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Review

LpR 106

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INTERVIEW WITH CASAMBI'S CEO MARK MCCLEAR

OPTIMIZING LIGHTING ENERGY EFFICIENCY

UNDERSTANDING UV LED SPECIFICATIONS

The Global Information Hub for Lighting Technologies and Design

INTERVIEW

Dr. Antonio Romano

VP R&D AT TRIDONIC

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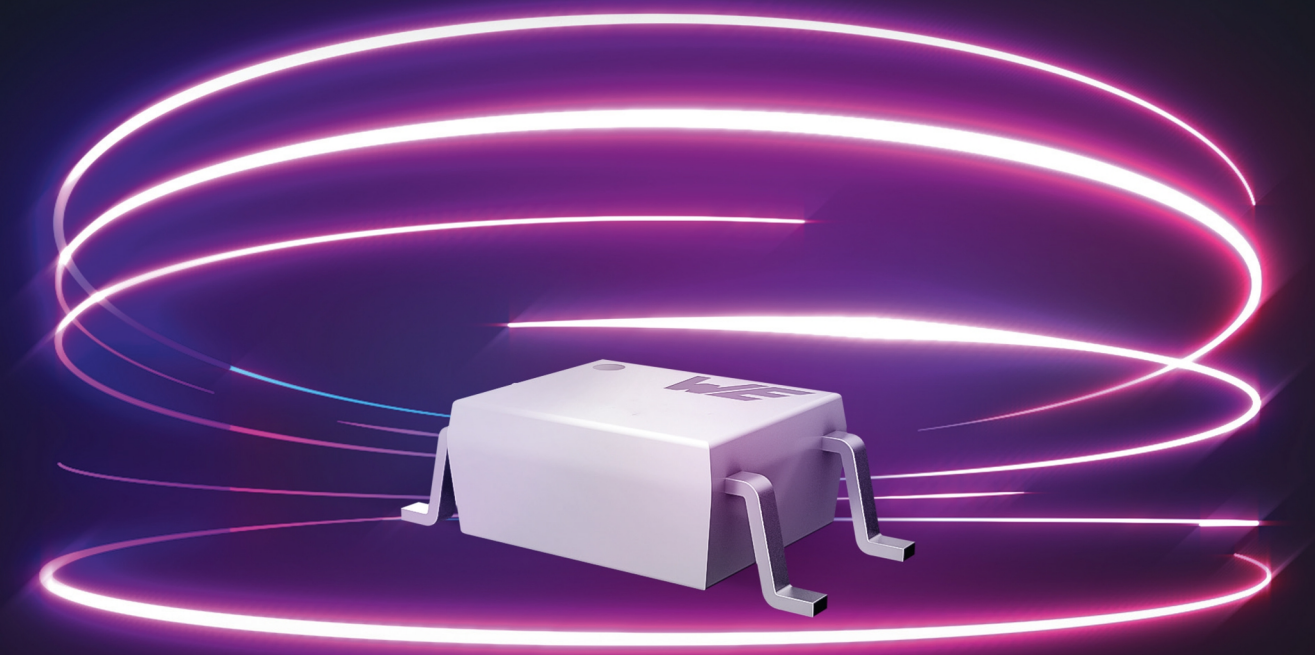

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2024's Final Edition: Game-Changing Insights and Technologies Shaping 2025 Lighting

In this issue of LED professional Review (LpR), we're shining a spotlight on lighting control innovations. Mark McClear and Antonio Romano share their expert perspectives on the world of controls and the solutions shaping the future of lighting.

We also feature the first segment of a two-part research report from Bartenbach, detailing their groundbreaking approaches to optimizing energy efficiency in lighting systems. The second installment will appear in the January/February issue. Two engineering-focused articles showcase exciting advancements: modern methods and a deeper understanding of thermal design, as well as UV LED specifications, opening doors to new applications and product innovations.

Tim Köbel from KIT introduces us to a rarely explored frontier—lighting controls that are, themselves, managed by light. This server-based approach is fascinating and could serve as a blueprint for entirely new lighting control systems. In our video chapter, we're excited to present three brand-new YouTube recordings on LpS Digital. In this three-part series, Luminus Devices takes us through the company's origins and their key focuses: Light for Living and Light for Working.

In Peter Dehoff's commentary it becomes clear that achieving 'good lighting' is a complex process requiring both technical expertise and a deep understanding of the needs and expectations of all stakeholders—from manufacturers to architects to end users.

With this installment, we wrap up our six-issue series for 2024. We thank you for your trust and wish you all a happy and successful start to 2025!

Enjoy your read!

Yours Sincerely,

Siegfried Luger

Luger Research e.U., Founder & CEO
LED professional, LpS Digital – Expert Talks on Light & Global Lighting Directory
International Solid-State Lighting Alliance (ISA), Member of the Board of Advisors
Member of the Good Light Group

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

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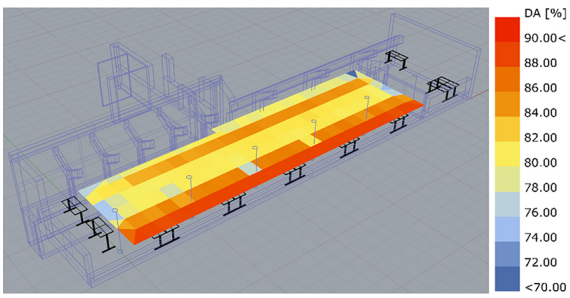
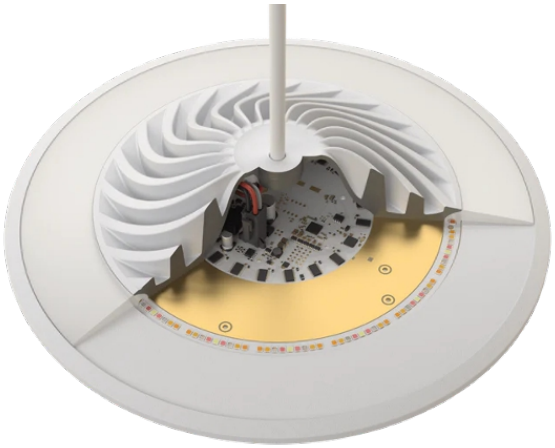
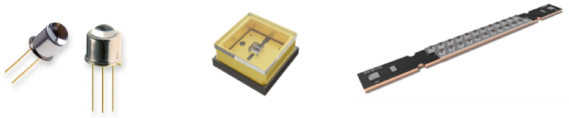


THERMAL DESIGN



LIGHTING CONTROLS

UV TECHNOLOGY



LPS DIGITAL TALKS

ADVERTISING INDEX

Peter DEHOFF

Peter Dehoff is Director Professional Associations and Standardization at Zumtobel Lighting, Austria, and is member of numerous associations and standardization organizations and chair of several working groups (CIE, ISO, CEN, ASI, DIN, ZVEI, AK licht.de, LiTG, LTG, FEEI, Lux Europa).

He is also President of the Austrian National Committee of CIE, Convenor of CEN TC 169 WG 2 “Lighting of workplaces”, Convenor of ISO JWG 5 “Lighting of workplaces”, Convenor of AK licht.de (ZVEI Germany), and Board member of lighting societies LiTG and LTG. Lecturer

/1/ TU Karlsruhe, Lighting Engineering: education

/2/ Zumtobel Lighting Dornbirn: employee since 1987

/3/ TU Graz, lecturer since 1994

/4/ TU Darmstadt: lecturer since 2011

/5/ LiTG 36 Lighting Quality – a process rather than a number

/6/ EN 12464 Lighting of work places

/7/ CEN TS 17165 Lighting System Design Process

/8/ CIE 222 Decision schemes for lighting controls

/9/ licht.wissen 19: Non visual effects of light

/10/ licht.wissen 21: Guide for Human centric Lighting

linkedin.com/in/peter-dehoff-90806449

Is There Good Light?

It depends on who is asked this question. Manufacturers of luminaires and components say a well-shaped product with LEDs, modern electronics and sensors is the prerequisite for good lighting. Architects and lighting designers say lighting that is well integrated into the building is good lighting. A user may say a luminaire that I like is good lighting. So is everything clear and simple? I have constantly pursued the question ‘What is good lighting?’ in my professional life and will take you with me to the stages /x/, that document my path and my involvement.

At university /1/ and in the course of my professional career /2/, expert knowledge has matured with technical terms, definitions and a network of people. Is knowledge enough for good light? With my students of architecture who only have a short course for lighting design /3, 4/ I start from scratch and first ask ‘questions about light’: initially without, then with reference to architecture. This intuitive approach reveals obvious knowledge and a surprising lack of knowledge. Then they ask themselves questions about light and they start to look for answers. They become curious about good light. Lighting quality is a process /5/: without being experts, the architect, client and customer make functional, biological, psychological and architectural demands on light - we have formulated 30 possible requirements in a simple way and free from expert terms that form the specifications for lighting design. Later, after lighting design and in a realized project, the lighting quality can be evaluated on the basis of these demands and expectations. Can good light be predicted? Lighting designers can draw on their experience, but also on standards /6/. When writing the standards as experts, we recommend measures as maintained illuminances, their modifiers, glare limitation, color, daylight and more to fulfil visual tasks in an appropriately illuminated room. Does compliance with the criteria guarantee good light? It is also advised to make lighting controllable, i.e. to give the user the option to change lighting levels or lighting scenes. This is a simple requirement, but one that is often not realized in practice. Decisions on lighting control and luminaire selection are made at different times and lighting is often a very late addition to the construction process. A lighting concept with controls should be drawn up very early and then put into service by all responsible parties i.e. lighting and electrical planning and installation which include luminaire selection. The lighting system design process /7/ starts with the client’s requirements for lighting quality. At this stage, the options future users will have to intervene in the lighting should already be established /8/. A decision scheme helps to select the control system with a view to energy efficiency, lighting quality and user acceptance. Ideally, the available lighting scenes should already be given a name during the design phase. The lighting control concept should be known and implemented by the electrical planner and later by the electrical installer. Reference should be made here to Human Centric Lighting, which requires planning and consideration of the long-term visual and non-visual effects of light on people /9,10/. Well-planned lighting scenes and, in particular, comprehensible operability by users are essential components of the concept. There is still a great deal of design potential here for lighting designers and products from the lighting industry.

In this, my beautiful world of good lighting, it is therefore important for everyone involved in the process to work together. It is important to recognize the interfaces and reduce possible sources of error. Clients are often not lighting experts and yet they have an idea of a lighting solution. Architects and lighting planners translate requirements into lighting concepts and ideally coordinate them with electrical planners. Installers realize lighting with suitable luminaires and comprehensible lighting control and put the system into operation. Knowing the lighting scenes, they label the operating devices. Thus, users have access to good light. That is the ideal world. ■

P.D.

Just when you thought your network was old-fashioned it became new and up-to-date with Salvador series from Casambi

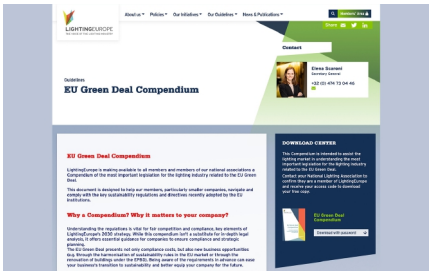
SALVADOR series from

CASAMBI

LightingEurope Launches Essential Compendium for EU Green Deal Legislation to Support Members in Compliance

www.lightingeurope.org

LightingEurope is providing a compendium of key EU Green Deal legislation for the lighting industry, aimed at helping members, particularly smaller companies, comply with new sustainability regulations.



This document supports understanding of essential rules for effective enforcement and fair competition, in line with the LightingEurope 2030 strategy. While it does not replace detailed legislative analysis, it is a valuable resource for compliance and strategic planning.

Elena Scaroni, LightingEurope's Secretary General, stated: "Our team has actively participated in the legislative process and is now assisting members with implementation by providing the knowledge and insight we have accumulated over the years in a single document. By understanding these requirements, companies can not only comply but also grab new opportunities in the green economy."

The Compendium includes links to official EU texts and commented summaries.

Teresa Selvaggio, LightingEurope's Director of Public Affairs added: "The summaries and comments are based on input from our staff, other trade associations we regularly work with, and even feedback from EU officials during legislative discussions."

The information represents LightingEurope's reading of the requirements and does not constitute an official interpretation of the legislative texts.

How to Access Your Copy

- LightingEurope Members: Download from the Member's area, Causeway.
- National Association Members: Request a password from your association to access the Compendium on the LE public website at this link.

Contact: Elena Scaroni, Secretary General (elena.scaroni@lightingeurope.org)

About LightingEurope
LightingEurope is the voice of the lighting industry, based in Brussels and representing 32 companies and national associations. Together these members account for over 1,000 European companies, a majority of which are small or medium-sized. They represent a total European workforce of over 100,000 people and an annual turnover exceeding 20 billion euro. LightingEurope is committed to promoting efficient lighting that benefits human comfort, safety and well-being, and the environment. LightingEurope advocates a positive business and regulatory environment to foster fair competition and growth for the European lighting industry. More information is available at www.lightingeurope.org. ■

Joint Statement – European Stakeholders United for a Level Playing Field for Online Marketplaces and Effective Enforcement

www.lightingeurope.org

The undersigned NGO's, consumer organizations and business and trade associations are severely impacted by the role of online marketplaces in e-commerce. We are united to request a level playing field for online marketplaces and effective enforcement.

It is a priority to close legal loopholes in the regulation and enforcement of online trade via online marketplaces during the 2024-2029 mandate. Insufficient responsibilities for online marketplaces and the ineffective enforcement of existing EU requirements harm the environment, consumers, the competitiveness of European businesses, the functioning of the internal market, and the credibility and impact of EU legislation.

While we understand that the role of online marketplaces is significant for the EU's economy, we want to draw attention to the ever-increasing number of non-compliant products available on the EU market through online marketplaces.

The massive direct imports via online marketplaces are very relevant in the EU internal market. However, insufficient responsibilities for online marketplaces and the ineffective enforcement of existing EU requirements harm the environment, consumers, the competitiveness of European businesses, the functioning of the internal market, and the credibility and impact of EU legislation, as for example, in the Green Deal and traditional product and chemical legislation.

Neither the Digital Services Act (DSA), nor Product Safety legislation nor the Green Deal have addressed this critical loophole: Online marketplaces are not considered economic operators nor to be placing products on the market.

We urge to address this loophole, and we propose some recommendations, to ensure that EU legislation ensures that all operators in the EU Internal Market comply with EU standards, fostering a fair and competitive European market, preventing unfair practices and enhancing enforcement by both Member States and European authorities. Those recommendations are:

- Recognition of online marketplaces as economic operators, and recognition that the online marketplaces are considered to be placing the products on the market if there is no other economic operator in the EU that can be considered to have placed the product on the EU market;
- Enhanced Obligations for online marketplaces;
- Improved Product Traceability;
- Equip Customs Authorities with better rules to stop illegal imports through small packages;

Thanking you for your consideration, we remain at your disposal should you have any questions. Please note that the statement is attached and also available here.

Yours sincerely,
Elena Scaroni, Secretary-General of LightingEurope on behalf of the undersigned signatories.

AGID; Applia; Assil; Assoluce; BBLV; BITVA; Continual; Danish Association of Play; Danish Chamber of Commerce; Danish Consumer Council; Danish Fashion & Textile; Danish Publishers; Danish Rights Alliance; Danmarks Nature; DUH; Dutch Toy Industry Federation; DVSI; Ecologists Without Borders Association; Ecos; EEB; EFIC; Eucolight; EURATEX; European Ventilation Association; Expra; Fair Resources Foundation; French Toy Association; Friends of the Earth France; Fundación Vida Sostenible; Humusz; Ifixit;

INCIEN - Inštitút cirkulárnej ekonomiky; Institute Circular Economy Lithuania; LAI; LIA; Lifestyle and Design Cluster; LightingEurope; Merk; NLA; Polish Association of Lighting Industry; Polish Zero Waste Association; PZPO; Repair&Share; Royal Danish Academy; Spanish Association of Toy Manufacturers; Swedish Association of Technologies; Swedish Commerce; Swedish Lighting Industry; Swedish Textile and Fashion Industries; Swedish Toy and Baby Association; Syndicat du Luminaire; Textiles Revolution; TIE; Umweltdachverband; Virke, the Norwegian Federation of Commerce; Voice of Irish Concern for the Environment, VOICE; WEEE Forum; ZERO; Zero Waste Europe. ■

Casambi Announces Generational Change in Board of Directors

www.casambi.com

Global leader in wireless smart lighting control, Casambi, is pleased to announce a significant leadership transition as part of its broader strategy for accelerated growth. Effective November 1, 2024, Kay Pawlik has assumed the role of Chairman of the Board, succeeding long-standing chairman Antti Kokkinen. This change marks a generational shift in Casambi's leadership, aimed at supporting the company's continued expansion in its core markets of EMEA, North America, and APAC.

Over the past year, Casambi has seen remarkable growth and is poised for even faster expansion in the coming year. Recent strategic decisions, both from the Board of Directors and Management Team, have set the stage for this next phase, which focuses on increasing market share, deepening expertise in lighting applications, and strengthening the organization to meet future demand.

Antti Kokkinen, who has served as Chairman for more than a decade, played a pivotal role in shaping Casambi's success. Under his leadership, the company transformed from a software startup with zero revenue into a global leader in wireless lighting controls.

"Antti's leadership has been instrumental in our journey to becoming the global leader in wireless lighting control. On behalf of the entire Casambi team, together with our shareholders, I would like to extend our deepest thanks to Antti Kokkinen for his invaluable contributions over the past decade," said Casambi CEO, Mark McClear. "We are incredibly grateful for his commitment and guidance over the years, and we are excited to welcome Kay as our new Chairman as we enter this new phase of growth."

Kay Pawlik, who has served on Casambi's Board since 2023, brings over 25 years of management and advisory board experience in the lighting industry, including leadership roles at ERCO and DIAL. He possesses deep expertise in both lighting applications and controls, combining strategic leadership with technical knowledge. This broad industry experience positions him well to take on the role of Chairman, where he will guide Casambi through its next phase of growth and innovation.

"I am honored to take on this new responsibility at such an exciting time for Casambi," said Kay Pawlik, the new Chairman of the Board. "The company has laid a strong foundation for the future, and I look forward to working closely with Mark and the entire team as we push forward with our ambitious growth plans."

