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LpR
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Nov/Dec 2020 | Issue 82


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A Time to also Rethink Lighting

We are currently experiencing a major global challenge with the pandemic. In addition to the difficult and tragic events, there is another side that is showing itself to us - a slowdown in many areas.

This slowdown allows us to look at things in a new way, think in a new way and apply our ideas to lighting and the lighting sector. Basically, everyone will probably do it in one way or another.

If we look back on the developments of the past years and take into account the new things that are opening up, we can derive the following elements:

We need sustainable, green lighting, intelligent lighting that can be linked to digital services, lighting that accommodates new forms and minimalism, lighting that is completely attuned to people, animals and nature, and lighting that integrates daylight - completely "natural" lighting.

With this in mind, you will find several outstanding features in this issue that provide an insight into these topics from LED spectra to IoT and innovations in lighting design.

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

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

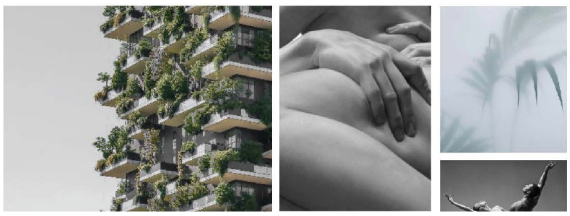
Yours Sincerely,

Siegfried Luger

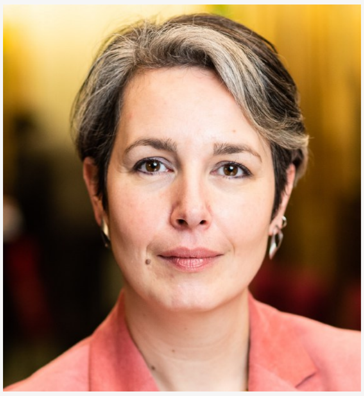
Luger Research e.U., Founder & CEO
LED professional, Trends in Lighting, LpS Digital & Global Lighting Directory
Photonics21, Member of the Board of Stakeholders
International Solid-State Lighting Alliance (ISA), Member of the Board of Advisors

Kristopher EVANS

Mains voltage, non-directional, $R_a = 90$		1,08	1,5	700	700	1,00	1,06	120	8,314	84 lm/W
Mains voltage (LED Tube G5), non-directional, $R_a = 80$		1,08	1,5	2.000	2.000	1,00	1,00	120	19,620	102 lm/W
Non-mains voltage, directional, $R_a = 95$		1,15	1,5	1.000	800	0,85	1,09	120	11,590	69 (86)* lm/W
Mains voltage (RGB, CLS), directional, $R_a = 80$		1,08	2,0	500	400	0,85	1,00	120	6,395	63 (78)* lm/W



ADVERTISING INDEX



Ourania GEORGOUTSAKU

Ourania Georgoutsakou is the Secretary General of LightingEurope, the voice of the lighting industry in Brussels. Ourania joined LightingEurope in April 2017 and is responsible for LightingEurope's strategy and impact. Her role is to represent Europe's lighting industry in the Brussels political arena, liaise with industry executives and manage the association's operations. She has over 15-years' experience of advocating for membership associations, previously working as Director of Public Policy in Europe for SEMI and as Senior Policy Coordinator with the Assembly of European Regions in Strasbourg and in Brussels.

Future Strategic Directions for the Lighting Industry

As another wave of restrictions enters into force across Europe, it's important to keep not only our chins up but also our eyes open, looking out at the next set of opportunities and challenges coming our way. 2020 has had its toll on the lighting industry also. We expect a decline in 2020, in line with the estimated EU-average decline in GDP of at least -8% (the impact will vary among countries and applications). The industry consensus is that the market will not reach its 2019 levels before the second half of 2022. Government stimulus measures to support renovation are currently being shaped and can help accelerate demand for lighting. The EU proposals set out in the Renovation Wave Initiative published mid-October aim to improve the energy efficiency of Europe's building stock – 75% of existing buildings are inefficient and achieving the EU's objectives will cost an additional € 275 Billion per year. The policy is accompanied by match funding, to be made available via EU programs, national recovery plans and private lending. LightingEurope is liaising with regulators and financers to shape renovation policies and financing tools. We recommend prioritizing non-residential buildings and the full renovation of luminaires to transition to LED systems, with mandatory minimum smartness and indoor environmental quality requirements. We also promote the uptake of UV-C disinfection technology as part of the integral design of safe and healthy indoor environments that minimise the transmission of infectious diseases.

Interest in UV-C disinfection technologies has boomed over the past months, to sustain this market potential the industry must now collaborate amongst suppliers but also with integrators and potential application customers to build market confidence and ensure existing guidelines and rules on how to source, install and use the technology are applied and adhered to.

New EU regulatory requirements will apply as of 2021 – make sure your company is prepared:

* The obligation to notify the presence in articles of substances of very high concern in the ECHA (European Chemicals Agency) SCIP database starts 5 January 2021.
* The new ecodesign and energy labelling rules apply as of 1 September 2021 and include new efficiency and quality parameters, the phase-out of certain conventional products, a new energy label and additional information requirements in EPREL.
* New component removability requirements will apply as of 1 September 2021 as a result of these new rules – the energy performance, labelling and information requirements each lighting product must satisfy will depend on whether light sources and separate control gears are removable and replaceable.

LightingEurope recently published a second version of guidelines for both laws, they outline our understanding of how the rules should be applied based on our discussions with EU and national regulators. Additional requirements on the circularity of lighting products will be shaped over the next 2 years in the EU and will drive the product design and business models. Be prepared for more around durability, preventing waste and encouraging reuse of components and of luminaires, additional information requirements and restrictions on the materials used in lighting products, to name just a few of the topics we are currently negotiating in Brussels.

The lighting industry can expect several challenges and opportunities coming our way. "Never waste a good crisis" they say. EU regulators are looking to shift the EU to a carbon-neutral circular economy and limit the continent's external dependencies. Companies can take the opportunity to adapt business models, product design and supply chain collaboration. LightingEurope will continue to offer the compliant platform for companies to exchange views on future business, technology and regulatory trends and to advocate for a positive business environment in Europe. ■

O.G.

Working inside a cave ?
SunLike
Dawn 4000K
Midday 5000K
Dusk 2700K
Intensity (normalized)
Sunlight
SUNLIKE
wavelength (nm)
Intensity (normalized)
Sunlight
SUNLIKE
wavelength (nm)
Intensity (normalized)
Sunlight
SUNLIKE
wavelength (nm)
We bring you the Sun
SEOUL

EVENTS

LpS Digital, The First Digital Lighting Conference and Exhibition – Awards and Announcements

As part of the LpS Digital Live Event, which was broadcast directly from the Festspielhaus Bregenz, the LpS Digital 2020 Awards were presented, and event announcements were published.

The LpS Digital Live Event was broadcast from the Lichtstudio at the Festspielhaus Bregenz. It was moderated by (from left to right) Siegfried Luger, Sarah Toward, and Dr. Günther Sejkora

The winner of the LpS Digital Conference Best Paper - LED professional Scientific Award 2020 is **Adria HUGUET-FERRAN**, Ph.D. Candidate, Researcher at the University of Barcelona, Spain for his paper **„Facing the Challenges of Spectral Engineering with a New Software Tool“**. This paper has been published in LED professional Review (LpR), Issue #81, Sept/Oct 2020, p58-p62 and the lecture is available on the LpS-Digital Youtube Channel `https://youtu.be/kesqTxPgbRs`.

Rationale of the Jury: The effects of spectral distribution of LED and LED systems on various parameters for light quality were examined systematically. It was shown that the quality parameters correlated weakly but it was necessary to optimize the spectral distribution in order to reach target values. A software tool was developed in order to carry out this optimization.

The winners of the LpS Digital Conference Best Paper – Trends in Lighting Design Award 2020 are **Monica Llamas and Florencia Castro**, both of MFA Lighting Design, B.A. of Architecture, New York for their paper **"The Poetics of Darkness"**. This paper has been published in LED professional Review (LpR), Issue #81, Sept/Oct 2020, p76-p81 and the lecture is available on the LpS-Digital Youtube Channel `https://youtu.be/FIdnvlgG6X8`.

Rationale of the Jury: Reflecting on cultural history, the authors came to the conclusion that light is almost always connected to positive expressions while darkness is assigned negative terms. Unfortunately, these attributes have found their way into the practice of lighting design. The authors advocate utilizing darkness creatively in the planning process and depending on the application, not only to allow for specific differences in light intensity, but to utilize them purposefully. They corroborate this thesis with practical examples.

The winners of the **LpS Digital Exhibition Best Product Awards 2020** were selected by evaluating the viewer data. The LpS 2020 product award winners are:

LpS DIGITAL AWARDS 2020

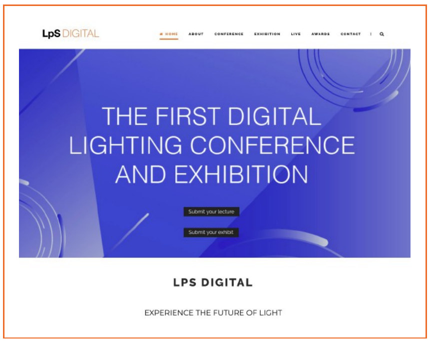
- **Bartenbach**: Personal Table Light (615)
- **Lifud**: Magnetic Integration Driver Technologies (916)
- **MKS Ophir**: Lighting Measurement Equipment (119)
- **Nichia**: 2-in-1 White LED (1471)
- **Nichia**: Light so Good – LED Portfolio (1418)
- **Samsung**: Full Spectrum Horticulture Lighting Portfolio (466)
- **Samsung**: Optimized Circadian Rhythm LED Portfolio (398)
- **Seoul Semiconductor**: New LED ERA Portfolio (580)

Luger Research e.U., the LpS organizer also announced that due to the Corona developments LpS 2021 will not take place in Bregenz.

The recorded live event, including the keynote speech by Dr. Norman Bardsley, can be viewed in full length via the web link: `https://www.led-professional-symposium.com/live`. ■

CALL FOR PAPERS

LpS Digital – Call for Papers



LpS Digital Website to sumit lectures and exhibits - `http://www.LpS-Digital.global`

LpS Digital has published the Call for Papers. You can now submit your lecture via the LpS Digital website (`www.LpS-Digital.global`).

In addition, exhibitors can also submit their contributions via (submit your exhibits). The partner and sponsor area is also open and they can already make the relevant reservations for 2021. ■

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

SIEGFRIED LUGER, LPS DIGITAL EVENT ORGANIZER

APPOINTMENTS, BUSINESS

Cree to Sell LED Business to SMART Global Holdings, Inc. for up to USD 300 Million

Cree, Inc. announced that the company has entered into a definitive agreement to sell its LED Products business unit (”Cree LED”) to SMART Global Holdings, Inc. for up to USD 300 million, including fixed upfront and deferred payments and contingent consideration. Upon closing, creates a pure-play global semiconductor powerhouse focused on providing disruptive technology solutions to high-growth segments including EV, 5G and industrial applications. Under the

terms of the agreement, which has been approved by the Company’s board of directors, Cree expects to receive an initial cash payment of USD 50 million upon closing and USD 125 million to be paid upon maturity of a seller note issued by SMART to Cree due August 2023. Cree also has the potential to receive an earn-out payment of up to USD 125 million based on the revenue and gross profit performance of Cree LED in the first full four quarters post-transaction close, also payable in the form of a three-year seller note.

”We are pleased to announce the sale of our LED Products business to SMART, which represents another key milestone in our transformational journey to create a pure-play global semiconductor powerhouse,” said Cree CEO Gregg Lowe. ”This transaction uniquely positions us with a sharpened strategic focus to lead the industry transition from silicon to silicon carbide and further strengthens our financial position, which will support continued investments to capitalize on multi-decade growth opportunities across EV, 5G and industrial applications. SMART has a strong platform and a solid track record of successfully acquiring and integrating technology businesses.”

Cree LED has one of the industry’s widest portfolios of highly efficient LED chips and high-performance LED components and represents one of the strongest brands in the industry. SMART is a global leader in specialty memory, storage and high-performance computing solutions serving the electronics industry for over 30 years. Leveraging SMART's diverse customer base and global operations, Cree LED will be well positioned to continue to deliver industry leading products.

"We are thrilled to welcome Cree LED to the SMART family," said Mark Adams, President and CEO of SMART Global Holdings. "As the leader in LED lighting technology with a highly respected brand and expansive patent portfolio, Cree has a track record of delivering best-in-class solutions and I am very excited about the opportunities that lie ahead for Cree LED as part of the SMART portfolio of products."

The transaction is subject to required regulatory approvals and satisfaction of customary closing conditions, and is targeted to close in the first calendar quarter of 2021. Following the closing of the transaction, SMART will license and incorporate the Cree LED brand name into the SMART portfolio of businesses.

In connection with the transaction, Morgan Stanley & Co. LLC is acting as financial advisor and Smith Anderson is acting as legal advisor to Cree.

About Cree: Cree (Nasdaq: CREE) is an innovator of Wolfspeed® power and radio frequency (RF) semiconductors and lighting class LEDs. Cree's Wolfspeed product families include silicon carbide materials, power-switching devices and RF devices targeted for applications such as electric vehicles, fast charging inverters, power supplies, telecom and military and aerospace. Cree's LED product families include blue and green LED chips, high-brightness LEDs and lighting-class power LEDs targeted for indoor and outdoor lighting, video displays, transportation and specialty lighting applications. - www.cree.com. ■

New CEO At Regent Lighting

On October 1, 2020, **Christoph Schüpbach** took over the operative management of Regent Beleuchtungskörper AG in Basel as the successor to Christoph Platzer. The Regent board has selected a proven leader with several years of experience in the industry as part of an international environment. Christoph Schüpbach is set to successfully develop Regent, which is already a competent international supplier of innovative lighting solutions and technologies for connected buildings. Christoph Schüpbach follows Christoph Platzer as the new Regent CEO. After over three years at the helm of the company, Christoph Platzer has decided, for family reasons, to leave Regent and return to his family in Austria, where he will focus on a new professional challenge. "We respect Christoph Platzer's wish to be closer to his family and thank him for his major efforts, the results he attained and the strategic way in which he set the course during his time as CEO at Regent. "At the same time, we are

Christoph Schüpbach

delighted by new CEO Christoph Schüpbach's appointment as his successor, given his international experience, knowledge of the industrial environment and ability to bring about the perfect conditions to ensure a company such as Regent will continue to progress", says Chairman of the Board Thomas Ernst. Under Christoph Schüpbach, Regent will continue to expand its position as a leading manufacturer of high-quality lighting products, bespoke solutions along with Connected Lighting solutions that form a significant part of the Smart Building Concept. Christoph Schüpbach joins Regent from the Schleuniger Group, which he headed as CEO for 11 years.

The Schleuniger Group is a leading provider of solutions for the cable processing and testing industry. It is part of the listed Metall Zug Group and employs around 1000 people on three continents. A graduate in mechanical engineering and holding an MBA from the University of Chicago Booth School, he previously spent six years with Bystronic as market manager for Northern Europe and then for NAFTA and Asia. Prior to this, Christoph Schüpbach worked for the ABB as head of the overvoltage protection division for ten years. ■

HUMAN CENTRIC LIGHTING

Research Project Combines Dynamic Daylight and Artificial Light for a New Quality of Light for Work Environments

A new approach to lighting design and technology is the focus of the Double Dynamic Lighting project conducted by the renowned Aalborg University in Copenhagen, supported and accompanied by several leading lighting companies. The research team led by Prof. Ellen Kathrine Hansen is exploring the combination of dynamic daylight and artificial light in a spatial context and opening up a new dimension for architects and lighting experts in supporting individual needs and different working requirements.

In a unique collaborative project, partners from the fields of lighting technology and solutions, including Tridonic, iGuzzini, Fagerhult and Zumtobel, have been working with Aalborg University for the past three years. "Rethinking Light" was the idea that inspired leading companies in the lighting industry to join forces in supporting new fundamental research into dynamic lighting by Aalborg University in Copenhagen.

The Double Dynamic Lighting (DDL) research project sets the guidelines for comfortable illumination of workplaces by combining direct and diffuse dynamic daylight and artificial light. The new approach of DDL will have a positive impact on perceived atmosphere, visual comfort, and work engagement. The results demonstrate the potential to use new sensor and lighting technologies to meet human needs. The project team produced proposals for lighting scenes based on the natural course of the daylight as well as current sky conditions. By exploring how a responsive lighting technology that reacts to and complements daylight inflow can reconnect man and nature, the findings can help to form a more holistic design approach in the future.

The DDL results (top left to bottom left) from the Aalborg University (bottom right) show an impact on perceived atmosphere, visual comfort, and work engagement compared to static lighting

The project is examining the spatial conditions in a dynamic lighting environment and their influence on the well-being of users. Practical design guidelines are being developed, tested and implemented in a series of investigations. This work is being conducted in existing working environments with dynamic light, in lighting laboratories at Aalborg University and in interactive, three-dimensional computer models.

The results of the field study demonstrate that it is possible to define dynamic light settings in response to the dynamics of daylight through a combination of direct and diffuse lighting. DDL was validated to have a positive impact on perceived atmosphere, visual comfort, and work engagement compared to static lighting. In general, it was confirmed that the combination of directional task lighting and diffuse ambient lighting in response to sky types and measured daylight levels in the workspace was preferred to standard static diffuse lighting.

An analysis of responses from interviewees reveals a large difference in perceived visual comfort between dynamic and static lighting periods, indicating that working with light zones and with direct and diffuse lighting components and uneven light distribution enable a high level of visual comfort to be achieved. The industry partners added their practical application knowledge and worked hand in hand with the university.

Prof. Ellen Kathrine Hansen, Head of Lighting Design in the Department of Architecture, Design & Media Technology, has this to say about the study: "The aim of the study is to apply an innovative mix of methods to create a holistic approach to lighting planning which can then function as a seal of quality in the lighting industry. A combination of biological, aesthetic and functional aspects will form the basis for the design process."

Statements from the participating companies:

Karin Zumtobel-Chammah, Chairwoman Supervisory Board, Zumtobel Group AG
A fundamental element of our DNA is our desire to improve health and well-being by providing the best possible light for both people and the environment and by customising lighting solutions to the different areas of application. And of course, our research and development projects constantly aim to achieve these improvements. We identified a great overlap between our research topics and the DDL project so we were convinced that the findings of this research on combining daylight and dynamic lighting technology would contribute to better health and well-being, and would help us understand certain topics much better. Working on a major project with different partners always augments the quality and relevance of the results. The set-up of this project was especially interesting, because some of the partners are actually our competitors. But since all of us were purely interested in investigating how the combination of daylight and dynamic lighting can contribute to better health and well-being, we were able to join forces and drive industry knowledge forwards.

Henrik Clausen, Director of Fagerhult Lighting Academy
For us it's also about knowledge. It is a challenge to enhance our general lighting knowledge. We need to do that in order to take advantage of all the possibilities for health and well-being that lighting can give us. We need to educate to create better awareness of how daylight and electric light function together. To get a handle on how to combine the dynamics of daylight and the dynamics of electrical light in the same installation. That's the basis of Double Dynamic Lighting. We need to spread this knowledge of how to

combine daylight and electric light among lighting professionals in terms of design, planning, application and sales. We have been working with Aalborg University on the research side of the DDL project because everything we do in product development and in sales is geared to bringing evidence-based lighting solutions to the market. Now we are preparing to bring knowledge to our partners, our staff and students in order to give them all a competitive advantage in the (still static) lighting market.

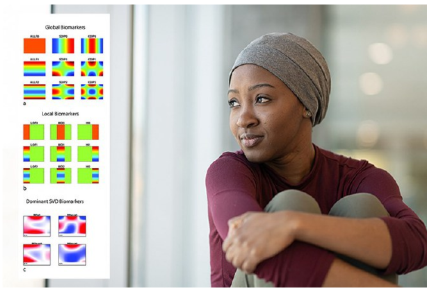
Peter Roos, Product & Project Solutions Director, iGuzzini
iGuzzini has always considered light as a tool for social innovation that can improve people's lives and well-being at every moment of every day. That is why our vision is 'Social Innovation through Lighting' and the reason why we have been conducting research on biodynamic light together with leading universities and institutes worldwide since 1988. The idea of the DDL research is to find new lighting design guidelines for workspace lighting which will improve the well-being of end users. So in the first instance it will be "all of us" living and working in spaces illuminated by applied DDL design guidelines who will benefit from the DDL research findings. We at iGuzzini believe that the lighting design community together with architects and lighting professionals will embrace the idea of Double Dynamic Lighting to create beautiful spaces we'll love to live in.

Hugo Rohner, CEO Tridonic
As a technology company of the lighting industry, Tridonic enables new solutions for customers and partners. DDL is a wonderful new challenge for us. We are transferring this fundamental research into solutions for our business partners. The first installation, which was set up at Aalborg University, is a great model for us and we are continually integrating the research in our installation at our headquarters and enabling our partners to have a DDL installation at their locations. In this way, we can learn more and continually develop the technology which is needed to implement DDL. We are sure that DDL will pave the way to lighting solutions which will provide individual answers to human needs and requirements. ■

LED Technology Shines the Light on Ovarian Cancer Treatment

Scientists estimate that nearly 60% of all cancer patients do not respond effectively to chemotherapy treatments. Even worse – many of those same patients experience toxic and sometimes deadly side effects. Now, a Purdue University scientist and entrepreneur is working to use simple LED light to help determine if certain chemotherapy options will work for specific patients.

"We are using a technique very similar to doppler radar used in weather to advance personalized medicine," said David Nolte, the Edward M. Purcell Distinguished Professor of Physics and Astronomy in Purdue's College of Science. "We take the LED light and shine it on biopsies. We then apply chemotherapy to the biopsies and analyze how the light scatters off the tissues." Nolte, who also is a member



Simple LED light helps to determine if certain chemotherapy options will work for specific patients. (Stock photo). Inset: Time-frequency biomarker masks

of the Purdue University Center for Cancer Research, said the light scattering dynamics give scientists and doctors detailed information about the likelihood of a chemotherapy drug being effective for a patient. Nolte said they have results within 24 hours. This first trial looked at biodynamic imaging on human patients with ovarian cancer.

"We look for signs of apoptosis, or what we call the controlled death of cells," Nolte said. "Apoptosis is the signal that indicates the effectiveness of the chemotherapy for this patient's tissues and tumors. For some cancers, there are so many treatment options available that it's like a doctor is trying to fit square pegs in circular holes until a desired outcome is found. We want to make this process better for patients."

Nolte has worked with several groups within the Purdue entrepreneurial and commercialization ecosystem, including the Purdue Foundry, on business plan development and management searches. AniDyn, a medical technology startup, was spun out of Purdue by professors Nolte and John J. Turek. AniDyn is focused on the development and commercialization of live-tissue imaging platform technologies.

Nolte also works closely with the Purdue Research Foundation Office of Technology Commercialization to patent and license his technologies.

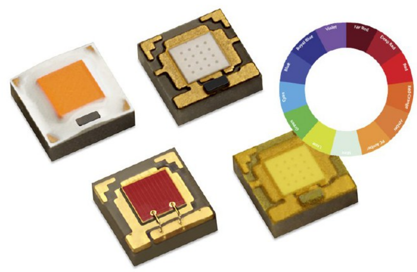
Abstract of the original paper:
"Intracellular optical doppler phenotypes of chemosensitivity in human epithelial ovarian cancer" Zhe Li, Ran An, Wendy M. Swetzig, Margaux Kanis, Nkechiyere Nwani, John Turek, Daniela Matei and David Nolte (nolte@purdue.edu)

Development of an assay to predict response to chemotherapy has remained an elusive goal in cancer research. We report a phenotypic chemosensitivity assay for epithelial ovarian cancer based on Doppler spectroscopy of infrared light scattered from intracellular motions in living three-dimensional tumor biopsy tissue measured in vitro. The study analyzed biospecimens from 20 human patients with epithelial ovarian cancer. Matched primary and metastatic tumor tissues were collected for 3 patients, and an additional 3 patients provided only metastatic tissues. Doppler fluctuation spectra were obtained using full-field optical coherence tomography through off-axis digital holography. Frequencies in the range from 10 mHz to 10 Hz are sensitive to changes in intracellular dynamics caused by platinum-based chemotherapy. Metastatic tumor tissues were found to display a biodynamic phenotype that was similar to primary tissue from patients who had poor clinical outcomes. The biodynamic phenotypic profile correctly classified 90% [88–91% c.i.] of the patients when the metastatic samples were characterized as having a chemoresistant phenotype. This work suggests that Doppler profiling of tissue response to chemotherapy has the potential to predict patient clinical outcomes based on primary, but not metastatic, tumor tissue. ■

SOLID STATE LIGHTING

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

Lumileds announced breakthrough flux delivery from the PC Amber, Lime and Royal Blue emitters in its LUXEON C and CZ Color Lines, the lighting industry's broadest lines of color LEDs. The incredible 17% leap in flux of PC Amber in LUXEON C LEDs supports more efficient, safer, and easier to design lighting for first-responder vehicles, tow trucks and construction vehicles.



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

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

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

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

LP LIEW, PRODUCT MARKETING MANAGER AT LUMILEDS

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

For more information on the LUXEON C Color Line, see `https://lumileds.com/products/color-leds/luxeon-c-colors/` and on the LUXEON CZ Color Line see `https://www.lumileds.com/products/color-leds/luxeon-cz-color-line/`

About Lumileds: For automotive, mobile, IoT and illumination companies who require innovative lighting solutions, Lumileds is a global leader employing more than 7,000 team members operating in over 30 countries. Lumileds partners with its customers to push the boundaries of light. ■

Research Shows that Streetlights Contribute Less to Nighttime Light Emissions in Cities than Expected

When satellites take pictures of Earth at night, how much of the light that they see comes from streetlights? A team of scientists from Germany, the USA, and Ireland have answered this question for the first time using the example of the U.S. city of Tucson, thanks to "smart city" lighting technology that allows cities to dim their lights. The result: only around 20 percent of the light in the satellite images of Tucson comes from streetlights.

The team conducted an experiment by changing the brightness of streetlights in the city of Tucson, Arizona, USA, and observing how this changed how bright the city appeared from space. Dr. Christopher Kyba from the GFZ German Research Centre for Geosciences led the team that conducted the experiment, and said the work is important because it shows that smart city technologies can be used to perform city-scale experiments. "When sensors and control systems are installed throughout an entire city, it is possible to make a change in how the city works, and then measure the impact that change has on the environment, even from outer space," Kyba said.

Smart City Lighting in Tucson: View of a street in Tucson with the lights set to 30 and 90 percent illumination

Over 10 days in March and April of 2019, Tucson officials changed the brightness settings for about 14,000 of the city's 19,500 streetlights. Usually, most streetlights in Tucson start out at 90 per cent of their maximum possible illumination, and dim to 60 per cent at midnight. During the experiment, the city instead dimmed lights all the way down to 30 per cent on some nights, and brightened them up to 100 per cent on others. The city lights were observed by the US-operated Suomi National Polar-orbiting Partnership (NPP) satellite, which is famous for its global maps of light at night. The satellite took cloud-free images of Tucson on four nights during the test, and on two other nights with regular lighting after the test. By comparing the city brightness on the 6 different nights, the researchers found that on a normal night, only about 20 per cent of the light in satellite images of Tucson comes from streetlights.

The results have important implications for sustainability, according to study co-author Dr. John Barentine from the International Dark-Sky Association. In a second experiment conducted at the same time, Barentine, Kyba and their co-authors measured the sky brightness over Tucson from the ground. They examined how varying the illuminance of street lamps affected the sky brightness, and showed that as with light emissions seen from space, most of the sky brightness over Tucson is also due to other sources. "Taken together, these studies show that in a city with well-designed streetlights, most of the light emissions and light pollution come from other lights," Barentine explains, including light sources such as bright shop windows, lit signs and facades, or sport fields. The authors say that local and national governments therefore need to think about more than just street lighting when trying to reduce light pollution.

According to the researchers, the difference in the streetlighting brightness on the different nights is barely perceptible to the people on the street, as our eyes quickly adapt to the light levels. They report that the city received no comments or complaints about the changed lighting during the test. There is also no evidence or suggestion that reducing lighting levels as part of the experiment had any adverse effect on public safety.

Kyba is therefore excited by the idea of performing such experiments more regularly, and in other municipalities. "Instead of dimming lights to the same level late each night, a city could instead dim to 45% on even days and 55% on odd days," Kyba suggested. "City residents wouldn't notice any difference, but that way we could measure how the contribution of different light types is changing over time." ■

SMART & IOT

DALI Alliance Unveils New Name and Logo

The Digital Illumination Interface Alliance (DiiA) announces that it will now use the brand name "DALI Alliance" to promote its ongoing activities that support market adoption of DALI lighting-control technologies, systems and products.

DALI® Alliance

"Our organization has not changed, but the new DALI Alliance name clearly aligns with our core purpose. We are an open, global consortium of lighting companies, and we are focused on promoting the use of DALI as the predominant international standard for digital lighting control."

PAUL DROSIHN, GENERAL MANAGER OF THE DALI ALLIANCE

To further build market recognition, the DALI Alliance will start to use a new logo based on the long-established and well-known DALI logo. DiiA will continue to exist, providing the member-focused administrative structure that supports the public-facing activities of the DALI Alliance. DiiA is a Partner Program of IEEE-ISTO. Please contact the DALI Alliance if you have any questions about this change. ■

D4i Sensors and Controllers for Smart, IoT-ready Luminaires

The DALI Alliance (DiiA) is now offering D4i certification of DALI-based control devices that are designed for mounting on LED luminaires. Eligible devices include light-level or occupancy sensors, as well as control nodes that can communicate wirelessly with external networks.

The DALI Alliance (DiiA) is now offering D4i certification of DALI-based control devices that are designed for mounting on LED luminaires

D4i is the DALI standard for intelligent, IoT-ready luminaires. By taking care of control and power requirements, D4i makes it much easier to mount sensors and communication devices on luminaires. In addition, intelligent D4i LED drivers inside the luminaire have the capability to store and report a wide range of luminaire, energy and diagnostics data in a standardized format.

D4i standardization also enables luminaires to make use of socketed connector systems, providing plug-and-play interoperability and future proofing. The DALI Alliance has worked with the Zhaga Consortium to standardize the D4i-based connector systems defined in Zhaga Book 18 (for outdoor luminaires) and Book 20 (indoor).

The joint Zhaga-D4i certification program has already qualified a number of D4i luminaires with Zhaga receptacles. Now, qualified D4i sensors and controllers with Zhaga connectors will also be eligible for Zhaga-D4i certification.

Specifications

The requirements for luminaire-mounted control devices are defined in the DALI Part 351 specification, created by the DALI Alliance, which builds on the IEC 62386 international standard. Qualifying D4i control devices implement Part 351 as well as meeting the requirements for DALI-2 certification.

Part 351 defines four different classes of control device (types A-D), and includes specific requirements for power consumption. There is also a mechanism to decide which control device takes priority when more than one is present. These types cover both indoor and outdoor applications, and include devices such as wireless network lighting controllers (NLCs), photocells (light sensors), movement sensors and timers.

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

"Certification of D4i sensors and controllers is a significant milestone for our members and their customers. The availability of qualified D4i control devices, alongside the many D4i drivers already available from numerous suppliers, brings further standardization to the market and simplifies the specification process."

PAUL DROSIHN, GENERAL MANAGER OF THE DALI ALLIANCE

More information can be found in the Part 351 specification, which is freely available on the DALI Alliance website here: www.dali2.org/specifications/download.html. D4i certification is open to all DALI Alliance members, and all D4i-certified products are listed in our online product database: www.dali2.org/products.

About the DALI Alliance

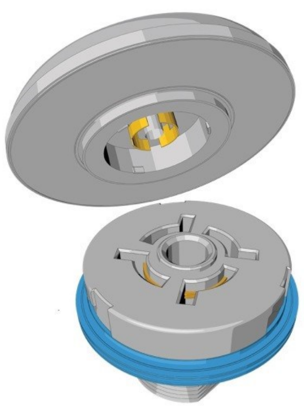
The DALI Alliance (also known as the Digital Illumination Interface Alliance or DiiA) is an open, global consortium of lighting companies spearheading growth of lighting-control solutions based on Digital Addressable Lighting Interface (DALI) technology. The organization is driving the adoption of DALI-2, the latest version of the internationally-standardized DALI protocol, and operates the DALI-2 and D4i certification programs to boost levels of cross-vendor interoperability. The DALI Alliance develops test specifications for product compliance testing, and also creates new requirements for additional product features and functions. ■

More information: www.dali-alliance.org

Zhaga's Book 18 Takes the Next Step Forward

Zhaga is planning a 3rd edition of the popular Book 18 specification for outdoor luminaires, that will allow for architectures combining an ANSI C136.41 dimming receptacle with a Zhaga receptacle. Book 18 Ed. 3.0 will enable Zhaga-D4i certification of hybrid luminaires as well as control devices with an ANSI interface in addition to the certifications already offered by Book 18 Ed. 2.0.

Zhaga introduced Book 18 Ed. 2.0 in November 2019 with the aim to create an interoperable system of an outdoor luminaire and sensing/communication modules, by defining the mechanical interface, the communication protocol and allowable power budgets. Book 18 Ed. 2.0 is based on a liaison between the Zhaga Consortium and the Digital Illumination Interface Alliance, the owners of the DALI-2 lighting protocol. Certified products can bear the Zhaga-D4i logo.



Zhaga will update the popular Book 18 interface specification to Ed. 3.0 enabling dimmable Zhaga-D4i certification of hybrid luminaires as well as control devices with an ANSI interface

The solution is not only designed to allow devices from different manufacturers to connect to luminaires from different manufacturers, but also to simplify the specification process. Specifiers, from a municipality or a utility, now only need to specify luminaires and control devices that are Zhaga-D4i certified and marked to know they will operate together.

While multiple manufacturers offer Zhaga-D4i certified luminaires and tender specifications are appearing that request such products, Zhaga is observing additional market needs for hybrid luminaires that have both the "Zhaga connector" and an "ANSI receptacle". These hybrid luminaires enable use cases that require the energy metering in a device to be calibrated on a regular basis, a process not supported in the current Book 18 Ed. 2.0, and devices that need more power than currently available through Book 18 Ed. 2.0. The hybrid solution also better fits established control practices in some regions. The hybrid solution still offers the sensing use cases based on the Zhaga socket, that can also be positioned underneath a luminaire, and maintains the interoperability promise of Zhaga Book 18 Ed. 2.0.

Zhaga sees Book 18 and the liaison with the DiiA as enabling smart cities by creating a platform that connects luminaires, drivers, control & communication devices and sensor input nodes. If you will; becoming the backbone of the smart city. Adding the ANSI interface gives this ecosystem further flexibility, allowing designers and specifiers options that will best suit their region of world and local compliance needs.

About Zhaga:
Zhaga is a global association of lighting companies that is standardizing interfaces of components of LED luminaires, including LED light engines, LED modules, LED arrays, holders, electronic control gear (LED drivers), connectors and sensor and/or wireless communication modules. This helps to streamline the LED lighting supply chain, and to simplify LED luminaire design and manufacturing. Zhaga continues to develop specifications based on the inter-related themes of interoperable components, smart and connected lighting, and serviceable luminaires. ■

More information: `www.zhagastandard.org`

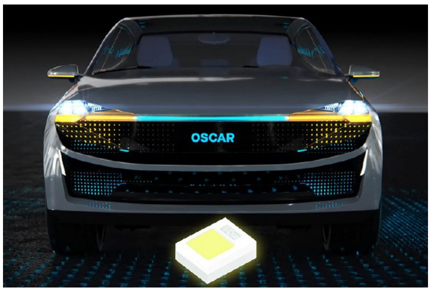
AUTOMOTIVE

New Generation of Osram LEDs Ensures Greater Safety when Driving

In a few years, LEDs will be the predominant light source in car headlights. Their compactness and energy efficiency in particular are major advantages over conventional technologies. LEDs also make it easy to achieve the brightness values required by today's manufacturers. Osram Opto Semiconductors is constantly working to further optimize high-quality LED solutions for the automotive sector. With significant leaps in performance in the Oslon Black Flat and Oslon Compact product families, the company shows where developments are headed in the coming years, and what other benefits headlight manufacturers can expect. The products are designed for use in high and low beam solutions.

In recent years, technological advances have contributed to the increasing popularity of LED-based headlamp solutions. The advantages of light-emitting diodes are obvious: thanks to their compact dimensions, they allow enormous freedom in design and achieve outstanding brightness values. Now LED manufacturers are looking to improve the already very high level of quality, in terms of brightness, energy efficiency and thermal performance.

Osram Opto Semiconductors is launching a new generation of 1 to 4-chip versions in the Oslon Compact PL product family. Like their predecessors, the ceramic components have an electrically insulated pad that makes it much easier to dissipate heat from the package. As a result, a higher current is possible, which allows the 1-chip version to achieve an outstanding brightness value of 395 lumens at 1 A with a chip area of 1mm². Thanks to the very small dimensions of 1.9x1.5x0.73 mm, the product is ideal for ADB (Adaptive Driving Beam) systems and in extremely space-saving system designs.



