATION
DECEMBER 1, 2020

LpR 82 | Nov/Dec 2020 ENQUIRIES

mailto:info@lugerresearch.com

Imprint

LED professional Review (LpR)
ISSN 1993-890X

Publishing Company
Luger Research e.U. | © 2001-2020
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