About Casambi
Casambi provides smart lighting control via intuitive applications that set new standards in user interaction with light. Our Bluetooth® Low Energy-based technology easily integrates into fixtures and devices, allowing manufacturers to craft bespoke Casambi Ready products. Bridging wireless and wired DALI worlds, we guarantee seamless interoperability between all products and with industry standards. Users can mix and match for tailored lighting networks, ensuring adaptability across settings while enjoying the rich functionality of the Casambi experience. In just one decade, Casambi has become a global leader with 300+ ecosystem partners and 5+ million devices sold into 200,000+ lighting projects worldwide. An end-to-end solution, Casambi empowers individuals and enterprises alike to illuminate spaces with efficient, customizable control. The Casambi app is freely available for iOS and Android. Casambi. Where ideas come to light. ■

Signify Proposes Appointment of CFO Zeljko Kosanovic to Board of Management

www.signify.com

Signify (Euronext: LIGHT), the world leader in lighting, confirms the appointment of Zeljko Kosanovic as Chief Financial Officer (CFO), effective from October 25, 2024.

The Supervisory Board will propose Mr. Kosanovic's appointment to Signify's Board of Management at the Annual General Meeting of Shareholders to be held in 2025.

"In the role of acting CFO, Mr. Kosanovic has consistently demonstrated the financial and leadership competencies required for this position," said Gerard van de Aast, Chair of the Supervisory Board of Signify. "We are pleased to confirm this appointment, and look forward to continue working with him in the future."

About Signify
Signify (Euronext: LIGHT) is the world leader in lighting for professionals, consumers and the Internet of Things. Our Philips products, Interact systems and data-enabled services deliver business value and transform life in homes, buildings and public spaces. In 2023, we had sales of EUR 6.7 billion, approximately 32,000 employees and a presence in over 70

countries. We unlock the extraordinary potential of light for brighter lives and a better world. We have been in the Dow Jones Sustainability World Index since our IPO for seven consecutive years and have achieved the EcoVadis Platinum rating for four consecutive years, placing Signify in the top one percent of companies assessed. News from Signify can be found in the Newsroom, on X, LinkedIn and Instagram. Information for investors is located on the Investor Relations page. ■

Ayça Donaghy, CEO of The LIA has been Appointed to the Board of LightingEurope

www.thelia.org.uk

The Lighting Industry Association (LIA) is pleased to announce the appointment of Ayça Donaghy, our CEO, to the Board of LightingEurope.

With over 15 years of experience in the electro-technical sector and an Executive MBA from London Business School, Ayça has shown exceptional leadership at The LIA. Her initiatives have focused on sustainability and addressing skills gaps within the industry, coupled with her continued advocacy for comprehensive regulations in the UK. Recently, she was recognized in the '40under40' competition, highlighting her impactful contributions and strong communication skills within the industry.

Ayça Donaghy's appointment to the Board of LightingEurope benefits LIA members in many ways. With her experience and voice on a broad platform, LIA members gain a strong advocate for their interests, particularly in shaping regulations that impact the sector, and this involvement opens up new networking opportunities for member organizations with key stakeholders across Europe.

"We are thrilled to welcome Ayça to our Board," said Elena Scaroni, Secretary General of LightingEurope. "She will bring strong value to our mission with her commitment to innovation and the skills gap."

Ayça commented on her new role "I am honored to join the Board of LightingEurope and to represent The Lighting Industry Association in this role. Together, we can drive innovation and tackle the pressing challenges our industry faces, particularly in alignment with Europe and sustainability. I look forward to collaborating with my fellow board members to advance our shared mission."

About the LIA: The Lighting Industry Association (LIA) is the largest trade association dedicated to lighting in Europe and is dedicated to serving the UK's lighting industry and its supply chain. The LIA offers technical support, training, and advocacy to drive product innovation and improve the quality, safety, performance, and sustainability of the UK's lighting market. https://www.thelia.org.uk/

About LightingEurope: LightingEurope is the voice of the lighting industry, based in Brussels and representing 33 companies and national associations. Together these members account for over 1,000 European companies, a majority of which are small or medium-sized. They represent a total European workforce of over 80,000 people and an annual turnover exceeding 15 billion euro. LightingEurope is committed to promoting efficient lighting that benefits human comfort, safety and well-being, and the environment. LightingEurope advocates a positive business and regulatory environment to foster fair competition and growth for the European lighting industry. More information is available at www.lightingeurope.org ■

DALI, TALQ and Zhaga Announce Collaboration to Unify Data Streams for Smart Street Lighting Solutions

www.dali-alliance.org

The DALI Alliance (DALI), the TALQ Consortium (TALQ) and the Zhaga Consortium (Zhaga) - each focused on defining international lighting standards to ease investment decisions for public and private entities - announce the signing of a liaison agreement to collaborate on unifying data streams for smart street lighting systems. The collaboration aims to provide a better choice of solutions with interoperable components and enhance communication across outdoor lighting systems.

DALI focuses on developing and managing digital lighting control specifications based on the IEC 62386 standard, enabling the widely recognized DALI-2, D4i, and DALI+ certification programs. Their commitment to interoperability and certification ensures that lighting components and systems can seamlessly integrate and communicate.

TALQ has developed and introduced a globally accepted standard for outdoor lighting systems using a standardized interface protocol for heterogenous outdoor device networks. The standard has also more recently been widened to include other smart city applications, like waste management, smart traffic, parking and environmental sensing. The TALQ Smart City Protocol enables consistent data to be used within smart city device networks and with the central management systems of cities and communities.

Zhaga, well-known for its work in creating interface specifications for LED light engines and sensor and communication modules, ensures compatibility across different manufacturers. By enabling interoperable LED components and their certification, Zhaga has helped to foster innovation and flexibility within the LED lighting industry.

The collaboration between these three organizations aims to streamline the exchange of data further, offering a unified approach for end-to-end communication and control in smart street lighting applications. The joint work will include a shared approach to achieving a unified data stream solution and exchanging visions on the requirements and architecture needed for such systems. This liaison will enable the respective specifications of DALI, TALQ and Zhaga to reflect the data and control requirements of outdoor lighting control systems.

"The D4i certification program plays a crucial role in enabling the seamless integration of streetlights into smart city applications, enabling interoperability and sustainability, while gathering critical data for asset management, diagnostics and energy monitoring," says Paul Drosihn, General Manager of the DALI Alliance. "By working closely with Zhaga and TALQ, we're fostering a future-proof ecosystem that enhances supply chain longevity, security, and the right to repair – building resilient infrastructure that supports smart cities for the long term."

"For us, it is a logical step to work together with DALI and Zhaga. Not only do we share the same goals, but the composition of the member companies also has a large overlap. The better the standards in the street lighting environment become, the more sustainable and future-proof the investment decisions of cities and operators will be," explains Simon Dunkley, Secretary General of the TALQ Consortium.

"We are thrilled to take this step forward together with DALI and TALQ. By combining our efforts and expertise, we are working towards a more interconnected and efficient future for smart lighting. This partnership ensures that we are all moving in the same direction, uniting our ambitions and promoting real-world interoperability," said Heinrich Thye, Secretary General of Zhaga.

This liaison signals a significant move towards aligning global standards in smart outdoor lighting. By creating interoperable solutions, the collaboration aims to reduce complexity for manufacturers and cities alike, ultimately fostering a more sustainable and efficient urban future.

About the DALI Alliance
The DALI Alliance (also known as the Digital Illumination Interface Alliance or DiiA) is an open, global consortium of lighting companies that drives the growth of lighting control solutions based on internationally standardized Digital Addressable Lighting Interface (DALI) technology. The organization operates the DALI-2, D4i, and DALI+ certification programs to boost the use of open, interoperable lighting control systems. For more information visit www.dali-alliance.org.

About the TALQ Consortium
Founded in 2012, the TALQ Consortium has established a globally accepted standard for management software interfaces to control and monitor heterogeneous smart city applications. The TALQ Smart City Protocol is a specification for information exchange, suitable for implementation in various products and systems. This way interoperability between Central Management Software (CMS) and Outdoor Device Networks (ODN) from different vendors is enabled, such that a single CMS can control different ODNs in different parts of a city or region. TALQ is an open industry consortium currently consisting of more than 60 member companies. For more information visit www.talq-consortium.org.

About the Zhaga Consortium
Zhaga is a global association of lighting industry members. Zhaga standardizes interface specifications for LED luminaire components, including LED light engines, LED modules, LED arrays, holders, electronic control gear (LED drivers), connectors, sensor and/or wireless communication modules and associated devices. The Zhaga interface standards enable multi-vendor ecosystem of interoperable products. To create trust in the interoperability of products from multiple vendors Zhaga has a certification and logo-program executed by third party test houses. Through its focus on interoperability, Zhaga contributes to circularity lighting via smart, connected lighting and serviceable luminaires, supporting the UN Sustainable Development Goal 11 for sustainable cities and communities. Zhaga has set up a partner and liaison program, working with recognized Standards Development Organizations and Alliances to maximize synergies, leverage external expertise and global acceptance. For more information, visit www.zhagastandard.org. ■

NEMA and IES Announce New Partnership to Enhance Lighting Industry Standards

www.nema.org

The National Electrical Manufacturers Association (NEMA) and the Illuminating Engineering Society (IES)—recognized leaders in development of lighting industry standards—announced a new partnership to foster innovation, collaboration and consistency in lighting technical standards.

The new partnership will enhance standards for lighting system performance, quality, safety, and sustainability. Specifically, the MOU identifies key areas of cooperation, including the sharing of subject matter experts and mutual participation in standards development committees. This collaborative effort will streamline the standards development process, ensuring comprehensive input from both organizations.

"NEMA is pleased to be working with IES to set technical standards that ensure consumers continue to benefit from safe and sustainable lighting systems," said Debra Phillips, NEMA President and CEO. "As a Standards Development Organization with a 100-year legacy in electrical standards, NEMA is proud to embark on this journey with IES to build upon the lighting industry's technical foundation at a time of rapid technological advancements and increasing demand for energy efficient and connected solutions."

"Our partnership with NEMA underscores our shared commitment to developing standards that are reflective of the progress in the lighting industry," said Colleen Harper, CEO and Executive Director of the Illuminating Engineering Society. "This collaboration is indicative of a continual effort for the impact of IES to be shaped by insights from partners through reciprocity."

About IES Established in 1906, the Illuminating Engineering Society is the recognized technical and educational authority on illumination. Our mission is to improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefit the public. We provide a variety of professional development, publications, networking and educational opportunities to our membership of engineers, architects, designers, educators, students, contractors, distributors, utility personnel, manufacturers and scientists in nearly 60 countries. Through our American National Standards Institute (ANSI) accredited process, we publish and maintain the Lighting Library®, with over 100 standards written by subject matter experts in our technical committees. In all our efforts, we strive to improve life through quality of light. To learn more about us, visit www.ies.org.

About NEMA The National Electrical Manufacturers Association (NEMA) represents over 300 electrical equipment and medical imaging manufacturers that make safe, reliable, and efficient products and systems. Together, our members contribute 1% of U.S. GDP and directly provide nearly 460,000 American jobs, contributing more than $250 billion to the U.S. economy. Learn more at www.nema.org ■

ABB and Zumtobel Group Partner to Advance Smart Lighting and Building Solutions and Direct Current (DC) Industry Applications

www.abb.com

The companies will focus on integrating ABB's building automation solutions with Zumtobel Group's lighting management systems ABB and Zumtobel Group will also target innovation in the use of direct current (DC) technology in full-scale industrial applications to reduce energy use and lower CO2 emissions. The strategic partnership will support more efficient, sustainable and user-friendly commercial, industrial and institutional buildings.

Global technology leader ABB and Austrian-based Zumtobel Group, a global leader in professional lighting solutions announce their strategic partnership aimed at advancing smart building solutions and direct current (DC) industrial product applications. The collaboration is set to create significant added value for customers in commercial, industrial, and institutional sectors by offering integrated, smart solutions for sustainable buildings.

The collaboration will leverage both companies' expertise in lighting, building automation, and electrification. It will focus on integrating Zumtobel Group's advanced lighting management systems with ABB's comprehensive building automation solutions. The combined expertise is expected to create more efficient, sustainable, and user-friendly smart building environments. The two companies will help to accelerate the adoption of sensor-based lighting solutions that enable businesses to optimize energy efficiency, increase occupant comfort and maximize the effectiveness of heating, ventilation and air conditioning (HVAC) control.

Both companies aim to drive innovations based on the latest developments in using DC technology in full-scale industrial applications. The use of DC technology is intended to support a resource-saving society by delivering several benefits for a modern industrial power grid: efficient integration of renewable energy, lower resource consumption, reduced feed-in power, stable grids and an open system for users. Both companies are active members of the Open Direct Current Alliance (ODCA), a Working Party of ZVEI e.V.

"Our partnership approach enables us to better address innovation, standardization, and sustainability and continue to pioneer new technologies," said Lucy Han, Executive Vice President for Building and Home Automation Solutions at ABB. "Standardization, through KNX, Matter and Thread is particularly important in assuring ease of use for customers, because alongside the rapid growth of the sector, we must drive simplicity. Technologies in commercial buildings need to talk to each other and by combining our strengths with partners like the Zumtobel Group, we can offer customers more comprehensive and innovative solutions for smart buildings and industrial applications."

Key aspects of the partnership include the joint development of integrated smart building solutions, especially around Zumtobel's LITECOM lighting system and continuous-row TECTON DC luminaire and ABB's DC protection devices as well as its ABB i-bus® KNX and ABB i-bus® DALI systems.

Oliver Vogler, SVP Corporate Strategy and M&A of the Zumtobel Group, underlines, "Collaborating with ABB allows us to expand our building management offering around sensor-based lighting, especially in DALI and KNX applications. Together, we can drive innovation in the rapidly evolving fields of smart buildings and smart energy solutions."

The companies will also explore additional cooperation opportunities in prefabricated building solutions and emerging technology standards such as the cross-manufacturer connection standard Matter and the network protocol Thread.

ABB is a technology leader in electrification and automation, enabling a more sustainable and resource-efficient future. The company's solutions connect engineering know-how and software to optimize how things are manufactured, moved, powered, and operated. Building on over 140 years of excellence, ABB's more than 105,000 employees are committed to driving innovations that accelerate industrial transformation. www.abb.com

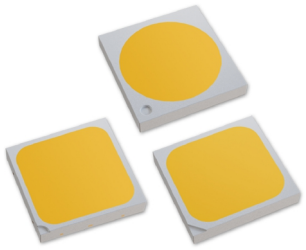
About ABB Electrification: ABB Electrification is a global technology leader making efficient and reliable use of electricity from source to socket possible. With more than 50,000 employees across 100 countries, we collaborate with our customers and partners to solve the world's greatest challenges in electrical distribution and energy management. We help businesses, industry, and consumers run their facilities and homes efficiently and reliably. As the energy transition accelerates, we are electrifying the world in a safe, smart, and sustainable way. go.abb/electrification

About Zumtobel Group: Zumtobel Group is an international lighting group and a leading supplier of innovative lighting solutions, lighting components and associated services. The Zumtobel Group's service offering is one of the most comprehensive in the entire lighting industry, including consultation on smart lighting controls and emergency lighting systems, light contracting, design services and project management of turnkey lighting solutions, as well as new, data-based services focused on delivering connectivity for buildings and municipalities via the lighting infrastructure. The Zumtobel Group is based in Dornbirn in the Vorarlberg region of Austria and is listed on the Vienna Stock Exchange (ATX Prime). Further information is available at z.lighting/group. ■

Conservation, Dark Skies, & Solar Lighting Drive 5050 LED Proliferation

www.lumileds.com

Lumileds' LUXEON 5050 LED portfolio has expanded with over 185 options across four product families, meeting the growing demand for conservation, dark sky compliance, and solar lighting.



New additions like the LUXEON 5050 HE Plus enable lower energy usage, sustainability, and CO2 reductions for high-volume applications such as street lighting and infrastructure.

There has been a rapid sophistication of industrial and outdoor lighting in the 8-years since the LUXEON 5050 Round LED was first introduced. Customer demand for tailored solutions that address community and country level requirements have driven significant expansion of Lumileds' 5050 portfolio and today there are more than 185 standard LEDs across 4 LUXEON 5050 product families with 3 voltage options: 6V, 24V, & 30V; 10 CCT choices from 1800K to 6500K; 3 CRI choices of 70, 80, or 90. Most recently, dark sky initiatives and outdoor lighting ordinances inspired development of NightScape Technology – with <2% blue content – which is also available in the LUXEON 5050 portfolio.

Good Light Group

The **Good Light Group** is a non-profit organisation. We are a group of scientists, lighting designers, sleep experts, and lighting companies focused on improving indoor lighting for health and well-being.

For more information: **info@goodlightgroup.org**

LUXEON 5050 HE Plus, the most recent addition, reduces application power consumption by 18% or more in critical infrastructure applications common to cities and businesses around the world. For high volume applications such as streetlighting, the cumulative impact of LUXEON 5050 HE Plus is lower energy usage, costs, and a reduction in annual CO2 emissions. Further, the lower-energy consumption supports the transition to low-carbon or no-carbon electricity supply and OEMs can achieve greater sustainability in their manufacturing process by reducing the physical material in both the heatsink and the system's driver.

LUXEON 5050 Round with the familiar round light emitting surface is original and most often deployed solution. Its combination of output, efficacy, and lumens/$ make it the global leader in the 5050 LED space. It's supported with an extensive selection of optics and complementary components that have developed over the last 8 years. In fact, optical solution provider LEDiL lists more than 200 lens and reflector choices to address a wide variety of applications and design parameters.

LUXEON 5050 Square offers the portfolio's highest light output levels while still delivering efficacy greater than 170 lumens/Watt. But perhaps the greatest advances brought to the portfolio was the outstanding corrosion resistance introduced with these parts and since applied to all LUXEON 5050 parts. The Epoxy Molding Compound (EMC package offers corrosion resistance comparable to a ceramic package. It enables significantly lower flux degradation and less color shift when used in harsh environments.

LUXEON 5050 HE, like the other LUXEON 5050 parts, delivers a combination of output, efficacy, lm/$, and robustness that supports OEM efforts to provide a range of options for any of their luminaires and to optimize value for their customers wherever possible.

Most Extended and Comprehensive LM80 Tests

Perhaps the most important data for LEDs used in critical applications with exposure to the elements is in the LM80 report and reliability datasheets that Lumileds provides to customers. While all 5050 LED manufacturers should provide both datasets, distinct and important differences between LEDs can be identified in this data. The LUXEON 5050 LM80 report covers over 17,000 hours of testing, and Lumileds provides customers with a comprehensive and detailed analysis of 16 different test items including: High Temperature Operating Life, Hydrogen Sulfide Test (15ppm H2S, 40C, RH 80%), and Temperature Cycle. Lumileds also reports detailed flux, forward voltage, and color maintenance data. Lumileds' extensive testing of the LUXEON 5050 line allows it to confidently claim L70 and L90 above 100,000 hours.

No industrial or outdoor luminaires should be designed without considering the longevity and robustness of the LEDs themselves. In these applications, exposure to everything from sulfur, smog, humidity, and heat, can affect the entire system. Lumileds has specifically engineered its 5050 LEDs to minimize risks of failure or premature degradation.