The successor generation of the Oslon Compact PL and new versions of the Oslon Black Flat S will increase market penetration of LEDs in headlights even further

In addition, the Oslon Black Flat S family expands to include a 1 and a 2-chip version. The special lead-frame-based components feature highest contrast values (>1:200) and very low thermal resistance – which allows for higher currents. The 1-chip variant reaches 395 lm at 1 A. The square lighting surface of the UX:3 chip makes optical design particularly easy for headlight manufacturers. The different technology concepts of the Oslon Black Flat S and Oslon Compact PL enable customers to choose the best possible combination of LED and PCB for their systems. Due to the product family's outstanding efficiency values of up to 130lm/W at 1A, headlights with smaller or even without heatsinks are conceivable in the future – leading to a potential reduction in system costs.

"LEDs such as the Oslon Compact PL and the Oslon Black Flat S will lead to an increasingly high penetration rate in vehicles, including small and mid-sized cars," explains Florian Fink, Marketing Manager Automotive Exterior at Osram Opto Semiconductors. "We always work in close cooperation with our customers to constantly improve our established product families and to push the limits of achievable brightness values even further in future".

The package dimensions remain the same in the new product generations of the Oslon Compact PL and Oslon Black Flat S, which allows headlamp manufacturers to easily exchange the products. ■

Nexperia Launches Industry-First LED Drivers in DFN Package with Side-Wettable Flanks

Nexperia, the expert in essential semiconductors, announced a new range of LED drivers in the space-saving DFN2020D-6 (SOT1118D) package. This case style features side-wettable flanks (SWF) which facilitate the use of AOI (automated optical inspection), and improve reliability. This is the first time LED drivers have been available in this beneficial package. The new leadless devices join Nexperia's wide range of LED drivers in leaded packages offering equivalent performance yet reducing PCB space by up to 90% compared to SOT223.

With a footprint of just 2x2 mm and a low profile of 0.65 mm, the new DFN2020D-6 LED drivers are available in NPN and PNP technology. They feature an output current of up to 250 mA (NCR32x types) and a maximum supply voltage of 75 V. Their high thermal power capability is at least equal to any other package for LED drivers.

The use of side-wettable flanks not only enables AOI techniques to be used - which is especially important for automotive customers – but also improves reliability. Devices with side-wettable flanks exhibit a greater resistance to shear forces, and can handle greater board flexing without cracking than devices without side-wettable flanks.

Nexperia's AEC-Q101-qualified DFN2020D-6 devices save up to 90% PCB space. The side-wettable flanks enable automated inspection (AOI) and improve reliability

Commented Frank Matschullat, product group manager at Nexperia: "The new DFN2020D-packaged parts with SWF address the concerns of various sectors – size, performance, ruggedness – so they are a perfect match for many diverse applications in general lighting, white goods and automotive. Nexperia is committed to deliver industry's broadest discrete portfolio in DFN technology, so introducing LED drivers in this rugged, space-saving package is a natural step. However, parts are also available in leaded SMD styles so customers can choose which to use." ■

UV LIGHT

Higher-Performance UV-C Solutions from Lumitronix Feature Nichia's New NCSU334B UVC LED

Following the successful introduction of the first UVC LED modules in August 2020, LED expert Lumitronix from Hechingen is expanding the existing concept of linear module solutions with three new, more powerful versions. These are as well mainly addressed to professional customers who are trained in handling UV-C radiation and can ensure a risk-free application.

Lumitronix's latest UV-C linear module solutions offer additional power and are built on high quality components from Nichia and LEDiL

In addition to the special linear UV-C optics Violet from LEDiL, which is used in two module versions, the Baden-Württemberg company relied on the latest UVC LED NCSU334B from Japanese LED manufacturer Nichia in the development of its products. The efficient UV LED emits a wavelength of 280 nm and is characterised by a high optical output of 70 mW at 350 mA. With twelve of these light-emitting diodes, which are installed on the modules from Lumitronix, a total optical output of up to 1176 mW can be achieved depending on the power supply. Compared to the modules with Seoul Viosys LEDs, this results in a four times faster disinfection performance and thus an extremely efficient neutralisation of germs, bacteria and viruses.

The first module variant is a ready-to-use all-in-one solution and is operated with constant voltage (48 V). The board, which is equipped with twelve Nichia NCSU334B UV-C LEDs and three signal LEDs (red, green, blue), is located in a robust aluminium housing that is very easy to install with screws. The violet optic is built into the cover. In addition, the aluminium case accommodates the PowerController V2, a compact control unit that enables a safe operation of the module.

Since UV radiation - especially in the UVC wavelength range used - has an extremely destructive effect on organic tissue and many inorganic materials, contact with living organisms should be avoided and, in the case of objects, limited to as short a period as possible. Lumitronix has addressed this problem and developed a concept for the safe operation of the LED module.

A combination of button, switch, motion sensor (still to be connected separately) and the three signal LEDs ensures that there are no people in the room where sterilization is to be performed. The UVC module can only be activated via the switch when the motion sensor registers no more movement after 10 seconds, the button is activated by closing the door and all safety conditions are fulfilled by a green signal LED.

The second module version also includes a circuit board with 12 NCSU334B LEDs and three control diodes as well as a cover with the rod lens of LEDiL. An external control unit can be easily connected. The constant current module (1050 mA) is primarily aimed at the processing industry, such as manufacturers of special luminaires or medical technology companies.

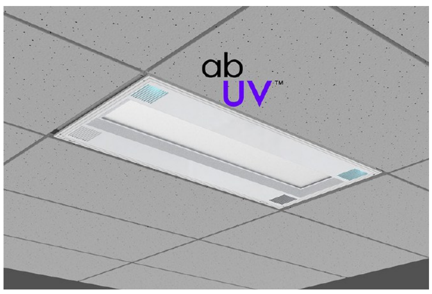
Last but not least, a third version is available in the form of an aluminium circuit board, which is equipped in the same way as the versions with housing. In this case, the optics have been omitted, but are available separately. Again, 1050 mA constant current is required for operation.

In addition to the three conceived solutions, Lumitronix also offers individual adaptations in terms of design and control. Ready-to-use complete solutions, which are tailored to the customer's requirements, are available on request. The expert knowledge of the Swabian LED company is aimed at the entire industry. Current projects include the fields of medicine, mechanical engineering and consumer end products. Nichia's new NCSU334B LEDs extend the range of applications for UVC LED technology, as the high output of the LEDs enables disinfection of larger areas or rooms within a very short period of time.

About Lumitronix: Lumitronix has been one of the leading specialists for LEDs and LED products for many years. As a competent partner for the industry, Lumitronix possesses broad application knowledge from numerous sectors. In 2012 Lumitronix has started to distribute the UV LEDs of the world market leader Nichia. At the same time the first customer-specific LED assemblies for UVA applications were produced. Since 2018, Lumitronix has been working intensively on the application possibilities of UVC LED technology, in particular on targeted disinfection with UVC radiation. In 2020 the first standard modules with UVC LEDs are produced in series and furthermore individual customer requirements are realised. The Swabian company, based in Hechingen, Germany, has ISO 9001 certification and is also the official distributor of market-leading manufacturers of LED technology. Lumitronix is not only involved in the distribution of LED products, but also develops and manufactures in-house according to customer-specific requirements. Two ultra-modern production lines with the latest machine technology allow the assembly of both rigid and flexible PCBs. A special feature of the flex production is the reel-to-reel processing, with which almost endless lengths can be realized. The production site in Hechingen furthermore provides the benefit of being able to respond quickly and reliably to individual customer wishes and requirements. Quality Made in Germany. ■

Energy Focus Launches Advanced UV-C Disinfection Product Portfolio Offering Airborne and Surface Disinfection Solutions

Energy Focus, a leader in sustainable LED lighting and human-centric lighting ("HCL") technologies, launched a portfolio of germicidal UV-C Disinfection ("UVCD") products, with advanced, patent-pending technologies designed to destroy 99.9+ percent of various pathogens, including influenza and coronaviruses such as SARS and SARS-CoV-2, in the air or on surfaces to improve indoor hygiene and sanitation. Three initial products – nUVo™, abUV™, and mUVe™ – complement each other to meet the needs of air and surface disinfection for commercial, industrial and residential indoor environments. The products are available for pre-order on the Company's e-commerce website, through its internal salesforce and distribution channel partners, and deliveries are expected to start during the first quarter of 2021.



One of the three Initial Products is an UV-C Air Disinfection Troffer Powered by the EnFocus™ Lighting Control Platform, the abUV™

Leveraging and integrating a broad range of rapidly advancing technologies - including LED lighting, UV lighting, electronics, software, sensors, cloud and AI - the Energy Focus UVCD solutions aim to provide impactful and affordable disinfection products for businesses and homes to effectively reduce infection risks. In addition to being ozone-free, the products are designed to guard against the risks of direct human exposure to UV-C rays. abUVTM and nUVoTM include enclosed, self-contained UV-C disinfection units that continuously inactivate viruses while reducing overall pathogen levels in the air. mUVeTM incorporates advanced sensor, machine vision and autonomous technologies to avoid human exposure during disinfection operations.

The core germicidal far ultraviolet (UV-C) lighting spectrum used in Energy Focus' new products, at 254 nanometers (nm) wavelength, has been scientifically proven to be effective for inactivating pathogens by breaking the DNA and RNA bonds in cells of certain bacteria, fungi, mold and viruses, making them incapable of duplicating. Other longer wavelength UV spectrums, such as UV-A and UV-B, are unable to directly inactivate viruses. And unlike other disinfectants that are composed of irritating and environmentally harmful chemicals, UV-C disinfection produces no harmful byproducts or environmental waste. In addition, while chemical disinfectants require extensive, expensive and unreliable manual deployment, we believe Energy Focus UVCD solutions are capable of providing affordable continuous disinfection with optimal effectiveness and safety.

James Tu, Chairman and CEO of Energy Focus said, "We are extremely pleased and proud to launch this groundbreaking portfolio of UV-C disinfection products as a comprehensive solution to help elevate hygiene and sanitation levels of buildings and homes. As the world faces the near universal presence of coronavirus today and recognizes the clear risks of other pathogens and pandemics in the future, indoor environmental safety has become an unprecedented priority and will outlive the current pandemic. We believe that these latest UVCD products - as part of our Human-Centric Lighting portfolio - can provide powerful, affordable and immediate solutions to help people return to common spaces for optimal social interactions and economic activities."

"The benefits of HCL, which aims to bring positive impacts to human health and wellbeing, range from improving productivity at work and the quality of sleep, to the hygiene of our spaces and the quality of the air that we breathe. This UVCD product portfolio perfectly aligns with our mission to enlighten and inspire for better living, and expands the "triple bottom line" benefits that we offer our customers - human health, environmental sustainability, and financial impacts - through advanced lighting technologies. In addition, as the awareness of air and surface disinfection turns permanent and the demand for UVCD expands from hospital operating rooms to everyday lives, Energy Focus' leading, long-term track record in quality, performance and safety, substantiated by our installations in mission critical facilities ranging from the US Navy and National Institute of Health to many other leading healthcare, education and commercial organizations, brings the quality and credibility necessary for quicker and wider adoption of UVCD products worldwide," continued Mr. Tu.

"We are equally proud of and grateful for the ingenious, diligent and collaborative work from our engineering and product development teams as well as our global technology and supply chain partners. Members of our whole product development ecosystem were able to pivot and crosspollinate seamlessly and tirelessly during the pandemic to invent, design, prototype and complete the development of these impactful products in an extremely timely manner. Now we look forward to rapidly and vastly expanding the reach of these UVCD solutions through our growing list of channel partners to meet the heightened and urgent disinfection needs of building owners and operators, as well as residential consumers."

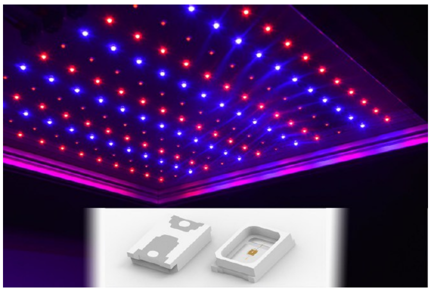
These products, which are now available for pre-order on /uvcd.energyfocus.com/ are expected to start deliveries in first quarter 2021 and shipments will be based on the timing and queue of the pre-orders. More information, including spec sheets for each of the products, is available at the above link. ■

HORTICULTURE

Würth Elektronik's Power-Saving WL-SMTW: Colors for Feeding Plants

SMT mountable LEDs in a 2835 package extend Würth Elektronik extensive range of horticulture LEDs. The three WL-SMTW series LEDs emit light of the wavelengths 450 nm (Deep Blue), 660 nm (Hyper Red) and 730 nm (Far Red) – ideal for applications controlling plant growth through specific light mixtures. Besides vertical farming and lighting in greenhouses, thanks to their efficiency, small size and minimal heat generation the WL-SMTWs, combined with the manufacturer's other LEDs are also suitable for classic LED applications like displays and backlighting.

A photosynthetic photon flux of up to 0.94 µmol/s at a current of just 150 mA, and the small size (2.8x3.5x0.8 mm) mean you don't even need three mid-power LEDs to replace a high-power LED. This allows larger-scale and more homogeneous lighting applications to be realized. With its Development Kit, Würth Elektronik is there for the developers of horticultural lighting solutions, to whom the WL-SMTW product is particularly directed. In the REDEXPERT online simulation platform there is a "Horticulator" in which lighting recipes can be created (https://redexpert.we-online.com/redexpert/#/smodule/26). All Würth Elektronik LEDs are available from stock. Free LED samples are provided.



A photon flux of up to 0.94 µmol/s at a current of just 150 mA from Würth's new WL-SMTW series LEDs allows larger-scale and more homogeneous lighting applications to be realized

Cooperation with research institutions

"Our new LED series offers excellent value for money and high luminosity – the Deep Blue LED is unique on the market in this respect," Harun Özgür, Division Manager, Optoelectronics at Würth Elektronik eiSos GmbH & Co. KG expresses his satisfaction about the new addition to horticulture LED range (http://www.we-online.com/leditgrow). Johann Waldherr, agricultural scientist in Würth Elektronik's LED team, explains: "The blue light plays a role in many plant processes, such as the formation of secondary metabolites. The illumination with spectra individually created from the different wavelengths of monochromatic LEDs becomes even more efficient with the new mid-power LEDs, yet at the same time more homogeneous. These three LEDs form a basic framework in combination with other LEDs of the WL-SMTW, WL-SWTP and WL-SMDC series, so it is possible to create specific lighting recipes for a wide range of the horticulturist's quality parameters, such as more blossoms, more fruit, more biomass, more vitamins, and so on. As our partners' innovation partner, we conduct intensive research and we have established a competence network with research institutions, sharing our knowledge with our customers.

For example, Würth Elektronik maintains research cooperations with the Dürnast Greenhouse Laboratory Center at the Technical University of Munich along with other research institutions. ■

TECHNICAL REGULATORY COMPLIANCE UPDATE

Segment	Product	Standard (Certification)	Region	Technical Regulatory Compliance Information
Safety	Luminaires	IEC 60598-1:2020	Europe/World	IEC 60598-1:2020 is a technical revision of IEC 60598:2014 A1:2017 due to the quick changing technologies and is introducing new or revised requirements like: EMF, POE, PELV, IPx9, UV protection of cable, constant light output function and programmable current output, alternative DC electric strength test, briging capacitors, touch current for interupted DC, mains inlet related to IEC 61984, electrical connection to class III plugs, fixation of cover for access to life parts, thermal test approach etc.
EMC	Equipment for general lighting purposes	IEC 61547 edition 3.0: 2020-03	Europe/World	IEC 61547 edition 3.0 was published in March 2020. This third edition cancels and replaces the 2nd edition, published in 2009. This edition constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition: a) extension of scope with end-user replaceable modules and the combination of end-user replaceable module and independent auxiliary; b) clarification of module testing in a host system; c) increased ESD and surge test levels for road and street lighting equipment; d) the introduction of ESD testing under normal operation and handling conditions; e) removal of line to ground surge test for self-ballasted lamps $\leq$ 25 W.
Safety	Semi integrated OLED	IEC 62868-2-1:2020	Europe/World	This standard sets the specific safety requirements for semi-integrated OLED products using the IEC 62868-1 as basis for the safety requirements. It is for voltages upto 120 V DC or 50 V AC at 50/60 Hz. Covered are integral, built-in or independent OLED modules.
Safety	Air cleaner with UVC and UVC water treatment equipment	CIE Position Paper regarding UV-C	Europe/World	CIE Position Statement on Ultraviolet (UV) Radiation to Manage the Risk of COVID-19 Transmission.
Safety	UV-C Radiation	IES CR-2-20-V1	Europe/World	Germicidal Ultraviolet (GUV) – Frequently Asked Questions. This Committee Report has been prepared by the IES Photobiology Committee in response to the 2020 COVID-19 pandemic, with the specific goal of providing objective and current information on germicidal ultraviolet irradiation (UVGI) as a means of disinfecting air and surfaces. The IES provides this information freely and will update it periodically, as more information becomes available.
Safety	UV-C Radiation	Position Statement on Germicidal UV-C Irradiation	Europe/World	Global lighting association position statement on Germicidal UV-C Irradiation; UV-C Safety Guidelines.

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

LpS Digital – Conference & Exhibition

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

Experience the Future of Light

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

Unique Global Reach in the Lighting Sector

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

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

Lighting Industry & Technology Channel

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

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

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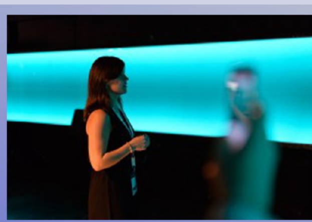

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Energy Efficient Building Controls – Kristopher EVANS, Market Development Manager for Internet of Things (IoT) at Cree Lighting

Kristopher EVANS
As Market Development Manager for IoT at Cree Lighting, Kristopher Evans works across departments to bring emerging technologies like sensors and software to LED lighting systems. Kris earned a Bachelor of Science in Environmental Science from Indiana University and is pursuing a Master of Science in Engineering Management from the Milwaukee School of Engineering. He believes technology is a critical ingredient to meeting our energy and human demands without destroying our planet, and throughout his career he's helped divert the carbon-sequestered equivalent of over 5 million trees through the electricity savings of his customers. Gardening, gaming, and the great outdoors are just a few of the places you'll find this gadget geek when he's not playing family handyman.

For many years the biggest efficiency gain has been achieved by the improvements in LED manufacturing technologies. Meanwhile, we are coming close to the physical limits in this respect and driver efficiency has become more important. But while daylight dependent lighting control is not new, with AI and IoT, controls got a boost resulting in them becoming a key element in energy saving. Cree Lighting, with its partners, has performed several projects and investigated the different aspects from energy savings to user-satisfaction and costs. Kristopher Evans, Market Development Manager for IoT at Cree Lighting, reported on the results at the LightFair virtual conference. LED professional was given chance to go one step further by discussing the findings and asking for background information.

LED professional: If you don't mind, we would like to start with a short introduction of yourself, your career at Cree Lighting and the company.

Kristopher EVANS: Certainly! I've been part of the Cree Lighting team for about six and a half years now and currently serve as its Market Development Manager for IoT. Cree Lighting, a company of IDEAL INDUSTRIES, is a market-leading innovator of LED lighting fixtures, lamps and commercial lighting solutions for interior, exterior, and intelligent lighting applications. We're committed to transforming the way people experience light through innovative technology and intelligence platforms that help make buildings more efficient and businesses more profitable.

LED professional: In your lecture, your fellow presenter said that "Lighting controls, when applied to projects, rarely reach their full potential". Could you please explain why?

Kristopher EVANS: Lighting controls have powerful capabilities, but not all of these capabilities are always taken advantage of in practice. In our presentation, Scott Schuetter of Slipstream, explained that an LED retrofit project can realize approximately 50% energy savings over the original fixtures, or about 3-8% total building energy savings, with the luminaires alone. From there, the percentage of lighting energy savings from controls depends on the level to which the controls are used. Additional measures, clever combination and utilization of sensors could boost this value to a level of 5-12% total building energy savings according to an analysis of Williams et al. from 2012 on "Lighting Controls in Commercial Buildings".

The controls could also be integrated with HVAC or plug load systems. Sometimes end users are only thinking of the lighting itself and not about how sensors can provide insights to other savings opportunities. To ensure that lighting controls reach their full potential, I recommend bringing all the stakeholders to the table from the beginning. Bringing in a company's IT director and working with an applications engineer like those on our Cree Lighting team, for example, gets everyone on the same page about what's possible and what will need to be done to make it happen.

LED professional: How big is the savings potential with clever controls in detail? Is this just true for networked lighting controls with IoT capability?

Kristopher EVANS: As I noted earlier, advanced network lighting controls can bring a total building energy savings of 5-12% based on the study done by Alison Williams and a team of researchers on lighting controls in commercial buildings. In addition to the 50% energy savings when retrofitting, implementing occupancy lighting may save another 24%, daylighting 28%, task tuning 36% and personal tuning 31% - all for a combined lighting energy savings of 38%.

Savings are highest when lighting controls are networked and have IoT capability but are not limited to that sphere. For example, a basic smart luminaire with a light sensor can follow a dusk-to-dawn pattern or auto-on/off/dim without being tied to a network. At the next level, a connected luminaire can use passive-infrared sensors and wireless networking to be able to auto-on/off/dim along with a group of local devices. Finally, a true IoT device with high level sensors and internet connectivity can be remotely monitored and controlled, provide data and analytics, and offer BAS and API integrations.

LED professional: Which scenarios are realistic and which sensors are needed? Is there also additional infrastructure that could or should be integrated in the system? What is possible?

Kristopher EVANS: What a lighting solution with controls looks like depends on the application - not every sensor is relevant to every application. We're zeroing in on how our solutions serve each vertical and have developed a series of case studies [1] to help people explore what solutions are relevant to their needs.

The horizon of what is possible is an exciting one to explore. On a basic level, lighting controls can make lighting better in a space, but it can go beyond that to serve other functions. Consider, for example, how lighting systems can become part of our emergency protocols. Pulsing lights could visually direct people to the exits. Using a wider variety of environmental sensors could detect harmful chemicals. The possibilities are endless.

Over time, underlying networks and software are becoming more sophisticated, useful and open. We want to be as open as possible with our secure platform and engage as many partners as possible. We believe that the future relies on partners coming together and collaborating for the betterment of the industry.

LED professional: You and your partners have been running several projects to prove the theoretical expectations of such systems. Could you give us a rundown of those projects?

Kristopher EVANS: In our recent Lightfair presentation, we reflected on projects we worked on with the U.S. Department of Defense (DOD) and the U.S. Department of Energy (DOE).

Starting in 2017, we undertook a luminaire level lighting controls retrofit project in office areas at the DOD's Truax Air National Guard Base and two buildings at the Selfridge Air National Guard Base. At Truax, significant sunlight is available; at Selfridge, sunlight varied across areas of the building. Our SmartCast ZR-FD series with luminaire-level occupancy and daylight sensors have been installed to allow the lights to power off when no one is in the space or dim when ample sunlight is available. These fixtures communicated wirelessly with each other and manual dimming switches.

The DOE project spanned five commercial building project sites and set out to replace existing fluorescent lighting with LED luminaires, as well as maximize energy savings through advanced lighting controls and integration with building systems. These facilities included two office buildings, a higher education facility, a mixed-use space and an outpatient clinic. The goal was to inspire the retrofit market to go beyond simple light fixture replacement with the real-world outcomes that this project could demonstrate using our SmartCast Intelligent Lighting Platform.

LED professional: Were there any highlights that surprised you, as a specialist, and that you can talk about in more detail?

Kristopher EVANS: I'll elaborate further on our DOE projects - these projects truly demonstrated the benefits of controls. As I mentioned, the five sites involved retrofitting luminaires as well as implementing advanced lighting controls and integrating with building systems.

Another interesting piece of this project is that the higher education site in this project was an historical building on the University of Minnesota campus. Historical buildings are not always the easiest for installing modern technology. The stone and other construction materials of such buildings can be disruptive to network signals. This ultimately did not end up being a problem here, but it's important for lighting designers and manufacturers to keep the building environment in mind when designing a system or creating a product.

LED professional: Could you tell us what technologies were used in this project?

Kristopher EVANS: Given the diversity of the sites in the DOE projects, a number of different technologies were used for different spaces, but the common thread is our SmartCast® Technology.

They used SmartCast® Technology to establish (a) "networked lighting control" as best defined by the DesignLights Consortium, (b) plug load control signals to a Legrand wireless receptacle control system, and (c) a digital sensor network to handle occupancy detection for other building systems. The SmartCast®

Type	Measure
Traditional Lighting Retrofit	Efficient LED Lighting
Advanced Lighting Control	Occupancy / Vacancy
	Daylighting
	Task Tuning
	Personal Tuning
Integrated Control - Plug	Workstation Plug Load Control
	Common Area Equipment Control
Integrated Control - HVAC	Thermostat Setback (Airside, Waterside, Baseboard)
	VAV Box Turndown (including off)
	Aggressive Pressure/Temperature Reset
	Ventilation Reset
	Demand Control Ventilation

Figure 1: Energy saving streams

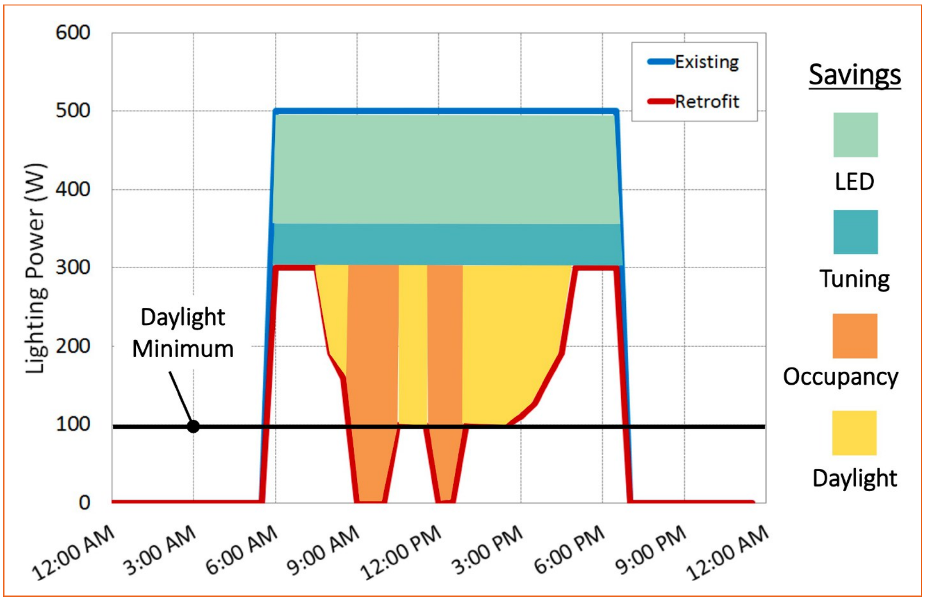


Figure 2: Idealized energy savings throughout a day

lighting network was then integrated with the customers' existing building automation system, like Johnson Controls Metasys, where we mapped the SmartCast® occupancy groups to the HVAC system. This allowed us to signal for "demand control ventilation" using the SmartCast® occupancy sensor network rather than a standalone sensor network, which is how it was being handled before. The latter example illustrates how we can consolidate hardware systems and share resources when we have open systems. Lighting is especially useful for this, given its highly distributed and elevated footprint of powered devices across a built environment.

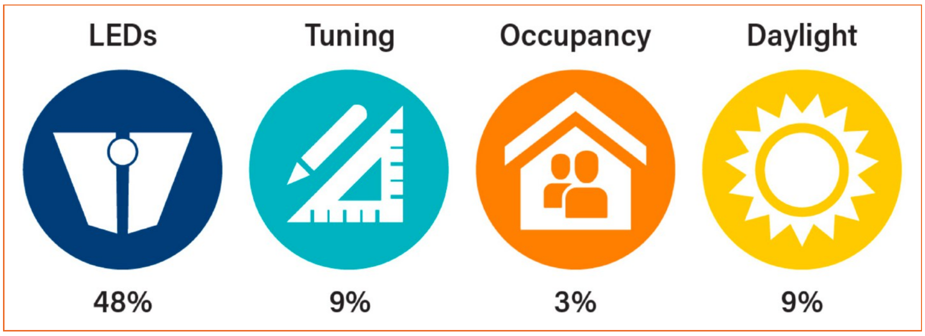


Figure 3: Calculated savings proportions

Metric	Units	DOD	Medium	Low
Capital Cost	$/ft²	$8.63	$5.46 [1]	$3.41 [2]
Rebate	$/ft²	($0.21)	($0.21)**	($0.21)**
Total Cost	$/ft²	$8.42	$5.25	$3.20
Utility Bill Savings	$/ft²	$0.42	$0.42**	$0.42**
Simple Payback	Years	20.2	12.6	7.7
Maintenance Savings	$/ft²	$0.05	$0.05**	$0.05**
Net Present Value*	$/ft²	$0.99	$4.17	$6.23
Savings-to-Investment Ratio*	-	1.12	1.79	2.95

Figure 4: Cost Effectiveness: *Lifetime of 33 years (100,000 hours and 3,000 hours annual usage); Utility rate inflation: 0.1%; Nominal discount rate: 3.1% | **Assumed | [1] Pacific Northwest National Laboratory, 2018, "Evaluation of Advanced Lighting Control Systems in a Working Office Environment", prepared for the U.S. General Services Administration and the U.S. Department of Energy, PNNL-27619. | [2] Osbourne et al., "LiTES Final Technical Report", prepared for the U.S. Department of Energy, February 2020 (expected)

LED professional: What were the measured findings?

Kristopher EVANS: The project has realized approximately 18% overall building energy savings. We measured a USD 0.12/sq. ft. utility cost savings from lighting and estimated a USD 0.07/sq. ft and USD 0.03/sq. ft utility cost savings from HVAC and plug load integration respectively. Exact measures are unavailable for the latter factors because of COVID-19 complications.

LED professional: But it's not all just about energy saving. Ultimately there are people in these workplaces. How they feel, their well-being and health are, at least, equally important. Can you comment on that?

Kristopher EVANS: Absolutely! Helping our customers achieve enhanced safety, well-being and productivity is part of our vision for our company and the industry as a whole. Healthier people make healthier organizations. For millions of years, humans woke up, lived and thrived under the reliable and natural movement of the sun and evolved a circadian cycle, a biological clock calibrated to align our physiology with the passing of the day. Now, many of us are spending over 90 percent of our time indoors and it can have a profound effect on health, performance and well-being. Fortunately, the industry is learning more and more about how artificial light can mimic natural light to mitigate that impact.

We want people to feel the best they can in the spaces they inhabit, and for organizations, it also makes good business sense. A healthier built environment opens the door for people to be more creative and productive. To this end, we've developed our Cadiant Dynamic Lighting Experience [2] to bring the sensation of natural light into spaces where windows aren't feasible.

LED professional: The factor of costs can't be ignored, though. Extended controls solutions are often not realized because initial costs, as well as maintenance costs, are regarded as being too high. Savings are felt to be too low for the expected ROI, and the future proofness of the current systems is also regarded as being unsecure. What do you say to that? What are the conclusions and which strategies promise to push this favorable technology?

Kristopher EVANS: While it is true that high initial costs can make such projects challenging at present, costs for advanced controls technology is decreasing with time. We're getting better at building systems that will cost less in hardware in components. Software is helping to reduce costs as well by enabling an easier setup process that in turn cuts labor and installation costs. Right now, labor quotes may be inflated because of an unfamiliarity and uncertainty surrounding new technology, but I anticipate this will improve as these systems become more common.

The cost-saving promise of IoT is its potential for ROI, and for this you have to evaluate ROI in a broader sense than just hard costs. For example, IoT technology offers better device monitoring, opening the door for businesses to be proactive, not reactive, on maintenance needs. This reduces downtime, improves experience, bolsters productivity—and as a result, can save money.

To concerns about future readiness, I say this: The openness of software systems is key for a solution to be future proof. Our world's systems are becoming increasingly integrated to work together in an automated way. If a device isn't open, it's not ready for this trend. To be clear, "open" doesn't mean necessarily "insecure." Truly future-ready, open products should be engineered with cybersecurity protections as an integral part of their design, ready for a dynamic environment of cyber threats. This is our approach. Cybersecurity can't be bolted on as an afterthought.

LED professional: In the lecture, your co-presenter concluded that it is important to "use best practices when photometric modeling". What does this mean, exactly?

Kristopher EVANS: Yes, Scott Schuetter highlighted photometric modeling among the lessons learned from our DOD project. The team found that photometric models, or digitally-generated floorplans showing how light is expected to distribute in and illuminate a space, to be very helpful for estimating the illuminance in a post-retrofit space. However, they're not always accurate. Our models could have been improved with better representations of interior furniture, like tall partitions and storage cabinets.

LED professional: Another remarkable conclusion concerns a point that we often asked manufacturers but has never been a topic for them. Your co-presenter also said: "Cybersecurity is increasingly important. Stand-alone systems reduce this risk." Does this mean you prefer stand-alone solutions?

Kristopher EVANS: This takeaway was one my co-presenter Scott of Slipstream made in relation to our DOD project, for which a stand-alone solution was necessary to accommodate the DOD's cybersecurity preferences. These restrictions are to be expected with military installations.

For most other applications, however, I recommend IoT solutions. A properly secured IoT device can promote stronger cybersecurity because it allows device firmware, software and security profiles to remain continually up to date. At present, organizations' perceived risk regarding IoT solutions is often higher than their risk tolerance. To flip that, the industry needs to earn customer trust by developing more solutions with cybersecurity central to the product design. Some manufacturers convert connected products to IoT products by bolting on cybersecurity as an afterthought, but this approach isn't enough. As more solutions become available with world-class cyber security, and as customers become more accustomed to and educated about these technologies, we'll see a shift in perception and stand-alone solutions will increasingly fall by the wayside.

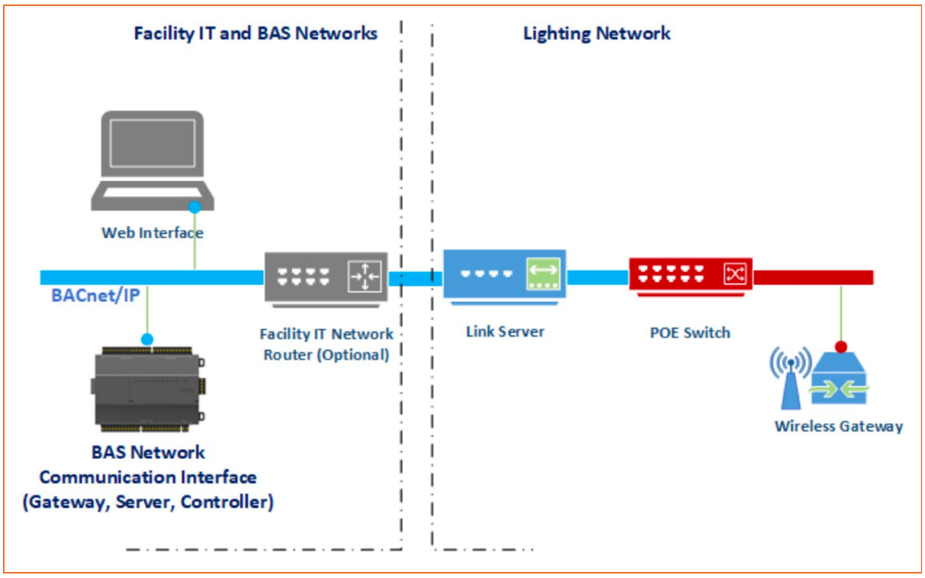


Figure 5: Integration of Lighting and HVAC

LED professional: One of the presented projects - I think it was the DOE Project - shows clearly the relevance of a well-structured process and careful planning. As digging deep would probably be too time consuming, could you please summarize the findings in regards to the process and highlight the two or three most important lessons learned?

Kristopher EVANS: The DOE project does present an excellent example of careful planning. Two key parts of the process were involving all stakeholders from the beginning - especially the customer's IT team - and appointing a member of the team as an "integration manager."

Having all stakeholders around the table was the most critical. In this project, we had continuous coordination between the customer's IT team, our engineers, and the technology integrators. Involving the "tech folk" early on ensures that everyone is on the same page about the customer's cybersecurity requirements and how fully integrated the solution can be with building systems and local IT networks.

We had some minor hiccups early in the project and overcoming them was easier because we had the IT administrator involved. Identifying a member of our team to be an "integration manager" was also helpful. This person had purview over all impacted systems and had the ability to ensure prompt collaboration to overcome system integration challenges.

LED professional: In the last part of your lecture you discussed your findings from a manufacturer's perspective. In fact, from the perspective of Cree Lighting. You compared the DOD project with the DOE project. What were some of your favorite findings and lessons learned?