Continued Development

As global energy costs continue to increase, efficiency gains pay increasing dividends to end-users and communities that need to lower municipal costs, reduce energy consumption, and support sustainability goals. All these objectives can now be achieved while also addressing dark sky initiatives.

"As communities continue to develop outdoor lighting guidelines and as alternative energy models come online, Lumileds will continue to develop and evolve the LUXEON 5050 line so as to provide OEMs with the ability to meet and exceed the increasingly granular requirements put forward by customers," said Mei Yi, Director of Product Marketing at Lumileds. ■

Lumileds Delivers 199lm/W for Outdoor and Industrial Lighting with New LUXEON 5050 HE Plus LEDs

www.lumileds.com

Higher LED efficacy drives lower energy costs even as rates increase.

Efficiency and energy sustainability are key drivers of LED selection for industrial and outdoor lighting applications. With its introduction of LUXEON 5050 HE Plus, Lumileds can deliver 199 lumens per Watt and 746 lumens of high-quality light output and reduce application power consumption by 18% or more in critical infrastructure applications common to cities and businesses around the world. Further, the lower energy consumption of LUXEON 5050 HE Plus supports the transition to low-carbon or no-carbon electricity supply. OEMs can achieve greater sustainability in their manufacturing process by reducing the physical material in both the heatsink and the system's driver.

As global energy costs continue to increase, efficiency gains pay increasing dividends to end-users and communities that need to lower municipal costs, reduce energy consumption, and support sustainability goals. All these objectives can now be achieved while also addressing dark sky initiatives. With CCT options as low as 1800K and 70 or 80 CRI, LUXEON 5050 HE Plus is the clear choice for on and off grid lighting solutions.

"Efficiency remains the key driver for outdoor and industrial lighting and the focus of our continuous improvement programs," said Mei Yi, Director of Product Marketing at Lumileds. "The efficacy gains achieved with our LUXEON 5050 HE Plus make it the highest-performing 5050 LED available today and these gains offer dramatic performance advantages for on-grid lighting and solar, off-grid, solutions."

In addition to the leading efficacy and output combination, Lumileds has:

- Lowered thermal resistance to an Rth of 1.1k/W so that smaller, less costly heatsinks can be used
- Established narrower flux bin widths of 25lm to facilitate accurate system design
- Hot-color targeted the LEDs at 85°C
- Advanced the most robust package to support a maximum drive current of 1.2A

LUXEON 5050 HE Plus joins an already powerful portfolio that includes LUXEON 5050 Round, LUXEON 5050 Square, and LUXEON 5050 HE. Both the HE and HE Plus parts have a square light emitting surface. The performance advances available in the HE Plus versions is also available in Lumileds SunPlus 5050 LEDs for the horticulture industry now.

All LUXEON 5050 LEDs are immediately available through Lumileds global distribution network.

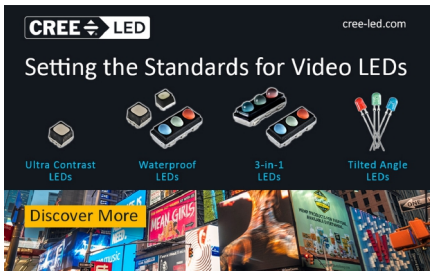
About Lumileds
Lumileds is a global leader in LED and microLED technology, innovation, and solutions for the automotive, display, illumination, mobile, and other markets where light sources are essential. Our approximately 3,500 employees operate in over 15 countries and partner with our customers to deliver never before possible solutions for lighting, safety, and well-being.

To learn more about our company and solution portfolios, please visit lumileds.com. ■

Learn How Cree LED Set the Standard for Video LEDs

www.cree-led.com

Setting the standards for Video LEDs: Waterproof LEDs, Ultra-contrast LEDs, 3-in-1 Lensed RGB LEDs, and Tilted Angle LEDs.



For decades, Cree LED has been at the forefront of video LED technology, setting the industry benchmark for large-format displays, digital signage and video screens used in sporting events, concerts and commercial installations.

Our expansive product portfolio and robust IP assets ensure our customers benefit from superior color performance and unmatched reliability. With a fabless manufacturing model, we offer unparalleled production flexibility and a secure, stable supply chain to meet the evolving demands of any business.

Building on a legacy of breakthrough advancements, Cree LED remains dedicated to pioneering the future of video LED technology, keeping our customers ahead of the competition.

About Cree LED
Cree LED offers one of the industry's broadest portfolios of application-optimized LED chips and components, leading the industry in performance and reliability. Our team delivers best-in-class technology and breakthrough solutions for focused applications in high power and mid-power general lighting, specialty lighting and video screens. Cree LED develops products backed by expert design assistance, superior sales support and industry-best global customer service.
cree-led.com ■

Casambi Rolls Out the Salvador Series 2000

www.casambi.com

Global leader in wireless smart lighting control, Casambi, is pleased to announce the launch of the Salvador Series 2000, the next generation in advanced lighting control systems. Building on the foundation of the popular Salvador Series 1000, the 2000 delivers cutting-edge functionality and versatility, allowing seamless integration of wired DALI drivers into Casambi's wireless ecosystem.

Designed to optimize both wired and wireless lighting networks, the Salvador Series 2000 brings unparalleled flexibility to a range of applications, from heritage refurbishments to modern office upgrades. This series enables DALI luminaires to operate as virtual devices within the Casambi network, giving users full control through the intuitive Casambi app.

Shipments for the Salvador Series 2000 will begin at the end of November 2024, with orders now being accepted.

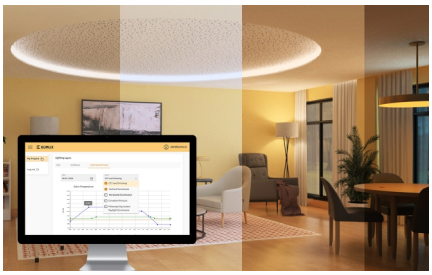
"With the Salvador Series, wired and wireless devices can seamlessly work together," stated Mark McClear, CEO of Casambi. "A hybrid setup could involve controlling luminaires via wired DALI alongside wireless Casambi Ecosystem products within the same lighting control system. This flexibility ensures our all-encompassing solution remains relevant across a wide range of applications, giving users the freedom to select the configuration that best suits their needs. Regardless of the environment, the Casambi experience, known for its rich functionality and user-friendliness, remains consistent."

About Casambi
Casambi provides smart lighting control via intuitive applications that set new standards in user interaction with light. Our Bluetooth® Low Energy-based technology easily integrates into fixtures and devices, allowing manufacturers to craft bespoke Casambi Ready products. Bridging wireless and wired DALI worlds, we guarantee seamless interoperability between all products and with industry standards. Users can mix and match for tailored lighting networks, ensuring adaptability across settings while enjoying the rich functionality of the Casambi experience. In just one decade, Casambi has become a global leader with 300+ ecosystem partners and 5+ million devices sold into 200,000+ lighting projects worldwide. An end-to-end solution, Casambi empowers individuals and enterprises alike to illuminate spaces with efficient, customizable control. The Casambi app is freely available for iOS and Android. Casambi. Where ideas come to light. ■

KUMUX Presents its Innovative Platform for the Optimization of Dynamic Lighting Design

kumux.io

KUMUX presents its latest advancement: the KUMUX Platform. This powerful tool enables designers to combine lighting aesthetics, human-centered principles, and circadian science to create optimized dynamic lighting environments.



KUMUX, dedicated to transferring the benefits of natural light to artificial light sources, has developed a revolutionary tool designed to optimize dynamic lighting design by integrating the most advanced scientific research on the impact of natural light on human health. With the help of artificial intelligence algorithms applied to lighting control systems and LED technology, KUMUX transforms indoor environments to promote people's well-being and quality of life.

KUMUX Service delivers dynamic lighting optimizing smart lighting systems that support human well-being. To empower lighting designers with the full potential of this service, the team has developed the KUMUX Platform, a configuration tool that simplifies the design and commissioning of dynamic lighting with these features:

- Optimized lighting settings: KUMUX Platform uses AI algorithms to incorporate solar data, science and standards into the dynamic lighting settings tailored to a specific project lighting design with any lighting fixture.
- Automation of optimized curves in any control system: KUMUX simplifies the commissioning process of the optimized dynamic lighting settings with major control systems, automating lighting levels and color temperature throughout the day.

KUMUX Platform: Elevating Lighting Design

KUMUX Platform offers substantial benefits that address common challenges faced by lighting designers. The Platform simplifies the dynamic lighting design process, providing guidelines, non-visual parameter calculations and presentation materials that significantly reduce the time required for lighting design.

Some of the included tools address the quantification of the wellness benefits associated with dynamic lighting, helping clients evaluate return on investment (ROI) more effectively.

Offering unparalleled customization and adaptability, KUMUX Platform ensures that each lighting solution is tailored to the specific requirements of each project, considering the application, luminaires spectrum, lighting layout, or standards and regulations to comply with.

In addition, the control architecture of KUMUX Platform, streamlines the configuration of dynamic lighting independently of the control system used, minimizing risks during construction and delivery. With data securely stored in the cloud, it allows remote updates of the lighting settings without affecting the existing control configuration.

New Features to Elevate Lighting Design

KUMUX Platform excels in offering precise solutions. It develops specific lighting configurations aligned with scientific parameters, facilitating automation of the control system and maximizing the impact of lighting on users' well-being. The KUMUX Platform offers advanced tools for lighting design, including:

- Custom settings for each project: Optimize the spectrum of each luminaire to adapt to the project objectives using AI algorithms. It can upgrade existing smart lighting projects where dimmable or tunable white fixtures are used, providing tailored solutions that maximize effectiveness and performance in each project.
- Integration with existing technology: Its commissioning system ensures the smooth implementation of dynamic lighting designs with all lighting manufacturers and main control systems such as Lutron, Casambi, Pharos, Summa, KNX and Inventronics (OSRAM),
- Efficient design tools: It provides a complete guide and documentation on dynamic lighting for well-being and performance that facilitates the process from conceptualization to commissioning, ensuring that the lighting delivered complies with the initial design.
- Dynamic lighting education resources: Provides resources to educate customers about the benefits of dynamic lighting, helping them make informed decisions.

KUMUX is positioned at the forefront of innovation in the lighting industry, with a value proposition that expands to encompass a holistic approach. KUMUX is a transformative solution that reshapes the industry landscape with a continued commitment to improving people's well-being and the sustainability of indoor spaces. ■

Electrónica OLFER: Casambi Profiles Versatility of the CBU-DA-1P

www.olfer.com

The new CBU-DA-1P is a Casambi device developed by Electrónica Olfer that has an integrated DALI Bus Power Supply with 100mA guaranteed current, which means that it can control up to 50 DALI LED drivers.

With this product, it is possible to create up to 8 DALI Groups without external tools and control the luminaires up to 8 zones independently. The CBU-DA-1P has a push button input for controlling Casambi devices and duplicated mains terminals (AC loop) for easy integration into lighting fixtures which facilitates its incorporation into any luminaire.

In this article, we are going to focus on one of the most important aspects of the product and what makes it one of the most versatile devices: more than 85 different Casambi fixture profiles available that offer us a wide variety of control modes to be able to use this device in any situation.

In order to choose the desired profile, we will need to connect the CBU-DA-1P unlinked and open the Casambi App, tap on "More -> Nearby devices -> Tap on the device icon -> Change Profile". Below, we will explain the control modes of some of the most notable profiles that are available for this product.

CBU-DA-1P PROFILES (excerpt)

- "DALI Broadcast" Simultaneous control of all connected DALI drivers.
- "DALI Broadcast + External" Simultaneous control of all connected DALI drivers. In addition, they allow the connection of DALI-2 brightness/presence sensors as well as DALI-2 push-button modules so that they appear in the app as if they were Casambi sensors or push-buttons (up to a maximum of 8 push-buttons).
- "DALI 1xDIM SA" … "DALI 8xDIM SA" Independent control of up to 8 connected DALI drivers. DALI addressing is done automatically and the app's user interface will display the same number of sliders as drivers the selected profile is capable of controlling (1 - 8 drivers).
- "DALI (1xGroup)" … "DALI (8xGroup)" Zone control of up to 50 connected drivers divided into up to 8 DALI groups. Drivers can be assigned to DALI groups directly from the Casambi app without the need to use any DALI programmer or external tool. The app's user interface will display the same number of sliders as DALI groups the selected profile can control (1 - 8 groups).
- "DALI DT6 TW" Connect two different DALI addresses (A0 - warm and A1 - cold) to control the color temperature independently of the power regulation of the luminaire.
- "DALI DT6 Dim to Warm" Connect two different DALI addresses (A0 - warm and A1 - cold) to control the color temperature depending on the power regulation of the luminaire. The light will be warmer at low dimming levels while it will be cooler at high levels.
- "DALI DT6 RGB" Connect three different DALI addresses (A0 – red, A1 – green and A2 – blue) to perform RGB color control.
- "DALI DT6 RGBW" Connect four different DALI addresses (A0 – red, A1 – green, A2 – blue and A3 – white) to perform RGBW color control. The white channel has a dedicated slider in the app.
- "DALI DT6 RGB/W" Connect four different DALI addresses (A0 – red, A1 – green, A2 – blue and A3 – white) to perform RGBW color control. A slider will appear in the app to control the proportion between the white channel and the RGB mix.

Through the following link you can consult the complete list of profiles, as well as the user interface in the app and the connection diagrams associated with each of the profiles: https://www.olfer.com/olfer-cbu-da-1p.html

As you have been able to discover throughout this article, the CBU-DA-1P device can provide solutions to a large number of projects since it allows you to control up to 50 DALI drivers and the available Casambi profiles encompass all the possibilities that we can find when we talk about DALI systems (groups, short addresses, DT6, DT8, RGB, TW, Dim to Warm, RGBW, XY…).

On the other hand, we can also connect DALI-2 input devices such as sensors and push-button modules to transform them into Casambi devices. In addition, the Olfer Electronics profiles perform an initial self-configuration of this type of device to ensure their compatibility in a transparent way to the user and without the need for expensive external tools to carry out their DALI programming.

Without a doubt, the new CBU-DA-1P is a useful and versatile tool that should be taken into account by any Casambi solutions integrator. ■

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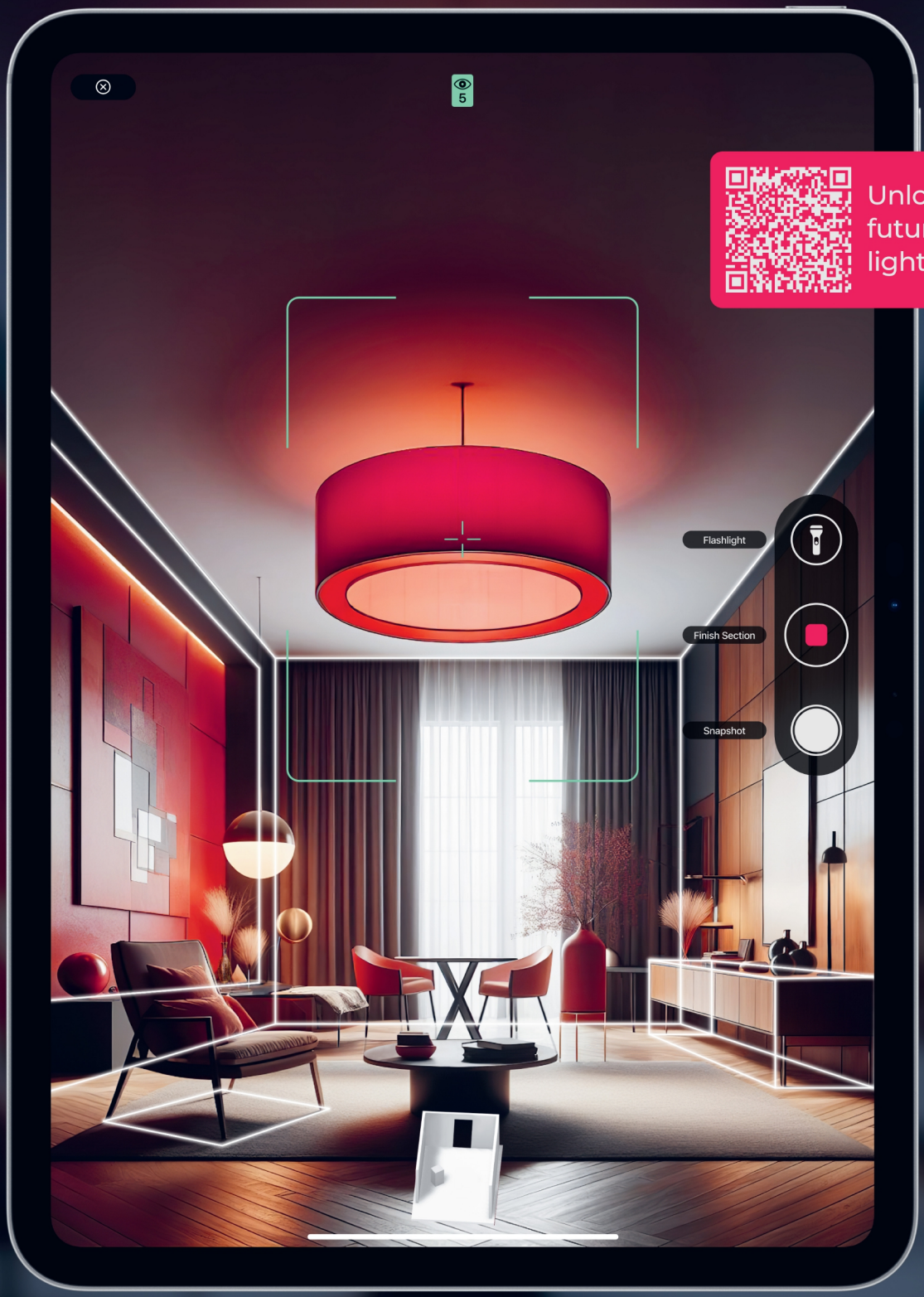

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Revolutionizing Lighting: How Wireless Control and Innovation are Transforming the Industry – Mark McClear, CEO of Casambi

Mark McClear:
"We provide the technology platform and services to support our ecosystem partners as they develop and bring unique Casambi Ready products to market. Over 300 partners have developed and marketed more than 2,000 Stock Keeping Units (SKUs) for the Casambi open ecosystem, with new products being introduced every day."

In this exclusive interview, we speak with the CEO of Casambi, who reflects on his transformative first year leading the company. With over 20 years of global experience in the LED and SSL sectors, he shares his vision for the future of lighting, where wireless controls and integrated technologies are reshaping the industry. This conversation delves into the challenges and milestones of his first year at the helm, and how Casambi is leading the charge in innovation, leveraging its international presence and open-ecosystem architecture to redefine lighting solutions for the next generation.