Kristopher EVANS: Earlier, we touched on the fact that the DOD project involved a standalone wireless control system without internet access. Though this means there were some limitations with what we could do from an advanced controls standpoint, it's still remarkable. It's a big tip of the hat to the lighting industry because military organizations have typically shied away from anything wireless because of perceived cybersecurity risks. This project didn't involve mission critical facilities, but it still represents great progress in the security of the products the lighting industry has developed and in growing understanding and trust of customers in this technology. This couldn't have been done five years ago. Looking forward, the industry will continue to improve cybersecurity and will need to embrace open systems to help drive the best value for customers.

LED professional: Many thanks for this comprehensive and very informative discussion. To complete the picture, I would like to learn more about future activities that Cree Lighting and you in this respect might be involved in. What can you tell us about "The Next Big Thing"?

Kristopher EVANS: Our award-winning Cadiant™ Dynamic Lighting Experience [2] provides a window into the future of LED lighting technology for us. A wall-mounted SmartCast® touchscreen with an intuitive interface provides fingertip control - it's this kind of ease-of-use for nontechnical end users that we'll continue to grow and develop. You see that already in the smart home space with app-controlled consumer bulbs and that should also become the norm for commercial lighting.

LED professional: **Many thanks, Kris. LED professional is looking forward to publishing some of your future findings either in the form of a technical article in LED professional Review (LpR) or an LpS Digital conference contribution. Stay safe and healthy.**

Kristopher EVANS: Thank you! I hope you and the LED Professional team stay safe and healthy as well. I look forward to discussing LED technology with you again. ■

References

[1] https://www.creelighting.com/applications/case-studies
[2] https://www2.cree.com/cadiant

About Cree Lighting

Cree Lighting, A company of IDEAL INDUSTRIES, is a market-leading innovator of LED lighting fixtures, lamps and commercial lighting solutions for interior, exterior, and intelligent lighting applications. Cree Lighting's cutting-edge technology delivers proven value for municipalities, as well as for education, automotive dealership, industrial and healthcare customers. The Cree Lighting team is committed to transforming the way people experience light through innovative technology and intelligence platforms that help make buildings more efficient and businesses more profitable.

Further information:
https://www.creelighting.com

The Energy Efficiency Calculation for "Light Sources" Under the New Ecodesign Regulation (EU) 2019/2020

A description for a better understanding of the new Ecodesign Regulations (EU) 2019/2020, with particular attention on the maximum allowed power P_{onmax} formula and how to apply it. The description details each parameter of the formula and gives a step by step explanation of how to calculate the new requirement for light emitting parts of luminaires that fall under the definition of "light source". Final consideration of the outcomes are given with some examples for calculating the minimum required luminous efficacy for certain light source types. These are intended to provide further evidence of how parameters may influence the calculation of energy efficiency limits of light sources. This article aims to help better understand the new Ecodesign regulations, with particular attention put on the P_{onmax} formula, and how to apply it. It will show how to calculate the new requirement for light emitting parts of a luminaire that falls under the new definition of "light source".

Preamble

The new EU Commission Regulation for ECODESIGN of Energy Related Products in the lighting sector is called Single Lighting Regulation because its aim is to combine the existing requirements given by three different legislative acts, the EC Regulation 244/2009, EC Regulation 245/2009 and EU Regulation 1194/2012.

Each of them sets a minimum requirement for energy efficiency of products covered by their single scope in a similar, but different way. Some limits are relevant to the "Maximum rated power (P_{max}) for a given rated luminous flux (Φ) (W)" for certain non-directional lamps and LED modules (Reg. 244/2009), some other limits are directly set in lumens per Watts, according to the type of other non-directional lamps (Reg. 245/2009), and the latest EU Regulation 1194/2012 limits the value of the "Energy Efficiency Index" of directional lamps, (e.g. LED, HID, filament, etc.). This EEI is calculated by the relationship between

- the power of the source (W) corrected for factors depending on the operating condition (e.g. operation with an external halogen lamp control gear), with
- the reference power (P_{ref}) conventionally calculated by another formula given by the Regulation and depending on the lumen output of the source.

The three different ways of calculation (acc. to P_{cor} / P_{ref} as in EU REG. 1194/2012, to P_{max} as in EC REG. 244/2009 and to lm/W limits as in EC REG. 244/2009) lead to possible confusion and uncertainties on the market because stakeholders usually have more than one type in their portfolio. It is also possible that a certain type is not clearly covered by cases regulated by the rule. Overall, the complexity in the management of technical data for a product is not the proper solution for any legislation which needs to be duly applied to guarantee a fair market.

The idea suggested by the consultant of the EU Commission's DG of ENERGY was to combine all items able to obtain the same results of current legislation in terms of energy into one single formula: the calculation may be performed for all kinds of lamps and LED modules already covered by the existing legislation, using the same rule for calculating the energy efficiency of lamps and modules (light sources) that are under the scope of the new EU Regulation 2019/2020 from 1st of September 2021.

The New Formula

The combination of all items considered by the existing legislation with additional items makes the formula more complex than before. Additional items arise from a new way of thinking related to the quality and the flexibility of the light (colour rendering index better than R_a 80) as well as the additional allowed power to be consumed by the light source designed to operate with smart functionalities, including wireless communication with sensors, detectors and Building Automatic Control Systems

(BACS). But in so doing, the formula becomes the only calculation method and it prevents any backsliding, when referring to calculated limits.

Energy efficiency requirements are now formulated for all types of light sources in a uniform manner using a formula that defines the maximum allowed power for a light source ($P_{on,max}$) according to the quantity of light emitted. This formula contains two parameters (threshold efficacy and end-loss factor) that are set differently for each light source type, where necessary. In addition, power bonuses apply for special circumstances (presence or not of a built-in control gear in the light source, directional or non-directional light emission, light sources connected in a network, and other special features of the light emitted).

Therefore, it is possible to highlight that for light sources typically used in households, a single efficiency requirement applies to all types. The level of this requirement is such that most LED lighting products can meet it, while many types of halogen light sources (HL) and compact fluorescent light sources (CFLi) cannot, and thus would no longer be able to be placed on the EU market after 2021.

The new formula is:

$$P_{\text{onmax}} = C \cdot \left(L + \frac{\Phi_{\text{use}}}{F \cdot \eta} \right) \cdot R \qquad (1)$$

Where

C is the correction factor (non-dimensional)
L is the end loss factor (W)
Φ_{use} is the useful luminous flux (lm)
F is the Efficacy factor (non-dimensional)
η is the threshold efficacy (lm/W)
R is the CRI factor (non-dimensional)

Light source description	η [lm/W]	L [W]
LFL T5-HE	98,8	1,9
LFL T5-HO, 4 000 ≤ Φ ≤ 5 000 *lm*	83,0	1,9
LFL T5-HO, other *lm* output	79,0	1,9
FL T5 circular	79,0	1,9
FL T8 (including FL T8 U-shaped)	89,7	4,5
From 1 September 2023, for FL T8 of 2-, 4- and 5-foot	120,0	1,5
Magnetic induction light source, any length/flux	70,2	2,3
CFLni	70,2	2,3
FL T9 circular	71,5	6,2
HPS single-ended	88,0	50,0
HPS double-ended	78,0	47,7
MH ≤ 405 *W* single-ended	84,5	7,7
MH > 405 *W* single-ended	79,3	12,3
MH ceramic double-ended	84,5	7,7
MH quartz double-ended	79,3	12,3
Organic light-emitting diode (OLED)	65,0	1,5
Until 1 September 2023: HL G9, G4 and GY6.35	19,5	7,7
HL R7s ≤ 2 700 lm	26,0	13,0
Other light sources in scope not mentioned above	120,0	1,5 (*)

(*) For connected light sources (CLS) a factor L = 2,0 shall be applied.

Table 1: Threshold efficacy (η) and End Loss factor (L) from EU Regulation 2019/2020

When the New Formula Applies

As soon as a light emitting part is classified by the supplier as a light source according to the new definition given by the Regulation (EU) 2019/2020, and so, it emits white light in a range between 60 lm and 82.000 lm at "Reference Control Setting", the new formula shall apply to calculate the maximum power that such light source absorbs during its normal operation. This concept is the same as originally implemented by the EC Regulation 244/2009, but as explained above, the new formula has been refined to also consider a bonus for light sources with a high colour rendering index (CRI expressed by R_a eight colours metric [1]) the case when the light emitted with high CRI is consuming slightly more than ordinary sources having $R_a = 80$.

Elements of the New Formula

R – CRI factor for quality in colour rendering of the light sources

Colour rendering index' (CRI) means a metric quantifying the effect of an illuminant on the colour appearance of objects by comparison with their colour appearance under the (D65) reference illuminant, and is the average R_a of the color rendering for the first 8 test colours (R1-R8) defined in standards. The CRI factor (R) is set to 0,65 for CRI $\leq$ 25 or, for CRI $>$ 25, it is calculated and rounded to two decimals by the specific formula:

$$R = \frac{\text{CRI} + 80}{160} \qquad (2)$$

where CRI corresponds to the declared R_a value for the light source concerned. It is self-evident that no changes to the final value of P_{onmax} would arise when CRI $= 80$ to have $R = 1$. To note that $R_a = 80$ is the minimum allowed by ecodesign implementing measures for most light sources.

[1] R_a is the mean of the CIE 13.2:1974 special colour rendering indices for a specified set of eight test colour samples and it represents the average of R1 - R8 values. Other values from R9 to R15 are not considered in this R_a calculation (e.g. R9 "saturated red", R13 "skin colour (light)", and R15 "skin colour (medium)"). In particular, R9 is an important index in high-CRI lighting, as many applications require red lights, such as film and video lighting, medical lighting, art lighting, etc. However, in general CRI (Ra) calculation the R9 is not included. But because when high R_a is obtained the R9 and above are generally improved, it is conventional assumed the rule sets the bonus for quality improved light source anyhow.

η – Threshold efficacy (set as benchmark)

Values for threshold efficacy (η) are specified in the **Table 1** of EU Regulation and they are given by a description depending on the light source type. These values listed in **Table 1** are originally intended for non-directional light sources, using the total luminous flux (Φ_{tot}) emitted by the light source as the Φ_{use}. For directional light sources (DLS), that use the (smaller) luminous flux in a cone as Φ_{use}, the values for (η) is adapted by means of the factor $F = 0{,}85$ for Directional Light Sources (DLS). This factor reflects that, on average for DLS, the flux in a cone is 85% of the total flux.

The table lists specific types already covered by current regulations while the last row in table "Other light sources" is provided to include all LEDs (but not OLEDs) and all other conventional light sources that have already been phased out by existing regulations, e.g. general light sources, mains voltage halogen lamps (directional and non-directional), high pressure mercury vapour lamps, linear fluorescent lamps T12, as far as they are in scope and not exempted. This is to avoid any backslide.

The limits for OLED are intended to allow these products on the market, thus not obstructing their further development.

Some derogation in timing for certain types are also given: G9, G4 and GY6.35 halogen lamps will continue to use the threshold efficacy ($\eta = 19{,}5$) in P_{onmax} formula until 1st September 2023. After this date, the halo-capsules will no longer be placed on the EU market, This also applies to T8 three-phosphor linear fluorescent 18 W, 36 W and 58 W lamps to which the value of 89,7 will no longer be applied.

T8 Halo-phosphate linear fluorescent lamps (less efficient than three-phosphor types) are not able to meet the requirements for fluorescent lamps T8 and thus continue to be phased out. Please note that T2 fluorescent lamps are currently not exempted and have no specific requirements, which means they also fall under "Other light sources in scope".

L – End loss factor

Originally, the end loss factor (L) intended to reflect constant power consumption that would be always needed, independent of the emitted luminous flux. This technical background has largely disappeared because the factor L has been established mainly by the legislator so that new requirements would match the requirements from existing regulations (a fine tuning of the new formula to the existing limits). The main effect of factor L is that low lumen output light sources have lower efficiency requirements than high lumen output light sources using the same technology. It is no longer useful to try to give a physical/technical meaning to the exact value of factor (L).

To "Other light source", including LEDs, 1,5 W for the End Loss power shall be applied; a higher value $L = 2{,}0$ W for connected light sources (CLS) is reasonable considering the additional power consumption of "data-connection parts" that cannot be easily excluded from the measurement of P_{on} for these light sources. The additional power consumption is assumed to be 0,5 W, which is the maximum allowed off-mode power consumption:

$$L = 1{,}5\ \text{W} + 0{,}5\ \text{W} = 2{,}0\ \text{W} \qquad (3)$$

Light source type	Basic C value
Non-directional (NDLS) not operating on mains (NMLS)	1,00
Non-directional (NDLS) operating on mains (MLS)	1,08
Directional (DLS) not operating on mains (NMLS)	1,15
Directional (DLS) operating on mains (MLS)	1,23
Special light source feature	Bonus on C
FL or HID with CCT > 5 000 K	+0,10
FL with CRI > 90	0,10
HID with second envelope	+0,10
MH NDLS > 405 W with non-clear envelope	+0,10
DLS with anti-glare shield	+0,20
Colour-tuneable light source (CTLS)	+0,10
High luminance light sources (HLLS)	+0,0058 • Luminance-HLLS - 0,0167

Table 2: Correction factor C depending on light source characteristics and (cumulative) bonuses

F, C – Other losses depending on construction constrains and on special features of light sources

Basic values for correction factor (C) depending on light source type, and bonus (additions to C value) for special light source features are specified in **Table 2** of the Regulation (EU) 2019/2020. The main reasoning for such C bonuses has already been given when describing the threshold efficacy (η) set as a benchmark, as mentioned above.

Construction constrains in making directional light emission is a reason for some light losses (the narrower the angle, the less efficient the light source). But because the complexity in finding an appropriate function, the legislation only refers to non-directional / directional light sources: in addition to the factor $F = 0{,}85$ for the flux difference, DLS get a power bonus of 15% ($C = 1{,}15$; see **Table 2**). This factor intends to reflect the additional reflection and refraction losses in DLS as compared to NDLS. The 85% for flux and 15% for additional losses are not related because they have been set for different purposes and their total of 100% is simply a coincidence.

To summerize the explanation given above, the F (Efficacy Factor) to be considered in the P_{onmax} formula is:

- $F = 1{,}0$ for non-directional light sources (NDLS, using the total luminous flux)
- $F = 0{,}85$ for directional light sources (DLS, using the useful luminous flux)

The definition for Directional Light Source (DLS) is still the same as in existing legislation: a light source with at least 80% of the emitted luminous flux within a solid angle having an apex cone angle of 120°. The above definition should not lead to mistakes in declaring the useful luminous flux of a DLS; a different solid angle shall be considered to measure the partial luminous flux:

- $\pi\ sr$ (apex cone angle of 120°) for light sources having a beam angle greater than or equal to 90°, and
- 0,586 $\pi\ sr$ (apex cone angle of 90°) for light sources having the beam angle smaller than 90°.

Final Consideration on the Outcomes

The threshold efficacy (η) is not the efficacy that the light source has to meet for being in compliance with the requirements: The minimum required luminous efficacy is lower, even more for low lumen output light sources.

Following examples (**Table 3**) in calculating the minimum required luminous efficacy, for certain LED light source types may be of help to better understand how each item of the P_{onmax} formula may influence the "minimum required luminous efficacy" set by the Regulation (EU) 2019/2020, for different types of light sources.

Further details for better understanding the new Eodesign EC Regulation, as well as the new Energy labelling EC Regulation for light sources are available at the LightingEurope website, where new versions of the two guidelines are published [1]. ■

References

[1] https://www.europeanlightingpriorities.eu/guidelines.php

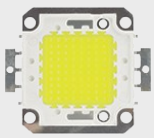
Type LED Light Source		C [W]	L [W]	Φ_{tot} [lm]	Φ_{use} [lm]	F	R	η	P_{onmax} [W]	Minimum Required Luminous Efficacy
Mains voltage, non-directional, $R_a = 80$		1,08	1,5	425	425	1,00	1,00	120	5,445	78 lm/W
Mains voltage, non-directional, $R_a = 90$		1,08	1,5	700	700	1,00	1,06	120	8,314	84 lm/W
Mains voltage (LED Tube G5), non-directional, $R_a = 80$		1,08	1,5	2.000	2.000	1,00	1,00	120	19,620	102 lm/W
Non-mains voltage, directional, $R_a = 95$		1,15	1,5	1.000	800	0,85	1,09	120	11,590	69 (86)* lm/W
Mains voltage (RGB, CLS), directional, $R_a = 80$		1,08	2,0	500	400	0,85	1,00	120	6,395	63 (78)* lm/W

Table 3: Examples in calculating limits for some type of light sources | *Luminous efficacy of the light source calculated by considering the total luminous flux (Φ_{tot})

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ABOUT ASSIL

ASSIL, Italian Association of Lighting Manufacturers, is member of ANIE Confindustria and represent about 80 companies manufacturing luminaires, electrical components for lighting, light sources and LED. These companies are the expression of technological excellence of the lighting Industry operating on the Italian market. ASSIL companies, with a total turnover of 2,8 billion euros, represent over 65% of the total Italian lighting turnover and over 8,700 employees. ASSIL is founding partner, member of the Executive Board and of the Association Committee of LightingEurope, the Association that represents the lighting industry in Europe. Mission of ASSIL is to represent, defend and advocate member companies to support the development of high-quality industry, built on innovation and internazionalization. Through training and technical dissemination, assistance and advice on standardization and legislation that regulate the sector, ASSIL creates and promotes a culturally advanced ecosystem of highly knowledgeable companies and professional.

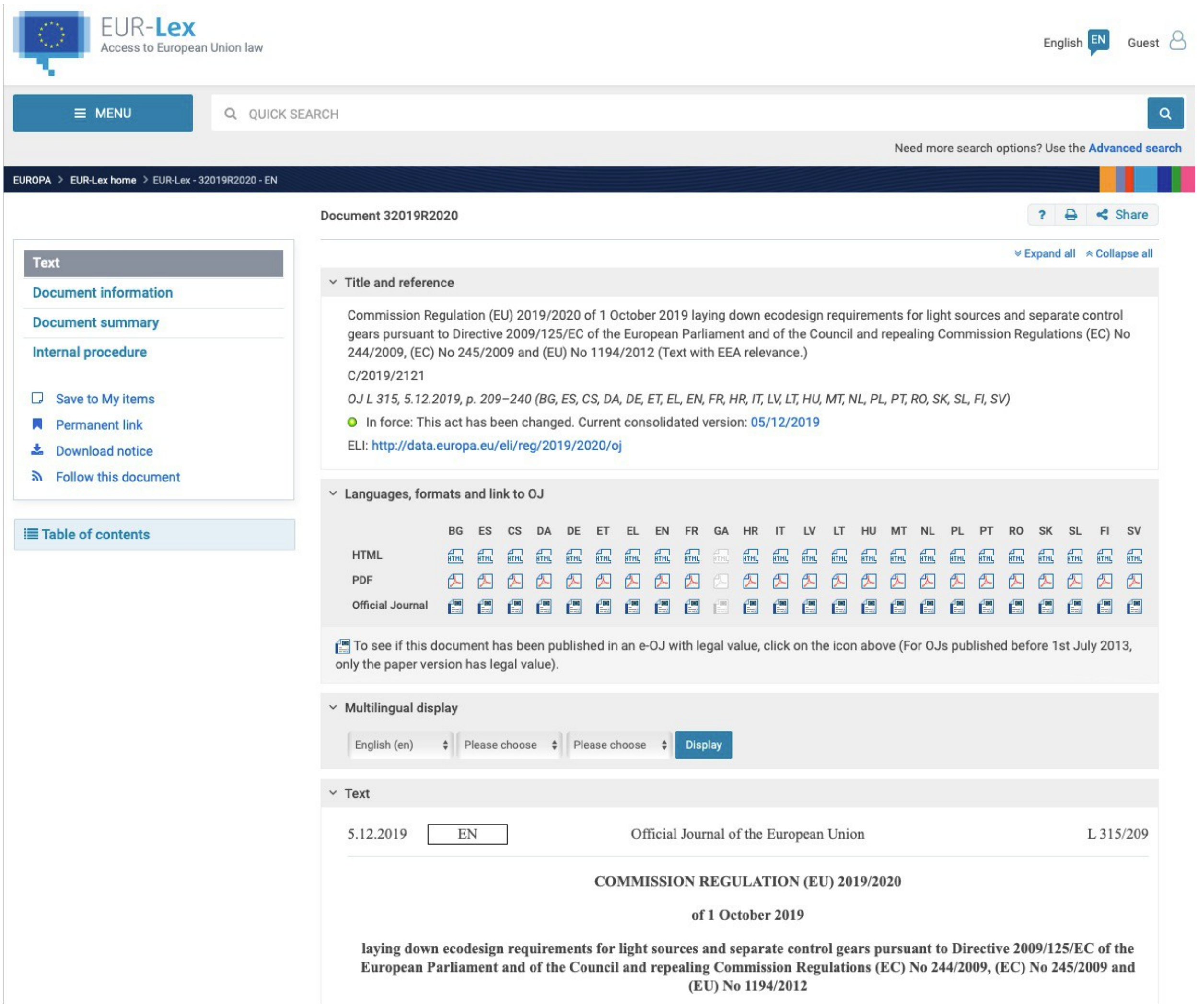

Figure 1: EUR-Lex platform to access the Ecodesign regulation document

Opportunities and Obstacles While Exporting Luminaires to North America and the Middle East

Today, the transformation to LED and the associated change in becoming part of the electronic industry is nearly completed. Most of the R&D activities are now dedicated to connected lighting products and Human Centric Lighting (HCL) applications – and both segments contain some risk. No standard has been established regarding connected lighting products, and HCL solutions still need to prove their benefits. Is the market really ready for such innovative products? The largest market for professional lighting products outside of the EU for the European lighting industry is North America followed by the Middle East (ME). But both markets seem to be difficult to reach. In North America, the market for connected lighting solutions started earlier than Europe, and the Middle East region raised their import regulation in 2019 significantly. But is it really so difficult to fulfill the expectations of these markets?

North America

From a technical perspective, the biggest challenge is exporting to North America. The requirement for 110 V (120 V for Canada) at 60 Hz in conjunction with UL Standards is often a major modification of a European product that already exists. A North American version of such a lighting product — a dedicated limited export product portfolio — is usually the answer.

Many companies have already managed to accomplish this step, and it seems to be easier than expected. In order to cover all safety aspects, a certification is useful but is it mandatory from a legal perspective? The answer is no. A UL Mark can be compared to the European ENEC but it is also different. In Europe, the voluntary ENEC mark is shown together with a two-digit number, e.g., ENEC 15, that indicates the issuer of the mark. This keeps it neutral and usually only insiders know which test house performed the test.

This is different for North America. The rules were defined for the U.S. by the Occupational Safety and Health Administration (OSHA) of the Department of Labor. OSHA supervises the different test houses which are accredited to perform the tests — often based on UL Standards. As a result of such tests, a mark is issued that demonstrates compliance with the relevant standard and discloses the issuer of the certificate at the same time. For example, a c**UL**us is issued by UL, a c**CSA**us is issued by CSA and a c**ETL**us is issued by Intertek. TÜV Rheinland, TÜV Süd, SGS, Bureau Veritas, MET, NSF QAI and PS are also currently recognized by OSHA to perform tests for luminaires. The information is public and can be looked up on OSHA's website [1]. The prefix "c" indicates that the certification is valid for Canada while the suffix "us" indicates the U.S. Such certificates can be issued for the U.S. or Canada only.

The next surprise for companies that intend to export to North America is that Underwriters Laboratories is a nonprofit organization dedicated to advancing the UL mission through the discovery and application of scientific knowledge. It is an affiliate of UL, dedicated solely to safety science and works on the development of standards. UL tests products to standards including UL Standards, as well as many others.

The knowledge around this safety mark is often beneficial because a lot of end users in the North American market request a special test house to run the tests. This is different from the behavior of European customers that cannot distinguish between the different ENEC marks. Therefore, a discussion with the potential final lighting customer helps to clarify the situation and avoids rejected certificates. To be very clear: from a legal prospective all certificates are fine, but it is the user who is asking for it, not the state.

Technical requirements

The next topic one should take note of are the different technical requirements. **Table 1** gives a high-level overview of the main categories of lighting products and the relevant standards. For track light luminaires, Canada has already harmonized its requirements with the relevant IEC standard which is clearly stated by the naming of the standard.

One aspect that is often misunderstood and causes confusion is when a Class 2 power supply is required for North America. European luminaire designers expect Class 2 to be equivalent with safety extra low voltage (SELV), but it isn´t. **Class 2 is**

	Standard		
Product Type	UL/CSA	IEC	Product type
	Fixed Luminaires		
Luminaires	UL 1598 CSA C22.2 # 250	IEC/EN 60598-1 IEC/EN 60598-2-1	Luminaire general requirements fixed general purpose luminaires
Luminaires - **recessed different design for NA**	UL 1598 CSA C22.2 # 250	IEC/EN 60598-1 IEC/EN 60598-2-2	Recessed luminaires
Track Luminaire Track (Canada shifts towards IEC + national deviation)	UL 1598 UL 1574/CSA C250.**570**	IEC/EN 60598-1 IEC/EN 60**570**	Track Luminaire + Track System
Street lighting	UL 1598	IEC/EN 60598-1 IEC/EN 60598-2-3	Luminaires for road and street lighting
Horticultural lighting	UL 1598 **UL 8800**	IEC/EN 60598-1 no equivalent	no special standard
Stage and studio lighting	UL 1573 CSA C22.2 # 166	IEC/EN 60598-1 IEC/EN 60598-2-17	Luminaires for stage and studios

Table 1: Comparison of major lighting standards

	Standard		
Product Type	UL/CSA	IEC	Product Type
	Power Supplies		
LED Control Gear/Driver/LED Arrays - non class 2 -	UL 1012 + UL 8750	IEC /EN 61347-1 IEC/EN 61347-2-13 IEC/EN 62031	General and safety requirements particular requirements LED modules
Power Units - class 2 - dry + damp = SELV + 42.4 V and max. 100 VA wet location = SELV + 30 V and max. 100 VA	UL 1310 + UL 8750	IEC/EN 61347-1 IEC/EN 61347-2-13	General and safety requirements particular requirements

Table 2: Comparison of major component standards

applicable to dry and damp locations when the voltage is limited to 42.4 V and max. 100 VA and for wet locations when the voltage is limited to 30 V. This might sometimes lead to a different luminaire design with multiple drivers **Table 2**.

Another important fact to mention is the performance aspect of the luminaire. In Europe, for professional lighting products, the **ENEC Plus** has been established. Unfortunately, knowledge of this mark is limited and so is the number of customers asking for it. **For professional lighting products in North America, the equivalent is the registration of the product in the Qualified Product List (QPL) of the DesignLights Consortium (DLC)**. DLC is a non-profit organization consisting of members that support the use of registered products with incentives which ultimately decrease prices for the user. Such registration is available for LED, horticultural lighting products and controls which fulfill the efficiency requirements [2].

Middle East

The situation in the Middle East is different. Many Middle East countries have been disappointed by the poor quality of some LED lighting products and have decided to raise the import regulations.

The good news for the European lighting industry: in general, the safety aspects are covered by the well-known IEC standards. We can assume that the technical requirements are therefore easier to meet. Due to the fact that the European standards, e.g., EN 60598-1, are derived from the relevant IEC standards, e.g., IEC 60598-1, only a few national deviations might need to be taken into account for the region.

Initially the whole region intended to establish the **G-mark (Gulf Conformity Mark)** comparable to our CE declaration. Unfortunately, drivers, lamps and luminaires have not been covered until now by this approach. Furthermore, the main countries within the region — United Arab Emirates and Saudi Arabia — established their own regulatory compliance scheme for lighting products. **So, a unique approach is not expected.**

United Arab Emirates (UAE)

The safety requirements for UAE are based on IEC 60598 without national deviations. Only a CB test report — not older than 3 years — is required. After an in-country registration process, the manufacturer can apply for an ECAS (Emirates Conformity Assessment Scheme) mark. **With a validation of three years, covering more models and mandatory third-party testing, an Emirates Quality Mark can be issued.** The product certifier's local presence helps support all administrative activities and helps smooth the process in order to achieve the required mark. Additional performance and functionality requirements can be met in-house. But for hazardous substances and ISO 17025, an accredited laboratory-issued test report is required.

Kingdom of Saudi Arabia

The situation has significantly changed here within the last two years. Since 2019, lighting products have needed to comply with the SASO 2902/2018, and **streetlights have needed to comply with SASO 2927 since 1st of September 2020.**

1. **To get access to the market requires an energy label** which is the starting point for all activities. It's important to mention the requirement for a long time (2,000 h) lumen maintenance test (when LM 80 data for the LED modules are available) in an accredited laboratory. Approximately 90 days should be available ahead of all projects within the country. Sometimes technical performance requirements might be an issue. The efficiency of control gear shall be at least 0.91% at 100% load which is sometimes a problem for a low wattage luminaire.
2. With the energy label, the second step to the SASO IECEE Recognition Certificate (mandatory since 1st of February 2019) can be started. **Based on the IECEE CB Test report** – again not older than 3 years – the certificate can be issued.
3. After the product and the importer have been registered, the SASO Shipment Certificate is issued and the products can pass customs.

From my point of view, the administrative tasks are the challenge not the technical requirements, and a test house with local experience and native speakers should be chosen to support the process.

As mentioned, since 1st of September 2020, additional requirements have existed for streetlights.

Such luminaires need to meet performance and special electrical and mechanical requirements. Here are a **few** examples:

- 120 lm/W luminaire and 140 lm/W @ 25 °C LED efficacy
- 70% (L70) after 50,000 hours
- Ra ≥ 70
- 3000–6000 K
- LEDs within 5 step MacAdam
- Overvoltage protection 10 kV
- Class I luminaire
- Constant voltage drivers are not allowed and the drivers need to be programmable DALI preferred or 0–10 V dimmable
- IP66 and IK08
- The control unit enclosure shall be designed to withstand a temperature between –10 °C to 85 °C

Streetlight luminaires have been covered previously by SASO 2902. All certificates based on SASO 2902 already issued, expired at the end of August 2020 and must be renewed according to SASO 2927. The above-mentioned requirements are not complete and cover only major aspects of this new regulation.

Most quality products might meet the requirements easily — perhaps only a very few changes are needed. **But the biggest challenge might be the requirement for the use of a multirange driver for 120–277 Vac at 60 Hz.** Some regions within Saudi Arabia are still supplied by 120 Vac. SASO decided to formulate this aspect as an all over requirement and not as a local specialty.

References

[1] https://www.osha.gov/dts/otpca/nrtl/nrtllist.html
[2] www.designlights.org
[3] mailto:AppliancesLighting.EU@ul.com

Conclusion

In general, these requirements are formulated in order to purchase safe, efficient, high-quality products for the country and the region. The lighting industry should be happy to see such specifications manifest the demand of high-quality products for the region. UL, with our presence in the Middle East, has local lighting laboratories around the world, and the Global Market Access team in Milan, Italy, can support all kind of export activities to North America, the Middle East and around the world [3]. ■

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Dr. Laschefski began his lighting career in 1995 as a member of the Lichttechnischen Gesellschaft (LiTG), Leader of the Interior Lighting team and head of the Support Center Gummersbach. He worked for Oktalite Lichttechnik until 2009 and in 2010 became a member of the management board for Schnick-Schnack Systems. He worked as the Business Development Manager for Alanod from 2010 till 2018 and is presently working for UL International Germany as the Industry Marketing Manager – Lighting EMEA.

LED Lighting Fixture Design Between Tradition and Innovation

Solid-State-Lighting technology is giving designers and industry almost unlimited freedom to develop new lighting products by completely revolutionizing the way the lighting fixtures can be conceived, designed, built and realized. LED technology is rapidly evolving in terms of performance (both quality and quantity of light) at lower costs, in terms of reliability of the technology (data from datasheets and continuous testing to derive LEDs effective performances under stress conditions), in terms of miniaturization and integration of components, and also in terms of digitization of lighting management and interaction. The disruptive innovation of LEDs allows for the envisioning of innovative lighting scenarios, systems and solutions in terms of appealing aesthetics, configurations, applications, and performance.

Historical and traditionally driven lighting companies have embraced this change with difficulty, but they are interested in being in step with the technological transition, while wishing to fully exploit their historical heritage. The design approach supports the improvement of the lighting companies thanks to their wider understanding of the dynamics of interaction between object, subject and context to design new artefacts based on the new dimension of cultural values and technological exploitation. Despite this, the complexity of designing LED lighting fixtures is increasing, considering the wide range of knowledge required. As a consequence, educational experiences aimed at teaching young designers how to conceive an LED lighting fixture require new tools, strategies and methods to address this complexity.

The paper presents the results of a research-based and educational experience that focused on the development of LED lighting fixtures taking, into consideration all the aspects related to tradition and innovation in terms of production, culture, materials and new lighting technologies. It aims to give an overview of the process of design, by presenting a best practice case study that was developed in collaboration with an Italian historical company: Barovier & Toso. This methodology was finalized to boost the vision of a traditional lighting fixture company that was willing to open their design path toward a complete and innovative transition to LED lighting, taking place in their history and past: envisioning trends (trend research), competitor analysis, technological mapping and scenario building toward possible innovative lighting concepts.

Introduction

Company Transition to Solid State Lighting Technology

The lighting sector has undergone a profound transformation thanks to the transition to solid-state-lighting (SSL); from 2011 to 2015, the global general LED lighting market saw a first wave of technological adoption [1] that largely translated into retrofit solutions for traditional lighting systems. Lighting fixtures were equipped with LEDs in order to obtain greater efficiency and reliability in terms of spectral power distribution (SPD), color rendering (CRI) and long-lasting lighting performance under high-stress conditions. At this stage, LEDs reshaped the landscape of traditional lighting, providing new LED light sources to replace traditional ones, all whilst remaining compatible with classic lighting fixtures. A second technological stage saw the creative adoption of LEDs, broadening horizons in terms of opportunities to design, construct and manufacture new lighting fixtures and systems characterized by a greater degree of freedom and flexibility in terms of expressive/formal languages, functionality and interaction [2], [3], [4]. At both stages of this journey, the design of LED lighting fixtures required a deep and combined knowledge of the fields relating to the different aspects involved, namely the thermal, mechanical, electrical, optical and photometric characteristics needed not just to achieve a more stable performance [5], but also to conceive creative approaches to the design of new solutions and yet unexplored scenarios. Furthermore, this knowledge must also be constantly kept up-to-date due to the fact that, as a part of the world of electronics, LEDs quickly become obsolescent. Besides this, historical and traditionally driven lighting companies have embraced the change with several complications derived by either the incremental and slow technological adoption, or by their strong historical heritage. In the most positive cases, this has caused gaps in the definition of lighting product portfolios, which sounds outdated if compared to their competitors. In the worst cases, it has led to the decline, failure and subsequent fall of many companies. Understanding the importance of being in step with the technologies and trends of lighting, while wishing to fully exploit their historical heritage, lighting companies are today called to improve their capacities and design processes, between tradition and innovation. In the general lighting sector, new, winning strategies have to be adopted by tailoring the solutions to match the customers' needs and expectations. This will also require innovative R&D. In the residential use of consumer market, by 2020, LED luminaires will account for about the 60% [6]. Conventional luminaires are going to decrease and LED based luminaires are going to accelerate their adoption by companies through unique integrated LED modules (LED + electronics) not separable from lighting. This design dimension requires a wider understanding of the dynamics of interaction between object, subject and context to design new artefacts based on the new dimension of cultural values and technological exploitation. Indeed, design embarks on an in-depth exploration of issues pertaining to the humanities and social sciences, as well as promoting, reclaiming and redefining our cultural heritage. This represents, not only a context for design, but also an opportunity to cultivate design research from a different perspective. Design is no longer merely an activity aimed at giving form and function to products, but rather something that has evolved toward a more articulated approach to design that also addresses the meaning and value of products, processes and services. The introduction of the concept of "humanization" indicates a growing interest in the research of the cultural aspects of design, moving beyond the functional, economic and aesthetic factors that have, until now, monopolized the attention of designers and researchers alike [7].

The design of new lighting systems based on LED technology within an historic company, deeply rooted in Italian territory, requires a complete and complex way of thinking. Design must not only interpret change, but also convey the cultural meanings and values of a long established tradition through the original and innovative adoption of technology. The ability to innovate within the confines of tradition is certainly not a new idea in the context of Italian creativity in the lighting sector. Many of the historical lighting fixtures produced by well-known Italian companies, as fully-fledged masterpieces in the history of design, have been adjusted to make them compatible with new LED lighting sources. One of the most famous examples of the encounter between LED technology and the Venetian glass craft and expertise is in the company Murrina, which redesigned a classic Venetian chandelier to incorporate LEDs, creating a synthesis between past and future [8].