Casambi.com

LED professional: **We are very pleased to conduct this interview with you on the occasion of your "First Year Anniversary as Casambi CEO." First of all, we would be interested in hearing about your career journey and how you ultimately ended up as the CEO of Casambi.**

Mark McClear: Absolutely, I'd be happy to share my journey with you. I've been in the lighting industry for what feels like forever, and I still remember the early days of LEDs when many just couldn't see the potential. It was tough, but also pretty exciting. I see the transition to wireless controls in much the same way.

I joined Casambi in February 2022 as the General Manager for North America. By that time, I had already spent 20 years in the LED and SSL sectors, working across more than 35 countries in Asia, North and South America, and Europe. I've been lucky to have worked with some amazing people, contributed to some of the early LED standards setting, and led some important, transformative organizations in our industry.

Becoming the CEO of Casambi was a real honor for me. We're at such a pivotal moment in the lighting world. Remember when lighting was all about stamped metal and screw-in lamps? Now we've moved to integrated LEDs, and it's clear that soon all luminaires will have embedded Bluetooth Low Energy radios and sensors. It's like watching the future unfold.

Casambi is in a fantastic spot to lead this shift. We're the only truly international lighting control platform out there, and our open ecosystem architecture is a game-changer compared to legacy proprietary systems. This approach is all about innovation and giving our partners and clients the flexibility they need to create the next big thing for their markets.

So, here I am, leading Casambi. After a year at the helm, I'm extremely excited about what's next. We have a talented global team. We've launched a game-changing new product family this year. It's a great time to be in this industry, and I'm thrilled to be part of it.

LED professional: **Casambi is a globally leading company in the field of lighting controls, particularly in wireless communications. What has made Casambi so successful?**

Mark McClear: Thank you.

Casambi is different in two important ways.

First, there is the Casambi open ecosystem. We provide the technology platform and services to support our ecosystem partners as they develop and bring unique Casambi Ready products to market. Over 300 partners—on their time and on their dime —have developed and marketed more than 2,000 SKUs for the Casambi open ecosystem, with new products being introduced every day.

The Casambi open ecosystem offers our clients the best sensors, switches, drivers, and controllers from leading manufacturers around the world. This allows them to select the components that fit their project perfectly – all Casambi Ready products work together regardless of brand and we offer an extremely easy way to Casambify those that are not. If they don't like the form, fit, function, price, delivery, or any other aspect of a given component, there are always alternatives within the Casambi ecosystem.

The open nature of Casambi ensures multiple sources for most system components, which not only keeps the supply chain robust but also fosters innovation and faster design cycles. Additionally, it provides transparency in pricing, governed by the market not dictated by propriety brands.

In contrast, a closed ecosystem, that is to say, a vendor-specific proprietary environment, often comes with limited choices and higher risk of supply chain disruptions. Casambi's open ecosystem represents a truly different and innovative business model, where clients benefit from flexibility, innovation, and price transparency, and our ecosystem partners have the opportunity to build a business with Casambi.

The second key to Casambi's success is simply that Casambi works. While many have attempted to develop their own wireless lighting control systems, none have matched the features, flexibility, reliability, and intuitive user interface of Casambi. Our system has proven its effectiveness across every continent and major market, with more than 200,000 projects and 6,000,000 installed nodes across more than 150 countries.

We have addressed more questions and solved more problems in wireless control than most can imagine, and built a global service, training, and support organization to address questions and issues as they arise. Casambi systems are installed in a wide range of applications, from warehouses and offices to retail spaces, residential areas, hotels, and heritage landmarks. We support networks of all sizes, from small installations with just a few nodes to large, multi-building systems with over 15,000 nodes. Casambi works well both indoors and outdoors with robust long-range capabilities. Our systems are also deployed in secure environments, including hospitals and airport control towers.

Bluetooth Low Energy technology was originally created at Nokia's Research Center, where the people who later started Casambi worked. Because of this, Casambi was able to fully understand and use BLE from the very beginning. In fact, they started developing their products before any BLE devices were even available on the market. For over 13 years, Casambi has been dedicated to being the foundation of smart lighting, consistently delivering the best possible user experience. This commitment is why Casambi is successful: Casambi works.

LED professional: Casambi's ecosystem is vast due to the different approach you've chosen. Let's delve a bit deeper into the business and partner model. How exactly does it work, and how can one become a partner of Casambi?

Mark McClear: As an analogy, I can explain that the Casambi open ecosystem is like the app store on your smartphone. If Apple and Android had created their respective app stores and then provided all the apps themselves, the apps available would have been limited by the capacities of these companies to imagine, develop, deliver, and support these proprietary apps. If something went wrong with, or if they wanted to add a new feature to one of their apps, users would have had no alternative but to wait for them to fix or update it. There would also have been very limited competition, no pressure to innovate, and this model would have afforded these companies near-monopoly economic power and the ability to extract revenue wherever, whenever, and however they pleased.

Closed ecosystem (a.k.a. "walled garden") lighting control companies—particularly in the US—are similar to this. They offer a limited number of components to support their systems and may threaten to void the warranty if you use a component from a source other than theirs. They tightly control and often bundle pricing to make it difficult for clients to understand what they are buying and paying for, and they frequently tie ongoing service and maintenance contracts to their system sales. The supply chain shortages and lead times of over 60 weeks on some components following the pandemic have clearly exposed another vulnerability of this model. Fortunately for all of us, Apple and Android chose an open ecosystem for their app stores.

Casambi is an open ecosystem as well. The best sensor manufacturers in the world are Casambi ecosystem partners, as are manufacturers of drivers, switches, and a host of other critical network components. With hundreds of ecosystem partners and thousands of SKUs, anything a client is looking for is probably already available in the Casambi open ecosystem. If a client needs something unique, we can refer them to the best, fastest, and most cost-effective partner who can quickly create the product they need for their project. And guess what? That innovative new product then becomes available and is part of the Casambi open ecosystem.

Becoming a Casambi partner is easy. Simply integrate a single SoC chip (we can help) into your hardware product. The chip includes Casambi software, ensuring communication with our user interface, along with free OTA (over-the-air) software updates, and 100% interoperability. Our team at Casambi will assess the radio functionality of your hardware for optimal efficiency, and we will promote your product on our website to help boost sales.

We have assisted dozens of our ecosystem partners worldwide in selling within their local markets and expanding into global markets. Partnering with our ecosystem is a priority (and one of our core company values). We want to help our partners build healthy, competitive, and profitable businesses, and we remain committed to providing the resources needed to make this open ecosystem vision a reality.

Our VARs and local sales partners are also essential members of our ecosystem, playing a crucial role in promoting and selling Casambi-integrated lighting products for various projects. They bid, build relationships, and offer tailored luminaires, often handling local manufacturing or representing international brands. Our Casambi Integration partners also enhance these offerings by providing customers with comprehensive solutions, including commissioning services and first-tier support. This cross-collaboration within the Casambi ecosystem further broadens market reach for all, boosts partner revenue, and ensures competitive advantage with advanced Casambi technology.

LED professional: Casambi recently launched a groundbreaking system extension called Salvador, which bridges the gap between wireless and wired systems, with a particular focus on DALI integration. What does this 360° ecosystem look like?

Mark McClear: The launch of the Salvador Series[1] this year is an extremely significant step in Casambi's mission to be the foundation for smart lighting. This new product family bridges the gap between wireless and wired systems, with a particular focus on DALI integration.

The Salvador Series 1000 seamlessly integrates wired DALI drivers into the Casambi system. When integrated, DALI luminaires appear as virtual luminaires in the Casambi network. This product family includes three models: SAL-1016, SAL-1032 and SAL-1064. For more information: casambi.com/ecosystem/salvador

DALI is a great, capable, and ubiquitous lighting controls protocol and standard (especially in Europe and parts of Asia). However, one of the challenges with DALI installations has always been that they typically require highly skilled personnel to commission the systems.

[1] Salvador Series https://casambi.com/news/casambi-is-now-taking-orders-for-salvador/

Another challenge is that adding a simple switch or additional sensor can be expensive and labor-intensive. With Salvador, however, adding another network component is simple. Salvador also brings the Casambi user interface to DALI lighting installations, so wired DALI system components appear in the Casambi app alongside wireless Casambi components. Commissioning a DALI system is now as easy as commissioning a system with the famously user-friendly Casambi user interface. All it takes is adding a tiny white module—Salvador—to your DALI system.

One of our great partners [I'm sure he won't mind me sharing this], Tom Pybus, Sales & Technical Manager for Holders Technology Australia, recently shared on social media his experience with the Salvador system, highlighting how effortlessly it replaced a defunct, outdated DALI controller. His entire project, from start to finish, was commissioned in half an hour. Naming, grouping, and building a scene were completed with ease, and the system responded reliably from up to 40 meters away. For those familiar with the painstaking process of setting up hard-wired DALI systems, the Salvador Series is indeed a game-changer.

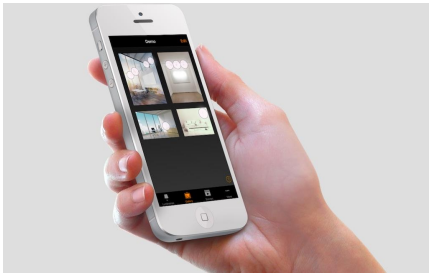
LED professional: Casambi, the wireless lighting company, now also offers wired solutions. The simplicity of wireless commissioning has been impressive, so can you tell us how the commissioning process works? Does this same simplicity extend to Salvador with its wired extension?

Mark McClear: Who said we were a wireless company? OK, while we are indeed known for our wireless solutions, we're actually a user experience company first and foremost, with a vision to be the foundation for smart lighting. We happen to think wireless is the best way to accomplish that, and the ultimate in cost and sustainability, but Salvador can help us build hybrid and even fully wired systems that are beautiful, functional, and save significant amounts of energy. Salvador is another tool in the toolkit to become the foundation for smart lighting.

As I mentioned earlier, once you hook up your DALI system to a Salvador, all the DALI luminaires appear in the Casambi app as Casambi Ready luminaires, which can be programmed in the app

Casambi Pro is a powerful planning and commissioning tool tailored to the unique needs of ambitious projects. It's aimed at installations with automated control systems comprising schedules, sensors, and switches. Casambi Pro isn't your end-user controller like the Casambi App is. Casambi Pro excels in particularly large sites that feature repetitive layouts. It empowers you to create and configure Casambi installations with greater efficiency, minimizing the need for extensive on-site technical configurations.

to your heart's delight. The beauty of the Casambi app is its simplicity—it's almost impossible to make a mistake. You can configure, reconfigure, add last-minute components (normally switches, sensors) and adjust as many times as you need until you're happy with the setup—no need for any specialized hardware, external expertise, or extensive setup time.



The Casambi app works as one of the user interfaces in a Casambi lighting control solution, as the commissioning tool and as well as a remote gateway. The Casambi app works with iOS as well as Android devices, like smartphones and tablets. The app is free to download by any end-user.

LED professional: Sustainability is a major concern in today's world. How is Casambi contributing to energy efficiency and environmental sustainability through its products?

Mark McClear: Internally, Casambi is committed to sustainability in every aspect of our operations. We adhere to strict supply chain practices, with a clear code of conduct and policies on conflict minerals and global human rights. We comply with all relevant EU Council Directives covering everything from efficiency and safety to the restriction of hazardous substances. But honestly, this is table stakes and just part of being a good corporate citizen.

LpR readers are well aware of the energy-saving potential of LED lighting, which can reduce energy usage by at least 50%. Smart lighting controls offer an additional 20-25% on top of that. Regulatory bodies in North America have recognized this and have begun mandating Luminaire Level Lighting Control (LLLC) as well as integration with HVAC and BMS systems. The most effective way to comply with these regulations will be through smart lighting controls. Casambi will play a key role in this effort to reduce energy consumption, in turn, lessening environmental impact and helping to conserve resources.

Similarly, the global phase-out of fluorescent lighting is leading to the widespread replacement of many lighting fixtures. As these luminaires are upgraded, some may be part of legacy systems with existing DALI control lines, while others may lack any previous control system. Instead of upgrading outdated DALI systems or installing new copper wiring, a wireless solution like Casambi, or a hybrid system using Salvador, can be used to achieve significant energy savings.

Finally, for new construction, every wired lighting control system requires copper wires. If you take the average lengths of copper wiring used in typical construction projects and a rough estimate of the number of new build projects occurring each year, we're talking anything between a million and 20 million km of cop-

per control line wires installed each year. Going wireless can significantly reduce the labor and transportation involved in installing thousands of kilometers of copper cables, as well as decrease the need for mining substantial amounts of copper in the first instance. Mining just one ton of copper generates approximately 4.7 metric tons of CO_2, which is about 250 times the CO_2 emitted by driving 100 km (approx. 62 miles) in your average gasoline car. While it may not be the most talked-about sustainability story in the lighting industry, it's certainly a compelling one!

LED professional: **Casambi is a pioneer in BLE mesh technology for lighting control. What are the next major technological advancements we can expect from Casambi? How do you envision the role of artificial intelligence and machine learning in enhancing Casambi's lighting control solutions?**

Mark McClear: I would say that both I, personally, and we at Casambi have been early adopters of AI, and we are already using it in many of our business processes. Additionally, some of our customers, with the help of our ecosystem partners, have pioneered innovative use cases such as counting people, inventory, and other objects, as well as measuring environmental parameters (temperature, humidity, CO, CO_2, etc.) and space utilization.

It turns out that a well-lit space requires luminaires at regular intervals, and a sensor can provide real-time data on how people are using the space. A grid of many sensors can generate data that can be mined for actionable information. This already exists, and I can envision how one of our ecosystem partners could extend this with AI to include predictive and behavioral modeling. In fact, take Calumino. They're using AI with their thermal sensors to study how people move and behave within spaces. This will make lighting and temperature control way more efficient and way more tailored - responding to the presence and behaviors of people in real-time. However, this kind of data and analysis falls outside Casambi's vision of being the foundation for smart lighting. To put it another way, referring back to the ecosystem point, I think this is a fascinating use case, and I fully expect our ecosystem partners to pioneer it. We will cheer them on, but pursuing this ourselves could dilute our vision and resources, and Casambi is unlikely to take it on directly.

LED professional: **Casambi has a significant presence in Europe. You also opened a regional headquarters in Singapore in 2022 and in the US five years ago. How does Casambi tailor its products and strategies to meet the specific needs of different regional markets?**

Mark McClear: This was a major challenge and learning curve for us. I may get together with my colleagues in Finland, Asia, and the US and write a book on this someday! The lighting markets in each of these regions have dramatically different drivers and structures. The players, regulations and working cultures are also completely different. And nobody cares that, "This is the way we do it in London, so of course it must work in Lahore (or Los Angeles)" or, conversely, "We just did this in Atlanta, we should try this in Amsterdam (or Auckland)".

I would say the key to our success in these new geographies has been our openness—both in terms of how we organize and compensate people, respect local customs and holidays, and ensure compliance with local electrical standards.

On the one hand, we have built completely independent ecosystems in the three markets, tailored to local needs and codes. On the other hand, we remain unwavering in our partnering ethos described above and, unexpectedly, have become experts in the global lighting market—a byproduct rather than an initial goal. After a lot of learning and adaptation, the North American market, in particular, has become a strong fit for Casambi, and North America could eventually become our largest region.

Similarly, we are very bullish about the potential in Australia, India, Singapore, and the Chinese export market, all of which are excellent fits for Casambi. We continue to see double-digit growth in Europe and are optimistic that Salvador can motivate the wired segment of that market to explore Casambi. We believe that once electricians, specifiers, and others experience the ease of commissioning Salvador provides, they may be more inclined to try full wireless solutions on future projects. Salvador is expected to gain significant traction in Asia for the same reasons. However, somewhat unexpectedly, we are also seeing very strong interest in Salvador from North America, prompting us to accelerate the development of specific form factors and voltages tailored to that market.

The common thread throughout all of this is listening, learning, being open-minded, and adapting.

LED professional: **What leadership principles do you believe have been most crucial to Casambi's success so far?**

Mark McClear: I have a quote that I love on the wall of my office in Finland from a famous American leader, Andy Stanley: "Leaders who refuse to listen will eventually be surrounded by people with nothing to say." While I can't promise to always agree with my colleagues, I do promise to listen, and they can hold me accountable to that. On my better days, I live up to this and I expect all people leaders at Casambi to do the same. This applies to our customers and partners as well, which is why we say "partners are our priority." It's one of our core values, and we talk about it constantly. Listening and partnering are fundamental, non-negotiable principles for Casambi. There are other important values too, and perhaps they'll make it into the book as well...

LED professional: **Can you share a significant decision or strategic move that you believe has been pivotal to Casambi's growth?**

Mark McClear: I must say that the design, care, and nurturing of the open ecosystem and the partnering ethos envisioned by our founders, Timo Pakkala and Elena Lehtimäki, have proven to be truly brilliant. This approach has allowed Casambi to focus on what we excel at—lighting controls software—and improve at a much faster pace than others who have diluted their efforts by attempting to do both software and hardware simultaneously, creating their closed "walled garden" models.

The Linfa Desk Light by Robonica Srl won Best Product. Their office solution merges LED lights with a hydroponic irrigation system, addressing both human well-being and sustainable indoor plant cultivation. With dual-tunable white LEDs and automated Casambi controls, it creates optimal lighting conditions for both plants and people, making it a standout in terms of design and functionality.

The Giorgio Franchetti Gallery at the Ca' d'Oro in Venice, Italy, won Best Project. This project, led by restoration architect Giulia Passante and lighting designer Alberto Pasetti Bombardella with ERCO, has beautifully revived the historic facade of this 15th-century palace. The restoration highlighted the palace's original vibrant colors and grandeur, brought back to life through cutting-edge lighting technology.

LED professional: Looking ahead five to ten years, what do you think the lighting control landscape will look like, and what role will Casambi play in it? What are your long-term visions for Casambi, both in terms of technology and market presence?

Mark McClear: The global lighting market is vast, attractive, and growing. I expect Casambi to remain independent, continue expanding, and gradually replace legacy wired control systems. Similar to the LED market in 2010, there are still large segments of the lighting industry that have yet to try Casambi. I used to say, "Nobody wanted to be the first to try LED, but they sure lined up to be second." I believe wireless lighting controls will follow the same pattern, with Casambi staying at the forefront. I expect continued growth across all regions, strengthening our ecosystem, and winning over those who are second in line, one at a time.

LED professional: In conclusion, we would like to discuss the Casambi Awards. What are they, and who are this year's winners?

Mark McClear: The Casambi Awards are our way of celebrating the incredible work our ecosystem partners do with our technology. Each year, we recognize outstanding achievements in architectural lighting projects and products, focusing on design, functionality, and sustainability.

We assemble a unique jury each year, composed of highly respected industry influencers from across the globe who evaluate entries in two categories; Best Casambi Ready Product and Best Casambi-controlled Project. They look for exceptional examples of lighting design, whether it's through innovative concepts, sustainable practices, or just that bit of magic. Winning projects are those that excel in being smarter, safer, and greener while adding a distinctive touch to the lighting landscape.

This year's winners exemplify these qualities perfectly. The Linfa Desk Light by Robonica Srl won Best Product. Their office solution merges LED lights with a hydroponic irrigation system, addressing both human well-being and sustainable indoor plant cultivation. With dual-tunable white LEDs and automated Casambi controls, it creates optimal lighting conditions for both plants and people, making it a standout in terms of design and functionality.

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Every year, we receive hundreds of amazing entries from around the world. I'm continually impressed by the creativity and ingenuity in our ecosystem. While Casambi provides the core technology, it's the exceptional creativity and innovation of our partners that truly brings it to life.

LED professional: Thank you, Mark, for your time and the valuable insights into current and future systems and trends! We wish you continued success in leading Casambi. All the best with your visions and strategic plans, and much success to you and your team!

Mark McClear: Thank you! ■

For additional information, please visit **casambi.com**.

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Recognizing the Excellence：
In. Licht X Works with WELL in HCL

Lighting Recipe Studio (LRS) is a professional light research institute and also a leader in the development of forward-looking light products. It has the most advanced light environment monitoring technology, combined with life science research, to create various advanced algorithms to provide the highest light quality for human health.

Game Changers to Reshape the Lighting Systems

Before, the researches of light & health were not well understood and applied without the regulations; recently, as we adapted light concept from the WELL standard, we discovered most of the lighting environments are not healthy enough for humans. Until now, with In. Licht portfolio, lighting data are visualised and able to interact with the dynamic lighting system, finally, we are able to build an adaptive lighting environment for a higher quality of health.

People-Oriented Design plus Works with WELL

Combined with the WELL standard by the International WELL Building Institute (IWBI) for healthy buildings, the advanced life science research results from the LRS team in light, emotion and brain cognition, allows them to establish the premium professional-level light meter for light quality and HCL - **In. Licht Ultra** and **In. Licht pro**, the 1st and 2nd lighting fact sensor to be listed by IWBI "Works with WELL" program.

INTERNATIONAL WELL BUILDING INSTITUTE MEMBER CORNERSTONE

From In. Licht pro to In. Licht Ultra

In. Licht pro is the most compact EML sensor by far recognized by Works with WELL and designed for better practical field application experience. In. Licht pro lighting sensor monitoring 5 key lighting indexes: Lux (Illuminance), EML (Equivalent Melanopic Lux), CCT(Correlated Colour Temperature), Visual Contrast, Uniformity

It provides real-time monitoring of light data in a super light-weight (40 g) device. Unlike any other light meters, In. Licht pro captures the key index of circadian rhythm, the Equivalent Melanopic Lux (EML), which can truly reassure residents in a healthy lighting environment. although In. Licht pro meets the needs of lighting industry personnel, but LRS is not satisfied just with this achievement.

Laboratory-grade Spectrum Meter to be Reveal

In higher-end professional spectrum analysis, many experts have to work in the lab for their tasks. Some equipment that can perform spectral analysis in the field are bulky, heavy, and requires handholding. In response to the needs of professionals, the team has developed a lab-grade spectrometer that is hands-free (might be the world's lightest, again) and also Works with WELL certified.

In. Licht Ultra equipes with the best-in-class CMOS linear IC and Flicker sensor, provides 8 key modes to capture the light data:

- Spectrum
- Illuminance
- Flicker
- S/P Ratio
- HCL indexes (EML, mEDI, CS, CAF)
- Quality of Light (CRI, Ra,TM-30 Rf & Rg & vector,
- SDCM, DUV,CQS)
- Flicker Risk (frequency, percent, index, SVM)
- Blue light hazard

Those key modes contains 27 plus indexes with further upgrade services, and the product will certainly provides the best lighting inspection experiences for the expertise.

In. Licht Ultra- which is expected to be launched in Q3 2024.
The lighting industry will look forward to it. ■

Pioneering the Future of Smart-, and Sustainable Lighting, Antonio A. ROMANO, VP R&D at Tridonic

Dr. Antonio A. ROMANO
"We are at the forefront of the transformation, and with the support of our people, partners, and customer feedback, we are shaping a future where lighting does more than illuminate spaces — it enriches experiences and fosters a healthier world."

In this exclusive interview, Dr. Antonio A. Romano, Vice President Global R&D at Tridonic, shares insights into the innovations transforming the lighting industry. Under his leadership, Tridonic is at the forefront of smart, sustainable solutions that integrate AI, IoT, and energy efficiency. Dr. Romano discusses how Tridonic is driving advancements that reduce environmental impact while enhancing well-being through human-centric lighting. From DC grids and AI-driven controls to the importance of cybersecurity and regulatory compliance, Dr. Romano explains how Tridonic balances innovation, cost-efficiency, and sustainability. In this interview, you will discover how Dr. Romano and his team are shaping the future of intelligent lighting, revolutionizing how we illuminate and interact with our environments.

www.tridonic.com

LED professional: **Thank you for taking the time for this interview. First of all, we would be interested in hearing about the course of your career and how you ultimately became the Vice-President Global R&D at Tridonic.**

Antonio A. ROMANO: I took on my current role at Tridonic in May 2020 coming from the Zumtobel Group where I was Head of R&D in a business unit, and before that, global Head of PMO for the entire organization.

After completing my academic studies, my journey of innovation started in the semiconductor industry, where I had global R&D and project management roles at STMicroelectronics, NXP, and ST-Ericsson.

From 2005 to 2007 I worked for a MEMS technology startup based in the USA that developed sensors and actuators for various industries. This role taught me the importance of agility and adaptability in innovation, driving rapid development cycles while maintaining technical excellence.

In 2010, I moved to Philips Lighting, where I focused on developing smart lighting systems and IoT-enabled solutions, overseeing global R&D and PMO teams in different business units. This work highlighted the transition from traditional lighting to connected, data-driven systems. At the Zumtobel Group and now at Tridonic, my focus has been on components for delivering cutting-edge, intelligent lighting solutions that meet evolving market demands. Leading innovation in this role involves not just developing new products but also addressing challenges such as cybersecurity, regulatory compliance, and sustainability.

LED professional: **We would like to discuss current trends in lighting starting with a topic that was also at the forefront of this year's Light & Building: Sustainability. How do you understand sustainability, and what does it mean for research and product development?**

Antonio A. ROMANO: Our corporate culture has a long-standing ecological foundation that we can build on. We are focused on creating lighting technology that can make a positive contribution to the planet and communities and at the same time improve everyone's well-being. Our products and solutions are designed to help mitigate the consequences of climate change. We use our technological expertise to create solutions that reduce the environmental impact, promote energy efficiency, and have a positive influence on well-being and the planet as a whole.[2]

In our R&D activities we focus on key areas, including energy efficiency, where LED lighting provides long-lasting products that significantly reduce energy consumption compared to incandescent or fluorescent lighting, leading to lower carbon emissions. Moreover, integrating sensors and the Internet of Things (IoT) allows for adaptive lighting systems that operate only when needed, enhancing both intelligence and sustainability. In terms of material selection, we prioritize recyclable, biodegradable and sustainably sourced options to minimize our environmental footprint. As an electronics manufacturer we therefore select eco-friendly suppliers, meticulously trace our supply chain and opt for components with minimal environmental impact, while emphasizing durability to reduce waste and the need for replacements. Our lifecycle approach involves designing products for easy disassembly to enhance recycling and end-of-life management, and embracing a circular economy model that encourages reuse, remanufacture or recycling of products to minimize resource extraction and waste. Additionally, our commitment to health and well-being is rooted in our understanding of the impact that lighting has on people. By maintaining natural rhythms, our systems can alleviate eye fatigue, brighten moods, and enhance productivity.

LED professional: **Lighting systems are increasingly evolving into more complex architectures with sensors, networks, data handling, and much more. Where is the journey heading in terms of lighting controls and what can be achieved with this, for example, in the context of human-centric lighting?**

Antonio A. ROMANO: Lighting systems are indeed evolving into complex architectures where humans and technology are interacting more closely than ever. We shape the connectivity components you have rightly listed into systems that make things much easier for people and ultimately lead to the convenient use of sophisticated technology. These smart

[2] https://www.tridonic.com/en/int/company/sustainability/sustainable-lighting

Tridonic is known for its expertise in the field of emergency lighting and wants to develop emergency lighting products for further markets. The EM ready2apply portfolio consists of ready-to-use emergency luminaires for both recessed and surface mounting on the ceiling.

systems can be applied to utilize energy more efficiently.

Smart and adaptive lighting means that dynamic controls can adjust lighting levels based on real-time data, such as occupancy and daylight, creating personalized, energy-efficient environments. Think of complex office buildings where people work in different areas at different times. As a facility manager, you need to know how much energy is being consumed and at what times, and whether less frequented rooms can be used more economically. This involves gathering reliable data which you could do with the help of the omnipresent lighting system. That's why we develop systems that are designed to provide good lighting, but that can also supply the Building Management System with data using sensors and controls. Thinking one step further-beyond the building management system–you come to the integration of IoT, which enhances holistic building management by linking lighting with central systems controlled from anywhere in the world.[3]

Human-centric lighting is another significant area. HCL systems can adjust color temperatures throughout the day to support natural circadian rhythms, improving alertness during the day and helping to relax in the evening. Settings can be personalized to enhance individual comfort and productivity. Energy efficiency and sustainability are improved by automated energy management systems that intelligently dim or turn off lighting when not in use, effectively reducing consumption. Predictive maintenance driven by data analytics can optimize performance, extending system lifespans and reducing downtime. Enhanced data utilization is made possible through sensors that provide insights into space utilization and information on energy-saving strategies. In healthcare settings, lighting systems equipped with biometric sensors can aid in patient recovery by adjusting illumination based on individual health data. Finally, user interaction and AI integration through voice and mobile controls further amplify accessibility in lighting management.

The resulting connectivity offers more and more possibilities - but it also generates greater complexity. This makes it an exciting and challenging task for us as developers not to make these systems too complicated for people to use, but rather to make the user experience and usability clear and convenient. After all, they should serve people, support well-being and be kind to the planet.

LED professional: **The connection between artificial and natural light plays a significant role. Well-being largely depends on whether we have a connection to the outside. What does a modern lighting system look like from this perspective, and what technologies are required?**

Antonio A. ROMANO: Modern lighting systems seamlessly integrate both artificial and natural light to enhance well-being. At Tridonic, we address this connection by employing dynamic daylight simulation, utilizing tunable white LEDs capable of mimicking natural daylight's color temperatures and brightness to support circadian rhythms. We also incorporate technologies that harvest natural light, ensuring that adequate artificial illumination complements existing natural light. Building integration is enhanced through biophilic design, which incorporates large windows and skylights to maximize natural illumination, while automated shading systems regulate sunlight exposure to maintain indoor comfort. Additionally, AI enables real-time adjustments to be made to strike a better balance between natural and artificial light based on current conditions and user behavior, ultimately improving health through enhanced exposure to natural light.

With these technologies, modern lighting can bring many benefits to end users. Harmonization with the human circadian rhythm, for example, supports alertness during the working day and relaxation phases at the right times. The lighting can also be customized to personal requirements. As a result, good lighting can promote overall well-being.

LED professional: **One topic that has become increasingly prominent lately is the use of DC grids for lighting. What is the current state of developments, and what can the market expect in this segment in the future?**

Antonio A. ROMANO: At Tridonic, we are actively engaged in the development of DC grids. These systems are gaining traction thanks to their efficiency and compatibility with renewable energy sources, sparking from major players outside the lighting sector as well. This shift coincides with rising energy costs and a growing desire to reduce dependence on fossil fuels.

DC grids are particularly suited for high-demand sectors such as data centers, where they enhance efficiency and integrate seamlessly with solar panels. Tridonic has recently joined the Current OS Foundation[4] as board members, which presents an exciting opportunity for us. Our intention is to promote DC technologies through experiential centers where customers can witness their functionality across various applications, including street lighting, vertical farming, and data centers as we strongly believe that this

[3] https://www.tridonic.com/en/int/controls/indoor/scenecom-evo-dali-2-lighting-control

[4] https://currentos.foundation/

is what customers need, considering the factors we have just mentioned.

We are currently working with some DC partners to provide drivers and luminaires for those projects.

LED professional: What influence, status, and significance will AI have for light, lighting controls, and their applications?

Antonio A. ROMANO: This is something we are dealing with intensively. AI, or more accurately, machine learning, is revolutionizing lighting by enabling intelligent, adaptive controls that optimize energy consumption and enhance user comfort. AI/ML technologies drive smarter lighting systems that adjust dynamically to real-time conditions and user behavior. And it is already helping with predictive analytics: AI can analyze patterns to predict maintenance needs and optimize lighting performance, reducing downtime and operational costs.

The significance of AI/ML extends to personalized lighting experiences and seamless integration with other smart building systems which fosters a cohesive and efficient building management ecosystem.

Our journey began with using data-driven algorithms to automate basic lighting functions, such as adaptive lighting that responds to external light levels, occupancy, and time of day. Early AI efforts were aimed at improving energy efficiency by automating light intensity and timing.

We then advanced towards more complex deep learning models, enabling lighting systems to learn from user behaviors and predict preferences. The systems now understand patterns of individual or group preferences, adjusting the lighting to suit various activities like work meetings, relaxation and presentations without manual intervention.

Our AI solutions are integrated with IoT devices and other smart building systems, such as HVAC, security, and shading. This interoperability allows for a holistic approach to building management, enhancing both occupant comfort and energy management.

With the inclusion of ML algorithms, we can move toward real-time optimization. The system collects continuous data and makes adjustments based not only on historical data but also on real-time inputs, offering predictive maintenance and even improving the lifespan of lighting components.

In one of our projects, we implemented an AI-controlled lighting system in a large office building. It has changed some aspects of the space. In the personalized workspaces, AI collected data about each employee's lighting preferences based on their activities, including preferred brightness levels and working hours. Over time, the system learnt patterns and automatically adjusted the lighting to the individual needs of each employee as they entered the workspace.

AI also achieved improvements in energy efficiency. It continuously analyzed occupancy patterns and the availability of daylight in order to optimize energy consumption. For example, the system dimmed the lights near windows during the day when there was plenty of natural sunlight, while ensuring that the interior spaces were adequately lit.

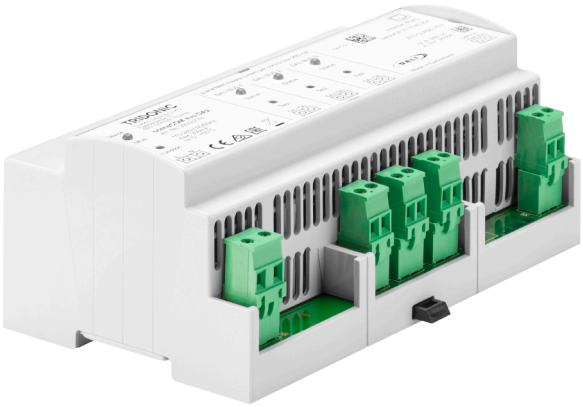
Integration with other systems was important for this project. The lighting system was also integrated into the office's HVAC system. When only a few people were present, the lighting was dimmed, and the HVAC system reduced the air conditioning without compromising comfort. Overall, the well-being of the employees was paramount. AI monitored circadian rhythms and adjusted the lighting to promote alertness and wellbeing by using cooler lighting in the morning to energize employees and warmer lighting in the afternoon to relax them.

LED professional: Product and system development faces the challenge of finding a balance between cost, progress, and political regulations. What are the key issues here, and what solutions do you see or have planned in Tridonic's roadmap?

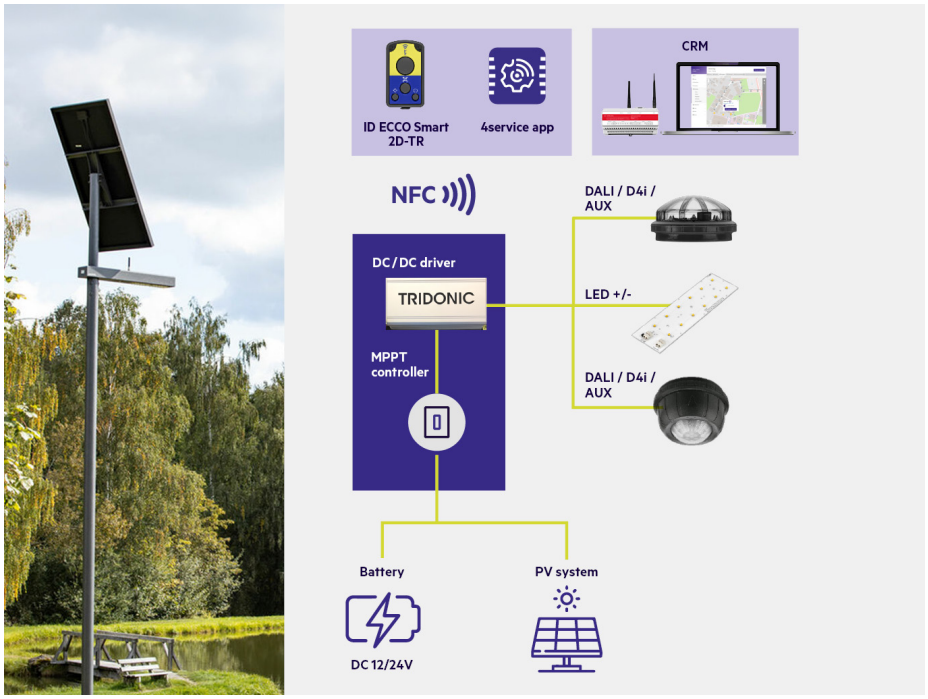
Antonio A. ROMANO: In product and system development, balancing cost, innovation and adherence to political regulations presents several challenges. Cost control is essential to maintain R&D expenses while ensuring cost-efficient production and profitability.

Our platform approach is designed to significantly enhance cost efficiency and accelerate time to market. Let me give some insights into our strategy in R&D. One of our approaches is about reusing. With our established libraries of intellectual property across multiple projects we minimize the need for redundant development work. These pre-built components are tested and validated, reducing the risk of errors and ensuring reliability. This also leads to faster prototyping. With ready-to-use IPs, we can quickly assemble prototypes and conduct preliminary tests. This reduces the time spent on developing components from scratch and allows us to focus on integrating and customizing them for specific needs.