Case Study

The research and the educational experiences were conducted for and with the historic Italian lighting company, Barovier&Toso (B&T), a Murano-based glassmaking company whose business started in the mid-13th century, thanks to the Barovier family [9]. Today B&T is sixth on the list of the ten oldest family businesses in the world that are still running successfully, as proven by centuries-old historical documents. Located on the banks of the Rio dei Vetrai, the historic canal of the glass island (Murano), the Palazzo Barovier&Toso and its ancient furnace embody the genius loci of the island, being an historical sign of resilience and tradition along innovation, superb manufacturing, art and design. B&T shines a spotlight on the precious heritage it has acquired over the centuries: traditional processes for the design and production of their lighting fixtures and the continuous rediscovery of ancient glass production techniques. The value of the company no longer lies solely in the projection of the brand image but is also defined by the tangible and intangible elements that constitute the invaluable heritage of knowledge that are preserved and passed down as "the company's expertise" [10].

Through a distinctive code encrypted in the material knowledge of glass joints processing, peculiar shapes and colors, B&T define the uniqueness, individuality and authenticity of the brand [11]. B&T has been looking for a future vision on the design path of lighting fixtures by considering two opposing factors: the technological innovation on one side, and the preservation and promotion of both material and immaterial values being part of their memory and background, on the other side. B&T sought for a new identity to be seen through a systematization of their past, by following a research and design approach. They launched a challenge aimed at the students: to imagine new lighting products capable of innovating within the framework of the tradition and values of the B&T brand. The challenge was to blend new lighting technologies with new trends and inspirations from the world of lighting design within the company's heritage and immaterial cultural assets: historical production processes, iconic elements of their collections and production capabilities, and brand recognition, all redefined in original and innovative ways. At the very beginning of the project, the Polimi team composed of academics, designers and lighting specialists, identified possible scenarios and defined the brief slogan: "Ceci n'est pas un chandelier". Although evoking the strong sense of identity to be respected and promoted, the brief addressed the need for redefining the product image in terms of functionality, technological application and aesthetic languages, also incorporating a more contemporary message.

Methodology

The paper presents the results of a research and educational experience focused on the development of LED lighting fixtures that took into consideration all the aspects related to tradition and innovation in terms of production, culture, technology and materials. The research part was conducted by the Polimi team under the Trend4Tradition Research umbrella with a particular focus on reading trends. The research phase focused on the analysis of the market and the competitors, the identification of new lighting technologies and manufacturing processes. The final aim was to define scenarios and vision for the future through cultural enhancement and technological innovation in the luxury-lighting sector. The design part was conducted inside the Metadesign Studio classes offered in the Product Design Programs of the Design School at Politecnico di Milano. The paper aims to give an overview of the methodological process of research and design, by presenting a best practice case study which was developed in collaboration with an Italian historical lighting company Barovier & Toso. Through a Metadesign approach [12], the students undertook a research path that allowed them to manage complex systems and design innovative solutions which stroke a balance between recognizability and originality, allowing students to develop their own personal design methods [13].

An Overview of the Research Strategy and Path

The preliminary research phase was set up and focused on the aim of mapping the luxury-lighting sector by exploring the context with a wider perspective in terms of investigated sectors of application, contexts of use, domain of knowledge and points of view. In particular, the overall domain of research covered the following aspects:

- Market and competitors: selection of case studies and exemplar products from companies that could be considered direct competitors of B&T, either because operating in the field of glass-works (glass factories), luxury, lighting design or product lighting design. The selection was also extended toward de-

signers that run single individual firms that work on bespoke lighting projects;
- Trends and inspirations: exploration of quantities, qualities or changes defining an incremental transition in a specific direction over a long period of time in order to grasp change factors and innovation in the luxury, lighting and glasswork sectors as well in the more general social, cultural, economic and political assets [14]. The selection of case studies focused not only on lighting, luxury and glasswork sectors but also on artistic installations whose performance utilized the latest available technologies, but also interesting approaches in terms of lighting effects and the manufacturing of the glass material.
- Technology: investigation and analysis of available technologies in terms of LED lighting sources, LED lighting engines and LED lighting materials already marketable or possibly customizable by the company. The selection of case studies and examples useful to map the technological state of the art included information regarding the material (glass) and immaterial (lighting) interaction by giving information and examples about the optical phenomena of both traditional supports (e.g. lenses) and physical behaviors (e.g. edge lighting with total internal reflection). The research also included the technologies available for the digital manufacture of glass.

Research Results and Lesson Learned

The research phase aimed at the product innovation process as a very preliminary and valuable approach for design consultancy. Competitor analysis, trend research, technological mapping and scenario building were the result of this process aimed at enabling creativity and innovation for B&T and for the subsequent phase of design, including students.

Competitor Analysis

Competitor analysis made it possible to gather insights from the luxury lighting sector, diving into the recent production of companies that carry out complete or partial production of lighting fixtures in glass.

The resulting insights defined a heterogeneous scenario among companies that could be differentiated in terms of three opposing factors:

- The manufacturing approach between the artistic and artisanal processes toward more massive and series-based production;
- The use of technologies in terms of lighting sources and interactive modality between a traditional and modern approach;
- The use of lighting for sensorial exploitation.

In particular, each competitor was analyzed to derive the main features and recognizable skills such as:

- The capacity to combine old and modern production techniques for glassworking,
- The capacity to produce new editions of an archetype and to translate it into a standing-piece,
- The progressive focus on the sensorial experience and interaction with users,
- The surprising ability to enhance imperfections and irregularities as elements of uniqueness,
- The reinterpretation of luminous effects through minimal reduction of crystal materials.

The analysis showed a general emergence of minimalism that has been highly reworked - and often led to extremes in the dematerialization and deconstruction - as well as the modularity. On the other hand, a focus on the typological variation driven by a more experimental approach to the glassworking processes toward interesting results in terms of lightness and luminous effects also emerges. The majority of the analyzed companies showed work on an installation scale through customization of the design of the piece and on-demand tailored luminous glassworks.

Trend research toward Macrotrends

The scope of trend research, traditionally, is to guide the design practice by identifying relevant signals in various areas of the exploration that are used to inform the further design phases. It is conceived as a hybrid research activity, that combines quantitative analysis in forecasting the aesthetic and perceptual features of products along with qualitative analysis on socio-cultural contexts [15] Trend research is fundamental at the very beginning of design processes to orient the actions [16], to stimulate lateral thinking [17] to make sense in time and space by understanding the past, decoding the present and imagining the future [18]. Trends are useful to collect informative seeds that already exist in the present as inspirational inputs toward change. By expressing this change, collected case studies were organized, synthetized and articulated to converge on five macrotrends:

- Light effects through the interaction between the material (glass) and the immaterial (lighting) and the sensorial luminous effects and experiences created by installation on a small, medium and large scale;
- Dematerialization of lightweight pieces both in terms of meaning and materials (reinterpreted lighthearted concepts) and in terms of materials (empty big volumes and weight reduction);
- Material mix through the exploration of the unconventional combination of high sensorial and precious materials;
- Modularity through the repetition of the same piece toward the creation of geometric, reconfigurable and re-combinable patterns;
- Organic shapes through natural inspiration of shapes and configuration.

Technology Mapping and Trends

The technological research has been synthetized by defining the main manufacturing sectors involved in the selection of the case studies. Subsequently, five macro-areas were clustered: integrated light, lighting fixtures, artistic lighting installations, optical technologies, lighting effects. Although separate, they present intersection and correlation. The phase of consolidation of the research contents focused on the definition of six different technological macrotrends useful to map the research and to highlight the areas of intervention and application of LED technology (**Figure 1**):

- Modular design, considering lighting engine modules that can be combined at the lighting product level and at the architectural level, to generate "architainment" effects through custom installations;
- Invisible Light Sources, considering edge-lighting technology and the integration of lighting sources in the structure toward the minimalism of the lighting fixture and also the exploitation of the luminous effect of the glass/optical materials;
- Small and Precious, in relation to the repetition of the single light element and in relation to the definition of extra small products, that resemble micro sculptures of light;
- Poetic lighting effects, considering both of the refractive light phenomena, dynamic effects of lighting given the digi-

tization of LEDs and the lighting fixture movement;
- Integration of light into the materials, both inside architectural partitions and inside the furniture;
- Digital manufacture of glass, specifying the advanced manufacturing glass production opportunities toward complex geometries and the variations of production.

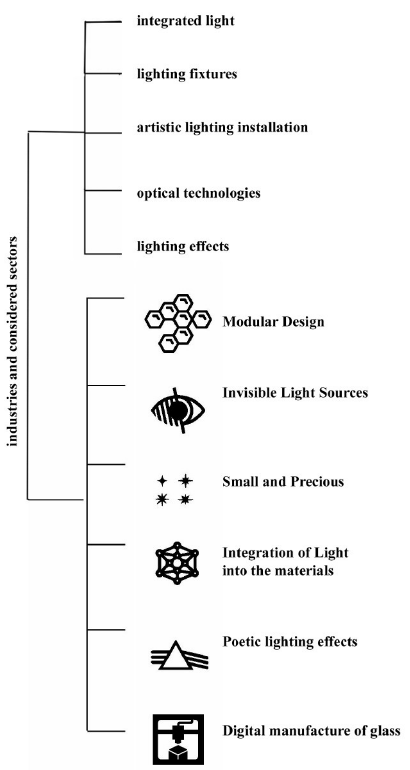

Figure 1: Technological input and constraints for the design phase

In particular:

- Vitrified Light, namely the concept of enhancing the characteristics of glass in combination with lighting through technology, techniques, effects and the integration of light into the material itself. The light sources become invisible or extremely reduced (considering the technology of edge-lighting and the integration of lighting into the structure);
- Mirror of Desire: highlighting the performative and interactive experience of lighting products in relation to the user and the setting;
- Luxury Perception: focusing on the contemplative/emotional effects of lighting (considering the phenomena of light refraction and dynamic effects).

An Overview of the Design Challenge

The course had a methodological purpose, offering both a series of theoretical lectures and a range of practical activities that are preparatory to the design of products or systems of services. Within this framework, the syllabus of this course was built around theoretical lessons, tools/tutorials intended as lessons to support the assignments and a practice–challenge-based outcome. This project-based Learning Module presented students with a problem or challenge to solve in the field of design, requiring gathering information from various resources, analyzing the context, and reflecting upon the complexity. The scope of this course, in particular, was to interpret a technological potential through the LEDs lighting source application by respecting not only a brand with high recognizability but also by valorizing the real heritage characterized by a strong identity. The course was divided into different phases:

- Methodology of Research and analysis: acquisition of the first design skills such as techniques and research methods for the understanding of the product system and interpretative readings of the project context.
- Ideation and Concept phase based on a series of assignments supported by practical activities and reviews to create Mood boards and Lifestyle boards.
- Project development of the main features of the product/service with a technical description/definition/design of the main characteristics of the product along with the surrounding communication system.

Results and Design Achievements

The educational experience ended with the creation of a catalogue made of 16 LED lighting products/systems. It has been analyzed in the following paragraphs to provide an understanding of how the transition to LEDs can be implemented in innovative lighting fixture designs. In the subsequent paragraphs the results are described in terms of achievements of the features of lighting fixtures and in terms of learning outcomes of the course.

Scenario Envisioning

Design scenarios were also produced as an outcome. Design scenarios were considered a way of promoting the cultural and traditional heritage in terms of studying and restoring glassworking processes through the characteristics of the material, but also integrating certain technological aspects. In the current technical, economic and socio-cultural circumstances, characterized by the convergence of many different actors in the design and production process, these scenarios first and foremost represent a pre-design tool for sharing articulated visions and the reasoning behind them [19]. Whilst preserving the cultural and traditional nature of the product, which has its roots in the Precious Heritage scenario, the future of B&T's approach to design was identified with three further scenarios (**Figure 2**), mapped through technological research (**Figure 1**).

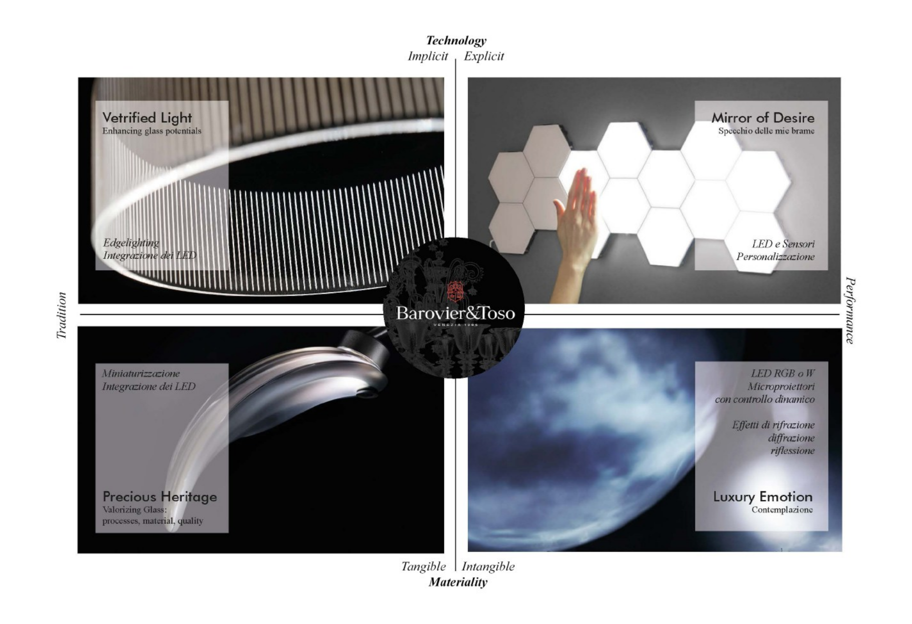

Figure 2: Mapping the technological possibilities of LEDs associated with the four scenarios for the future development of B&T

Innovative Luminous Landscapes

LED technology has been flexibly applied, generating new expressive/formal languages, new aesthetics, new functionalities and a new level of lighting performance. As such, some proposals aimed to provocatively turn the company catalogue on its head whilst respecting B&T's cultural heritage. Most of the proposals were far from the design of a classic lighting fixture. As an example, the proposed pendant luminaires reinterpreted the idea of producing a masterpiece of light and glass, by emphasizing the dematerialization of its structure and components, transparency, lightness and light integration in the material. Flexibility, modularity and configurability were new features that enabled the possibility of creating new lighting landscapes. Lighting elements could be assembled in different morphologies, adapted to different contexts and customized on an architectural scale.

Holistic LED Lighting Fixture Project Management

All the proposals were designed to simultaneously tackle the design of the various interfaces of the lighting fixture: optical, photometric, electrical, mechanical and thermal. The positive consequences of this approach was that all the projects were characterized by a dematerialization of the light sources, integrated into the form and body of the fixture (the Vitrified Light scenario): the LED lighting sources disappear into the structure and the glass material becomes the only perceptible form of light. Finally, the customized design of integrated heatsink allowed for the design of more lightweight - and largely invisible - lighting engines, making for a more attractive aesthetic as well as better-performing, longer-lasting lighting systems.

Figure 3: Mood board for the Luxury Perception Scenario – Aura Concept: Indoor Greenhouse (credits G. Bianchi – P. C. Wei – R. Maltoni – M. Santin)

Figure 4: Mood board for the Luxury Perception Scenario – Bloom Concept (credits E. Ceria – G. Mazzoccato – C. Riva – F. Sciretta)

The New Contemporary Luxury

The Luxury Perception scenario was reinterpreted in a more contemporary sense, including a lot of attention on the subject of nature, both in the action of feeding the plants integrated into the lighting systems and in the design of lighting fixtures inspired by organic and biomorphic shapes (**Figure** 3).

Some solutions improved the lighting effect achieved with the use of miniaturized lighting systems integrated into the glass as a way of making full use of the optical properties of the material and reducing glare and uncomfortable situations. Most of the proposed lighting fixtures used only white light (with a high color rendering index and a color temperature of 3000K - 3500K) to interact with the colors of the glass itself and the specific manufacturing techniques, creating new poetics of light effects: refraction, digital dynamism and movement towards an overall sense of flexibility with regard to the achievable lighting atmospheres. Finally, one proposal focused on the creation of a multi-sensory user experience, incorporating an olfactory experience in addition to the visual one, toward a general sense of well being (**Figure** 4).

Glassworking Enhancement

Many ideas converged towards promoting local and traditional production processes (the Precious Heritage scenario), citing some peculiar forms of glassworking, such as the use of pear wood molds and reintroducing them into the final product (**Figure** 5). Other proposals focused on particular finishes and production methods for glass, such as "rostrato" ('beaked', a sort of spiked effect) and "ballotton" (a cross-relief pattern effect). These traditional features were extrapolated, simplified, stylized and iconically reused to ensure the preservation of B&T's brand recognition.

Lighting as a Dynamic Material

Technology has been interpreted in terms of new functionalities for interaction with lighting systems, with a view to customizing the fixture and its lighting effect (the Mirror of Desire scenario). Numerous proposals explored the theme of the tangible manipulation of the fixture, allowing the user to transform the final effects and atmosphere created by the light by rotating, moving, shifting or replacing the glass elements. Only one solution explored the theme of digital interaction through the use of presence and movement sensors capable of creating different lighting scenarios without directly touching the lighting fixture. (**Figure 6**).

Learning Outcome of the Course

The learning module was aimed to unveil the complexity of the creative process by tackling the following aspects:

- understanding the historical and artistic identity of the lighting company,
- analyzing the reference market,
- investigating the technological aspects related to innovative lighting systems,
- exploring the production processes related to lighting products,
- understanding the production processes and the features related to glass materials
- analyzing the typological-formal values of product design.

Figure 5: Mood board for the Precious Heritage scenario - Batch Concept: museum in a lamp (credits M. Fassi, G. Fazzini, E. Longoni, M. Poggi)

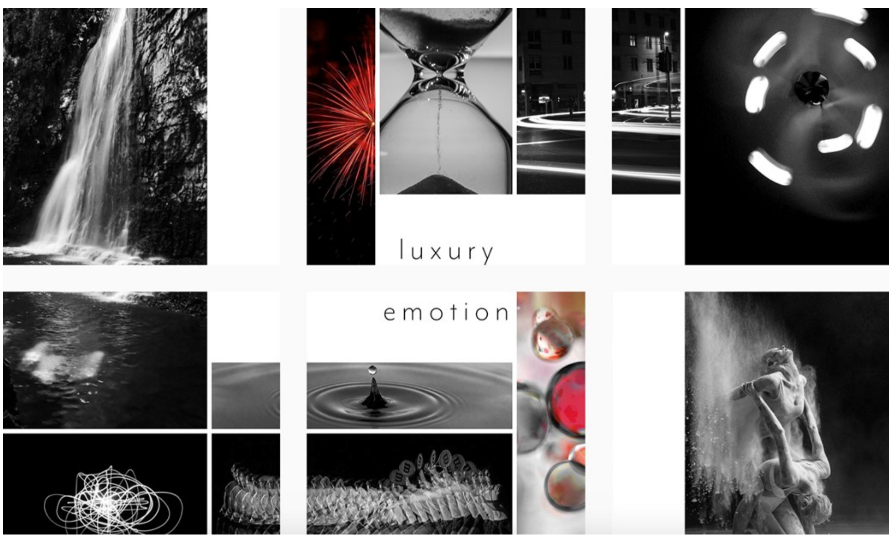

Figure 6: Mood board for Mirror of Desire Scenario - Gravity Concept: motion and emotion (credits S. Antonellini, D. Campo, L. Regalin, G. Massari)

Students were able to pursue an understanding of the reference market and the structure a product repertoire, a definition of the lighting characteristics, knowledge of trends research and design scenarios, to design product concepts in the LED lighting domain and define and technically describe the main characteristics of the lighting fixtures.

Conclusion

This paper presented the methodology of research and design to boost the vision of a traditional lighting fixture company which was willing to open their design path toward a complete and innovative transition to LED lighting taking place in their history and past. Envisioning trends (trend research), analyzing the context, devising possible innovative lighting scenarios and concepts of lighting fixtures, defining and technically describing the main characteristics of the product has been achieved thanks to solid preparation of a design based research. Indeed, design has been considered the central factor of the innovative humanization of technologies and the crucial factor in cultural and economic exchange. In a period of technological shifts in the lighting sector, it is pivotal to envision how the new technology (LEDs and digitalization of lighting) can express their untapped potential through a consistent product design strategy. The design-driven innovation conveys the meaning of the technology to customers, dealing with aesthetics, style, and function, and offers consistency with emerging social and cultural trends [20].

Moreover, considering the wide range of knowledge required to design a lighting fixture, educational experiences aimed at teaching young designers how to conceive an LED lighting fixture require new tools, strategies and methods to address this complexity. Furthermore, the activity of Metadesign, guides and supports the management of this complexity through a preliminary research path that includes understanding the historical, cultural and artistic identity of the company, as well as analyzing the target market. The objective was to design possible scenarios and innovative concepts in line not only with the requirements of a highly recognizable brand, but also with the promotion of a significant heritage characterized by a strong identity enhanced by new technologies. This experimental educational experience proved to be mutually enriching for both the students and the company. The students learned to interact with complex design contexts and content, facing the challenge of responding to a brief launched directly by a company. The company received a new vision of its brand that was reinterpreted through the eyes of future generations of up-and-coming young designers. They were confronted by different opportunities of transitioning toward an innovative technology through the conservation and enhancement of their roots and unique know-how. Designers are involved in this process of innovation and resignification of processes and products both as a sense-maker through a deep and wide research and creators of both meaning and models, prototype and propositions toward a positive change of the company and brand. Even at the stage of concept, the proposal of the students will be able to be part of B&T history in the pages of their next catalogues. ■

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Daria Casciani has specialized in lighting design by earning a doctorate in 2014 at the Politecnico di Milano with her research entitled: "Urban social lighting. Exploring the social dimension of urban lighting for more sustainable urban nightscapes". In 2014, she started teaching project works of Lighting Design for Hospitality and LEDs Product Lighting Design at the Master in Lighting Design & LED Technology and since 2015 she has been adjunct professor at the School of Design of the Politecnico di Milano. She currently develops design and research projects at the Department of Design of the Politecnico di Milano. Working on the new perspectives of the design of LED lighting systems, her main research topics are the new perspectives of LED based lighting fixtures. Since 2011, Daria has participated in more than 15 international peer-reviewed conferences and has written more than 30 scientific papers about her studies.

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References

[1] M. Moec, H. Weiss, T. Noll and F. Holts, "New Form Factor Luminaires and New Light Effects", LED professional, Luger Research e.U, no. 48, pp. 16-21., 2015

[2] McKinsey & Company, "Report: Lighting the way: Perspectives on the global lighting market", 2012 [Online]. Retrieved from: https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/automotive%20and%20assembly/lighting_the_way_perspectives_on_global_lighting_market_2012.ashx.Accessed:07-May-2020]

[3] European Commission, "Lighting the Future. Accelerating the deployment of innovative lighting technologies.", Brussels, 2011 [Online]. Retrieved from: https://publications.europa.eu/en/publication-detail/-/publication/d9c733b3-32a9-42da-8481-0e9e585076cb/language-en.[Accessed:07-May-2020]

[4] Joint Research Centre Technical Report, "Status of LED-Lighting world market in 2017". Ispra, 2018 [Online]. Retrieved from: https://e3p.jrc.ec.europa.eu/sites/default/files/documents/publications/jrc113302_status_of_led_lighting_world_market_in_2017_bertoldi_v3_no_identifiers-1.pdf

[5] D. Casciani, D. Paleari and M. Rossi, "Il design del Solid State Lighting: una sperimentazione continua", Luce, vol. 5, no. 295, pp. 58-64, 2011.

[6] The Boston Consulting Group. How to win in a transforming lighting industry.2015. [Online]. Retrieved from: http://image-src.bcg.com/Images/BCG-How-to-Win-in-a-Transforming-Lighting-Industry-Nov-2015_tcm9-88535.pdf [Accessed:07-May-2020]

[7] K. Krippendorff, The semantic turn. A new foundation for design. London - New York: Taylor & Francis, 2006.

[8] Zunyue Liu, "Made in Italy, branding in China". Editore: Lampi di Stampa (29 aprile 2015) Collana: TiPubblica, 2015, p.54

[9] Barovier & Toso, "Barovier.com", 2020. [Online]. Retrieved from: https://www.barovier.com/it. [Accessed: 10-June- 2020]

[10] M. Urde, S. Greyser and J. Balmer, "Corporate brands with a heritage", Journal of Brand Management, vol. 15, no. 1, pp. 4-19, 2007

[11] D. Aaker, Building strong brands. Simon and Schuster, 2012

[12] A. Van Onck, "Metadesign", Edilizia Moderna, vol. 85, p. 53, 1964

[13] M. Celi, F. Ramponi, "Creativity and Group working. Collaboration and Problem Based Learningas Boosting Activity in Design Creative Process". In EduLearn 2009, Proceedings of thebInternational Conference of Education and new learning technologies. Barcellona, 2009

[14] A. Hines, A., P. Bishop. "Thinking about the Future: Guidelines for Strategic Foresight", Hinesight Edition, Huston TX. 2015

[15] M. Celi e C. Colombi "Innovating trend research practice through a data driven-approach: a blended experience within the design field" in Proceedings of 10th International Conference of Education, Research And Innovation, Seville, 2017, pp.6580-6588. ISBN 978-84-697-6957-7

[16] M. Celi, J. Rudkin, "Drawing food trends: Design potential in shaping food future". Futures, 83,pp.112-121, 2016

[17] E. De Bono, "Serious creativity, using the power of lateral thinking". Harper Collins Publishers,1992.

[18] M. Aaltonen, T. Barth, "How do we make sense of the future?: An analysis of futures research methodology – v2.0". Journal of Future Studies 9(4):45-60, 2005

[19] M. Celi, "Ricerca, visualizzazione e scenari per l'innovazione di processi e prodotti", in Indesit & Design innovation (ed.), Materials driven design, Fausto Lupetti – Dodici edizioni, Milano, 2012

[20] R. Verganti "Designing breakthrough products". HarvardBus. Rev.89,pp. 114–120.2011

Chromaticity Shift Behavior in LED Packages

A systematic investigation of chromaticity shift behavior was conducted on the four major LED package platforms used in lighting applications – i.e., ceramic-based, polymer-based, chip-on-board (COB) packages and chip-scale package (CSP). LM-80 data sets from major LED manufacturers were used to evaluate the recently released method from the Illuminating Engineering Society (IES) for projecting long-term chromaticity shifts (TM-35-19).

The accuracy of the TM-35-19 method to predict chromaticity shifts was evaluated through a series of six case studies. This analysis found that TM-35-19 often provides conservative estimates of chromaticity shift magnitude, but it is much less likely to produce a reliable estimate of chromaticity shift direction. The model appears to be more accurate when the emergence phase of the terminal chromaticity shift is known and there is at least some data to indicate that emergence has occurred. The high degree of sensitivity of the projection accuracy with the length of the LM-80 test measurement interval is a challenge because the chromaticity shift projections can be significantly impacted by what information the LED manufacturer provides in the LM-80-15 report. However, such a model could be beneficial to the lighting industry provided that its limitations are understood.

Introduction

There is a diverse set of LED packages available in the market place designed to tackle an array of different lighting applications. Because of the various LED package families available, there is a wide set of materials and methods of construction used to create these light sources. To better understand the LED lifetime and reliability, a study evaluating the four major phosphor-converted LED package platforms: ceramic-based, polymer-based, chip-on-board (COB) packages, and chip-scale packages (CSP) was undertaken. LED packages rarely fail abruptly (i.e., suddenly stop emitting light), but rather experience parametric failures, such as degradation or shifts in luminous flux or chromaticity point, owing to their materials and methods of construction. The importance of chromaticity stability varies by application, and it may be more detrimental than lumen depreciation for some applications, such as museums or retail stores where multiple lamps or luminaires are used to illuminate a wall, or where objects are being evaluated based on color, such as in a hospital or factory.

The various LED packages can be grouped into 4 major platforms, as illustrated in **Figure 1**:

- High-power ceramic-based LEDs (1–5 W) consist of an LED die mounted onto a ceramic substrate with phosphor-silicone composite on top of the die and a molded silicone hemispherical lens. These are typically used for applications that require high power and high reliability or small source sizes such as directional lamps.
- Mid-power polymer-based LEDs (0.2–1 W) contain one or two small die mounted onto a metal lead frame embedded in a polymer cavity and filled with a phosphor containing encapsulant. These LED packages evolved from the plastic leaded chip carrier type of electronic packages. They are primarily used in omni-directional applications.
- Chip scale packages (1–3 W), also referred to as package-free LEDs, consist of a flip-chip LED die coated with phosphor to create a “white chip”; some styles contain white reflective sidewalls around the die to create a top side emitter. Since the package has a similar footprint to the LED die itself, they can be closely packed together in LED arrays with compact overall source size.
- COBs (10–80 W) vary largely in size and power level. They contain many small LED die mounted to a metal core printed circuit board (PCB) or ceramic substrate, which are then coated with a phosphor containing encapsulant. These are used when high luminance is required from small source size or high lumen density is needed.

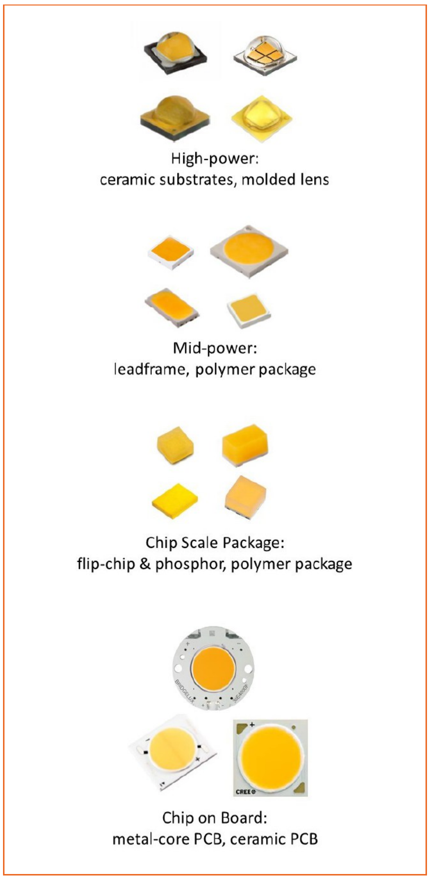

Figure 1: Representative examples of LED packages from the four main platforms, including (from top) high-power ceramic-based LEDs, mid-power polymer-based LEDs, CSP LED packages, and COB LEDs

Methodology

To evaluate the reliability and lifetime behavior of LED packages, the use of consistent experimental measurements is valuable. In 2008, the Illuminating Engineering Society (IES) published the LM-80 standard, an approved method for measuring the lumen maintenance of solid-state (LED) light sources, arrays, and modules [1]. The LM-80-08 procedure required measurements of lumen output and chromaticity for a representative sample of products (typically 20-25) to be taken at least every 1,000 hours, for a minimum of 6,000 hours at each of multiple test conditions. When combined with IES TM-21-11, a projection methodology, it allowed a projection of the rated luminous flux maintenance life using an exponential decay model [2].

In 2015, IES and the American National Standards Institute (ANSI) approved a revision to LM-80 (called LM-80-15) to provide a standardized approach to collecting and reporting both luminous flux and chromaticity maintenance data [3]. The individual chromaticity coordinates (u' and v') are required in LM-80-15, whereas LM-80-08 only required the chromaticity shift magnitude (△ u'v'), which does not inform the direction of the color shift.

While a methodology for projecting lumen maintenance was available in 2011, projecting chromaticity shift proved a much tougher task. The ability to project chromaticity shift for LED packages would help give the industry more information about the expected long-term behavior of LED packages that are integrated into the luminaires. After much work at the committee level, ANSI and IES released TM-35-19 at the end of 2019 to project chromaticity maintenance, using the individual u' and v' chromaticity coordinates reported in the LM-80-15 data sets [4].

The work published in this paper is part of a long-term study on LED package reliability. LM-80 data was analyzed across multiple manufacturers from 2011-2020 to provide new insights into LED-level factors impacting performance. Many Tier 1 LED manufacturers provided over 400 different LM-80 records (**Figure 2**) to our team to help provide insights into commonalities observed across many manufacturers with respect to LED packages reliability.

A first study into the behavior of LED packages occurred in 2014-15 looking at LM-80-08 reports generated between 2011-2015 to assess lumen and chromaticity maintenance across different package platforms and materials of construction[5]. A subsequent study began in 2019 to see how LED packages have improved since the first study with reports from 2018-2020 being evaluated. The study of chromaticity maintenance was aided by the much greater availability of LM-80-15 reports with the individual u' and v' coordinates. This paper will focus on the data collected since 2018.

TM-35-19 Analysis

ANSI/IES TM-35-19 was recently published based on the differential chromaticity analysis (DCA) method, which allows the projection of future values of the u' and v' chromaticity coordinates from the LM-80-15 data. The DCA method applies a curve fit to the data looking at the differential chromaticities and extrapolates the changes in relative chromaticity. It projects the time at which magnitude of the chromaticity shift exceeds an acceptable level (e.g. △ u'v' of 0.004 = CS4 or 0.007 = CS7). Note that the DCA method shall not be used to predict color shifts in excess of △ u'v' $= 0.01$. The TM-35-19 report includes the projected CS4 and CS7 hours and a vector plot of the projected chromaticity shift direction, as seen in **Figure 3**.

Description of LED Light Source Tested (manufacturer, model, catalog number)	Value
Nominal ANSI C78.377 Chromaticity bin, K	
Sample size	
Number of failures	
DUT drive current, mA	
Tested case temperature, °C	
Test duration, hours	
Measurement interval, hours	
Reference time, hours	
Reference δu'	
Reference δv'	
δu'* slope	
δu'* intercept	
δv'* slope	
δv'* intercept	
Reported CS4, hours	
Reported CS7, hours	

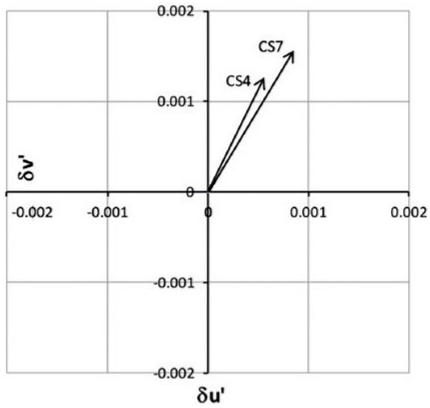

Figure 3: Sample of the information to be included in the TM-35-19 report including a table with the reported CS4 and CS7 hours (time for the chromaticity shift to reach △ u'v' of 0.004 and 0.007, respectively) and a vector plot showing the direction and magnitude of the color shift [4]

The DCA model assumes three phases of behavior from LEDs seen in △ u'v' over time:

- Incubation – a rapid short-term increase in △ u'v' followed by an extended period where it is essentially constant;
- Recovery – sometimes the incubation period is followed by a decrease in △ u'v'; and
- Emergence – increases as an approximately linear function of time until a chromaticity shift threshold is reached, often considered the terminal chromaticity shift mechanism.

Note that there is not always a recovery period observed in all packages. Sometimes the package moves from incubation straight into emergence. This transition on how fast emergence comes about can be linked to stress level in the package (temperature or drive current). **Figure 4** shows two examples of the LED packages moving throw the phases of behavior over time.

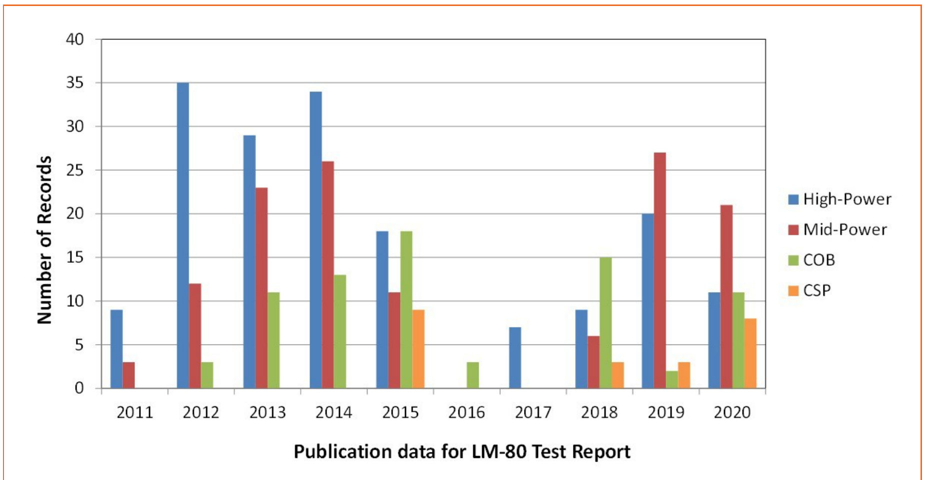

Figure 2: Distribution of LM-80 data sets collected by year of testing completion and LED package type

The goal of this study was to understand how accurate TM-35-19 was at predicting the chromaticity shift of LED packages. Three criteria were used to determine how well the projection worked.

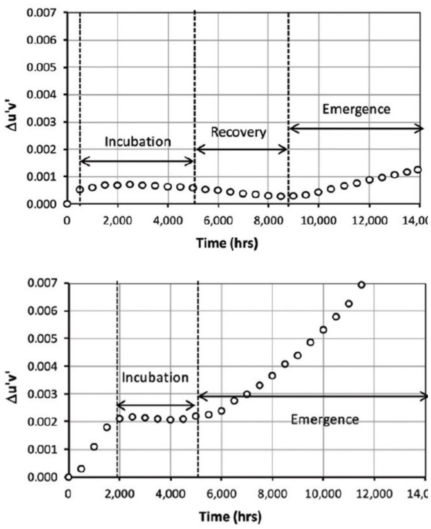

Figure 4: Examples of LED chromaticity shift behavior illustrating incubation, recovery and emergence phases (top) and incubation following directly by emergence phase (bottom) [4]

1. The model should provide accurate projections for chromaticity shift magnitude (△ u'v'). At a minimum, estimates should be conservative – i.e. give a lower CS4 or CS7 value – since the risk for longer projected chromaticity maintenance could result in LED parametric failure earlier than projected by TM-35-19.
2. The model should accurately project the chromaticity shift directions. It should predict a shift in line with the known physical degradation mechanisms in LED packages.
3. The model should provide chromaticity projections with a consistent pattern across the data sets for a given LED product at test conditions that produce the same phase of chromaticity shift (i.e., incubation, recovery, and emergence); however, the time at which different phases and the corresponding chromaticity shifts occur may change depending on the stress level.

Note that these criteria are not mutually encompassing. For example, the model could accurately predict future values of the chromaticity shift magnitude (△ u'v') but could do a poor job with predicting the direction of the chromaticity shift, or vice versa.

This study analyzed 146 data sets that met LM-80-15 reporting requirements, 115 of which had 10,000 or more of test data. To understand the ability of TM-35-19 to predict future chromaticity shifts, its accuracy relative to these 3 criteria was evaluated through a series of six case studies. These results will be summarized here, but more details for the entire study can be found in a recently published report [6].

Case Study 1 - High Power LEDs

This case study considered a high-power LED under high stress operation. This LED was tested at 700 mA and 120 °C for 12,000 hours. The LM-80-15 data (blue curve) was input into the TM-35-19 DCA model and the behavior was projected to 24,000 hours (red curve), as illustrated in **Figure 5**.

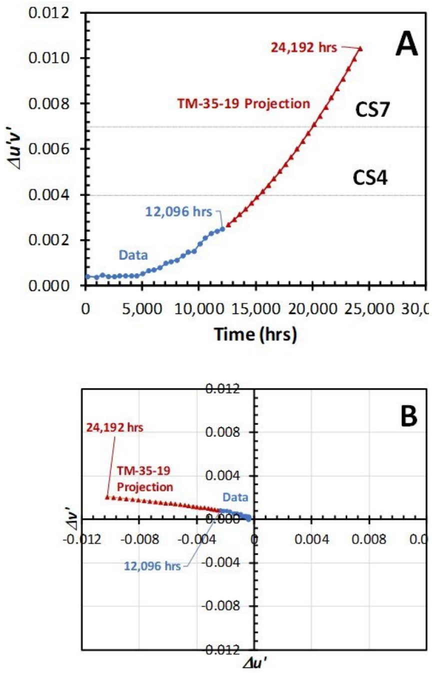

Figure 5: TM-35-19 projections for a population of high-power LEDs in ceramic-based packages for Case Study 1, with (A) showing the magnitude of the chromaticity shift, and (B) showing the projected direction of the chromaticity shift. The blue circles are the experimental data, and the red triangles show the TM-35-19 projections. The LEDs were operated at 120 °C and 700 mA

Key findings: The model provides a reasonable △ u'v' projection for this data (meeting Criterion 1). Criteria 2 and 3 are met as the projections are a continuation of existing data sets.

Case Study 2 – High-Power LEDs Under Longer Test Duration

This next case study was based on the same high-power LED product as Case Study 1, but evaluated a data set with a longer LM-80-15 test duration. In this case, the LED was still measured at 700 mA but at 85 °C instead of 120 °C. As before, 12,000 hours of the measured LM-80 data (blue curve) was used in the TM-35-19 projection (red curve) and compared to the measured 24,000 hours of LM-80 data (gray curve) in **Figure 6** to see how accurate the projection was when using the first 12,000 hours of measured data.

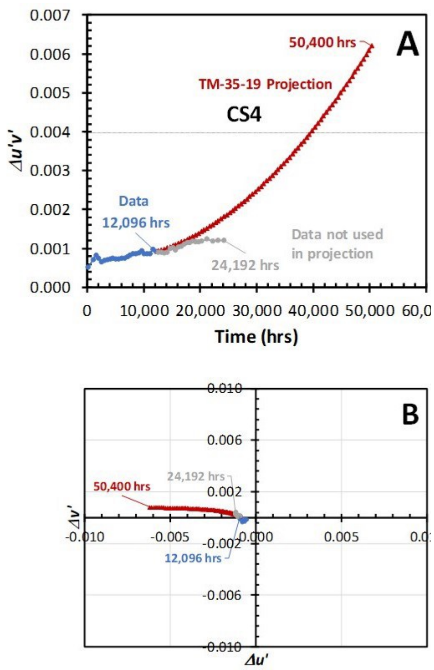

Figure 6: TM-35-19 projections for the population of high-power LEDs in ceramic-based packages in Case Study 2, with (A) showing the magnitude of the chromaticity shift, and (B) showing the projected direction of the chromaticity shift. The blue circles are the experimental data, the red triangles show the TM-35-19 projections, and the gray circles show extra data not used in the projections. The LEDs were operated at 85 °C and 700 mA

Key findings: The projection shows a conservative estimate for △ u'v' (satisfying Criterion 1), but the projection for △ u' is much larger than the measured 24,000 hours of data shows. The projection shows a chromaticity shift in the green direction, but the real data shows more of a change towards yellow. The predicted chromaticity shift direction appears inaccurate (not meeting Criterion 2).

Case Study 3 – High-Power LEDs With Varying Test Intervals

The third case study was based on the same high-power LED product as the first two case studies but explored the sensitivity of the DCA model to measurement interval. LM-80-15 data sets at two different measurement intervals – every 504 hours to every 1,008 hours – were compared. In this case study, all 24,000 hours of measured data was fed into the TM-35-19 projection (**Figure 7**).

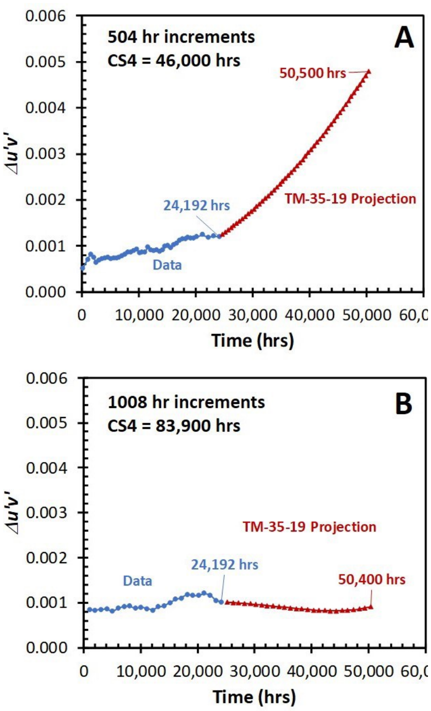

Figure 7: TM-35-19 projections for a population of high-power LEDs in ceramic-based packages for Case Study 3, with (A) showing the magnitude of the chromaticity shift at measurement intervals of 504 hours, and (B) showing the magnitude of the chromaticity shift at measurement intervals of 1,008 hours. The blue circles are the experimental data, and the red triangles show the TM-35-19 projections. The LEDs were operated at 85 °C and 700 mA

Key findings: The projection for △ u'v' is not conservative when using the 1,008 hour measurement interval. It predicts a CS4 time nearly double that projected with the 504 hour measurement interval,thus failing Criterion 1. There is also a different projected direction of color shift for the two intervals, which fails Criteria 2 and 3 [6].

The first three TM-35-19 case studies, performed on the same high-power LED product, are compared in **Table 1**. The following outcomes were determined from this comparison:

- The times for the LED to reach CS4 and CS7 follow the expected trend, showing lower times for higher stress conditions.
- The large increase in CS4 and CS7 times that occurred with a change in the measurement interval indicates a high degree of sensitivity to that parameter.
- This is potentially an issue because the chromaticity projections can be significantly impacted by what information an LED manufacturer provides in the LM-80-15 report. A reported measurement interval could potentially be selected to improve the TM-35-19 projections.
- Most LM-80 reports only provide data up to 10,000 hours and in 1,000-hr increments. Case Studies 1 through 3 suggest that such data would be highly susceptible to inaccuracies when using the TM-35-19 method.

Case Study 4 – COB LEDs

This case study evaluates COB LEDs measured data sets of 12,000 hours under different test conditions (currents and temperatures) – 85 °C at 3300 mA (blue curve) and 105 °C at 2400 mA (purple curve) in **Figure 8**.

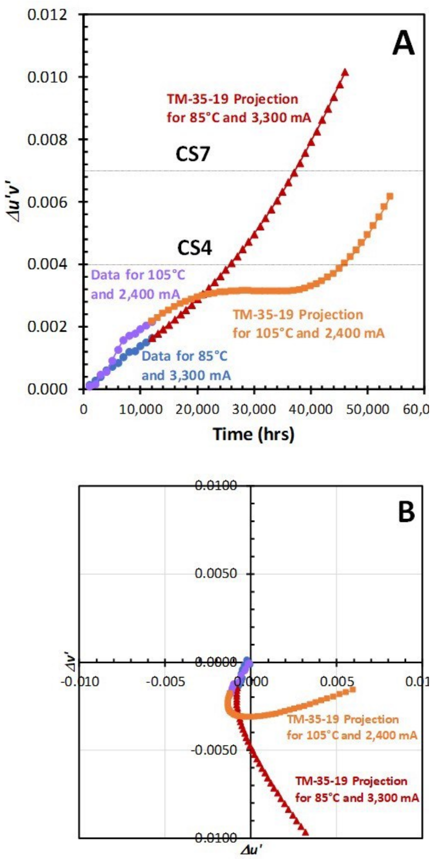

Figure 8: TM-35-19 projections for a population of COB LEDs with a metal-core substrate used for Case Study 4, with (A) showing the magnitude of the chromaticity shift and (B) showing the projected direction of the chromaticity shift

Key findings: The CS4 and CS7 times occurred much sooner at the lower temperature condition than at high temperature. This fails Criterion 1 (not a conservative estimate). The model projects significantly different chromaticity shift directions for the two conditions – driven by a significant difference in the projected values of △ v' versus time. The 85 °C measurement is predicted to shift to the magenta direction which is not a color shift mechanism that has been seen in white phosphor converted LED packages [6]. This fails Criterion 2 because the projected chromaticity shift direction is highly unlikely. The disparity in projected chromaticity shifts for these two samples violate Criterion 3.

Case Study 5 – Mid-Power LEDs

In this 5th case study, the TM-35-19 projections of a mid-power LED package were evaluated using 10,000 hours of the measured LM-80-15 data (blue curve) for the projection (red curve) at 85 °C and 150 mA, as seen in **Figure 9**. This was compared to the measured 17,000 hours of LM-80 data (gray curve) to see how accurate the projection was when using the first 10,000 hours of measured data.

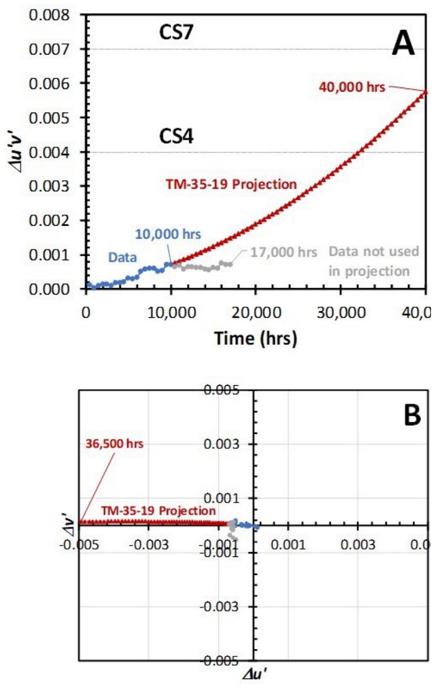

Figure 9: Experimental data and TM-35-19 projections for LEDs housed in a polymer-based package operated at 85 °C and 150 mA, with (A) showing the chromaticity shift and (B) showing the chromaticity shift direction. The first 10,000 hrs of data (blue circles) was used in the TM-35-19 projections (red triangles), with the additional data shown in gray

Key findings: The projection for △ u'v' is conservative (meeting Criterion 1) since it appears to reach CS4 well before the full 17,000 of measured data (gray curve) predicts. The model though appears to over-estimate △ u', resulting in a projected green shift that deviates from what the extra measured data shows. The 17,000 hours of measured data shows a shift in the blue direction (due to the v' component entering the emergence phase of chromaticity shift). This fails Criterion 2 by predicting an inaccurate chromaticity shift direction.

Test Conditions	Test Duration (hrs)	Measurement Interval (hrs)	CS4 (hrs)	CS7 (hrs)	Evaluation Criteria Met	Case Study
120 °C and 700 mA	12,096	504	15,400	20,100	Yes	1
85 °C and 700 mA	12,096	504	39,700	53,700	Yes	2
85 °C and 700 mA	24,192	504	46,000	61,000	Unclear	3
85 °C and 700 mA	24,192	1,008	83,900	102,500	No	3

Table 1: Comparison of the TM-35-19 results for Case Studies 1 through 3

If the full 17,000 hours of LM-80-15 data is now used in the TM-35-19 projection, the predicted behavior changes (**Figure 10**). The 10,000 hour data set was still in the "pre-emergence" phase and resulted in a green shift – contradicting the results from the 17,000 hours of measured data. When using the full 17,000 hours in the projection, the LED has reached the "emergence" phase and projects a magenta shift (highly unlikely with known physical degradation mechanisms of pc-LEDs). Projection for △ u'v' is conservative (meeting Criterion 1) when using 17,000 hours of LM-80 data, but △ v' is likely over-estimated resulting in projected magenta shift (failing Criterion 2).

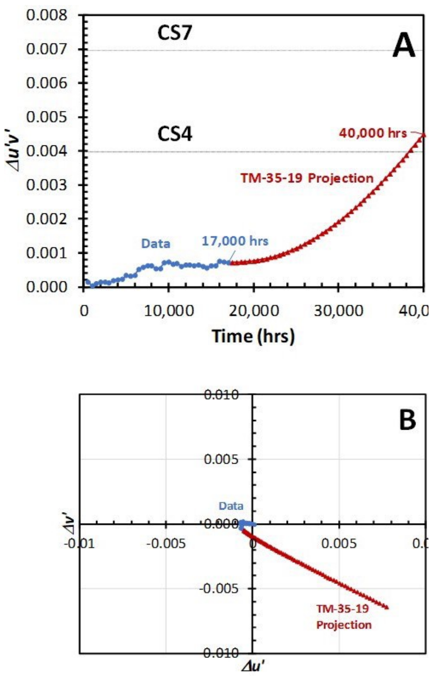

Figure 10: Experimental data and TM-35-19 projections for LEDs housed in a polymer-based package operated at 85 °C and 150 mA, with (A) showing the chromaticity shift magnitude and (B) showing the chromaticity shift direction. The entire 17,000 hrs of data (blue circles) was used in the TM-35-19 projections (red triangles)

Case Study 6 – CSP LEDs

The final case study evaluated a CSP LED tested under different stress conditions for 17,000 hours – 85 °C (blue curve) and 105 °C (purple curve) at 1050 mA, as shown in **Figure 11**. Testing at different temperatures resulted in "emergence" being reached at 105 °C but the LED was still "pre-emergence" at 85 °C after 17,000 hours. This different phase status at the different test conditions resulted in a different predicted chromaticity shift behavior by the TM-35 model. Pre-emergence, the CSP is showing a yellow shift and post-emergence, the yellow shift turns around back to shift in the blue direction.

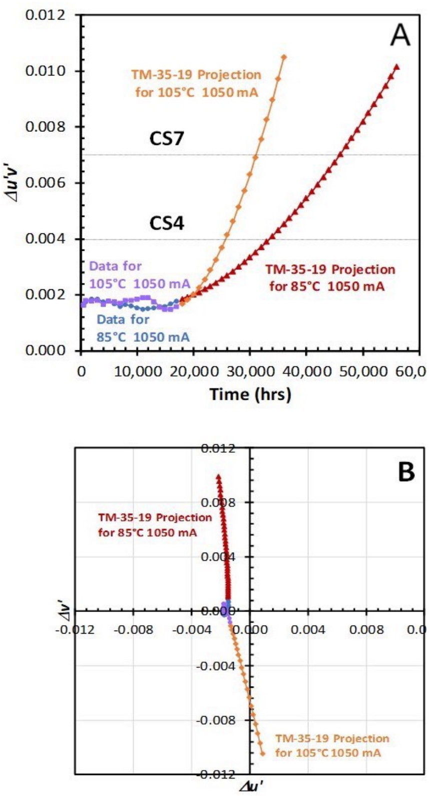

Figure 11: Experimental data and TM-35-19 projections for identical populations of the same LED product in CSP LEDs operated at two different conditions, with (A) showing the magnitude of the chromaticity shift and (B) showing the projected direction of the chromaticity shift for the 17,000 hours of measured data at 85 °C and 105 °C

Key findings: Projection for △ u'v' is conservative (meeting Criterion 1), but there is some uncertainty about the projected chromaticity shift direction (failing Criterion 2). The model likely over-estimated the change in △ u' at 105 °C, which pulls the chromaticity shift towards the magenta direction instead of the blue.

Conclusion

The TM-35-19 methodology for projecting chromaticity shift was evaluated in the four major LED platform in 6 case studies using LM-80-15 data sets from a variety of Tier 1 LED manufacturers. The model is a conservative projection for the magnitude of △ u'v' in LED packages (the predicted time to CSx is usually less than the actual CSx time). In particular, the model works best when the emergence phase is known and there is at least some data to indicate that emergence has occurred.

The model does not appear to accurately predict the direction of the chromaticity shift. Chromaticity point predictions often do not coincide with the known physical degradation mechanisms in types of LED packages being evaluated.

There is a high degree of sensitivity of the projection accuracy with the length of the LM-80 test measurement interval. This is potentially an issue because the chromaticity shift projections can be significantly impacted by what information an LED manufacturer provides in the LM-80-15 report. However, even with such shortcomings, such a model could be beneficial to the lighting industry provided that its limitations are recognized.

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About LED Lighting Advisors
LED Lighting Advisors is an engineering firm providing technical and market expertise for the LED lighting industry. Services include technical guidance for product development and manufacturing, technology evaluations, developing research strategies, intellectual property analysis, and expert witness engagements.

References

[1] Illuminating Engineering Society. (2008). IES LM-80-08 Approved Method: Measuring Lumen Maintenance of LED Light Sources. New York.
[2] Illuminating Engineering Society. (2011). IES TM-21-11, Projecting Long Term Lumen Maintenance of LED Light Sources. New York.
[3] American National Standards Institute and Illuminating Engineering Society. (2015). ANSI/IES LM-80-15 Approved Method: Measuring Luminous Flux and Color Maintenance of LED Packages, Arrays and Modules. New York.
[4] American National Standards Institute and Illuminating Engineering Society. (2019). IES TM-35-19, Technical Memorandum: Projecting Long-Term Chromaticity Coordinate Shift of LED Packages, Arrays, and Modules. New York.
[5] Hansen, M. Package Impact on Color Shift in LEDs. Presentation at the 2016 Strategies in Light Conference, Santa Clara, CA.
[6] Davis, L. and Hansen, M. (2020). Lumen and Chromaticity Maintenance Behavior of Light-Emitting Diode (LED) Packages Based on LM-80 Data. U.S. Department of Energy, Washington, D.C.

Analysis of Heat Paths in LED Retrofit Lamps

Phosphor-based white LEDs have undergone a significant increase in performance and luminous efficacy. Still, the significant heating of the phosphor caused in part by the unavoidable Stokes shift is an issue to be resolved. Thus, the dimensioning of the heat path is an important part of the design process of a luminaire. As the LED manufacturer already optimizes the LED chip itself, the luminaire manufacturer is responsible for good thermal contact of the chip to the printed circuit board (PCB) and possibly also to the housing of the luminaire. Adequate cooling helps to increase the lifetime of the LEDs significantly, but it is also a relevant cost factor. Thus, detailed knowledge of the heat path properties is essential for a competitive product.

Infrared thermography offers a contact-free and automatable method to obtain information on the surface temperature. Furthermore, it allows to measure the temperature distribution over a relatively large area, but can also be combined with microscope optics to achieve spatial resolution on the micrometer scale. Though static thermographic images are used to detect hotspots and temperature gradients, they are less helpful to identify weak points along the heat path between LED and heat sink.

In this work, several LED-based lamps are studied by infrared thermography. A technique is applied that allows to image the thermal properties of the individual components comprising the heat path. The spatially resolved, transient temperature measurements are analyzed for the thermal resistance as well as the thermal relaxation time constants of every component in the heat path. Analyzing the contributions of each part of the samples allows for a deeper insight into the performance of the corresponding heat path. While the total thermal resistance is useful to predict the temperature of a component in the thermal equilibrium, the thermal impedance is used to predict the temperature changes under dynamic loads. Pseudo-color images of the above described parameters allow for an intuitive comparison of the LED retrofit lamps under study. For eight different lamp types, the corresponding heat path is studied in detail.

Introduction

LEDs have a significantly longer operating life compared to other light sources. The enormous lifetime advantage allows to use permanently installed LEDs in luminaires. This opens up a high degree of design freedom, while also providing high electrical efficiency and low production costs. Nevertheless, lights with replaceable illuminants still make up a significant part of the light sources used in everyday life, as they are already installed and used for many decades. LED retrofit lamps are a typical replacement for incandescent light bulbs or fluorescent lamps.

The market for retrofit lamps is characterized by strong competition. Since the cooling system makes a significant contribution to the total cost of a lamp, material-saving and efficient cooling is of great importance. In the low-price sector, this leads to a situation where the cooling system, in particular the material used, is often pushed to the limit of what is technically tolerable. In mass production, this can lead to significant differences in quality and reliability.

In this work, a selection of commercially available LED retrofit lamps is investigated for the performance of their cooling mechanisms. The analysis is conducted via infrared thermography. To obtain detailed information about the thermal properties of the various elements of the heat path, the method of *Network Identification by Deconvolution* is applied [1]. For this purpose, transient thermal measurements are performed on all samples. Details of the evaluation procedure are explained in the following.

Theoretical Background

A common way to describe the temperature response of a device is to construct an electrical equivalent circuit. Such a circuit consists of resistances, R_i, and capacitances, C_i, that mirror the thermal behavior of the device. An example of a suitable circuit with n components is the Foster network, as shown in **Figure 1**.

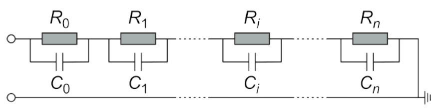

Figure 1: Electrical equivalent circuit in the form of a Foster network with n elements

The temperature response of a device, $T(t)$, to a time dependant power, $P(t)$, is completely described by the complex s-plane impedance of the equivalence network, $Z(s)$. The aim of *Network Identification by Deconvolution* [1] is to construct the components of the s-dependant impedance, $Z(s)$, from the time dependant thermal impedance, $Z_{\text{th}}(t)$, the latter being experimentally determined. The thermal impedance, $Z_{\text{th}}(t)$, can be calculated with the time constant of each RC-component, $\tau_i = R_i \cdot C_i$ by [2]

$$Z_{\text{th}}(t) = \sum_{i=1}^{n} R_i \left(1 - \mathrm{e}^{-t/\tau_i}\right). \qquad (1)$$

As real systems typically show responses on a wide range of time scales, it is useful to perform a transition from a linear time scale to a logarithmic one with the logarithmic time $z = \ln(t)$. The thermal impedance is then called $a(z) = Z_{\text{th}}(t = \exp(z))$. For an optimal description, a large number of components is necessary. Thus, the limit $n \rightarrow \infty$ is taken and **Equation** (1) becomes

$$a(z) = \int_{-\infty}^{\infty} R(\zeta) \left(1 - \exp\left(-e^{z-\zeta}\right)\right) \mathrm{d}\zeta \tag{2}$$

with the logarithmic time constant spectrum $R(\zeta = \ln(\tau))$. Its derivative

$$\frac{\mathrm{d}}{\mathrm{d}z} a(z) = \int_{-\infty}^{\infty} R(\zeta) \exp\left(z - \zeta - e^{z-\zeta}\right) \mathrm{d}\zeta \tag{3}$$

can be interpreted as a convolution of the time constant spectrum, $R(\zeta)$, with the weight function

$$w_z(z) = \exp\left(z - e^{z}\right), \tag{4}$$

resulting in

$$\frac{\mathrm{d}}{\mathrm{d}z} a(z) = (R \otimes w_z)(z). \tag{5}$$

From **Equation** (5) the time constant spectrum, $R(\zeta)$, can be determined by a deconvolution of the derivative, $\mathrm{d}a/\mathrm{d}z$, with respect to $w_z(z)$. Nevertheless, the capacitances, C_i, of the Foster network constructed in this way do not represent the actual thermal capacitances, as the capacitors are not connected to ground. Therefore, an equivalent Cauer network has to be constructed, as shown in **Figure** 2.

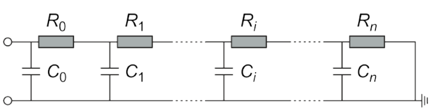

Figure 2: Electrical equivalent Cauer network with n layers. In each layer the capacitance is connected to ground. All resistances are connected in series

The transformation can be achieved by continued polynomial division, as described in [3]. Parallel resistances and capacitances with the impedance $Z_n(s)$ are split off from the n-layer network recursively by applying

$$\frac{1}{Z_n(s)} = s\,C_n + \frac{1}{R_n + Z_{n-1}(s)}. \tag{6}$$

Starting point for the iteration is the impedance $Z(s)$ of the Foster network. The resulting thermal resistances, R_n, and thermal capacitances, C_n, correspond to the physical properties of the layers and interfaces comprising the heat path.

The thermal structure function is defined as the thermal capacitance integrated along the heat path as a function of the thermal resistance integrated along the heat path starting from the heat source. Structure functions diverge when the integrated thermal resistance reaches the stationary thermal resistance, R_{th}, because the surrounding bath has an approximately infinite thermal capacitance.

Experiments

Sample Set

The sample set comprises eight different types of commercially available LED retrofit light bulbs with E27 sockets, more details are listed in **Table** 1. Apart from lamp type C, all lamps were bought in 2020. For better statistics, several specimens of some lamp types were purchased and measured.

Lamp Type	Luminous Flux (lm)	Power (W)	CCT (K)	No. LED
A1	806	7.5	4000	11
A2	806	8.0	2700	14
B1	806	8.5	4000	14
A2	806	8.8	2700	9
C	806	9.0	4000	19
D	1000	10.0	2700	14
E	806	10.0	2700	27
F	1055	11.0	2700	15

Table 1: Specifications of the different lamp types investigated

The lamp types A1/A2 and B1/B2 are sold under the same brand name and differ only in color temperature. The measurements are performed twice on two different lamp sockets, one of which is mainly made of metal, while the other is thinner and made of plastic.

Experimental Details

The experimental setup consists of a thermographic camera system (InfraTec ImageIR 8380S) with a resolution of 640 × 512 pixels and a noise-equivalent temperature difference of less than 25 mK. To increase the sampling rate of the camera to 500 Hz, it is operated in half-frame mode (320 × 256 px). A data acquisition device (National Instrument USB 6003) is used to switch the supply voltage via a solid-state relay and to trigger the thermographic measurements at specific times.

Besides the removal of the white dome to allow a direct view onto the LEDs, the lamps are used in the experiments without any further modification. Prior to the measurement, the lamps are mounted in sockets and operated for an hour to reach thermal equilibrium. Subsequently, the supply voltage is switched off and thermographic images of the cooling process are recorded for another hour. Over the course of these measurements, the initial sampling rate of 500 Hz is reduced to 0.1 Hz. This was done with regard to the logarithmic time scale used in the subsequent evaluation. In addition, this leads to a significant reduction in the required memory space and computing time. Furthermore, the effect of different socket types is investigated.

Calculation Details

To calculate the time constant spectrum, *Network Identification by Deconvolution* is used with slight modifications which are briefly explained in the following. For a more detailed description of the implementation, the reader is referred to [4]. The calculations described below are performed separately for each pixel in the image sequences. For all lamp types, an identical evaluation procedure is applied.

First, the thermal impedance, $Z_{\text{th}}(t)$, is calculated from the initial temperature, T_0, the measured transient temperature, $T(t)$, and the power step, P, via

$$Z_{\text{th}} = \frac{T_0 - T(t)}{P}. \tag{7}$$

The measurement of P includes a precise knowledge about the electrical behavior as well as a value for the emitted optical power of each LED. As the optical power has not been measured, the power, P, is assumed to be unity.

Next, the logarithmic thermal impedance, $a(z)$, is calculated. The data points are subject to noise and not evenly spaced in logarithmic time. Because of this, the numerical calculation of the derivative, $\mathrm{d}a/\mathrm{d}z$, is not trivial. Locally weighted scatterplot smoothing (LOWESS) is applied to obtain a local approximation of the measured data via a polynomial of low order at predefined values z_i. Subsequently, the time constant spectrum, $R(\zeta)$, is determined by solving **Equation** (5) via Bayesian deconvolution [5].

Evaluation

Individual Evaluation

The following evaluation focuses on the LEDs only, as their functionality is essential for every LED-based lamp.

Figure 3 shows exemplarily a thermographic image of lamp type A2. Each LED is clearly visible as a hotspot where the LED temperature reaches over 100 °C. In addition, a part of the PCB legend text and the copper pattern providing electrical contact are seen. These structures are visible as they have slightly different emissivity values compared to the board. The surface of an LED typically has a good emissivity and is assumed to be unity here.

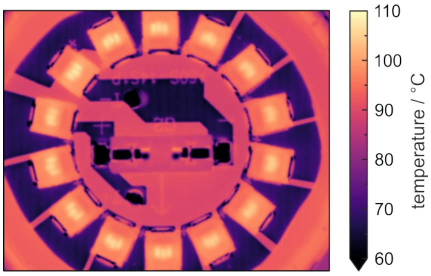

Figure 3: Thermographic image of lamp type A2 at the end of the heating process. The LEDs are clearly visible as hotspots. A part of the PCB legend text and the copper pattern are also seen

Figure 4 shows for four different lamp types the LED cooling curves on a logarithmic time scale. Each curve represents an average over all LEDs of a specimen. Apart from the different starting temperatures, the cooling curves show a significantly different behavior. Several steps of temperature relaxation can be identified which differ in both height and duration.

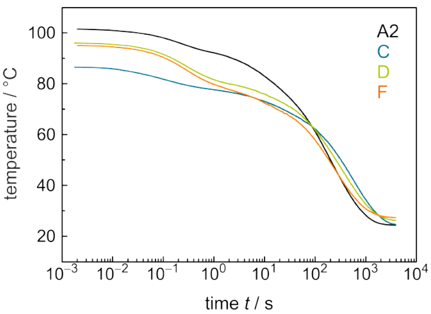

Figure 4: LED cooling curves for four different lamp types. Each curve represents an average over all LEDs of a specimen

The above-described cooling behavior is also reflected in the corresponding time constant spectrum, as shown in **Figure 5**. Here, each cooling step corresponds to a maximum. The area under the maximum is proportional to its contribution to the total temperature difference from start to finish. This is only the case, as the power step, P, is set to one. Thus, the *total* area under the curve is proportional to the *total* temperature difference from start to end. Each thermally significant component of the LED heat path can be related to a maximum in the time constant spectrum. The maximum at approximately 200 ms in **Figure 5** is assigned to the LED, while the maximum at approximately 10 s belongs to the PCB. The last two maxima in the time range of several minutes are assigned to the lamp socket and/or the lamp housing.

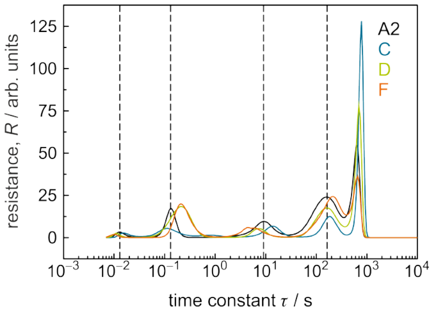

Figure 5: Time constant spectra of the cooling curves, as shown in Figure 4

Figure 6 shows exemplarily the amplitudes of the time constant spectra at the time constants indicated in **Figure 5** by vertical dashed lines. The upper left and right image show that the typical cooling dynamic of the LEDs in the retrofit lamps is of the order of 10 milliseconds and 100 milliseconds, respectively. The bottom left image shows an amplitude that is relatively evenly distributed over the entire PCB, while the bottom right image shows significant cooling which also includes the outer rim of the lamp.

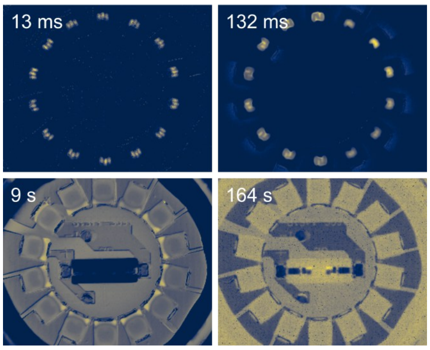

Figure 6: Amplitude of the time constant spectrum for lamp type A2. The corresponding time constants are indicated in Figure 5 by vertical dashed lines

Ensemble Evaluation

In contrast to the above evaluation, where lamp type A2 has been evaluated exemplarily for its cooling behavior, in this section, the complete lamp set (**Table 1**) is statistically evaluated.

As this analysis focuses on the performance of the LEDs, the spatially resolved

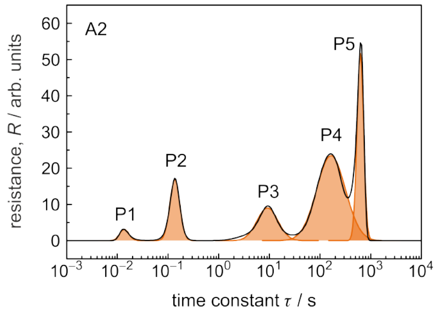

Figure 7: Time constant spectrum averaged over one LED. Five Gaussian distributions (orange curves) approximate the area under the curve

data are averaged in the following evaluation. In the case of lamp type A2, the 14 glowing spots from the LEDs, as seen in the top images of **Figure 6**, roughly correspond to the areas over which is averaged. A Gaussian distribution is fitted to the peaks of the averaged time constant spectrum for each LED. This is shown exemplarily in **Figure 7** for one of the LEDs from lamp type A2. The areas comprising the peaks P1 to P5 form the basis for further analysis.

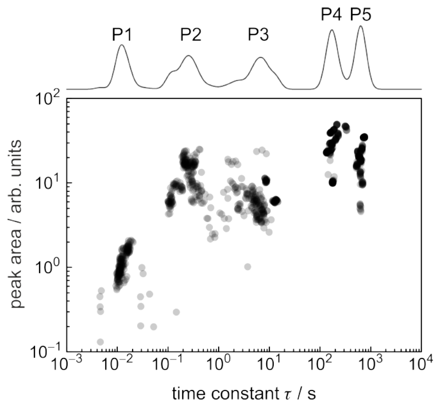

Figure 8: Density plot of the peak areas comprising the time constant spectra of all LEDs from all investigated lamp types

The area under the Gaussian curves are calculated for all LEDs of all lamp types and are subsequently plotted versus the corresponding time constant, as shown in **Figure 8**. In the results, both socket types (metal and plastic) are included. **Figure 8** comprises more than 1000 data points. As expected, the points separate in five clusters, which correspond to the five peaks labeled P1 to P5. This means that the lamps investigated here share a common design principle. A closer look reveals a sub-structure within the clusters which is probably caused by the slight differences between the lamp types investigated.

In **Figure 9** all maxima belonging to lamp type A2 and B1 are indicated as orange and blue dots, respectively. While for both lamp types the points for the P1 cluster are very close to each other, the P2 cluster separates both in time constant and peak area. This reveals a significant difference in design or mounting process between the two lamp types. The P3 cluster, which corresponds to the cooling of the PCB, shows a large variance for lamp type A2. In contrast, the points for lamp type B1 are closely grouped.