In terms of customizable solutions, we have our powerful firmware architecture. Integrated in the devices, it provides a versatile foundation that can be tailored to fit various applications. This means



Integration in Building Management Systems is the task of the application controller sceneCOM evo with its interfaces. This scalable DALI 2 control solution for interior lighting can centrally control, monitor and maintain the lighting from individual floors to entire buildings.



On the R&D agenda: Tridonic is developing further components to offer a complete system for solar-powered outdoor lighting.

Tridonic's Multichannel Outdoor Solution enables Outdoor lighting applications to improve safety while minimizing the impact on ecological surroundings, using Tunable White for outdoor lighting.

we can adjust the firmware settings to optimize performance and features based on the specific requirements of each project. The ability to customize firmware without altering the underlying hardware or IP libraries means we can adapt our solutions more rapidly. This flexibility allows us to meet unique customer requirements efficiently.

Both reusable IPs and adaptable firmware, streamline the development process. This approach significantly shortens the time required to bring our product from concept to market. We spend less time on initial development and testing, leading to faster deployment of solutions.

Our platform approach allows us to respond quickly to changes in market demands or customer feedback. If adjustments are needed, we can make firmware changes or tweak existing IPs rather than starting from scratch, ensuring that updates and new features are delivered promptly.

Reduced development time and the ability to repurpose IPs lead to lower costs. We avoid the expense of developing new components for each project and minimize the resources needed for testing and integration. Our development teams can focus on innovating and adding value to each project. This not only speeds up the process but also allows us to explore new possibilities and features more effectively.

In summary, our platform approach offers significant advantages in terms of time to market by accelerating development processes, reducing costs, and enabling rapid customization. This leads to faster delivery of high-quality, tailored solutions that meet the specific needs of our customers.

Adhering to strict regulatory requirements, particularly concerning cybersecurity aspects like the EU's NIS2 directive, adds time and costs to development. We are actively deploying robust encryption, stronger authentication methods, and routine updates to safeguard against unauthorized access and ensure data security, even though it increases costs. Additionally, keeping pace with rapid technological changes is crucial for creating adaptable, future-proof products. To address these challenges, we have dedicated teams focusing on innovations in various areas, from power conversion and data management to emergency protocols, sensors, and ASIC designs.

Looking ahead, our roadmap aims to capitalize on these factors by developing modular designs to enhance production efficiency and simplify regulatory compliance, collaborating with external partners for cutting-edge technological trends, and investing in sustainable practices to reduce long-term costs. We provide robust cybersecurity with strong encryption and authentication, safeguarding data and ensuring compliance with regulations. Our seamless over-the-air updates allow for easy implementation of security patches and new features, keeping products secure and adaptable to emerging needs.

LED professional: What are the key product families Tridonic is currently offering, and what is in the pipeline?

Antonio A. ROMANO: Let me start with our strategic direction. Outdoor lighting will be one of the areas we plan to invest in significantly over the coming years. Our goal is to provide complete solutions. We already offer lighting controls, and we're partnering with various companies to fully manage luminaires and street lighting systems.

This product family also includes solar lighting solutions. For instance, we have products for off-grid locations and areas with limited daytime illumination. These

solutions allow energy to be stored during the day and used at night. We're developing proprietary technology and algorithms to manage battery charging and discharging more efficiently, and we aim to bring this to market by the end of 2025. The technology is already developed—we just need to industrialize it. Ideally, we want to manage the entire process internally for greater efficiency.

The second product family is emergency lighting, which will expand in the coming years.[5] We already offer emergency drivers and converter batteries, often in "ready-to-apply" bundled solutions.

We are currently operating internationally with our emergency lighting business and are particularly successful in the United Kingdom. Moving forward, we plan to expand this offering into new markets, like the U.S. This will require adapting to new regulations and introducing slightly different features. Markets like southern Europe, including France and Spain, have different requirements compared to the UK.

Smart buildings call for smart solutions—and sensor-based systems are key here. That's the third area: namely systems & services. We're currently working on new camera-based sensors. We've already launched Sensor X, and we're working on an indoor version that will be ready by June 2025.

LED professional: What are the advantages of this?

Antonio A. ROMANO: These sensors will not only count people but also recognize shapes. They can detect whether people are talking, using a phone, or even if someone is in distress, such as having a heart attack and falling down. Initially, the sensor will focus on counting people to optimize space usage, but additional features will be added over time.

LED professional: Is there another key area?

Antonio A. ROMANO: Yes, data is our fourth focus. We're investing in artificial intelligence and machine learning. We've recently added data specialists to our team, and we're committed to this area because data is crucial for our customers.

[5] https://www.tridonic.com/en/int/emergency-lighting/emergency-lighting

The newly built Ospedale Galeazzi in Milan was planned according to strict sustainability criteria, to which the sophisticated lighting management also contributes. The interface infrastructure enables future system data to be communicated without any problems.

We offer an individual consulting service called Light Coach, which leverages sensor data to provide insights into system functionality. We work closely with customers to ensure they are getting the most out of the data, and based on their feedback, we fine-tune the system.

This is primarily focused on indoor applications. The data stays within the system, and only aggregated, anonymized information is available. Indoor data helps facility managers optimize operations, such as knowing which rooms don't need cleaning or which luminaires are nearing failure, allowing for preventive maintenance. This is where most of the data-driven improvements occur.

LED professional: How are your systems linked to Building Management Systems (BMS)?

Antonio A. ROMANO: Lighting control is more precise than other systems because it requires more specific targeting. While we have no intention of entering the BMS market directly—due to the dominance of major players we see great potential in partnering with companies in this field.

Our ambition with our Lighting Management System is to integrate more deeply with BMS. By combining lighting and sensing, you get more granular control. Unlike traditional systems that only provide basic lighting functions like on/off and dimming, we can offer far more precise control at the luminaire level. This is where our partnerships become valuable.

For example, we recently collaborated on a major project at a new hospital in Milan, where 16,000 luminaires were installed. We were able to integrate with the BMS to provide seamless data and control, making it easy for facility managers to identify and address issues.[6]

LED professional: Can you discuss the challenges related to the global supply chain?

Antonio A. ROMANO: In 2021 and 2022, the European and Western lighting industries were heavily impacted by component shortages, which delayed our roadmap by about a year and a half. During that time, we had to redesign products using available components. This process took up about 20% of our R&D budget, as we had to create new designs using alternative components.

The shortages eased by the end of 2023. To prevent disruptions we identify critical components early in the design process and ensure alternative options are available. For example, we design products with enough space for different transformer sizes, allowing flexibility if one component becomes unavailable.

[6] https://www.tridonic.com/en/int/reference-projects/reference-ospedale-galeazzi-sant-ambrogio-italy

Wireless lighting control for a complete shopping mall: Tridonic supplied basicDIM Wireless passive module G2 application controllers and drivers for the various luminaires in the Lotte Mall in Hanoi, Vietnam. The application controllers can be managed wirelessly via an Android or iOS device and do not require a gateway.

We apply the same principle to ICs, microcontrollers, and MOSFETs. If it makes sense, we build in these options from the start to avoid delays.

LED professional: Where are your R&D centers located globally?

Antonio A. ROMANO: We have multiple specialized R&D locations.[7] In Porto, Portugal, we have 70 people working on software development. In Spennymoor, UK, about 40 people are focused on emergency lighting. In Ennenda, Switzerland, we have our sensor competence center. In Jennersdorf, Austria we have an R&D center with experts for light sources. Dornbirn, Austria, is primarily responsible for platform development. Between Jennersdorf and Dornbirn, we have around 60 people, including solution architects. We also have development teams in Nis, Serbia, and Shenzhen, China.

LED professional: With this array of new trends and tasks, the question arises of how you are addressing these challenges. What research collaborations and activities are you pursuing outside your organization and in partnerships to effectively develop new solutions?

Antonio A. ROMANO: We prioritize collaboration with innovation centers, leading universities, and research organizations. We are engaged with the University of Newcastle and T/U Eindhoven in areas like digital twin development, power electronics and sensor technologies, ensuring we provide our customers with state-of-the-art solutions.
Our partnerships also include collaborative efforts with V-Research and the University of Applied Sciences Vorarlberg, focusing on innovative lighting system management and enhancing the power density of LED drivers, leading to significant miniaturization, reduced material usage, and waste.

Our comprehensive R&D activities has led to a remarkable portfolio of patents within our industry. Tridonic files 50-60 new patents annually, making us the second-largest patent applicant in Austria.

LED professional: Do you have a closing statement that succinctly characterizes the trends in the lighting sector?

Antonio A. ROMANO: The lighting sector is undergoing a profound transformation toward greater awareness of our interactions with the environments in which we live. We are moving beyond mere illumination by respecting our planet and therefore embracing energy-efficient LEDs. Smart systems are being designed with a focus on adaptability, promoting well-being, comfort, and sustainability. This shift transcends technology; it is about crafting environments that enhance our daily lives and contribute to a healthier planet.

At Tridonic, we are at the forefront of this transformation, and with the support of our people, partners, and customer feedback, we are shaping a future where lighting does more than illuminate spaces — it enriches experiences and fosters a healthier world.

LED professional: Thank you, for your time and the valuable insights into current and future systems and trends, Antonio! We wish you continued success in leading the R&D at Tridonic. All the best with your visions and strategic plans, and much success to you and your team!

Antonio A. ROMANO: Thank you, Siegfried! It has been a pleasure discussing what is happening at Tridonic. ■

For additional information, please visit www.tridonic.com.

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[7] https://www.tridonic.com/en/int/company/about-tridonic

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Optimizing Lighting Energy Efficiency (Part I) – Behavioral Aspects of Energy Consumption

Dipl.-Ing. Johannes WENINGER[1,3], Team Leader Research at Bartenbach, and Dr. techn. Sascha HAMMES[2], M.Sc., Researcher at University of Innsbruck

In the pursuit of current climate and environmental goals, enhancing the energy efficiency of lighting systems proves to be crucial. However, the existing discrepancies between predicted and actual energy consumption demonstrate that, despite efforts, the full potential for energy savings has not been realized, as a comprehensive understanding of the factors influencing the energy consumption of artificial lighting systems is still lacking.

In recent years, Bartenbach has conducted numerous studies in its Living Lab in collaboration with the University of Innsbruck, which aimed at improving both the energetic predictability and operational efficiency of lighting systems. In this two-part series the results are presented in a consolidated manner. While this part focuses on the identification of the factors that influence energy consumption, the second part will primarily address mitigation strategies. The results not only reveal clear energy-saving potentials but also highlight the need for a fundamental shift in current approaches.

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Introduction

Despite extensive efforts to improve energy efficiency and reduce environmental impact, buildings today remain responsible for approximately 26% of global greenhouse gas emissions and 30% of global energy demand [1], with an increasing trend. Artificial lighting systems are a significant contributor to this consumption [2]. In recent years, both technological advancements and improved building modeling processes have already contributed to substantial progress. Nevertheless, many buildings still fail to meet the energy targets set during the planning and simulation phases.

Several studies [3,4] indicate that actual energy consumption can exceed initial estimates by up to three times. This poses a critical issue, as the energy efficiency of installed systems is rarely evaluated after commissioning. Consequently, the incorrectly assumed accuracy of planning specifications poses significant challenges to achieving energy and environmental goals. Therefore, to improve the long-term energy efficiency of lighting systems and reduce the risk of inaccurate energy demand estimates, a deeper understanding of the causes of current discrepancies, as well as a comprehensive assessment of their magnitude, is essential [5].

Numerous studies that have examined this issue [6,7,8] show that the discrepancy between actual and predicted energy consumption, known as the energy performance gap (EPG), is closely linked to concepts of optimal energy use. This means that not only structural and design factors need to be considered when determining energy performance, but also the influence of user-related aspects [5]. Due to the resulting complexity of estimating a building's energy consumption, deviations from forecasts often arise from the interaction of several factors [7]. These influences range from inadequate fine-tuning of control systems and suboptimal settings and installation of technical components [6] to measurement errors and uncertainties in building modeling specifications [4].

Moreover, unrealistic assumptions in climate data forecasts [9] and occupancy models during the planning phase [7] contribute to these deviations. System failures or improper use of systems by building occupants further exacerbate the problem [5,8]. It is important to note that building users typically lack mechanisms to assess the energy impact of their actions, leading to decisions driven by immediate personal needs that may not align with long-term energy-saving strategies [10]. Consequently, uncertainty in user behavior is widely recognized as a significant factor in the accuracy of energy demand forecasts during the planning phase [11].

From a planning perspective, the significant influence of user behavior on the performance gap can be attributed to the lack of detailed information on organizational and socio-cultural factors during the planning phase. Assumptions about occupancy behavior are based on empirically validated, standardized models developed for broad applicability [12]. However, workplace occupancy patterns are influenced by individual factors such as work tasks, organizational roles, and social conditions, which vary between organizations and individuals. As a result, the energy impacts of occupancy profiles are often stochastic [13] and do not align with the static models used in current simulations. This issue is particularly evident in environments with

variable social structures, such as flexible working hours or remote work. Additionally, workplace-specific dynamics, such as the frequency of meetings depending on position in the company [14], present challenges that are inadequately accounted for in existing models.

Several approaches have been developed to address these challenges in building simulations. For example, discrete Markov processes, utilizing statistically significant predictors chosen through forward and backward selection [15], provide a statistical approach to modeling individual behavior. In recent years, machine learning techniques have also been increasingly employed [16,17].

Ongoing research projects, including the "Energy in Buildings and Communities" program of the International Energy Agency (IEA EBC) [11], focus on improving methods for modeling user behavior and integrating them into simulation environments. However, a comprehensive quantification of the multidimensional factors influencing energy demand and contributing to the performance gap remains difficult. Thus, the existence of EPGs and the development of appropriate countermeasures remain central research topics to avoid inefficient building operation and ensure the achievement of energy efficiency goals.

To participate in scientific progress and improve the energy efficiency of buildings in the long term, Bartenbach converted the open-plan office of its R&D department into a Living Lab in 2019. Since then, high-resolution data on user behavior and building performance has been collected as part of an ongoing usage evaluation. Over the past few years, this data has been used in several studies to assess the building's lighting energy consumption compared to simulation models and to evaluate the impact of various influencing factors.

Given the significant influence of user behavior on the accuracy of energy efficiency forecasts made during the planning phase, the analyses primarily focused on individual and organizational influences, as well as their interactions with other relevant factors such as daylight availability, seasonal fluctuations, time of day, and building usage.

The consolidated results on behavioral influences on energy consumption, which are subsequently presented in the first part of this two-part article series, highlight the need to integrate behavioral aspects more strongly into the strategic planning of artificial lighting systems to optimize energy efficiency.

Description of the Living Lab

The R&D building of Bartenbach in Aldrans, Austria, consists of a 160 m² open-plan office that provides space for up to 28 workstations. However, to ensure optimal operation and maximum comfort for employees, the office is primarily used by 18 people, distributed across nine work zones. Four zones, each designed for two people, are located on the north side and are supplied with daylight via skylights. Five additional zones, also used by two people but capable of accommodating up to four, are located along the fully glazed southern facade (**Figure 1**).

Both the daylight and artificial lighting in the office are designed to be energy-efficient and comfort-optimized right from the planning process and have been continuously improved over several years. The lighting systems in the study area can be controlled separately for each work zone to accommodate individual lighting preferences and significantly reduce the system's overall energy consumption [18]. As part of a tunable white control approach, the artificial lighting system provides a variable color temperature range, from 5,000 K in the

Figure 1: Interior view of the Bartenbach R&D building. The right side shows the skylights of the north side, while the left side features the fully glazed south facade with extended sunshades.

Figure 2: Exterior view of the Bartenbach R&D building showing the static daylight system on the south facade.

morning to 2,200 K in the evening, to support the circadian rhythm of building users. Additionally, the artificial lighting system responds to occupancy through passive infrared sensors (PIR; Thermokon, RDI). The implemented switch-off delays are set based on an industry standard of 15 minutes [19] to prevent incorrect system shutdowns. Additionally, the necessary artificial lighting is reduced by horizontal illuminance sensors (Thermokon, LDF 1000A) mounted on the desks, based on the available daylight. In the office, a normative standard of 500 lx according to EN 12464-1 is assumed as the target value.

To maximize daylight usage, the office features a large glazed area on the southern facade. On average, horizontal illuminance levels of over 500 lx are achieved at workstations between 9:00 AM and 4:00 PM, resulting in a daylight autonomy (DA) of 81.56% (**Figure 3**). To prevent glare and overheating, automatically controlled shading systems are installed on the exterior of the southern facade and the interior of the northern skylights. Additionally, the building is equipped with an external static daylight system (**Figure 2**), adapted to the specific conditions and geographic location of the building. To ensure high user acceptance, the automatic control of the artificial and daylight systems can be overridden by users in each work zone via switches.

Occupancy in the building is highly dynamic, particularly due to the option of flexible working hours. Core working hours in the building are set from 9:00 AM to 12:00 PM, Monday through Friday. Additionally, the organizational framework allows for remote work and flexible hours between 6:00 AM and 8:00 PM. To capture individual occupancy behavior, PIR sensors (NodOn, PIR 2-1-01) are installed under each workstation, with detection areas limited to the specific desk. The building is centrally controlled by a programmable logic controller (PLC, BECKHOFF, CX5140-0141), which also logs all sensor data and actuator system states. With over 100 sensors in the R&D building, comprehensive monitoring of the visual and thermal situation indoors and outdoors, the energy demand, as well as user presence and absence at their workstations, is ensured in compliance with data protection regulations.

Since 2019, all sensor data in the building has been collected in high resolution and stored in a machine-readable data format (.csv). Continuous data, such as from lighting and environmental quality sensors, is recorded every minute. Status-based information, such as workstation occupancy or window opening states, is recorded individually upon status changes. The collected data has also been made partially available for research purposes [20].

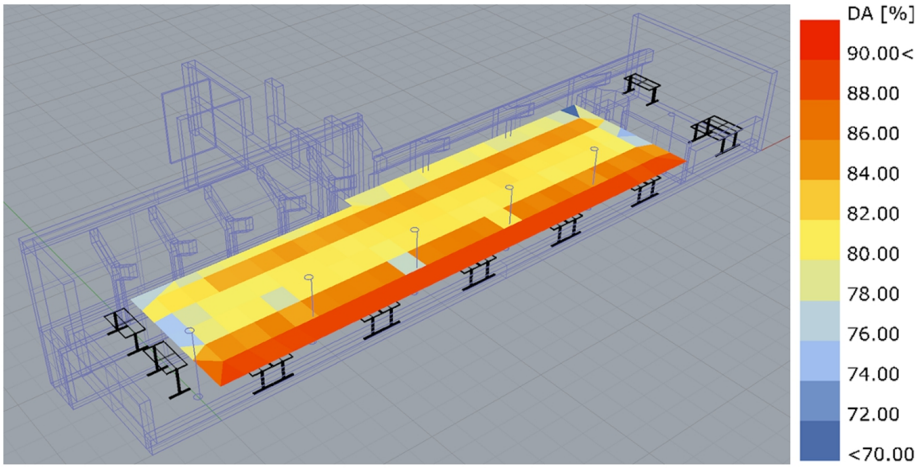

Figure 3: Daylight simulation of the open-plan office, implemented with Radiance; simulation related to the normative minimum illuminance of 500 lx according to EN 12464-1; reference time: 8:00-18:00, daylight savings time not considered, calculated with glare protection.