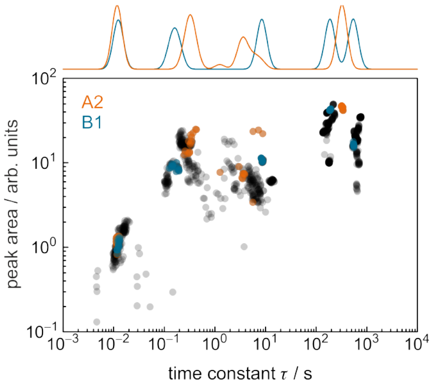

Figure 9: Density plot of the peak areas comprising the time constant spectra grouped for each investigated lamp

In the experiment, repeated measurements on two different lamp sockets are conducted, one of which is mainly made of metal, while the second one is thinner and made of plastic. In **Figure 10**, the starting temperatures of all LEDs are compared to each other for both socket types. For lamp types A1, A2, C, and E, the use of a metal socket results in a noticeable increase in temperature. For lamp types B1, B2, D, and F, the use of a plastic socket leads to an increase in the median temperatures which are indicated as horizontal lines. Notably, lamps of similar designs such as type A1 and A2 as well as B1 and B2 behave similarly.

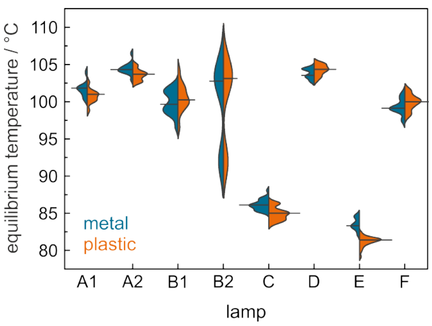

Figure 10: Violin plot of all starting temperatures for two different socket types (metal and plastic). The horizontal lines indicate the median temperatures

Conclusion

In this work, transient thermographic image sequences are used to determine spatially resolved time constant spectra. A range of different LED retrofit lamps is investigated and statistically analyzed. The cooling performance of various parts of the LEDs is compared to each other. This allows to rank the thermal impact of various design decisions in practice. It turned out that for some lamp types the mounting (metal/-plastic socket) has a significant impact on equilibrium phosphor temperatures. ■

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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.

CO-AUTHORS: Nils J. ZIEGELER (South Westphalia University of Applied Sciences), Prof. Dr. Stefan SCHWEIZER (Fraunhofer Application Center for Inorganic Phosphors, South Westphalia University of Applied Sciences).

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.

References

[1] V. Szekely, “Identification of RC networks by deconvolution: chances and limits”, IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol. 45, no. 3, pp. 244-258, 1998
[2] Y. Ezzahri, A. Shakouri, “Application of network identification by deconvolution method to the thermal analysis of the pump-probe transient thermoreflectance signal”, Rev. Sci. Instrum., vol. 80, no. 7, 2009
[3] Y. C. Gerstenmaier, W. Kiffe, G. Wachutka, “Combination of thermal subsystems modeled by rapid circuit transformation”, 13th International Workshop on Thermal Investigation of ICs and Systems (THERMINIC), pp. 115-120, 2007
[4] N. J. Ziegeler, P. W. Nolte, S. Schweizer, “Thermal equivalence networks for analysis of transient thermographic data”, 26th International Workshop on Thermal Investigation of ICs and Systems (THERMINIC), unpublished
[5] T. J. Kennett, W. V. Prestwich, A. Robertson, “Bayesian deconvolution I: convergent properties”, Nuclear Instruments and Methods, vol. 151, no. 1-2, pp. 285-292, 1978

Micro-LED Displays: New Opportunities for Nitride-Based Red LED Technologies

Phosphide-based LEDs are widely used for conventional red LED applications. Even with the recent progress of nitride-based red LEDs, their performance is still not competitive with phosphide-based red LEDs. However, the requirements for the micro-LED display application are different compared to conventional applications which make nitride-based red LEDs attractive despite lower performance. For successful micro-LED volume production, cost and yield are inevitable but silicon industry manufacturing excellence on large substrate diameters like 200 mm or 300 mm could be the solution. Therefore, when grown on a Si substrate, nitride-based red LEDs offer opportunities for micro-LED display applications.

In this article, Atsushi Nishikawa, CTO at ALLOS Semiconductors GmbH, and Prof. Kazuhiro Ohkawa, principal investigator of the Energy Conversion Devices and Material (ECO Devices) laboratory at the King Abdullah University of Science and Technology (KAUST) will describe the issues and recent progress on high-Indium (In)-content $In_xGa_{1-x}N$ red LEDs and the combination of such red LEDs growth on a Si substrate (GaN-on-Si). The findings are based on 17 years of research and development at ALLOS Semiconductors and KAUST.

Red LEDs for Micro-LED Display Application

Micron-sized light-emitting diodes (micro-LED) have huge advantages for next-generation high-performance displays compared with conventional liquid-crystal displays (LCDs) and organic light-emitting diode (OLED)-based displays. One of the distinguishing features of micro-LED displays is high-energy efficiency which could dramatically reduce the energy consumption for large size displays for TV applications and increase the battery run-time for small size displays for mobile applications like smartwatches, augmented reality (AR) glasses or smartphones. Incredible product prototypes have been demonstrated from many companies since the first demonstrator of such novel displays was shown by Sony in 2012 [1] but technical challenges to produce such micro-LED displays which cause low yield and high cost are still presently existing. Thus, the status of micro-LED display development is to evaluate and assemble the options proposed along the entire supply chain of micro-LED display production, for example, GaN epitaxy, flip-chip thin film process, substrate removal, LED chip mass-transfer and testing. Among them, using nitride-based red micro-LEDs is one aspect attracting attention for the development.

For full-color display, each pixel consists of three tiny micron-sized LEDs emitting in the three primary colors: red, green and blue (RGB). $In_xGa_{1-x}N$ alloys are a suitable material to fabricate micro-LED displays because its bandgap energy can be tailored with its In content adjusted for these three primary colors [2][3]. However, while $In_xGa_{1-x}N$-based blue LEDs have achieved record-high external quantum efficiency (EQE) exceeding 80% [4], the EQE degrades significantly with higher In content to achieve longer wavelength emissions [5]. For green, the EQE is already significantly lower but is still the material of choice for any green LED application today, while phosphide-based red LEDs (AlGaInP-based LEDs) are the market's choice for red. This is because despite recent progress of $In_xGa_{1-x}N$-based red LEDs, their In content is even higher than for green thus impacting their performance and rendering it uncompetitive against the AlGaInP LEDs in conventional applications. However, the requirements for micro-LED display applications are different compared to conventional LED applications which make $In_xGa_{1-x}N$-based red LEDs attractive even with lower performance. This is because it opens the way for the production of full color micro-LED displays by using only one material system and low-cost, high-yield manufacturing equipment as we will explain below. At the same time

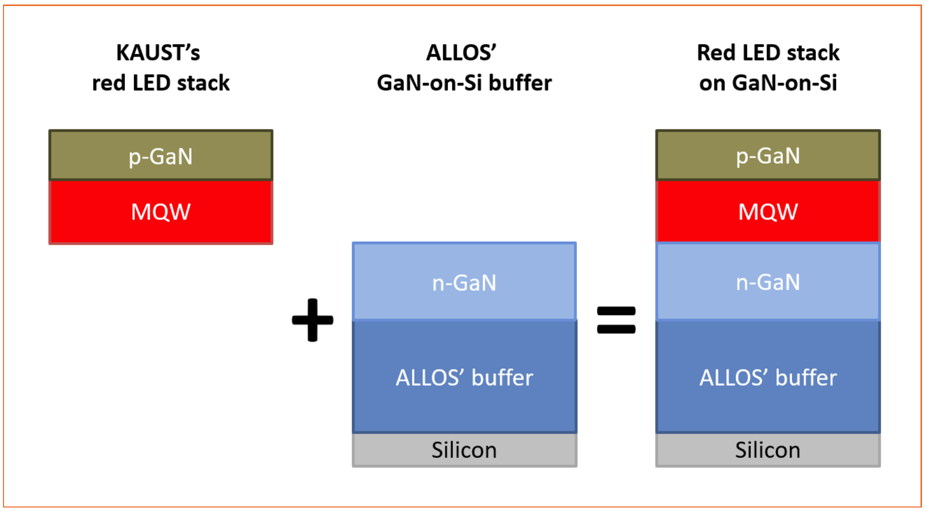

Figure 1: ALLOS' established methods of integrating different LED stacks with its high crystal quality and strain-engineering buffer technology were used in the collaboration

this approach does not requires any color conversion technology, which is another promising approach to contribute the red light component but has its own complexity and yield challenges.

Synergy with GaN-on-Si Technology

Nitride red LEDs are typically grown on sapphire substrates because it is the conventional and most common substrate for GaN growth. However, there are several other substrates available for GaN growth such as Si, SiC, Ga_2O_3, $ScAlMgO_4$, and even GaN bulk substrate. The key criteria of the substrate choices for the micro-LED display application are cost and yield because the consumer display market is very cost-sensitive. For successful micro-LED volume production, cost and yield are inevitable, which is only possible with silicon industry manufacturing excellence on large substrate diameters like 200 mm or 300 mm. This option can only be offered with nitride-based red LEDs grown on a Si substrate, which is not possible for conventional phosphide-based LEDs [6]. Several other beneficial factors play a role to reduce cost and increase yield. These stretch from reducing complexity by being able to use the same material system and thus the same growth reactors via the same chip processes and driving voltages to be able to use the same wafer diameter for all three colors. In other words, not the EQE but cost and yield as well as system level considerations can be the dominating parameters in micro-LED displays. Furthermore, matching the wafer size when combing the LED wafers (e.g. by wafer bonding) with CMOS driver wafers is important for micro-LED displays with extremely high PPI. With GaN-on-Si the use of the advanced technology nodes of 300 mm silicon process lines can be enabled for more functionality and increase of energy efficiency of the CMOS driver.

The GaN-on-Si used for the work in this article was developed with focus on strain-engineering to overcome hetero-epitaxy issues with large lattice mismatch between GaN and Si. Due to the precise strain-engineering technology, we are able to achieve excellent emission uniformity. Emission uniformity standard deviation of 0.57 nm for 200 mm GaN-on-Si blue LED epiwafer is achieved [7] and also scale up to 300 mm diameter [8]. Together with the cost and yield advantages in the entire supply chain of micro-LED display production, nitride red LEDs have a huge opportunity to contribute to micro-LED adaptation when grown on a Si substrate. In a collaboration with red nitride expert Prof. Ohkawa, methods of integrating this high crystal quality and strain-engineering buffer with different red LED stacks could be developed [9] (**Figure 1**).

Red Nitride LEDs Suffer from Low Efficiency Due to High In Content

In order to achieve red emission from $In_xGa_{1-x}N$-based LEDs, In content needs to be increased in the $In_xGa_{1-x}N$ multi-quantum wells (MQWs). Two main issues arise which result in the EQE degradation at this longer emission wavelength. At first, high-In-content causes phase separation in $In_xGa_{1-x}N$ MQWs and large lattice mismatch between $In_xGa_{1-x}N$ MQWs and GaN barrier layers, introducing more non-radiative recombination centers due to degradation of crystal quality and increase in threading dislocation [10]. Second, high-In-content causes stronger piezoelectric polarization fields within the MQWs, which decreases the overlap of the electron and the hole wave functions due to the quantum-confined Stark effect (QCSE) [11][12]. This results in lower radiative recombination rates in the $In_xGa_{1-x}N$ MQWs and thus lower EQE.

Much effort has been devoted to overcoming the issues mentioned above in the last decade. Huang et al. took an approach to insert a 1-nm-thick AlGaN interlayer between an $In_xGa_{1-x}N$ QWs and barrier layers for local strain compensation of the higher In content in the MQW [13]. The output power and EQE at an injection current of 20 mA were measured to be 1.1 mW and 2.9%, respectively, at an emission wavelength of 629 nm with a full width at half maximum (FWHM) of 53 nm. Vadivelu et al. demonstrated a nanocolumn red LED with $In_xGa_{1-x}N$ MQWs where emission wavelength was 633 nm with a full width at half maximum of 185 nm [14]. Nanocolumn structure can reduce the influence of the QCSE and maintain high crystal quality even for higher In-content. However, the light output power at an injection current of 20 mA was still low as 26 µW. Doping a rare earth element, europium, into GaN, Nishikawa et al. have fabricated a red LED where emission wavelength was 621 nm with a full width at half maximum (FWHM) of 1 nm [15]. This ultra-narrow spectrum is due to the emission from Eu ions in the GaN. After the first demonstration, Mitchell et al. reported a maximum EQE of 9.2% at an injection current of 2 mA and 3.3% at 20 mA [16]. In summary, nitride red LEDs tend to have lower EQE because of low-quality $In_xGa_{1-x}N$ and local strain due to large lattice mismatch. In the next section, we will describe the recent progress on nitride-based red LEDs to improve crystal quality and compensate for the local strain in MQWs.

Recent Progress on Nitride-Based Red LEDs

The KAUST team has modified a horizontal metalorganic chemical vapor deposition (MOCVD) reactor design to increase the In content in $In_xGa_{1-x}N$ for realizing $In_xGa_{1-x}N$-based red LEDs with a longer wavelength and higher EQE [17]. Reducing the ceiling height from 7.5 mm to 5.0 mm increases the gas temperature above the substrate due to radiation heat from the ceiling which enhances the chemical reaction at the substrate surface. From the simulation using the code of CFD-ACE+ (ESI, France) with the Nitride-MOVPE database (Wave Front, Japan), the team found that atomic In and decomposed NH_2 concentrations around the substrate surface are much higher in the case of the smaller ceiling height. These higher atomic In and decomposed NH_2 concentrations efficiently suppress the In re-evaporations from the $In_xGa_{1-x}N$ growth surface, resulting in the higher In content in $In_xGa_{1-x}N$ [18]. Thus, the modification of the reactor design successfully extends the emission wavelength by 100 nm. In addition, increasing a period of MQW from 5 to 16 periods further extends the emission wavelength up to 740 nm due to the strain relaxation in the $In_xGa_{1-x}N$ MQWs (**Figure 2**). As a result, the team demonstrated the $In_xGa_{1-x}N$-based RGB LEDs with various In contents on the same reactor. It is noteworthy that high-In-content $In_xGa_{1-x}N$ red LEDs can be grown at relatively high temperatures with this modified reactor which could improve the crystal quality of $In_xGa_{1-x}N$ and EQE of the red LEDs.

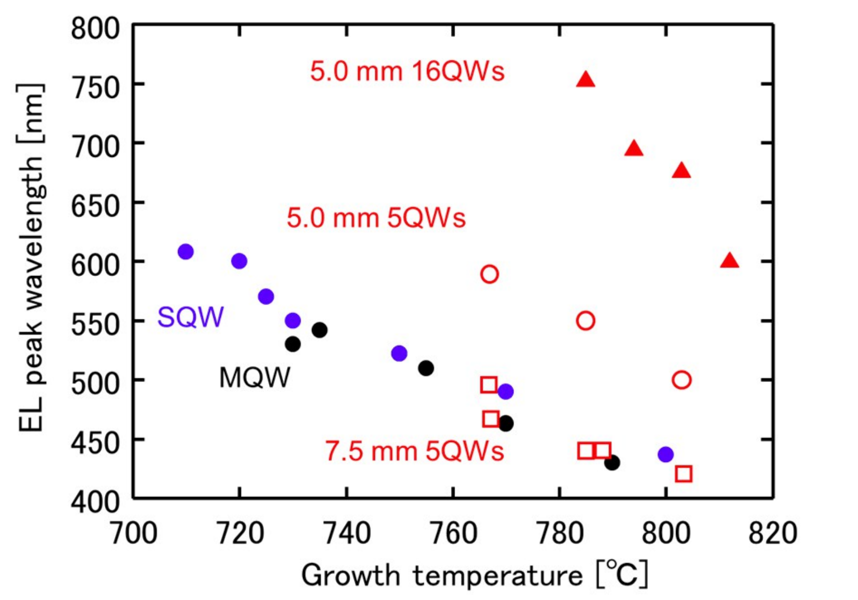

Figure 2: Dependence of the EL peak wavelength from $In_xGa_{1-x}N$ MQWs grown in the reactor with the ceiling height of 5.0 mm and 7.5 mm from the substrate surface. Extension of the emission wavelength is achieved with the modified reactor with the ceiling height of 5.0 mm. Further extension of the emission wavelength up to 740 nm is observed with 16 periods of MQWs due to the relaxation of the strain in InxGa1-xN MQWs

Recently, the team has intensively investigated the effect of residual in-plain stress in $In_xGa_{1-x}N$ MQW and found that emission peak and EL intensity (**Figure 3**) of $In_xGa_{1-x}N$ MQWs strongly depends on in-plain residual compressive stress and dislocation density of underlying n-GaN layer [19]. Growing $In_xGa_{1-x}N$ MQWs on an 8 µm-thick n-GaN layer on a sapphire substrate, an EQE of 1.6% was achieved at an injection current of 20 mA with the emission wavelength of 633 nm. Therefore, the collaboration between the $In_xGa_{1-x}N$-based red LED technology and the developed thick and high-quality GaN-on-Si technology not only aims to enjoy the benefits for cost and yield from the silicon matured process but also aims to improve $In_xGa_{1-x}N$-based red LED performance through the combination of the strain-engineering technology and the understanding on the local strain control around MQWs.

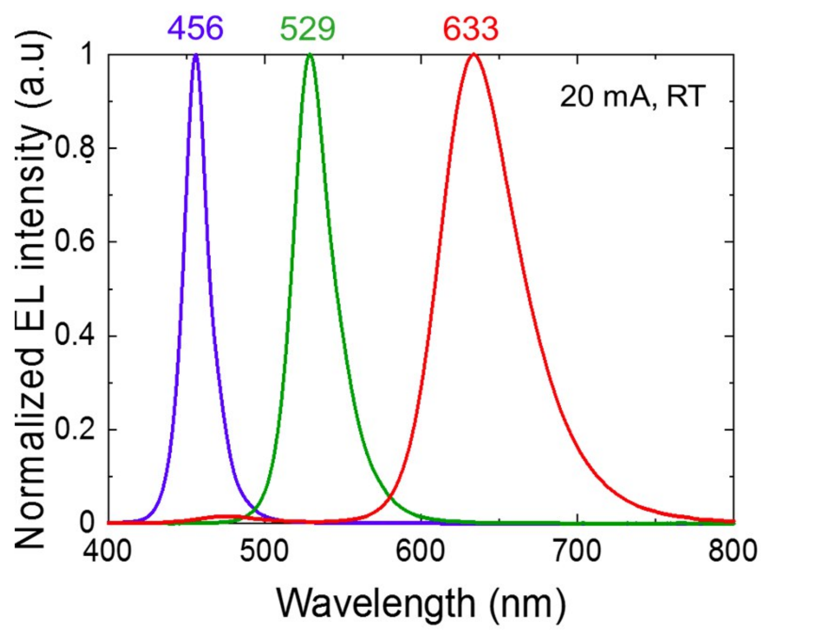

Figure 3: Normalized EL spectra from $In_xGa_{1-x}N$-based RGB LEDs with various In contents

Conclusions

Nitride-based red LEDs have a huge opportunity to contribute to the mass market adaptation of micro-LEDs displays. The growth on a Si substrate plays a crucial role in the necessary cost and yield improvements. The teams of both KAUST and ALLOS combine their unique technologies to handle the strain and optimize growth conditions for GaN-on-Si red LEDs. To this end, the red LED stack will be grown on top of the GaN-on-Si-buffer layers, which will be fine-tuned during the collaboration to optimize the performance of the red LED stack. ■

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Dr. Atsushi Nishikawa is Chief Technology Officer of ALLOS Semiconductors, a GaN-on-Si developing and licensing company focusing on micro-LED display technologies. Nishikawa has more than 18 years' experience in MOCVD growth of III-nitride. Prior to co-founding ALLOS he was head of epitaxy at GaN-on-Si pioneer AZZURRO Semiconductors and worked in GaN-related research at NTT labs and Osaka University. At ALLOS he continues to head the advancement of the technology as well as the transfer of ALLOS' GaN-on-Si technology to its customers' reactors.

About ALLOS Semiconductors
ALLOS Semiconductors is an engineering and consulting company helping clients from the semiconductor industry worldwide to master GaN-on-Si technology and unleash its benefits. The ALLOS team builds on longstanding experience in the GaN-on-Si space and offers a complete set of services based on its unique and patent protected technology.

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Kazuhiro Ohkawa is a professor at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. He is the principal investigator of the Energy Conversion Devices and Material (ECO Devices) laboratory. Also, he is a Fellow of the Japan Society of Applied Physics. He received the Ph. D. degree from the University of Tokyo, Japan. He worked for Panasonic, University of Bremen as a lifelong honorary professor in Germany, and Tokyo University of Science. His research interests are crystal growth mechanism and optical devices. He has developed a nitride MOVPE simulation. It becomes a useful technology for LED/LD and electronic device companies. He invented nitride photocatalysts that work as water splitting or artificial photosynthesis. His group developed a novel flow-channel of MOVPE. This MOVPE technology made it possible to grow high-In-content high-quality InGaN and resulting in red LEDs. He served as a technical advisor to approximately 20 companies in the fields of LEDs & LDs, MOVPE, and photocatalysis.

References

[1] SONY, news releases, 2012, https://www.sony.net/SonyInfo/News/Press/201201/12-005E/
[2] S. Nakamura, M. Senoh, N. Iwasa and S. Nagahama, Jpn. J. Appl. Phys. 34, L797 (1995)
[3] T. Mukai, M. Yamada and S. Nakamura, Jpn. J. Appl. Phys. 38, 3976 (1999)
[4] Y. Narukawa, M. Ichikawa, D. Sanga, M. Sano, and T. Mukai, J. Phys. D: Appl. Phys. 43, 354002 (2010)
[5] B. Damilano and B. Gil, J. Phys. D: Appl. Phys. 48, 403001 (2015)
[6] B. Slischka, A. Nishikawa, and A. Loesing, Semiconductor Today, 15, 48 (2020)
[7] ALLOS Semiconductors, SID Display week 2019, Session 25.1. and press release, 2019, https://www.allos-semiconductors.com/news/display-week-2019/
[8] ALLOS Semicondcutors, press release, 2020, https://www.allos-semiconductors.com/news/first-300-mm-wafer/
[9] ALLOS Semiconductors, press release, 2020, https://www.allos-semiconductors.com/news/red-led-collaboration-en/
[10] S. Nakamura, Science, 281, 956 (1998)
[11] T. Takeuchi, S. Sota, M. Katsuragawa, M. Komori, H. Takeuchi, H. Amano and I. Akasaki, Jpn. J. Appl. Phys. 36, L382 (1997)
[12] T. Takeuchi, C. Wetzel, S. Yamaguchi, H. Sakai, H. Amano, I. Akasaki, Y. Kaneko, S. Nakagawa, Y. Yamaoka and N. Yamada, Appl. Phys. Lett. 73, 1691 (1998)
[13] J. Hwang, R. Hashimoto, S. Saito and S. Nunoue, Appl. Phy. Express 7, 071003 (2014)
[14] R. Vadivelu, Y. Igawa and K. Kishino, Jpn. J. Appl. Phys. 52, 08JE18 (2013)
[15] A. Nishikawa, T. Kawasaki, N. Furukawa, Y. Terai, and Y. Fujiwara, Appl. Phys. Express 2, 071004 (2009)
[16] B. Mitchell, V. Dierolf , T. Gregorkiewicz and Y. Fujiwara, J. Appl. Phys. 123, 160901 (2018)
[17] K. Ohkawa, T. Watanabe, M. Sakamoto, A. Hirako and M. Deura, J. Cryst. Growth 343, 13 (2012)
[18] K. Ohkawa, F. Ichinohe, T. Watanabe, K. Nakamura, D. Iida, J. Cryst. Growth 512, 69 (2019)
[19] D. Iida, Z. Zhuang, P. S. Kirilenko, M. Velazquez-Rizo, and K. Ohkawa, Appl. Phys. Lett. 116, 162101 (2020)

International Solid State Lighting Alliance (ISA)

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

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

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

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

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Quo Vadis Biogenic Phosphors?

White light-emitting diodes (WLEDs) consist of a blue-light emitting chip that is covered with yellow-emitting inorganic phosphors based on rare-earth or toxic materials that are regulated by a few countries. Indeed, they are one of the most critical bottlenecks when trying to ensure the sustainable development of WLEDs. In this context, several groups have focused on developing cheap and environmentally friendly organic phosphors based on polymers, small molecules, complexes, etc. ARTIBLED is a European FET-OPEN initiative that aims at advancing organic phosphors based on fluorescent proteins as emitters and artificial or biogenic polymers as a packaging matrix. This will lead to a new class of color down-converting filters or biogenic phosphors for the next generation of sustainable WLEDs. Herein, Dr. Rubén D. Costa and his colleagues, Dr. Cortajarena, Dr. Coto, Dr. Barolo, Dr. Ghersi, and Dr. Oberdorfer provide an overview of ARTIBLED, highlighting the recent results in the development of the first devices, based on fully biogenic phosphors.

White light-emitting diodes (WLEDs) are the future of artificial illumination promising to reduce 20% of the global electricity consumption and annual emissions equivalent of 35 million tons of CO_2 by 2025 [1]-[4]. Commercial WLEDs consist of a highly efficient blue-chip covered by a color filter or inorganic phosphor, such as Ce_3^+ doped yttrium aluminum garnet (Ce:YAG) and Cd-based quantum dots (CdQDs). A major concern about the WLED technology is its sustainable development with respect to the inorganic phosphors due to toxicity, ecological footprint, scarcity, high costs, and lack of efficient recycling protocols. Indeed, both, US and EU governments, mandate the search for eco-friendly, sustainable, and low-cost color filters for the next generation of WLEDs [1]-[4].

Introduction

Many groups are revisiting the development of organic phosphors for white LEDs, which combine dyes, conjugated polymers, coordination complexes, fluorescent proteins, etc. as emitters and polymer matrices as packaging [5]-[9]. However, meeting high stabilities (thousands of hours) at high luminous efficiencies (>100 lm/W) under operation conditions still represents a challenge. Up until now, the best organic phosphors are based on perylene diamide dyes (700 h at >120 lm/W) [6] and hybrid iridium(III) complexes-silica nanoparticles (10,000 h at ca. 5 lm/W) [9], while biogenic phosphors based on fluorescent proteins have recently stood out, achieving green bio-hybrid LEDs (BioHLEDs) with efficiencies of 130 lm/W and stabilities of 3,700 h [10], and white devices with efficiencies of 50 lm/W and stabilities of 400 h [10]-[14].

Up until now, there are two types of biogenic phosphors (**Figure 1**):

- Biogenic emitters like fluorescent proteins stabilized in polymer matrices [10]-[14] and metal organic frameworks [15]-[16]
- Artificial emitters stabilized in biogenic matrices like DNA [17], proteins [18], and cellulose [19].

In this context, FET-OPEN initiative ARTIBLED aims at engineering artificial fluorescent proteins in combination with biogenic packaging matrices to develop fully biogenic phosphors for LED applications.

Strategy in a Nutshell

In the beginning the team worked in parallel on the design of upscale synthesis protocols of highly efficient and stable protein scaffolds and organic chromophores that are functionalized to spontaneously recognize each other. The protein scaffold further shields the organic chromophores from the surroundings, allowing for the achievement of high concentrations without affecting the photoluminescence quantum yields and to operate under ambient conditions preventing photo-assisted oxidation and emission quenching. This strategy implies a fine *in silico* evaluation of *de novo* and modified protein scaffolds as well as the characterization of the equilibrium and electronic structures of the chromophores inside the protein cavity (**Figure 2**).

Once the candidates are selected, synthetic DNA constructs are purchased and expressed in *Escherichia coli*. The purified protein scaffolds are experimentally tested for chromophore binding and the photophysical properties of the new artificial fluorescent proteins in both, polymer and biogenic matrices, are studied under temperature and irradiation stress scenarios.

In a second step, the most stable and emissive artificial fluorescent protein-based coatings are integrated as color down-converting filters in BioHLEDs. Here, low- and mid- power LED chips are used to evaluate the photostability and the conversion efficiency of the biogenic phosphors prepared with polymer and biogenic matrices as discussed in the following section.

Finally, advantage is taken of the unnatural amino acids technology designing a new orthogonal tRNA-synthetase system to directly introduce the chromophore modified with novel/unnatural amino acids into a protein synthesized by the ribosome. The optimized genetic code will be further transferred to a bioengineering company for a large-scale production of the artificial fluorescent proteins. In parallel, a fine optimization with respect to device architecture and driving conditions will be realized to establish the reliability of the new BioHLEDs.

First Fully Biogenic Phosphors

Silk fibroin is a representative fibrous protein that has been widely applied to tissue engineering, drug delivery, diagnostics, and sensing due to its excellent mechanical and thermal features (**Figure 3**). For instance, the silk fibroin from the Bombyx mori cocoon feature high tensile strength values around 300–740 MPa, while the spinning rate of the silk fiber allows the achievement of similar mechanical properties to those obtained with the Nephila spider dragline silk with a breaking strength of 1.3 Gpa **[20]**-**[23]**. Depending on the type of silk fibroin natural source, refractive indexes of ca. 1.5, high transmittances, and thermal conductivities over 200 W/mK have been achieved **[20]**-**[23]**. In addition, silk fibroin shows a high compatibility with artificial and biological emitters, allowing its wide use in, for example, bio-based lasers and optical fibers. Indeed, several authors have reported silk-one dimensional distributed feedback lasers with low pump threshold intensity (< 180 µJ/cm^2) **[20]** and optical fibers with very low optical losses (< 0.2 dB/mm) **[21]**. However, their use in LEDs has been limited to two contributions.

Silk fibroin usage in LEDs:

- Ag nanowires doped silk fibroin films used as highly conductive and transparent electrodes for top/bottom LEDs **[22]**
- Silk fibroin hydrogel lenses applied to WLEDs to control light-extraction efficiency and spatial distribution **[23]**

Recently, we demonstrated that silk fibroin films can also be applied as a packaging matrix to stabilize fluorescent proteins in BioHLEDs **[24]**. In short, dried silk fibroin films showed a highly interconnected network, leading to transmittances of > 85% across the visible range, high mechanical stabilities (1,000 bending cycles of 5°), and hardness and reduced modulus values of 0.5 GPa and 8 GPa, respectively. These values were similar for films with optimized mass ratio between fluorescent proteins and silk fibroin. Likewise, the stabilization of fluorescent proteins in polymers, their photophysical features were totally preserved upon embedding them into the silk fibroin matrix. Thus, BioHLEDs with both fluorescent proteins embedded into polymer and silk fibroin films featured similar color down-conversion efficiencies and overall luminous efficiencies of around 40 lm/W. In contrast, the thermal features of the silk fibroin matrix efficiently assisted in the dissipation of the heat generated in the biogenic phosphors upon increasing the applied currents. For instance, these devices reached working temperatures of 40°C @ 200 mA and 70°C @ 200 mA for fluorescent proteins color filters prepared with silk fibroin and polymers, respectively. This was nicely translated to devices with enhanced stabilities (L50; time to reach 50% of the initial emission intensity operating at 200 mA) of 2 h vs. 2 min (on chip) and > 500 h vs. 280 h (remote) 200 mA (**Figure 3**).

The major limitation of these fully biogenic phosphors is the large morphological changes under thermal and irradiation stress scenarios over time. This promotes a low deactivation of the fluorescent proteins via the protonation of the ionic form of the chromophore. However, this could be overcome modifying the structure of the silk fibroin, cross-linking the silk fibroin matrix, and decorating fluorescent proteins with strains of silk fibroin. These actions along with the design of new artificial proteins are on-going in our laboratories.

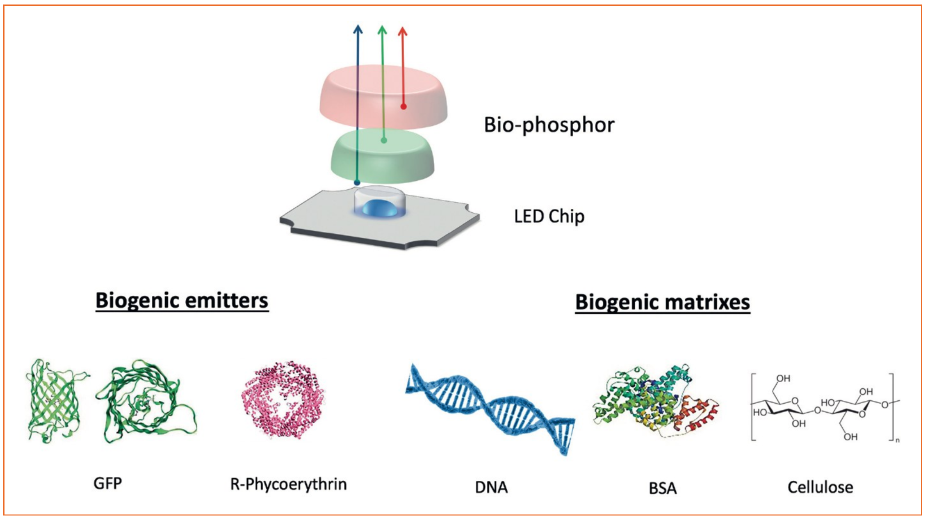

Figure 1: Sketch of Bio-HLED (top). Example of the state-of-the-art biogenic phosphors (bottom)

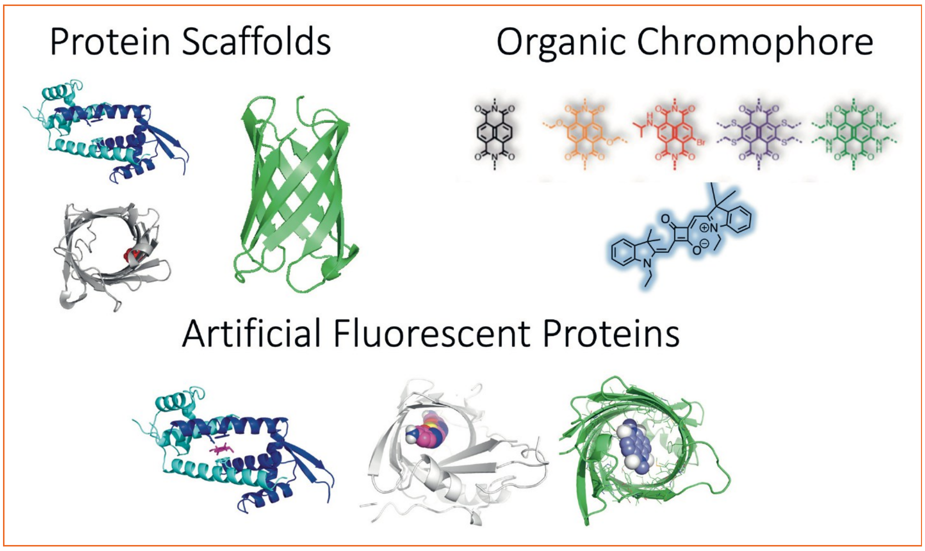

Figure 2: Example of the in silico artificial fluorescent proteins by combining protein scaffolds and organic chromophores

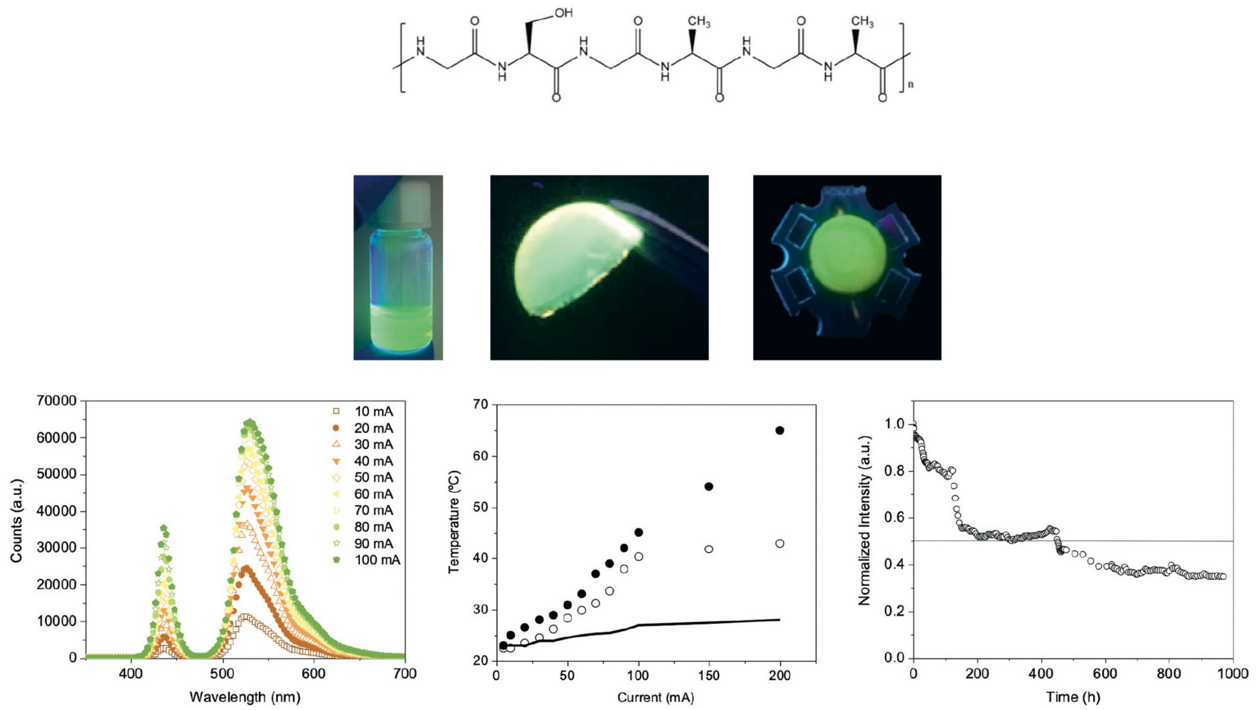

Figure 3: Silk fibroin structure (top) and picture of the biogenic phosphors mixing fluorescent proteins and silk fibroin in solution (mid-left), dome film (mid-center), and in a BioHLED (mid-right). BioHLED emission spectra (bottom) upon increasing the applied current (left), the increase of the temperature in biogenic phosphors based on polymer (solid symbol) and silk fibroin (open symbol) matrices upon increasing the applied current (center; as reference the temperature of the LED chip is provided in a solid line), and the stability of the BioHLED with the silk fibroin biogenic phosphor operating at 200 mA (right)

Conclusions

The extensive replacement of old-fashioned lamps/bulbs by the highly efficient and stable WLEDs is doubtlessly the future of artificial lighting, but we must start looking for the next challenge in this field. How can we ensure the sustainable development of WLEDs for future generations? This implies the optimization of the recycling process, but, in the long run, we must provide a sustainable solution for the fabrication of innovative components without compromising both, device performance and environment. ARTIBLED represents one of these initiatives, sharing a multi-disciplinary expertise to develop fully biogenic phosphors as the next-step in the BioHLED technology. Herein, we have shown the concept and first results using a silk fibroin as a biogenic packaging matrix that reduces thermal stress, leading to enhanced stabilities without compromising luminous and conversion efficiencies. In the near future, we will provide more innovative examples combining novel artificial fluorescent proteins and biogenic matrices. ■

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Rubén D. Costa completed both his B.Sc/M.Sc studies (2006) and PhD (2010) in Chemistry at the University of Valencia (Spain). From 2011–2016, he was a Humboldt postdoc and Liebig junior group leader at the Friedrich-Alexander-University Erlangen-Nürnberg (Germany). In 2017, he moved part of his group to IMDEA Materials (Spain) as senior program leader. In 2018, he expanded his labs to the U. Waseda (Japan) as Associate Professor.

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The European FET-OPEN initiative ARTIBLED includes a consortium of six research groups from Spain (CIC-biomaGUNE - Dr. Cortajarena; CFM-CSIC - Dr. Coto), Italy (UNITO - Dr. Barolo; ABIEL - Dr. Ghersi), Austria (TU Graz - Dr. Oberdorfer), and Germany (TUM - Dr. Costa).

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[2]The consortium aims at engineering innovative artificial fluorescent proteins and biological matrices to develop fully biogenic phosphors for white light-emitting diodes. This constitutes the major thrust of ARTIBLED that merges the expertise in the synthesis of fluorescent dyes, theory and simulation of optoelectronic processes, protein design, bio-engineering, and optoelectronics.

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References

[1] European Commission: http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=1127
[2] European Commission: https://op.europa.eu/en/publication-detail/-/publication/7f3762be-aafe-11e6-aab7-01aa75ed71a1/language-en/format-PDF/source-141480389
[3] European Commission: https://ec.europa.eu/health/sites/health/files/scientific_committees/scheer/docs/scheer_o_011.pdf
[4] US Department of Energy: https://www.energy.gov/sites/prod/files/2020/01/f70/ssl-rd-opportunities2-jan2020.pdf
[5] N. J. Findlay, et al., Adv. Mater., 2014, 26, 7290
[6] J. He, et al., Green Chem., 2018, 20, 3557
[7] X. Wang, et al., J. Mater. Chem. C, 2020, 8, 240
[8] C. Ezquerro et al., Mater. Horiz., 2019, 6, 13
[9] E. Fresta, et al., Adv. Funct. Mater. 2018, 28, 170701
[10] A. Espasa, et al., Nat. Commun., 2020, 11, 879
[11] M. D. Weber, et al., Adv. Mater., 2015, 27, 5493
[12] C. F. Aguiño, et al., ACS Omega, 2018, 3, 15829
[13] V. Fernández-Luna, et al., Adv. Funct. Mater., 2019, 29, 1904356
[14] S. Sadeghi, et al., Adv. Mater. Tech., 2020, 5, 2070035
[15] X. Wang, et al., J. Mater. Chem. C, 2020, 8, 240
[16] X. Wang, et al., RSC Adv., 2019, 9, 9777
[17] M. S. P. Reddy et al. Sci. Rep., 2016, 6, 32306
[18] K. Benson, et al., Adv. Funct. Mater., 2017, 27, 1702955
[19] J. Gotta, et al., Adv. Funct. Mater., 2018, 28, 1706967
[20] S. Toffanin, et al., Appl. Phys. Lett., 2012, 101, 091110
[21] X. Qiao, et al., ACS Appl. Mater. Interfaces, 2017, 9, 14665
[22] N. Qi, et al., RSC Adv., 2015, 5, 50878
[23] R. Melikov, et al., Sci. Rep., 2017, 7, 7258
[24] V. Fernández-Luna, et al., Mater. Horiz., 2020, 7, 1790

Characterization of UV Radiation Sources

Since the beginning of this unfortunate situation caused by the COVID-19 virus, many companies, research centers and lighting designers have adopted UV radiation as a new tool in their projects and research. For a reasonable prediction on the amount of potentially germicidal energy, we have to guarantee proper measurements and especially, spatial distribution. Marc Ballbè, Technical Director at Asselum Luminotecnics, S.L. will explain the complexity of this task and show how to use it correctly for meaningful and reproducible results.

Applications in the disinfection of pathogens with UVC radiation sources have proven effective in multiple activities. Frequently, the chosen radiation sources have been low pressure mercury lamps thanks to their spectral emission at 253.7 nm, very close to the maximum sensitivity peak of DNA and RNA [1]. UV LED technology has not yet entered with force due to its low efficiency, but it is expected that in the next few years its performance will increase considerably and may become the choice when designing UV radiation disinfection equipment. The article will not just explain what else to consider, but also give hints on the requirements of equipment and how to transform the knowledge from visible light measurement to the UV domain.

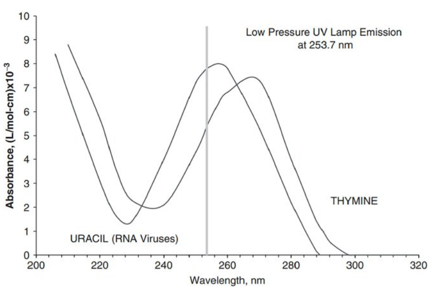

Figure 1: Uracil absorption spectrum compared to that of thymine and the wavelength peak of low pressure mercury [1]

UV Radiation Source Tests

Since before the global pandemic, the characterization of UV radiation equipment for disinfection was very simple. Most of the time, one-off measurements were made in the equipment facility itself at its usual location, rather than in a laboratory.

The data that we can find in a commercial data sheet of a UV lamp or UV complete equipment is the radiant flux (W) (the radiant flux is the amount of electromagnetic energy per unit of time, not to be confused with the power consumed). In some cases, some irradiance values are also included (They are expressed in W/m^2 or $mJ/cm^2 s$) indicated at a specific distance.

The value of the radiant flux (W) of a UV lamp can be interesting to indicate the amount of potentially germicidal energy that we will have for our project. But it does not help us to calculate elimination times for a given pathogen if we have the dose values in mJ/cm^2. It is as if we were trying to calculate the lighting project of an office to obtain 500 lux and U0 of 0.6 with only the value of 3000 lm of a standard LED screen. The Irradiance values (W/m^2) are useful as long as they indicate the distance that this UV lamp / system emits said irradiance. However, we can only know with precision our germicidal potential and calculate the levels of elimination at the distance presented in the technical sheet. These calculations are only accurate in the same direction that the manufacturer has performed the measurement, we cannot expect irradiance levels to be maintained over the entire surface that the lamp is radiating.

In the case of lamps, the point of maximum intensity is usually obtained on the perpendicular axis of the lamp, so that the intensity values will decrease as we move away from the perpendicularity of the lamp. This is why a spatial characterization for UV radiation sources is necessary in order to perform more reliable calculations in projects for disinfection facilities with UV sources.

Spatial Characterization of UV Equipment

The systems for measuring and characterizing UV radiation lamps and equipment are very similar to those used in photometry measurement (380–780 nm). The big difference is that they have to be prepared to have a special sensitivity to short wavelengths between 100 nm and 400 nm. Radiometers are photometers with sensors sensitive to specific wavelengths. However, it is not possible to obtain an extensive sensitivity that can cover the entire UV range.

Radiometers

UV radiometers measure incident radiation or irradiance normally in W/m^2. The photoreceptor is usually a silicon (Si) photodiode that improves its responsiveness to UV rays with a spectral sensitivity between 190 nm and 1100 nm. The drawback is that it is not possible to obtain an extensive sensitivity that can cover the entire UV range. Most radiometers are only sensitive to a narrow range of wavelengths. Normally, a different calibration is necessary for each spectral distribution that needs to be measured with the radiometer. This results in a fairly high measurement uncertainty if appropriate correction factors are not applied (**Figure 2**).

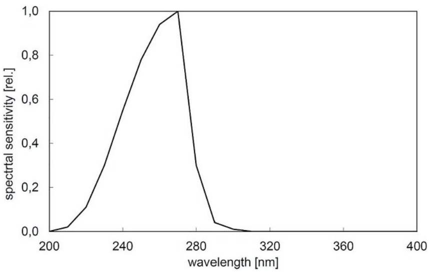

Figure 2: Sensitivity curve of a UVC radiometer. The point of maximum sensitivity corresponds to the wavelength of 270 nm. Instead, its sensitivity to other wavelengths drops dramatically [2]

Spectroradiometer

Another type of sensor to measure irradiance values are spectroradiometers. The main difference between a spectroradiometer and a radiometer is the sensor that performs the measurement. In a radiometer, it is usually a photodiode with a certain spectral sensitivity, while in a spectroradiometer the sensor is a monochromator. The main advantage of the spectroradiometer is the ability to accurately measure the irradiance (W/m^2) of any radiation source regardless of its spectral power distribution (**Figure 3**).

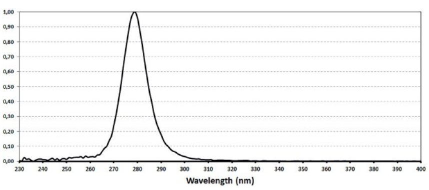

Figure 3: Irradiance measurement using a UV spectroradiometer. It allows a complete analysis for each wavelength of the source under test

Gonio-Spectroradiometer

The equipment previously mentioned only allows the measurement of point values at a specific distance from the radiation source. To characterize a UV lamp or equipment spatially, a gonio-spectroradiometer can be used. This equipment has the advantage of the automatic gonio-photometer system and the measurement capacity of a spectroradiometer.

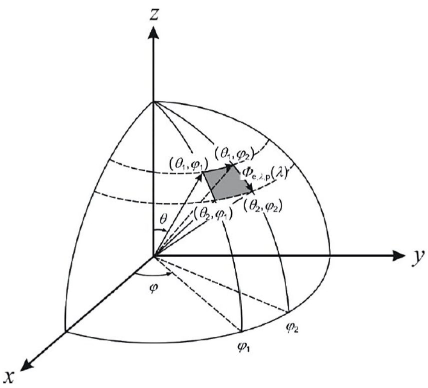

Figure 4: Scan of a point source defined in CIE 239 [4]

With this system, you can scan the entire source and characterize the spatial shape of the radiation. It is also possible to achieve the spectral distribution in the range of the necessary wavelengths. With this information, we can know both the radiant flux (W) and the way to distribute the radiation in space. In this way, calculations and projects of the irradiance levels that would be obtained by installing UV radiation disinfection lamps or equipment can be carried out more accurately and much faster (**Figure 4**, **Figure 5**).

Why Can't We Use a Conventional Goniophotometer?

Humans are not capable of perceiving ultraviolet radiation. Our eyes, like the radiometers explained above, have a defined spectral sensitivity. In the case of humans, our sensors have sensitivity in the area that we know as the visible range of the electromagnetic spectrum. This can be better understood by analyzing the sensitivity curve of the human eye defined by the CIE. The curve $V(\lambda)$ defines the sensitivity of humans to electromagnetic radiation in the range of 380–780 nm (**Figure 6**).

The instruments that allow us to quantify the lighting levels (we understand lighting as the energy that we perceive and can detect with our eyes) also have to have the same 380–780 nm measurement range and have a sensitivity similar to the V luminous function (λ). Precisely, the most important quality parameter of a lux meter is the difference between the spectral response of the sensor compared to the sensitivity curve of the human eye. This parameter is known as the spectral response $f1'$ [4].

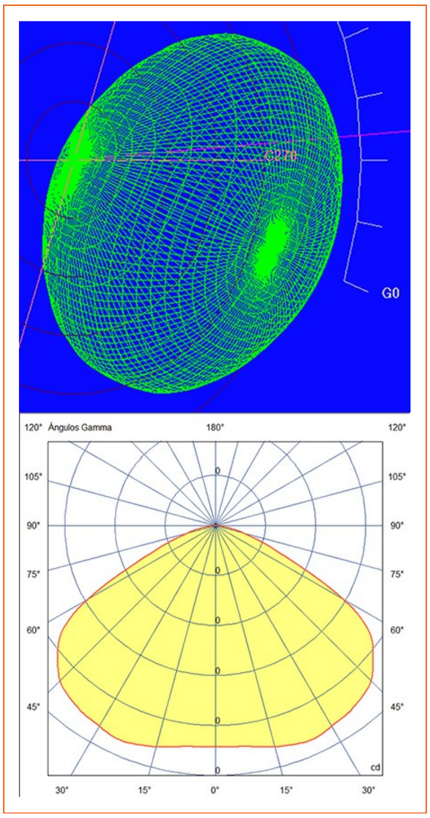

Figure 5: The top figure shows the radiometric solid of a UVC LED made using a gonio-spectroradiometer. On the bottom, the polar representation of radiant intensities (W/sr) of the same UVC LED (Source: Asselum Laboratory)

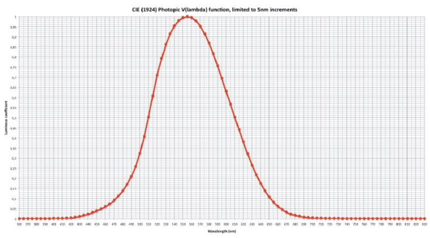

Figure 6: The human eye sensitivity ($V(\lambda)$) curve is one reason why a conventional goniophotometer is not suitable

It is for this reason that it is not suitable to measure UV sources with light meters, color meters or spectroradiometers in the visible range. In many cases the equipment would not only fail to detect any signal but it could generate an aberrant signal caused by UVA radiation in the instrument's sensor. Another reason not to characterize UV sources with gonio-photometers is the different reflection property of materials to UVC short-wave reflection. Very short wavelengths (200–280 nm) are reflected much less than visible radiation.

The polar distribution of radiant intensities (W/sr) of a luminaire with aluminum reflectors and a low pressure mercury lamp is shown in **Figure 7**.

The visible waves are reflected in the aluminum reflector causing the typical lateral opening in fluorescence luminaires with reflectors. While UVC short wavelength radiation is not reflected and absorbed by the reflector material. Many of the UVC LED technology disinfection equipment also have color LEDs built in for safety measures that indicate if the equipment is on.

This can also lead to poor characterization if visible radiation is not adequately suppressed in the overall characterization of the system. The following figure shows the polar distribution in the range of 200 nm to 800 nm. As can be seen, an asymmetric distribution appears despite the fact that the UVC LEDs are centered on the reflector. This happens by having the LED visible on the side (**Figure 8**).

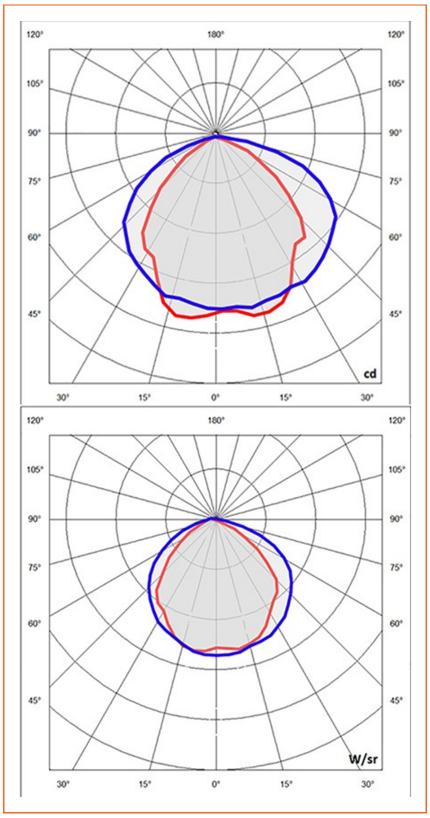

Figure 7: On the top, the polar distribution of intensities in the visible range (380–780 nm) On the bottom, the polar distribution of radiant intensities in the UVC range (200–280 nm)

Not only is it a problem of spatial characterization, but including the visible radiation values in the germicidal radiation levels can cause a calculation error both in irradiance levels (W/m^2) and in pathogen elimination times (**Figure 9**).

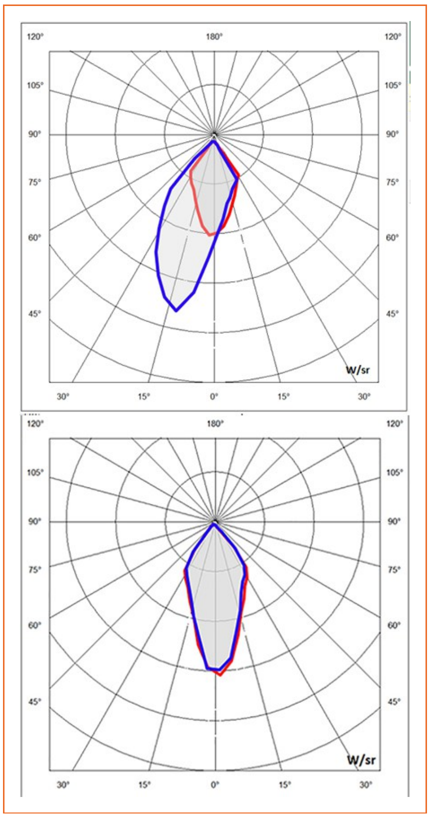

Figure 8: On the top, the distribution of radiant intensities (W/sr) 200–280 nm. On the bottom, the same test filtering the radiation at 200–350 nm

IES TM 33 and OXL Files

All the measurements in the gonio- spectroradiometer have to be inserted in a format that allows the exchange of data between platforms and to be able to manage, analyze and calculate these results. For the photometry data, we use the IES and EULUMDAT photometric files. These formats are basically a matrix of the light intensities (Candela or Candela per Kilolumen) measured by a goniophotometer. However, these formats were designed in the last century and are not prepared to incorporate the information of the spectral power distribution.

The new XML formats [5] that have emerged in the United States with the IES TM33, and in Italy with the UNI XML and OXL from the company Oxytech, allow the storage of photometric and radiometric information and, above all, the spectral power distribution, in addition to other technical information. With these files you can perform calculations in commercial lighting calculation programs such as Litestar 4D and Relux among others **Figure 10**.

Conclusions

This pandemic has caused the entire chain in the general lighting sector to adapt to the new needs that have arisen. Manufacturers, component testers, manufacturers of measuring instruments and laboratories that were used to working in the visible range of radiation have had to learn and adapt their procedures and increase their commercial catalogues. The industry has had to get used to working with spectral distributions, new measurement systems, such as gonio-spectroradiometers and, finally, the limitation of the photometric files of the past century such as the eulumdat and IES files has been demonstrated. I hope that all this knowledge can also be applied in areas such as HCL, lighting for horticulture and much more, once we have defeated the virus. ■

AUTHOR: Marc BALLBÈ

Marc Ballbè is CEO of Asselum, an accredited ISO 17025 lighting laboratory with more than 15 years of experience performing photometric and radiometric tests. He has received his electrical engineering degree from the Polytechnic University of Catalonia (UPC) and a Master's Degree on Industrial Automation and Domotics from La Salle University. He is member of the technical committees for tests, calibrations and management of photometric files at CIE and IESNA. Marc Ballbè manages the group for technical seminars and scientific dissemination in the CICAT Lighting Cluster. He has co-authored the technical guide for the use and installation of UV radiation carried out by CICAT.

References

[1] Ultraviolet germicidal irradiation handbook. Wladyslaw Kowalski.
[2] Technical sheet radiometer model RMD of the company Opsytec Dr. Groebe
[3] CIE 239:2020 Goniospectroradiometry of Optical Radiation Sources
[4] Definition of a Spectral Mismatch Index for Spectral power Distributions
[5] `https://www.led-professional.com/resources-1/articles/rethinking-the-photometric-data-file-format`

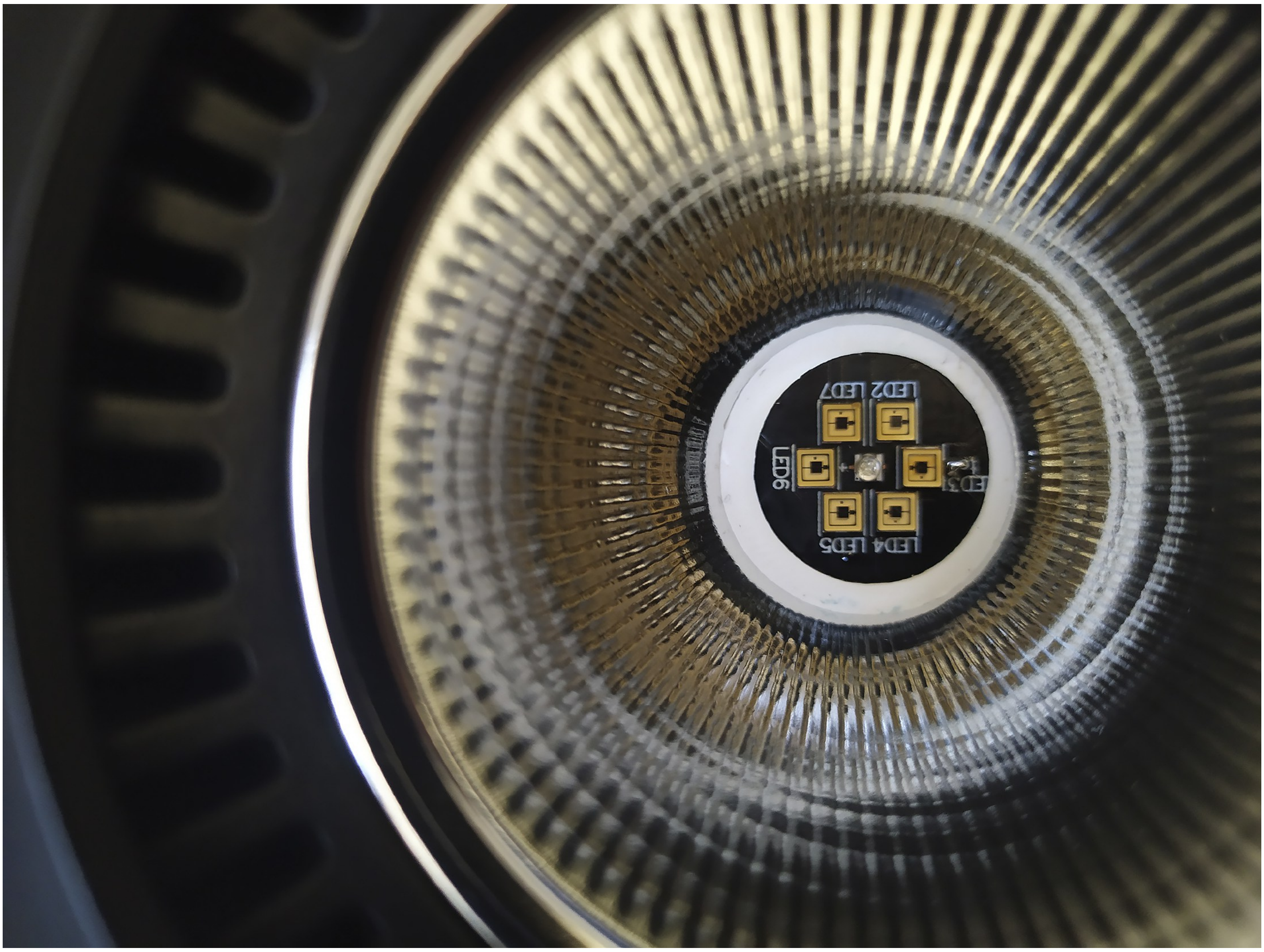

Figure 9: Example of inserting the color safety LED in the center of the optical system to have the same intensity distribution in the visible and UVC bands (Image Credit: Lamp Lighting and JVV Grup)

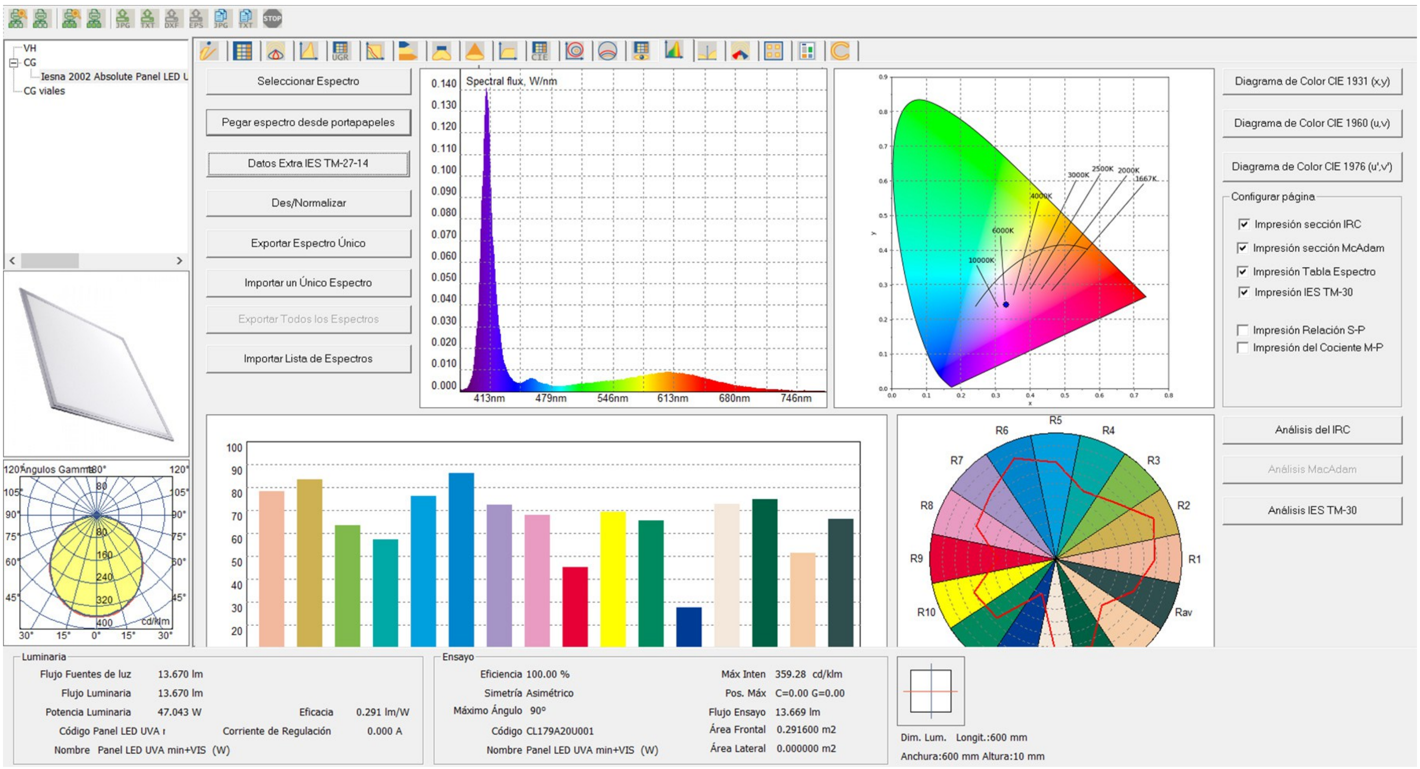

Figure 10: Photometric and radiometric file in OXL format - photometry, radiometer and image

Appropriate Uses for UVC LED Technology for Disinfection Applications

With the recent threat of COVID-19, there is a strong focus on UV disinfection and many companies are pushing to sell their UV products. It is certainly a fact that UV LEDs deliver precisely controlled light intensity and dosage to provide various levels of inactivation, but there are still open questions and concerns that need to be answered and discussed: Are UV LEDs really suitable for COVID-19? Which wavelengths are, in general, the right choice for disinfection? Is it safe to use them? Theresa Thompson, PhD Application Scientist at Phoseon, casts light on these and many more UV light questions, especially UV-C light for disinfection applications.

UV-C light is known as "germicidal UV" for its effectiveness in decontamination and disinfection. While particular wavelengths affect different bonds within biological molecules, both nucleic acids and proteins can be modified by deep ultraviolet light. Thus, both microorganisms and biological material can be inactivated with the right dose and wavelength of light. This article will highlight the appropriate uses for UVC LED technology for disinfection applications along with supporting research related to the different levels of inactivation.

The Difference Between Decontamination, Disinfection and Sterilization

These terms are often used interchangeably, and can even have different meanings for different groups. Therefore, it is important to clearly define their meaning for a common understanding (**Table 1**).

Common Applications for UV LED Disinfection/Decontamination

While UV LED technology can be a great ally for most laboratories by increasing accuracy and consistency of results while reducing time and cost in experiment trials, there are specific areas of study were UV LED can make a tremendous impact.

Specific areas where UV LEDs have greatest impact:

- **Improving RNA driven protocols and results:**
  Completely inactivating RNase [1], an enzyme that degrades RNA samples, can improve results. RNases are present on most surfaces
- **Vaccine development research and manufacturing:**
  Testing with UV LED can be a fast track to rapid and cost-effective virus inactivation; an essential technique when developing vaccines
- **Microbiology laboratories:**
  Whether the purpose is to reuse or to properly dispose of equipment, disinfection is an everyday necessity in microbiology labs. As opposed to other techniques, UV LED technology has proven to achieve high levels of disinfection in microplates or pipets [2] while leaving no chemical residue behind. This zero-trace result is rarely seen by other disinfection approaches.

How to Choose the Best Wavelength for Disinfection

The standard recommendation is a comparison model approach, starting with literature review: what have others done in similar situations and how successful were they? As you look for wavelengths that match your specific goals, make sure to keep in mind some characteristics about the target species for inactivation.

Relevant characteristics of the target species:

- Size
- Structure (including similar amino acids and ionic behavior)
- Kingdom and Family
- Biochemical information such as reaction pockets or active sites
- The microenvironment of chromophores

Wavelengths, dosage levels, and exposure time will all be impacted by the characteristics above. In addition, the object or organism that will be released from contaminants must be taken into consideration as well. For example, if mammalian cells or culture media will be subject to disinfection, it's important to be aware of the possible UV cellular response(s).

Wavelengths Used for Common and Challenging Contaminants

$\lambda \leq 222$ nm

Studies of the 200–222 nm wavelength range predict its ability to inactivate microbes while remaining safe for humans. This is due to the fact that light in the 200–222 nm range can only transverse small organisms such as bacteria or viruses, and generally does not affect larger biological samples like stratum corneum [4]. There are not many conclusive and specific reports on the 222 nm mechanism of action, most assume DNA damage through dimer formation. Protein UV absorption at this range is attributed to peptide bonds [5]. Given sufficient irradiance and dose, some argue inactivation due to protein damage could be possible.

$\lambda = 254$ nm

254 nm UV light deactivates biomolecules by attacking the structure of nucleic acids. This is the common wavelength used by low pressure mercury UV lamps.

$\lambda = 260$–265 nm

It is known as an effective bactericide and has shown great results against viruses like the Influenza A [3]. It also relies on nucleic acid damage as a mechanism of action and it is available in UV LED lamps.

$\lambda = 275$–280 nm

This wavelength range is able to deactivate biomolecules through disturbing their protein structures. This is due to the peak absorption of the aromatic amino acids Tryptophan (W) and Tyrosine (T) at this wavelength range [5]. These structural modifications interfere with protein functionality, therefore resulting in the inactivation of the target organisms. For example, this wavelength acts on RNase A via an effect on the aromatic amino acids proximal to disulfide bonds, reaching its complete inactivation (Column 1 of **Table 1**). It has shown great results against common bacteria (such as *S. aureus*) and proven effective against fungi like *Aspergillis brasiliensis* and *Clostridium difficile* (in synergy with 365 nm) [3].

$\lambda = 365$ nm

This wavelength is thought to target the Lysine side chain and help destabilize the reaction pocket of enzymes like RNase A. RNase A is one of the most challenging contaminants in laboratories. The complete inactivation of this enzyme in a matter of minutes (or even seconds) opens up new possibilities, making research faster and more accurate. The 365 nm wavelength has also been effective in synergy with 278 nm for fungi inactivation [3], and 365 nm has been shown to produce single-strand DNA break [6].

$\lambda = 405$ nm

Wavelengths in the 400–420 nm blue-purple range have been shown to have antimicrobials effects, with peak effect on *S. aureus* at 405 nm [7]. The proposed mechanism of action relies on the formation of oxygen radicals, highly reactive oxygen species, which often lead to oxidative damage and cell death [8]. Research on visible light used for disinfection is at an early stage. Its germicidal efficiency is known to be less of that of UVC light, however with high enough dosages, complete inactivation of organisms may be possible.

What is the Best Wavelength for Disinfection?

The answer to this question is highly dependent on experimental goals, however, there are two competing candidates for the leading position. Traditionally, the standard peak wavelength for disinfection has been 265 nm, since this is the known absorption maxima for nucleic acids. Inactivation occurs due to dimer formation [9]. For many decades mercury lamp systems have been available for disinfection utilizing one of the emission peaks of mercury, 254 nm (which also deactivates molecules by attacking nucleic acids). This wavelength is close enough to the absorption peak to be effective.

In the last decades, 275–280 nm has been known as the peak absorption for proteins, essential aromatic amino acids being most affected at these wavelengths. Biomolecules can then be inactivated by disrupting bonds and thereby influencing secondary and tertiary structures. For example, the 280 nm wavelength excites the aromatic group of the amino acid Tryptophan, which destabilizes nearby disulfide bonds. The resulting chemical damage to these vital structures (S-S bonds) can be deactivation of molecules with minimal chance of reformation. One of the greatest challenges for disinfection and decontamination is the ability of microorganisms and enzymes to repair or reform after a period of time. Most cells contain a dimer repair mechanism for nucleic acid repair and damaged proteins are generally recycled within cells. Viruses cannot directly repair

Decontamination	Disinfection	Sterilization
Inactivation of biological molecules DNA, RNA, Enzymes	Inactivation of microorganisms Virus, Bacteria, Fungi	Inactivation of all mcroorganisms that reaches at least 6 log reduction
Current Techniques: Chemicals, Heat, Scrubbing, Rinsing	Current Techniques: Chemicals, Heat, Ethlene Oxide, Steam	Current Techniques: Chemicals, Heat, Ethlene Oxide, Steam
UV LEDs effectively inactivate hard-target biological molecules, even RNase A	UV LEDs effectively inactivate microorganisms such as Influenza A, Clostridium difficile spores, Aspergillis brasiliensis, and Staphylococus aereus	UV LEDs are on the verge of reaching sterilization levels for difficult and clinically-relevant pathogens

Table 1: Definition of the terms decontamination, disinfection and sterilization as used in this article

themselves and must infect a host in order to take advantage of any cellular repair mechanisms. The main objective is then to either damage the host organism so much that the repair mechanism starts failing, or damage the virus enough that it cannot be readily repaired. Both greater dosages and the synergistic effect mentioned previously could contribute to the lack or repair.

265 nm and 275–280 nm are the most effective wavelengths for disinfection. Depending on the assay in question one may be more beneficial than the other. If working at the DNA level, 265 nm would ideal; if at the protein level, 275–280 nm works best. All in all, the high-power UV LED systems available at 275 nm have enhanced performance that positions them well above any mercury lamp.

Can UVC LED Technology be Used for SARS-Cov-2 Virus?