Study Results

The studies conducted on the existing discrepancies between simulated and actual energy consumption can generally be divided into two broad categories: (1) the evaluation of the impact of model assumptions used on the resulting energy consumption estimate of building simulations, and (2) the analysis of the factors that determine actual energy consumption during operation. To achieve the most comprehensive analysis possible in both aspects, machine learning methods and mathematical optimization methods were used in addition to conventional statistical approaches. In addition, both real and synthetic data sets were used, which were partially generated by sampling methods. The studies presented below were thus able to not only systematically incorporate usage behavior into the investigations, but also quantify the influence of user combinations on both an individual level and in comparison with other influencing factors.

The Distortions of Model Assumptions

In general, energy consumption always results from a causal relationship arising from various influencing factors and their implementation in control systems. The extent to which this interdependence affects the outcomes of energy simulations, particularly concerning the occupancy model used, was examined in a 2021 study [21]. In this study, the building's energy consumption from September 2020 to October 2020 was simulated using several different control methods for the daylighting system, incorporating various assumptions regarding glare assessment and the corresponding limitation of available daylight indoors. Additionally, both static and dynamic occupancy models were simulated and compared with actual energy consumption data. To validate the accuracy of the simulations, an additional comparative simulation was conducted using actual measured workplace occupancy data.

The results showed a generally strong alignment with actual energy consumption, with an underestimation of about 14% due to the hourly resolution of the weather data, compared to the actual consumption of 121 kWh when using real occupancy data in the simulation. Although the study found that both the assumed control method and the occupancy model had a significant impact on the simulated energy consumption, the influence of the occupancy models was notably higher. Moreover, the resulting energy consumption was, on average, underestimated by approximately 50%. These discrepancies can largely be explained by the high availability of daylight, which in many cases shifts the primary use of artificial lighting to the early morning and late afternoon (**Figure 4**).

Due to the flexible working hours of the employees, occupancy during these times is highly variable, with significant differences in the start and end times of the workday. Static occupancy models are inherently unable to capture these variations, which result from individual behavior enabled by organizational flexibility. Adequately accounting for this variability in dynamic models also proves highly challenging. Although the dynamically assumed

occupancy models in the study yielded better simulation results, the deviations from actual energy consumption were still significantly underestimated.

The results of this study already highlight the overarching importance of model assumptions regarding user behavior in simulations for existing discrepancies compared to actual energy consumption. However, despite these insights, the study did not directly quantify the impact of user behavior on the building's overall energy demand.

The Influence of User Behavior

In the context of integrated, sensor-coupled control approaches, the energy demand for artificial lighting is determined by two factors: (1) the currently available amount of daylight, which is supplemented by artificial lighting to meet the normative minimum lighting level at the workplace, and (2) the actual use of the workplace in terms of occupancy. In most cases, the presence and absence of individual users must be considered collectively, as general lighting typically illuminates multiple workstations simultaneously. Therefore, the energy efficiency of the overall system is directly influenced by the alignment of individual presence patterns within the respective lighting zones (**Figure 5**).

When it comes to fully quantifying the impact of individual user behavior on the resulting energy consumption of a building, this presents a significant challenge. Examining only a specific scenario of space utilization can lead to significant distortions due to more or less suitable user combinations. Thus, it is necessary to investigate all possible user combinations within a commonly used lighting zone while also accounting for their distribution across all available zones in order to obtain a comprehensive representation. However, even for smaller office spaces, such as the R&D office building with 18 users, this leads to over 3×10^{29} possible spatial distributions of individuals. Consequently, solving this task within a finite time frame is impossible.

To still achieve a potential quantification of the impact of individual behavior, a simulation-based study conducted in 2022 applied a two-stage optimization process using graph-theoretical algorithms **[22]**. Real occupancy data from building users between July 2021 and November 2021 were paired for all combinations of two users, and the corresponding energy consumption was calculated based on the daylight availability measured in each zone. These data were then optimized for both user combinations and zonal assignments for best- and worst-case scenarios.

The results showed an increase in energy demand for artificial lighting of approximately 83% from the best-case to the worst-case scenario (**Table 1**). For comparison, the actual energy consumption of the artificial lighting system during the nearly 100-day study period was around 83.8 kWh. Since the values were calculated with the same system configuration, the derived range reflects only user-related influences. The significant impact of individual behavior on the total energy demand of artificial lighting installations is not only confirmed by these findings but also highlights why current simulation assumptions, which generally result in equal energy consumption across all scenarios due to a lack of individual variation, are insufficient for accurately estimating the performance indicators of real-world operations.

Nevertheless, the results do not provide a sufficient quantification of user-related influencing factors, as they are accompanied by two significant limitations. To circum-

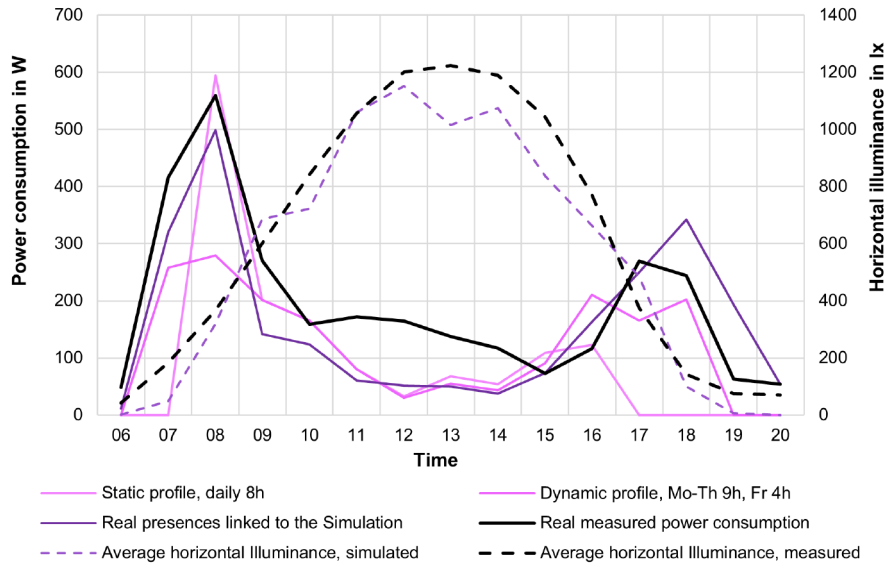

Figure 4: Average energy demand of different occupancy models, supplemented by the simulated and measured illuminance and the real energy demand from September 2020 to October 2020 [21].

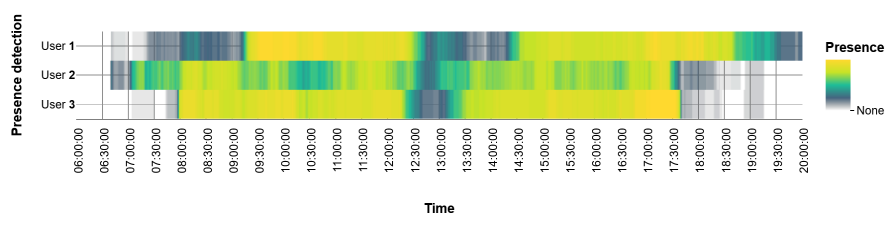

Figure 5: Exemplary representation of three real workplace occupancy profiles in the open-plan office, averaged daily in the period from September 2nd, 2020, to November 3rd, 2020 (yellow greenish: high occupancy, blue to grey: low occupancy, transparent: no occupancy).

Occupancy Schemes		Adjustment of Room Position	
		Best-case scenario	Worst-case scenario
Adjustment of the user pairing	Best-case scenario	58.4 kWh	88.2 kWh
	Worst-case scenario	86.4 kWh	96.7 kWh

Table 1: Overview of the influence of user combination and room positioning on the energy consumption of the artificial lighting system in the open-plan office for the period from July 1, 2021, to November 19, 2021 [22].

vent the problem of NP-completeness, the applied method used a two-step optimization process, thereby decoupling the alignment of individual profiles from their assignment to the workstation zones. As a result, the analysis could no longer ensure the overall minima and maxima of energy consumption, as potential interdependencies between the individual assignments may not have been sufficiently considered. Furthermore, the evaluation was based on a modification of user placement within the building and the resulting energy consumption of the overall system. A mutual comparison of several influencing factors was not possible due to the applied method, and thus the overarching impact of individual factors could not be proven. For these reasons, two currently unpublished follow-up studies **[23,24]** were conducted in 2024 to address both aspects.

Towards Complete Quantification

To overcome the issue of the decoupled approach, the energy demand for artificial lighting was simulated for different room occupancy scenarios over the period from February 2022 to January 2023, using real daylight availability and occupancy profiles **[23]**. To achieve a representative sample size, a total of 10.24 million samples were generated using Monte Carlo simulation, each comprising a fully randomized variation of user pairings and their position in the room. The necessary calculations were carried out on the VSC-5 of the Vienna Scientific Cluster (Austrian National Supercomputing Centre) in multiple batches distributed across several nodes, with each batch parallelized and evaluated on 128 CPU cores. The calculation of the samples took approximately 60,000 core hours.

The calculated energy consumption of the 10.24 million different samples showed an approximate normal distribution (**Figure 6**). The mean artificial lighting energy demand was determined to be 239 kWh ±12 kWh, with the most energy-intensive combination resulting in an artificial lighting energy demand of 285 kWh, and the minimum determined to be 183 kWh. The resulting range between the minimum and maximum values of 102 kWh essentially confirms the deviations derived from the two-step optimization process on a relative level. Interestingly, further analyses showed that only a few specific user combinations were primarily responsible for the minimum and maximum energy ranges. A closer examination of the relevant combinations using an ANOVA revealed both a significant main effect regarding occupancy times ($p < .001$) and an interaction effect between profile type and time of day ($F(14, 120) = 1.98$, $p < .05$, $\omega 2 = .03$).

Combinations with generally higher occupancy times resulted in higher energy demand. On the other hand, Bonferroni-corrected post-hoc tests indicated that the main differences in resulting consumption were attributable to the early morning time. To what extent individual factors or daylight availability are primarily responsible for the energy consumption of artificial lighting systems was addressed in the second follow-up study.

For the same period, a synthetic dataset was generated that included not only user combinations and the resulting energy consumption but also all other potentially influencing factors **[24]**. These included general indicators for the time of day and year, the location of the zone within the building, as well as key features related to the daylight availability. Both all continuous input features and the corresponding energy consumption as the target criterion were calculated based on real data. In addition, comparable features and target values were derived through dedicated building simulations or assumptions, and feature-specific gaps were calculated. Overall, 16 features were derived (four continuous values, each based on the real situation, simulation assumption, and resulting feature gap, plus four indicator features), which were calculated for all user combinations and workspace zones. Considering the monthly and hourly resolution, this resulted in a 16 x 231,336 matrix (approximately 4 million dedicated individual values).

To analyze the influence of each input feature on the resulting energy consumption, regression analyses were conducted using a histogram-based gradient boosting regression tree. The overall fit of the derived models was determined using the coefficient of determination R^2, which describes the proportion of variation in the test data that can be explained by the derived regression model. The models were then interpreted using SHAP (SHapley Additive exPlanations) analysis.

With an R^2 of 0.979, the modeling of the factors' influence on real energy consumption proved highly accurate. A closer analysis of the individual feature contributions in the model (**Figure 7**) revealed that the duration of occupancy at workstations had the greatest influence on the resulting energy consumption, with a positive correlation, meaning longer average durations led to increased energy consumption. Other similarly significant features were the south-north location of the zone in the building (while southern zones contributed to an increase in energy consumption, northern zones led to a reduction) and the duration of insufficient lighting at the workstation (positive correlation, meaning increases in this duration led to higher energy consumption).

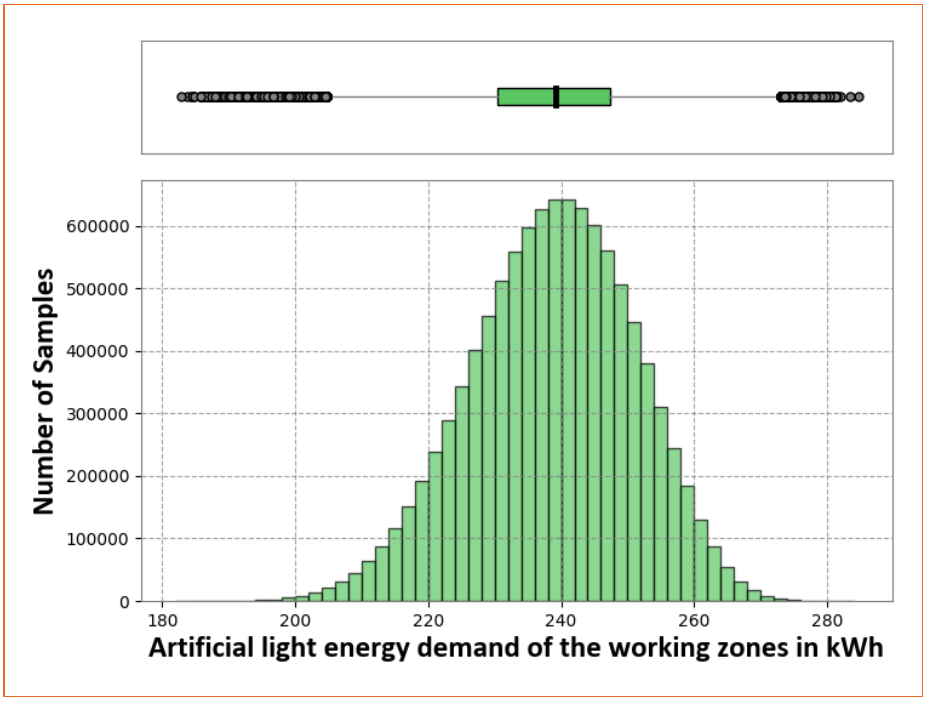

Figure 6: Frequency distribution of the artificial light energy demand calculated using high-performance computing for the time period between February 2022 to January 2023 for all 10.24 million random samples [23].

More interesting, the modeling of the energy performance gap based on the individual feature gaps also resulted in an R^2 of 0.952, indicating that the deviations between the simulation and the real situation could be almost fully explained. A detailed analysis of the contributions of individual features (**Figure 8**) showed that the majority of the discrepancy was due to differing assumptions about occupancy. The difference in occupancy time was assigned more than five times the feature importance of the second most important input feature.

Discussion

Most of the occupancy models recommended in today's literature have been empirically validated and consist of a uniform distribution throughout the day with variability in the assumed duration of presence. However, the results of the presented studies clearly show that the dynamics of real presence patterns are often inadequately represented by such models, leading to significant performance gaps. To close these gaps, it is necessary to give greater consideration to both socio-cultural and work process-related aspects in the future, as they have proven to be the primary factors influencing user behavior.

Although deviations from dynamic models can generally be influenced by additional modulators such as the aftereffects of meetings or high daylight availability, these factors are difficult to model due to short-term changes **[21]**. The results of individual studies emphasize the importance of the concept of Post-Occupancy Evaluations (POE), which can help identify and assess the strength of relevant modulators based on real-world operation data. Long-term studies and extensive monitoring approaches offer insights into workplace and energy usage patterns, as well as key environmental factors, which can then be evaluated in a context-specific manner and used to improve performance.

The potential added value addressed by POEs is also confirmed by the results, as extensive building monitoring is a key feature of the Living Lab and served as the starting point for the studies presented within this article. A transparent analysis of historical data helps to break down existing performance gaps. The understanding gained enables the development of more accurate occupancy models and simulations, which in turn can better predict actual energy performance and ultimately reduce performance gaps in the future.

Additionally, data analysis of occupancy patterns and user interactions also helps in designing systems that better consider lighting targets such as energy efficiency, visual comfort, and health-effective light doses. Furthermore, POEs allow the derivation of post-commissioning measures to improve energy demand, which is largely shaped by the individual behavior of building users.

Limitations

However, it should be noted that, while the consolidated study results clearly demonstrate the substantial influence of individual user behavior on the energy consumption of the building, this remains a case study. Personal influences on energy consumption are inherently tied to individual behavior. Different building users, different usage scenarios, or alternative organizational uses of the building can therefore lead to different results. While the study results generally provide similar indicators, it must be assumed that further case studies with different usage patterns are necessary to make a general statement.

Additionally, it should be considered that the studied building benefits from an above-average availability of daylight. This results in large portions of the day not relying on artificial lighting to meet normative requirements, leading to greater variability in energy consumption during the edges of the day. Since these periods typically experience higher fluctuations in occupancy times, it is possible that the influence of occupancy behavior has been overestimated in the presented results. Whether this overestimation exists and to what extent it manifests would require comparative studies, which are currently not available.

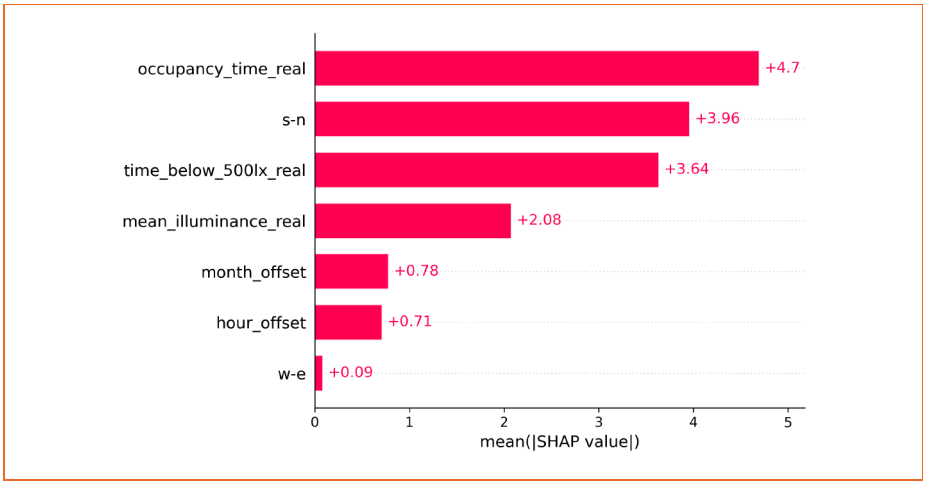

Figure 7: Results of the SHAP analysis for the explanatory value of the individual feature gaps on the real energy consumption between February 2022 to January 2023 [24].