UV LEDs have proven effective against some of the most challenging contaminants, raising the question of whether it would work against the biggest current global threat, SARS-CoV-2. UVC LED technology can be used to decontaminate surfaces and instruments in a laboratory setting, and potentially air and water that have come in contact with the SARS-CoV-2 virus. It should be used in applications where no one is present at the time of disinfection. UV-C light in the 260–280 nm range most relevant for disinfection is harmful to human skin. In fact, the World Health Organization warns against using ultraviolet disinfection lamps to sanitize hands or other areas of the skin - even brief exposure to UVC light can cause burns and eye damage [10].

While data is limited in regards to this novel virus and the best wavelength for its complete inactivation, the information gathered to date can point us in the right direction. Many research efforts are focused on developing "information libraries". Whether they contain active sites, mutations, or genomic information; having a place where this knowledge is accessible to scientists is imperative for progress. Similarly, developing a wavelength library can be very useful to research labs. So far, we know that novel SARS-CoV-2 and Influenza A (inactivated at 265 nm) are both enveloped RNA viruses and may be susceptible to UV inactivation under similar conditions. The presence of envelope and nucleoproteins suggest that both could be susceptible to inactivation at 280 nm.

UV Light Safety Precautions

Since ultraviolet light has proven to be damaging to humans when in direct contact, protective measures are recommended: wearing safety goggles and gloves, restricting access to areas where UV light is in use, and preventing skin exposure to the light source. When working with UVC LED light, shielding is required to eliminate the possibility of direct eye or skin exposure.

The International Ultraviolet Association (IUVA) and RadTech North America are educational and advocacy organizations that would like to inform the public that there are no protocols to advise or to permit the safe use of UV light directly on the human body. UV light under the conditions known to kill such viruses can cause severe skin burns, skin cancer, and eye damage. There is information that a specific type of UV light, sometimes called "far UV-C" (at wavelengths from 200–225 nm) can disinfect viruses without damaging skin and eyes, but this information is considered to be preliminary and there are no protocols to ensure that it is applied effectively and safely. These organizations strongly recommend that anyone using UV light to disinfect medical equipment, surfaces, or air follow all recommended health and safety precautions and to avoid direct exposure of the body to the UV light [11].

Conclusions

Applied correctly, using the correct wavelength and intensity for the target contaminant UV-C is a mighty weapon against dangerous bacteria, viruses and other germs. To defend COVID-19 viruses, 260–280 nm is seen to be ideal as the best absorbance

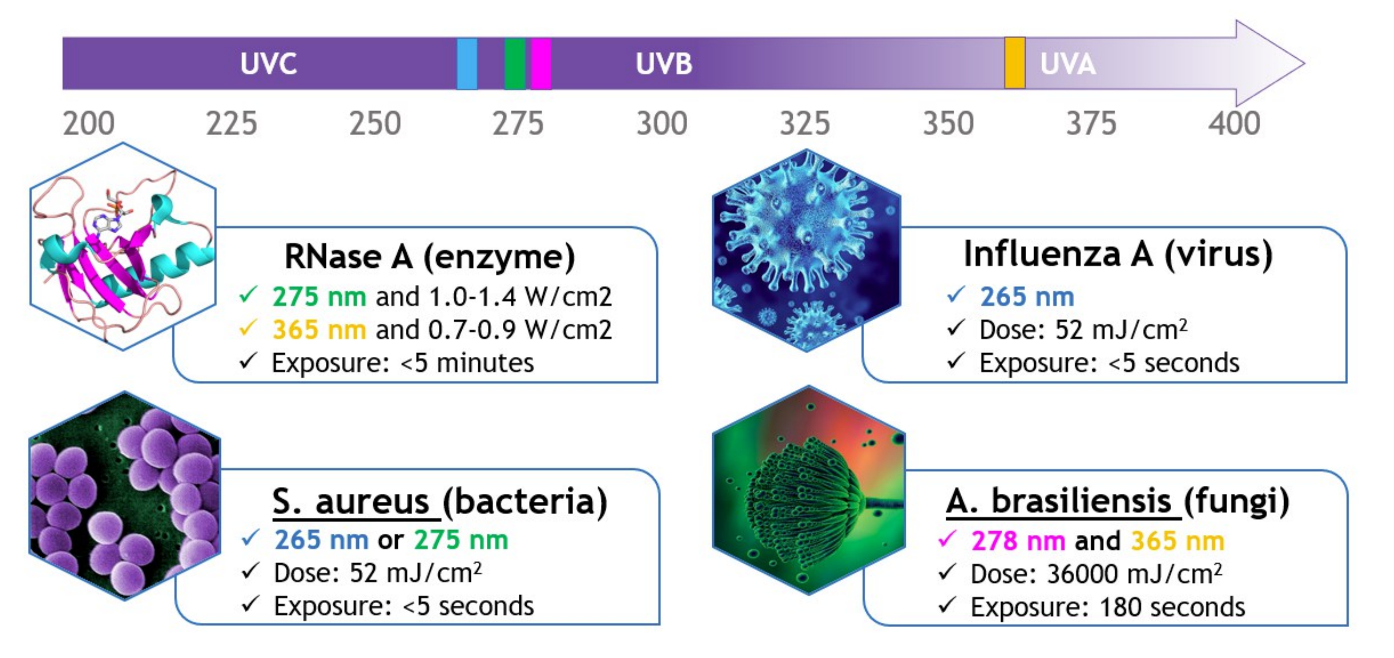

Table 2: Overview on the different UV wavelengths and their target contaminants

range for nucleic acids is 240–275 nm and 275–280 nm corresponds to absorbance by protein aromatic side groups [5]. However, it is important to keep in mind that safety precautions have to be taken seriously as UV light does not selectively just damage germs but may also affect any other tissue and cell. ■

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About Phoseon
Phoseon's UV LED curing solutions are one of the most reliable on the market. Starting from 2002 in Portland Oregon USA, Phoseon Technology foresaw the value of LEDs for both Industrial Curing applications and Life Sciences solutions. Building from their strong background in solid-state semiconductor devices, Phoseon utilizes native diodes and Semiconductor Light Matrix™(SLM) technology to manufacture LED systems. With over 300 patents worldwide, Phoseon has earned the reputation for technological innovation, quality and reliability. As a market leader with a broad portfolio of UV LED units and offerings for key markets, Phoseon welcomes the opportunity to work jointly with clients in developing further innovative solutions.

References

[1] Thompson T, Eliason G, Pasquantonio J. Irreversible inactivation of RNase A on a surface by UV LED. American Society of Human Genetics Scientific Sessions 2017 (poster)

[2] Taggard K. How Contaminated Are Pipetman? Whitepaper, Phoseon Technology

[3] Thompson T. Effectiveness of UV Light-Emitting Diodes for Inactivating Biomolecules and Microorganisms.Whitepaper, Phoseon Technology

[4] Buonanno, M., Ponnaiya, B., Welch, D., Stanislauskas, M., Randers-Pehrson, G., Smilenov, L., Brenner, D. J. (2017). Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light. Radiation Research, 187(4), 493-501

[5] Schmid, F. (2001). Biological Macromolecules: UV-visible Spectrophotometry. Encyclopedia of Life Sciences. doi:10.1038/npg.els.0003142

[6] Peak, J. G., Pilas, B., Dudek, E. J., &; Peak, M. J. (1991). DNA Breaks Caused by Monochromatic 365 nm Ultraviolet-A Radiation or Hydrogen peroxide and Their Repair in Human Epithelioid and Xeroderma Pigmentosa Cells. Photochemistry and Photobiology, 54(2), 197-203. doi:10.1111/j.1751-1097.1991.tb02007.x

[7] Maclean M, MacGregor SJ, Anderson JG, Woolsey G. (2008). High-intensity Narrow-spectrum Light Inactivation and Wavelength Sensitivity of Staphylococcus aureus. FEMS Microbiol Lett; 285:227–232

[8] Ramakrishnan, P., Maclean, M., Macgregor, S. J., Anderson, J. G., &; Grant, M. H. (2016)

[9] Cytotoxic Responses to 405nm Light Exposure in Mammalian and Bacterial Cells: Involvement of Reactive Oxygen Species. Toxicology in Vitro, 33, 54-62. doi:10.1016/j.tiv.2016.02.011

[10] Besaratinia, A., Yoon, J., Schroeder, C., Bradforth, S. E., Cockburn, M., &; Pfeifer, G. P. (2011). Wavelength Dependence of Ultraviolet Radiation□induced DNA Damage as Determined by Laser Irradiation Suggests that Cyclobutane Pyrimidine Dimers are the Principal DNA Lesions Produced by Terrestrial Sunlight. The FASEB Journal, 25(9), 3079-3091. doi:10.1096/fj.11-187336

[11] University of California - Santa Barbara. "Ultraviolet LEDs Prove Effective in Eliminating Coronavirus from Surfaces and, Potentially, Air and Water." ScienceDaily. ScienceDaily, 14 April 2020

[12] Cohen, Gary. UV Industry Associations Discourage the Use of UV Light on the Human Body to Disinfect Against Coronavirus. IUVA

Optimum LED Lighting for Green Walls

Green walls are of increasing interest as they offer several benefits: They purify the air, reduce the ambient temperature and create a sense of well-being. But especially indoors, they need appropriate illumination. A consortium consisting of Lighting Research & Design, NDYLIGHT and University College London (UCL), with Lumenpulse AlphaLED, WonderWall Direct and Xicato conducted a collaborative research study called 'Optimum White LEDs'. The authors, Dr. Amardeep M. Dugar along with Peter Raynham, Roger Sexton, David Gilbey, Rick McKeever and Morris Costello present the results in regards to plant health and user appreciation of three different light sources of different Spectral Power Distributions (SPDs).

'Optimum White LEDs' was a collaborative research study to find the optimum lighting for green walls by testing white LED light sources of different Spectral Power Distributions (SPDs). 'Optimum' lighting here means fluence and spectrum that is biologically effective to keep green walls healthy and maintenance-free, as well as visually effective to provide them with the most natural appearance. The experimental set-up consisted of three green walls illuminated with three different SPDs, for a period of 5 months from September 2019 to January 2020. Plant health in terms of leaf and stem growth patterns was monitored and documented at the end of the 5-month period. User appreciation tests via semi-structured interviews with a statistically significant number of student participants from UCL, along with other participating lighting professionals and architects were performed.

Background

A 'green wall' is a descriptive term used to refer to all forms of vegetated wall surfaces, which can be further subdivided into two major categories: Green facades and living walls [1][2].

Distinctive differences between green facades and living walls:

- Green façade systems are composed of climbing plants or cascading groundcovers trained to cover specially designed supporting structures [3].
- Living walls are composed of pre-vegetated panels, vertical modules or planted blankets fixed vertically to a structural wall or frame; there are various forms of living walls, with the main differences occurring between designs for interior and exterior built environments [3].

The generic objective for most green wall projects has been the aesthetic and ornamental value relating to qualitative improvement of human experience as opposed to quantitative evaluation of materials and system performance [4]-[6]. Measurable improvements to the human condition in terms of health, well-being and productivity have been reported by the use of green elements such as green walls in interior environments [7]-[11]. Robust green walls, however, require appropriately specified: plants for geographic location and hardiness zone; growing medium to sustain the chosen plants; irrigation levels to meet watering and nutritional needs of plants; microclimatic conditions such as humidity, light and temperature [2].

Of the many resources required for growing and maintaining robust green walls within interior environments, light is one of the most important – apart from photosynthesis, it is required for several physiological processes in overall plant development such as photomorphogenesis and reproductive stage development [12][13]. Additionally, insufficient lighting can cause stoppage of water intake by the green walls resulting in excess soil-water build-up, which may lead to toxic anaerobic environments breeding soil-borne pathogens, molds, bugs, etc. as well as root rot [14]. While natural sunlight has the perfect balance of fluence and wavelengths necessary for the growth of green walls, greater control over their growth and maintenance is possible by the appropriate use of artificial light [12][15].

The amount and ratio of different wavelengths from a light source in terms of correlated color temperature (CCT) and SPD determine growth and maintenance patterns of green walls. Agronomically, light-emitting diode (LED) technologies have the potential to cover fluence and wavelength requirements of green walls, while allowing specific wavelengths to be enriched, thus supplying the light quantity and quality essential for different phases of plant growth [15]-[17]. The idea that plant growth, under natural sunlight, could be mimicked using blue and red LEDs has generally led to blue-red combinations being used for growing green wall systems: red (650–665 nm) wavelengths perfectly fit with the absorption peak of chlorophylls and phytochromes; supplemented blue (460–475 nm) wavelengths allow higher photosynthetic activity by providing better excitation of different types of photoreceptors [15][16][18][19]. However, research confirms that specific blue-red spectrum LEDs used for functionalistic food production cannot be applied for the illumination of green walls: the spectrum enables fast growth for market consumption usually making plants appear unnatural; whereas illumination of green walls in an interior environment should help them grow at an appropriate speed, which reduces maintenance costs, and provides them with a natural appearance [20]. Additionally, green walls will appear purplish grey under blue-red spectrum, which makes visual assessment of plant health difficult thereby negating their aesthetic and ornamental value [20][21].

This small-scale qualitative pilot study argues that white LEDs normally used for architectural lighting applications offering all the main bands of wavelengths in the photosynthetically active radiation (PAR) spectrum (390–700 nm) enable plant-growth at an appropriate biological speed, while rendering a natural visual appearance to green walls within interior environments [22]. Photosynthetic photon flux (PPF) derived from the total amount of PAR has the most effect on plant growth as more PPF means more photons and more power, and is a parallel to lumens. Photosynthetic photon flux density (PPFD) determines the number of incident photons and is a parallel to illuminance. While keeping the illuminance and its consequent PPFD constant, the study aims to arrive at the optimum CCT and SPD for biologically- and visually-effective illumination of green walls. Biological effectiveness is assessed in terms of growth at an appropriate speed that reduces maintenance costs. Visual effectiveness is assessed in terms of natural appearance that is visually appealing to people.

Materials and Methods

Three identical green walls with six different plant species as listed in **Table 1** were illuminated with three different CCTs/SPDs of white LED light sources as provided in **Figure 1**. A total of 106 subjects in smaller groups of seven or eight were presented with this experimental set-up and expected to complete a questionnaire. The independent variable for this experimental setup is the SPD and CCT of the light sources. The starting point was a practical one having an SPD most commonly used in offices: 4000 K. The second SPD had a warmer CCT sometimes used in offices but also hotel foyers and shopping malls: 3000 K. The third SPD is less often used in these application areas, nevertheless fitting with the hypotheses that plants grow best and appear most natural under daylight: 5600 K. The dependent variables are the plant-growth patterns and people's responses towards the appearance of these plants.

A-F	Species
A	Aspar D Sprengeri
B	Asple Antiquum
C	Hedera He Wonder
D	Maranta Fascin
E	Nephr Ex Emina
F	Radermachera Sinica

Table 1: Six different species of plants used in the green walls

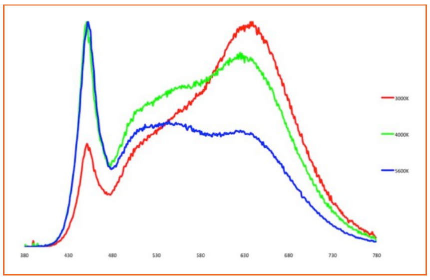

Figure 1: The three different CCTs and SPDs of LED light sources used in the experiment

The track-mounted spotlights as depicted in **Figure 2** were specified considering the flexibility and installation requirements of the experiment. These luminaires are equipped with 5600 K 5000 lm daylight module running at 350 mA, 4000 K 1300 lm and 3000 K 1300 lm modules both running at 700 mA. Each luminaire consists of 60° wide-beam specular reflectors to ensure an even and smooth light distribution across the entirety of the green wall bays at an average efficacy level of 92 lm/W. Two luminaires of each CCT/SPD were assigned for each of the three living walls leading to a total of eighteen luminaires.

The luminaires offer on-board dimming through DALI Pro. Mounted on a three-circuit track, each luminaire was connected to a separate circuit, allowing for individual CCT/SPD grouping per green wall and seamless switching control during active demonstrations. Control was designed such that, during the visual assessments by test subjects, scenes could be recalled from a touch panel with a one-second fade-time. The scenes had all three walls being lit by each CCT/SPD, with an "All Off" scene between each for adaptation purposes. For all other times when visual assessments were not taking place, each wall was lit with a different CCT/SPD. A clock timer was used to switch the lighting on and off each day for a period of 12 hours between 7:00AM to 7:00PM.

The SPDs were analyzed according to the ANSI/IES TM-30-18 and the results are listed in **Table 2**, in terms of the measured CCT of the sources, their color fidelity and color gamut. All of the sources have very good color properties. The number of photons, in the band 400 nm to 700 nm, per 1000 light source lumens was also calculated. By convention the number of photons is expressed in mols, which is the total number of photons divided by Avogadro's number. In the sources with the lower color temperature have higher relative photon output, this was expected, as lower color

Figure 2: Track-mounted spotlight with 60° beam angle

Source [Nominal CCT]	CCT [K]	Color Fidelity $[R_f]$	Color Galumt $[R_g]$	Relative Photon Output [µ/klm]
3,000	2,976	96	102	17.32
4,000	4,105	93	102	16.48
5,600	5,551	93	101	16.30

Table 2: Light source properties

temperature means more light at the longer wavelength end of the spectrum and thus lower average photon energy. The lower photon energy means there are more photons for a given radiated power.

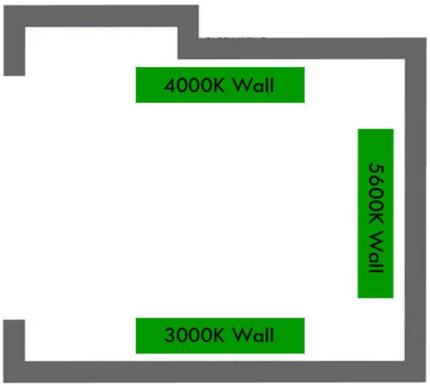

Figure 3: Schematic layout of the three green walls arrangement in a confined room

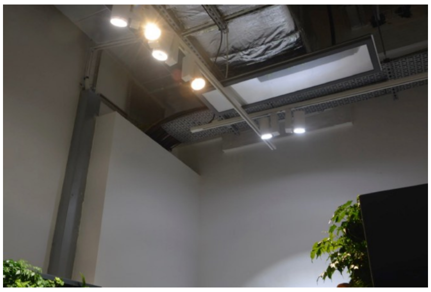

Figure 4: Luminaire arrangement in the ceiling for lighting the three green walls

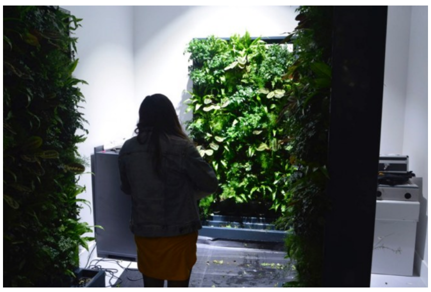

Figure 5: Subjects' appraisals of green walls using a survey questionnaire

The green walls were installed within a confined room (3.5 m by 3.2 m) with no windows or external source of light as depicted in **Figure 3**. The room used had been designed as a storage area with no ventilation or thermal control. Each wall was lit with a different color of light source and for purpose of simplicity the walls are referred to as Walls 3000 K, 4000 K and 5600 K.

To allow the plants to grow, in a way expected in an interior, each of the walls was lit using a set of two track-mounted lights. The lights were mounted at a height of 2.5 m and 1.0 m away from the face of the wall as shown in **Figure 4**. The lights were aimed to create an illuminance of approximately 1200 lux on the vertical at the top of the wall and about 500 lux at the bottom of the wall. In this part of the experiment it was important that each wall only received light from a single set of light sources. To reduce the amount of inter-reflected light in the test room the floor was covered with dark carpet tiles. The worst problem with spill light was at the bottom of the walls; switching of the lights for a given wall and measuring the illuminance of the wall due to spill light from the other two tested this. After the mitigation, measures that had been put in place of the illuminance at the base of the wall due to inter-reflected light was 20 lux.

The intention of this experiment was to obtain feedback from subjects with appropriate educational and professional backgrounds in designing built environments so as to comprehensively review and comment on the naturalness and visual appeal of the green wall. Therefore, it was decided to involve subjects with a design background such as architects, landscape architects, lighting professionals and students in the experiment. A selective sampling method was used where specific invitations were prepared and sent to a selected number of architects, lighting professionals and students. Additionally, by ensuring that all the 106 subjects who agreed to participate in the experiment given identical treatment, the influence of any form of individual characteristics was eliminated. The experiments were conducted over a period of six specific days from 03 December 2019 to 29 January 2020 based on the availability of the subjects.

The subjects were asked to respond to each wall and lighting condition by completing a questionnaire as shown in **Figure 5**. A trial experiment of showing the walls to some subjects who did not take part in the main study and asking their opinions about the walls in a semi-structured interview further developed the questionnaire.

The key issues found were naturalness and the appealing nature of the walls in the environment. There were a number of other terms that were also raised by the trial pool of subjects. Thus, the questionnaire started with two questions set as bipolar semantics on a 5-point scale asking about naturalness and visual appeal of the walls. The other issues were addressed by the use of ten pairs of opposed adjectives. The adjective pairs used in the experiment are listed in **Table 3**. To reduce the possibility of bias the 20 words were arranged in a random block and subjects were asked to circle all the adjectives that applied.

Opposite Adjectives			
Ugly	Beautiful	Happy	Sad
Interesting	Boring	Natural	Artificial
Healthy	Sick	Tiring	Refreshing
Calming	Stimulating	Bright	Dim
Vivid	Subdued	Colorful	Dull

Table 3: Pairs of opposed adjectives which were arranged in a random block to reduce the possibility of bias

On arrival at the test site subjects were greeted with refreshments and brief introduction to the use of green walls. During the introduction the presenters spoke only in general terms and were careful not to give any details of the experiment to the subjects. The subjects visited the test room in groups of varying size from one person on their own to nine people at the same time. Before the subjects entered the test room the lighting on all walls was set to the first color temperature for the test. When all of the subjects had appraised all three walls, the lighting was dimmed and turned off for about 15 seconds, after which lighting with the next color temperature was turned up. The appraisal of the walls was carried out again and the lighting changed again and then the final appraisal was carried out. The order in which the light sources were used was randomized.

Results and Analysis

The results are broadly classified under biological effectiveness in terms of plant health, and visual effectiveness in terms of peoples' responses towards the lighting of the green walls. Out of the 106 participants surveyed for this experiment, 39 are practicing architecture professionals, 51 are practicing lighting professionals, and 16 are students. Age and gender of the subjects were not recorded, as these were not considered as criteria for assessment.

Biological effectiveness was assessed both in terms of leaf and stem health. Leaf health was assessed based on a comparative qualitative rating scale of 0 to 4 where

0 correlated to a plant with completely dry leaves, and 4 correlated to a plant with green leaves. Each of the plant species was assessed individually based on this rating scale and then the rating was averaged for each species mounted on each wall. The average leaf health of all the six plant species for each of the three walls after five months of experimentation is listed in **Table 4**. Species B, D and F reported the greenest leaves, while species C reported the driest leaves across all the three walls. Almost all the plants of species C had withered. On an average, Wall 5600 K reported the greenest leaves across all species.

Stem health was also assessed based on a comparative rating scale of 1 to 3: 1 correlated to the plant wall with the longest and unhealthiest stems; 3 correlated to the plant wall with the shortest and healthiest stems. Instead of measuring each individual plant, it was decided to measure the overall plants overhangs for each wall from four different heights i.e. 350 mm, 700 mm, 1050 mm and 1400 mm from the base of the wall. These three lengths were then averaged and the wall with the shortest overhang was assigned 3, while the wall with the longest overhang was assigned 1. Wall 5600 K reported the shortest and strongest stems, while Wall 3000 K reported the longest and weakest stems. The comparative growth patterns of the green walls before and after the five-month period of experiment are depicted in **Table 5**. The average stem health of the green walls before and after the five-month period is depicted in **Table 6**.

Visual effectiveness was primarily assessed based on the naturalness and appealing nature of the green walls. **Figure 6** and **Figure 7** represent the distribution patterns of the participants' responses for naturalness and visual appeal respectively on a scale of 1 to 5. Participants demonstrated an inclination towards 4000 K for both naturalness and visual appeal, as the green wall illuminated with 4000 K received the highest scores as shown in **Table 7**. A lexical analysis of the adjectives used to describe the lighting of the green walls are listed in **Table 8**, which again demonstrates an inclination towards 4000 K for a healthy and natural appearance of the plant walls.

Discussion

Growth and health of green walls in controlled artificial environments to a large extent is dependent on the types of plant species used in the green wall design. Out of the six plant species monitored under identical experimental conditions, three (B, D, F) demonstrated good growth, two (A, E) demonstrated average growth, while one (C) demonstrated bad growth. Popular belief that high illuminance levels e.g. 5000–10 000 lux ensure growth and health of green walls can be questioned as reasonably well plant growth patterns were observed in this study under average illuminance levels of 1100 lux. Warmer CCT and red spectrum cause unhealthy stem elongation, which is more prominent in the green wall illuminated with 3000 K. In general, for green walls, 5600 K is most suitable for controlled growth and health, while 4000 K is most preferred by people for naturalness and visual appeal. Therefore, the main discussion point drawn from this pi-

	Wall 3000 K	Wall 4000 K	Wall 5600 K
A (Aspar D Sprengeri)	2.00	1.75	2.27
B (Asple Antiquum)	3.67	3.70	3.63
C (Hedera He Wonder)	0.00	0.13	0.00
D (Maranta Fascin)	3.40	3.29	3.83
E (Nephr Ex Emina)	1.00	1.29	1.17
F (Radermachera Sinica)	3.79	3.67	3.90
Average	2.31	2.31	2.47

Table 4: Average leaf health of the six plant species after the five months of the experiment

Time Period	Wall 3000 K	Wall 4000 K	Wall 5600 K
Green walls **before** the five-month experimentation period			
Green walls **after** the five-month experimentation period			

Table 5: Comparative growth patterns of the green walls before and after the five-month experiment period

CCT		Average Stem Health
Wall 3,000 K	Rating	- 1 - Longest stems but elongated and slender
	Reasoning	High content of red spectrum leads to elongated and weak stems
Wall 4,000 K	Rating	- 2 - Long stems but thicker and sturdier
	Reasoning	Balanced content of all spectrums leads to long yet strong stems
Wall 5,600 K	Rating	- 3 - Shortest stems but thickest and sturdiest
	Reasoning	Low content of red spectrum leads to shortest and strongest stems

Table 6: Average stem health of the three walls after the fifth month of the experiment

lot study involves a blend of 4000 K and 5600 K to achieve a biologically - and visually - effective illumination of green walls. Blending could imply various options ranging from the development of a dedicated single output LED module, time-based SPD changes via a tunable white module or a blended lighting design using two different light sources, 4000 K and 5600 K.

Next Steps

The obvious next steps for this study are to firstly, experiment with just such a blended solution as is discussed above, and possibly a timed approach with tunable white solutions. With controls and tunable light sources playing a major role in all future solutions, it might be worthwhile to test such tunable solutions to achieve biologically- and visually-effective illumination of green walls. And secondly, to experiment on a larger scale with a more focused species of plant types that are more robust for interior green wall applications. Additionally, a larger group of survey participants from the general public need to be involved so as to obtain feedback representing a broader cross-section of the general public. ■

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A trained architect and an advocate for all the elements of lighting – design, education and research – Dr. Amardeep M. Dugar founded Lighting Research & Design based on these elements. After completing an M.A. in architectural lighting from the University of Wismar, Germany, he went a step further to pursue a Ph.D. in architectural lighting from Victoria University of Wellington, New Zealand to solidify his academic & professional leadership role into a career at a higher level.

In the area of lighting design, his notable projects include the Hotel Arcadia, Coimbatore & Medical Society Building, Berlin, which were awarded the IES 2013 Section Award & IALD 2004 Award of Excellence respectively. He was also awarded 2016's 40-Under-40 Hottest Lighting Designers in the world by the Lighting Magazine. In the area of lighting education, he has been teaching at several architecture schools & presented lectures at several international conferences such as IALD Enlighten 2014 & 2016; IES Annual Conference 2012 & 2015; IES Research Symposium 2016; Light Fair International 2014; Light Focus 2004 & 2006; PLDC 2007, 2009, 2011, 2013, 2015 & 2017. In the area of lighting research, his achievements include First place at the IISF 2016 – Young Scientists' Conclave & numerous papers in international publications such as LR&T, LEUKOS, LD+A, JL&VE, PLD & mondo*arc.

In 2015, he embarked on an ambitious journey as the Co-Coordinator for the International Association of Lighting Designers' (IALD) India Region. Most of his time was spent unselfishly in organizing & un-

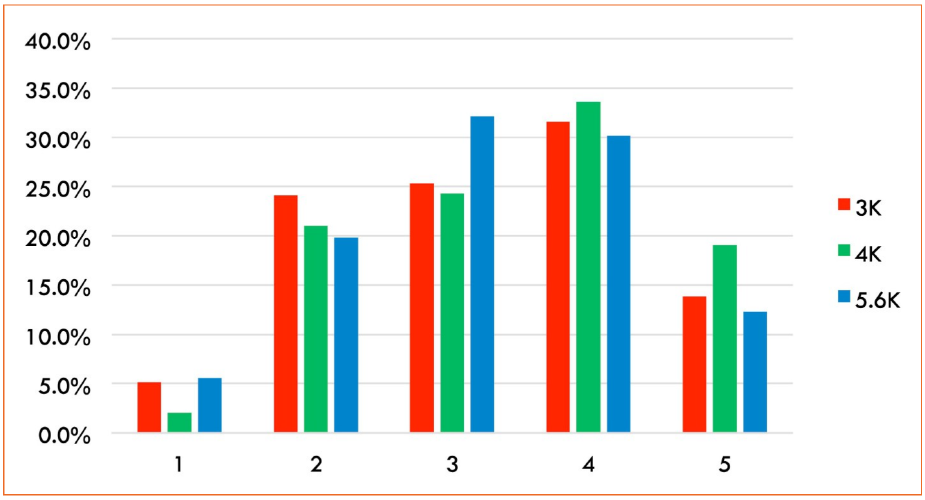

Figure 6: Naturalness distribution of participants' responses for the three walls (where 1 stands for unnatural and 5 stands for natural)

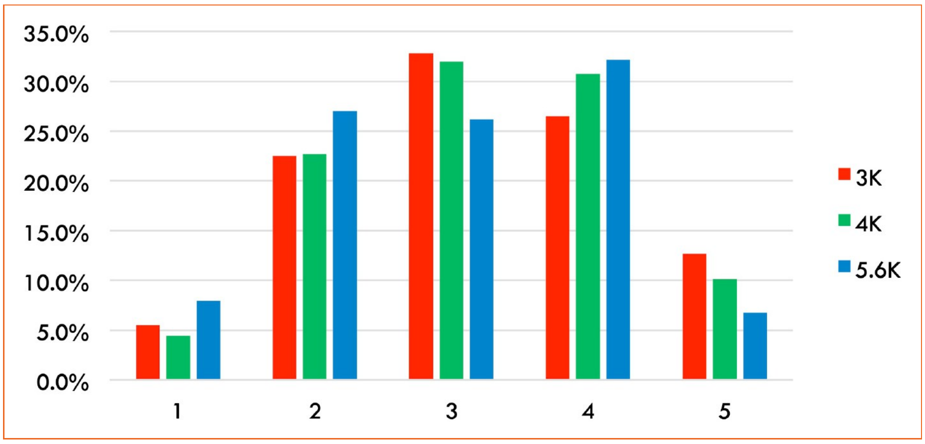

Figure 7: Visual Appeal distribution of participants' responses for the three walls (where 1 stands for very appealing and 5 stands for least appealing)

	Wall 3000 K	Wall 4000 K	Wall 5600 K
Un/Natural	3.20	3.48	3.29
Un/Appealing	3.10	3.18	3.04

Table 7: Average score on naturalness and visual appeal for the three walls (1 means unnatural and 5 natural / 1 means very appealing and 5 least appealing)

	Wall 3000 K	Wall 4000 K	Wall 5600 K
Alive/Healthy	11	18	13
Artificial/Plastic	18	12	20
Colorful/Vibrant/Vivid	24	18	19
Glossy/Shiny/Waxy	7	10	14

Table 8: Lexical analysis of the adjective use counts for the three walls (number of counts)

dertaking IALD India Light Workshops, a series of practical hands-on educational light installation workshops for professionals & studentsthroughout universities in India.Taking place at university campuses, eight workshops have been conducted in cities across India namely Bangalore, Chandigarh, Chennai, Delhi, Hyderabad, Kochi and Mumbai. In total, more than 1,500 students and 90 lighting professionals have participated and benefited from these events.

References

[1] Tamási A, Dobszay G. Requirements for Designing Living Wall Systems – Analysing System Studies on Hungarian Projects. Period Polytech Archit. 2015;46(2):78–87

[2] Sharp R, Sable J, Bertram F, Mohan E, Peck S. Introduction to Green Walls: Technology, Benefits & Design [Internet]. 2008. Available from: www.greenroofs.org

[3] Sharma P. Vertical Gardens – An Innovative Element of Green Building Technology. In: International Conference (GYANODAY 2015). Greater Noida, INDIA; 2015. p. 42–8

[4] Hosey L. The Shape of Green: Aesthetics, Ecology, and Design. 3rd ed. Washington, DC, USA: Island Press; 2012

[5] Grinde B, Patil GG. Biophilia: Does visual contact with nature impact on health and well-being? Int J Environ Res Public Health. 2009;6(9):2332–2343

[6] Culver AL, Mumford J, Anderson M, Fediw K, Lewis M. Living Walls: Communicating the aesthetic, environmental, productivity and health benefits of plants in the built environment. [Internet]. 2014. Available from: GreenPlantsforGreenBuildings.org

[7] Largo-Wight E, Chen WW, Dodd V, Weiler R. Healthy Workplaces: The Effects of Nature Contact at Work on Employee Stress and Health. Public Health Rep. 2011;126(1-suppl):124–30

[8] Adamson K, Thatcher A. Do Indoor Plants Improve Performance Outcomes?: Using the Attention Restoration Theory. In: Bagnara S, R T, S A, T A, Y F, editors. Advances in Intelligent Systems and Computing. Florence, ITALY: Springer, Cham; 2019. p. 591–604

[9] Raanaas RK, Horgen KE, Rich D, Sjøstrøma G, Patil GG. Benefits of indoor plants on attention capacity in an office setting. J Environ Psychol [Internet]. 2011;21(1):99–105. Available from: https://doi.org/10.1016/j.jenvp.2010.11.005

[10] Bakker I, Voordt TJM Van der. The influence of plants on productivity: a critical assessment of research findings and test methods. Facilities. 2010;28(9/10):416–39

[11] Neuwenhuis M, Knight C, Postmes T, Haslam SA. The relative benefits of green versus lean office space: three field experiments. J Exp Psychol Appl. 2014;20(3):199–214

[12] Canham AE. Artificial Lighting for Plant Growth. Light Res Technol. 1954;19(8):235–61

[13] Sekhar S, Darshan Panda, Kumar J, Mohanty N, Biswal M, Baig MJ, et al. Comparative transcriptome profiling of low light tolerant and sensitive rice varieties induced by low light stress at active tillering stage. Nature. 2019

[14] Westerduin E. The Ultimate Guide to Living Green Wall Lighting [Internet]. Available from: www.suiteplants.com

[15] Darko E, Heydarizadeh P, Schoefs B, Mohammad R. Sabzalian. Photosynthesis under artificial light: the shift in primary and secondary metabolism. Philos Trans R Soc B. 2014;369(1640)

[16] Ouzounis T, Rosenqvist E, Ottosen C-O. Spectral Effects of Artificial Light on Plant Physiology and Secondary Metabolism: A Review. HortScience. 2015;50(8):1128–1135

[17] Promratrak L. The effect of using LED lighting in the growth of crops hydroponics. Int J Smart Grid Clean Energy. 2017;6(2):133–40

[18] Schoefs B. Chlorophyll and carotenoid analysis in food products. Properties of the pigments and methods of analysis. Trends Food Sci Technol. 2002;13(11):361–71

[19] Sabzalian M, Heydarizadeh P, Zahedi M, Boroomand A, Agharokh M, Sahba M, et al. High performance of vegetables, flowers, and medicinal plants in a red-blue LED incubator for indoor plant production. Agron Sustain Dev. 2014;34(4):879–86

[20] Zielinska-Dabkowska KM, Hartmann J, Sigillo C. LED Light Sources and Their Complex Set-Up for Visually and Biologically Effective Illumination for Ornamental Indoor Plants. Sustainability. 2019;11(2642)

[21] Kim H-H, Wheeler RM, Sager JC, Yorio NC, Goins GD. Light-Emitting Diodes as an Illumination Source for Plants: A Review of Research at Kennedy Space Center. Habitation. 2005;10:71–78

[22] Dugar AM, Dileep M, Burhani H. White LED Light Sources – Merging Architectural and Horticultural Lighting Applications within Interior Environments. Int J Hortic Crop Sci Res. 2019;9(2):83–93

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