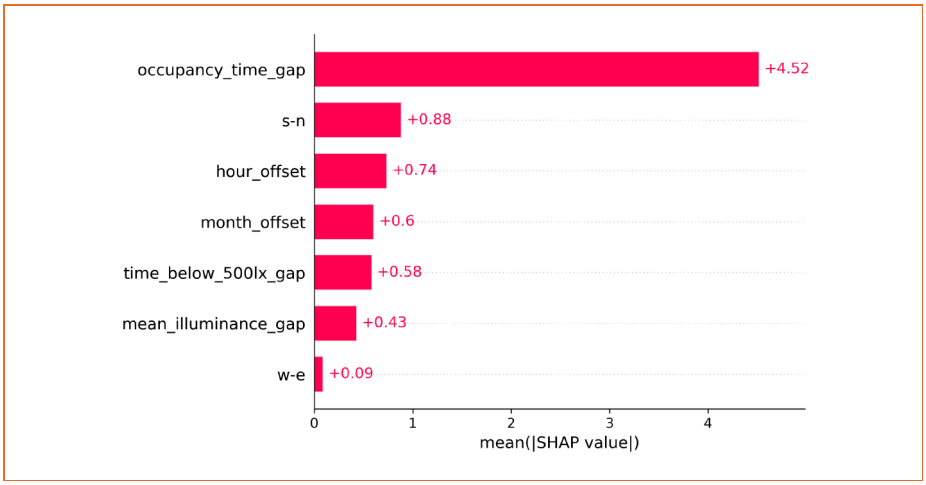

Figure 8: Results of the SHAP analysis for the explanatory value of the individual feature gaps on the energy performance gap between February 2022 to January 2023 [24].

Conclusion

In light of current climate and environmental policy discussions, improving the energy efficiency of buildings has become crucial for achieving increasingly important societal goals. The lighting sector, as one of the largest consumers of electricity in buildings, can make significant contributions in this regard.

However, the realization of this potential is currently hindered by inaccuracies in both the planning process and energy simulations. User behavior, which is influenced by individual as well as organizational and social conditions, can be considered a central factor, as its impact significantly affects the qualitative aspects of requirements resulting from planning processes. As a result, not only are there significant deviations from the predicted energy consumption, but there is also a risk of incorrect system sizing, erroneous specification of requirements, or ineffective definition of control strategies.

Accordingly, improving the methods and models currently in use is essential, particularly with regard to the planning of artificial lighting control systems. However, it is important to understand that this challenge not only concerns the effects of user behavior on building performance but also the understanding of user behavior itself. It remains unclear to what extent user behavior is truly determined by individual factors, or whether cultural or organizational influences significantly limit individuality.

The present first part of this two-part article series focused primarily on studies illustrating and quantifying the current issue. There are currently various approaches to improving user models. In particular, advanced approaches that use data-intensive modeling techniques, such as machine learning algorithms, are gaining increasing importance in this area. However, the availability of relevant data remains significantly limited, as data collection is complex, and performance evaluations of buildings after occupancy are still rarely conducted, despite their potential to effectively utilize existing opportunities. The main reasons for this are often the cost and resource intensity associated with adjusting control systems during operation.

Nonetheless, pursuing approaches to address the current problem can be worthwhile and can be effectively followed even at reduced complexity levels, as we will illustrate in the next issue in the second and final part of this article series on optimizing lighting energy efficiency. ■

Acknowledgments
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Dipl.-Ing. Johannes Weninger (left) studied architecture at the Leopold-Franzens-University of Innsbruck with focus on architectural theory and worked as an external lecturer and research associate at various universities in Austria and Germany in the field of Artificial Intelligence and Cyber-physical Systems. Until 2018 he was a research associate at the Karl-Franzens-University Graz in the Department of Biological Psychology. Since 2016 he has been working at Bartenbach research on the topics of non-visual light effects, digitization and machine learning. He has headed Bartenbach's research team since 2022.

After studying electrical engineering, **Dr. techn. Sascha Hammes, M.Sc.** (right) worked as a specialist planner for electrical building equipment and in the research and development department of Bartenbach. As part of an industry-related dissertation on user-centered lighting and the potential of post-occupancy evaluations, he completed his doctorate at the University of Innsbruck, where he has also been employed as a post-doctoral researcher since 2022. He is particularly involved in research projects in the areas of building automation systems, especially user-centered systems, sensor technology, and data analysis.

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Innovative Lighting Meets Advanced Engineering: Inside the Creation of the Luvo LED Lamp

Omid JAVANMARDI, Design Engineer at Luke Roberts Lighting and
Alex FISCHER, Product Manager and Co-Founder at SimScale

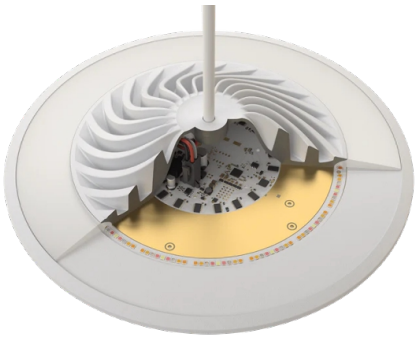
A team of tech and design enthusiasts introduced the "Luvo," a Matrix LED lamp that lets users control the light's direction and adjust brightness and color dynamically through a few taps on their iOS and Android app. This patented technology enables independent control of the lamp's upper and lower LEDs, allowing for customizable lighting whether over a dining table, a reading couch, or for ambient relaxation. The lamp also learns the user's lighting preferences and automatically adjusts to preferred settings for maximum convenience. Engineering simulation using cloud-native technology was extensively used in the design of the new lamp.

Omid Javanmardi, Design Engineer at Luke Roberts Lighting since 2018. Omid is the lead mechanical engineer and thermal analysis specialist at Luke Roberts Lighting and was also the production manager for the Luvo pendant lamp. Luke Roberts (short LR), founded in 2014 in Vienna, is an innovative smart lighting company that combines advanced technology with modern design to improve the lighting experience in homes and offices. **(left)**

Alex Fischer, Product Manager and Co-Founder at SimScale With a background in computational mechanics and control technology, Alex Fischer has worked for ten years in a range of product and engineering roles, building a fully cloud and web-based simulation platform. He is a co-founder of SimScale and leads the company's thermal management and electronics solutions. **(right)**

The Perfect Pendant Lamp — Luvo

The Luvo pendant lamp was developed using a fully cloud-native design stack including Onshape and SimScale. With Luvo, users no longer just turn the light on and off. The user can decide exactly where it should shine, how bright, warm, or colorful. This brings ultimate flexibility to lighting and the right light for every mood and space. The Luvo lamps' main function is a smart LED lamp with over 300 multi-colored LEDs giving 4400 lumens at a color temperature of 2700 - 4000 Kelvin that directs light in any direction.



Luvo pendant lamp with integrated sensors and AI-powered learning features to enhance user experience.

Comparative Thermal Analysis and CFD Simulation of Heat Sink Designs in the Luvo LED Lamp

By leveraging advanced simulation tools, LR evaluated improvements in LED performance and longevity through optimized heat sink designs, emphasizing the importance of effective thermal management in LED lamps.

The team employed thermal analysis and computational fluid dynamics (CFD) simulation to evaluate the performance of two heat sink designs in dissipating heat from the Luvo pendant lamp. The two designs included a heat sink with straight fins and a heat sink with a spiral fin layout, both made from die-cast aluminum. The simulation setup incorporated 84 LEDs as a heat source with a total heat load of 40 watts. The objective was to compare the effectiveness of these heat sinks in reducing the temperature within the LED lamp, which is crucial for maintaining efficiency, extending operational lifetime, and preventing potential failure. The performance and longevity of LEDs are highly dependent on effective thermal management. Inadequate heat dissipation can lead to increased junction temperatures, reduced efficiency and lifespan, and potentially lead to failure.

Exploded view of the Luvo pendant lamp showing its component parts.

Two heat sink designs were considered:

- Design Option 1: Straight fins
- Design Option 2: Spiral fins layout

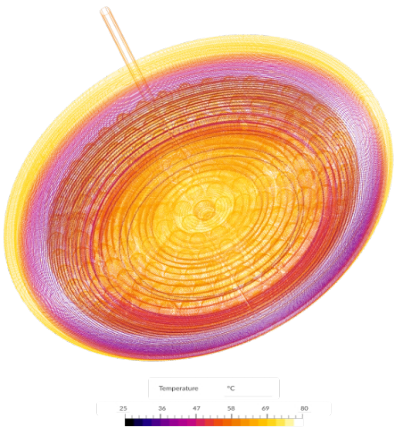
Both proprietary designs are constructed from aluminum, a material with excellent thermal conductivity. The comparison aims to determine which design dissipates heat more effectively through natural convection. The CFD simulations are performed using

SimScale, a cloud-based engineering simulation platform. The setup includes:

- Heat Source: 84 LEDs generating a total heat load of 40 watts.
- Boundary Conditions: Natural convection in an ambient environment.
- Material Properties: Aluminum for the heat sinks.

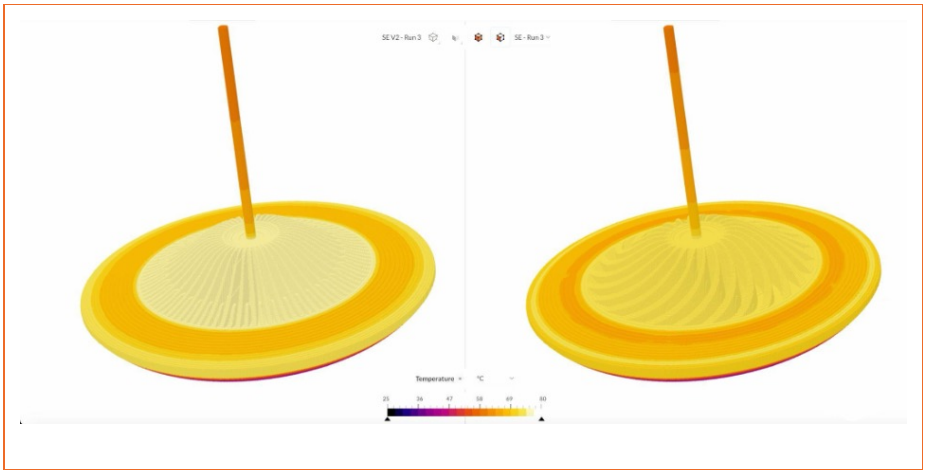
The simulations are used to generate insights into the temperature distribution and heat dissipation rates inside the LED lamp. LR could determine the better design with these simulation results:

- Heat Dissipation Efficiency — the spiral fin layout enhances airflow around the heat sink, promoting better natural convection compared to the straight fins. The improved design leads to more efficient heat dissipation, preventing excessive temperature buildup within the LED lamp.
- Temperature Distribution — the thermal analysis reveals that the spiral fin design maintains a temperature of 2 degrees Celsius lower than the straight fin design under the same load conditions. This temperature difference is significant for LED performance and longevity.

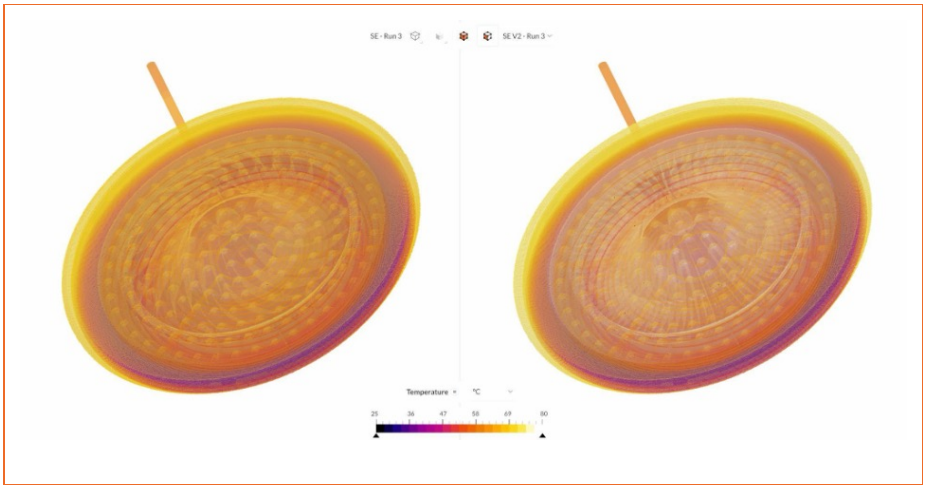


Luvo pendant lamp heat transfer simulation using SimScale.

The reduced temperature achieved by the spiral heat sink design ensures a more reliable operation of the LEDs. Lower temperatures correlate with higher efficiency, a longer lifespan, and a reduced risk of thermal-induced failures. The aluminum material is further evaluated using the extensive materials library available in modern simulation tools to consider alternatives. Reducing the overall weight and amount of aluminum used is important for cost efficiency and also the embodied carbon in the product, something lighting manufacturers including LR are increasingly conscious of.



Straight heat sink (left) and spiral heat sink design (right).



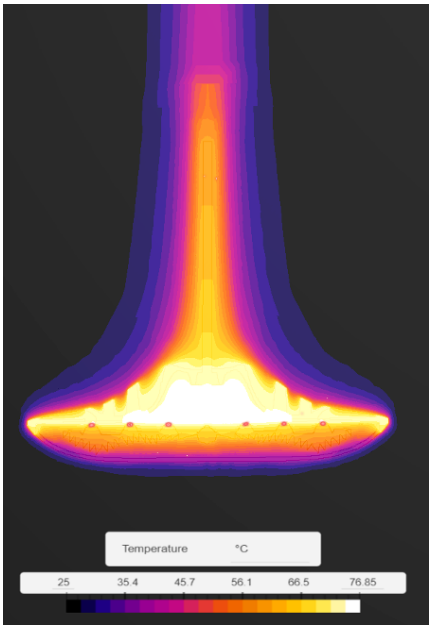
Temperature visualization of the straight heat sink design (left) and marginal improvement with the spiral heat sink (right).

Using simulation, the team saved months in the design and development workflow - from concept over prototyping, testing, redesign, and retesting. The corresponding cost saving can be thousands of Euros for each of the design options for a product in development. The cumulative savings for a whole product pipeline are significant. Much of the savings come from not having to prototype every iteration or do a thermal test. Design engineers can simply refine the CAD design and simulate it. In this case the design team at LR regularly simulated ten designs in parallel which was possible using fully cloud-native simulation tools. ■

For more information visit the following websites:

www.luke-roberts.com

www.simscale.com



Heat dissipation of the LED pendant lamp using the spiral heat sink.

Automated Server-based Lighting Control Through Music Metadata

Tim KÖBEL[1,2], M.Sc., Master Thesis at Karlsruhe Institute of Technology (KIT)

The aim of this project was to develop an application that enables the retrieval of music metadata from a server and uses it to control various dynamic light effects on an LED panel, featuring a 3D light effect and open API with low latency. A web application executable on Android and Windows operating systems was chosen as the foundation. To achieve this, a Representational State Transfer (REST) API was implemented for communication and a binary search algorithm for data processing. Additionally, a WebRTC peer-to-peer connection was integrated for real-time audio data transmission. The control is managed through a custom-developed user interface.

The open architecture and configurable settings within the application ensure that it is prepared for future expansions and adaptations. This provides a basis for further research and development in the area of parametric control of lighting effects. Future work could integrate advanced algorithms or AI for pattern recognition into the backend servers, allowing the application to extend its use beyond music recognition.

Introduction

Dynamic lighting effects play a central role in musical performances, no longer serving solely for illumination but visually enhancing the music. To enable such lighting effects outside of large stages, technical solutions that react to music already exist. Another key development in recent years is the advancement of data processing, which now includes the use of complex algorithms and artificial intelligence. This allows for the recognition of music by algorithms and its evaluation based on various criteria by AI.

The combination of lighting effects with algorithmic pattern recognition and the analytical capabilities of AI enables the implementation of light shows where different effects are automatically changed depending on the song, artist, or music metadata. This would allow for automated control of the light show and its effects, reducing personnel requirements for large performances. Additionally, customizable light shows would become more accessible to smaller artists or for personal use.

To realize this concept, an application was developed that enables real-time communication between the light fixture and the corresponding backend server for data processing. The application retrieves relevant music metadata, processes it, and then controls the light fixture according to the effects predefined in the application.

The platform for the web application requires both a network connection and a microphone for audio data transmission. The light fixture used is an LED panel, where several LED strips are arranged behind a special fabric. The fabric creates a three-dimensional effect, where the light from the LED points transitions into curves. The name of these lights is “lixl”, as shown in **Figure 1**. The effects of the lights can be controlled via the application, depending on the music track.

Existing Solutions

The adaptation and control of lighting to music is already a feature of many applications today. One of the most well-known systems for controlling lights in private households is the combination of “Philips Hue + Spotify” from “Signify” and “Spotify AB.” This system adjusts the lighting to the beat of the music, allowing users to freely modify the lighting ambiance and the intensity of the effect. However, this requires both a “Philips Hue” and a “Spotify” account [1]. Using the open-source software “WLED” by Christian Schwinne [2], it is also possible to create similar lighting effects without needing such an account. “WLED” forms the foundation of the “lixl” firmware and supports various lighting effects that react to frequencies or volume changes [3]. It serves as a representative of many other applications and lighting systems that respond to volume, frequency, and beats per minute (bpm).

There are also such applications for computers. In the professional field, “Madrix” by “inoage GmbH” is a notable example. This software supports “Sound to Light” (S2L) effects and allows the conversion of different frequencies and volumes into lighting effects [4]. However, the specific effect must be selected by the user and then reacts to the music, which applies equally to all platforms. The same principle is true for the “SignalRGB” application, though it is designed for private users [5], unlike “Madrix.”

As part of this work, the music-reactive effects will be expanded. The aim was to develop a control system that enables the automatic exchange of effects and their adaptation to corresponding metadata, without requiring manual intervention. This will be achieved through the use of AI or an algorithm. As a consequence, no human intervention would be required in the control of the effects.

The master’s thesis was supervised by Professor Dr. Neumann, and Dr. Chris Herbold was the advisor.

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App Concept

Figure 2 shows the schematic structure of all key functions. The CORE serves as the storage for global variables. It is not directly accessible through the UI but only through the corresponding functions and their UI elements. A large portion of the functions build on one another. The “Lighting API” and the “Music Recognition API” form the foundation for the main part of the application.“

UI-Design

The UI design is based on three fundamental principles: the KISS (Keep It Simple and Stupid) principle **[6]**, the ISO standard 9241-110 for the ergonomics of human-system interaction **[7]**, and the UI design of the web interface for “lixl” lights.

The KISS principle is applied in the menu structure shown in **Figure 3**. It is designed to ensure ease of use and includes the following items: “Music to Light,” “Music Recognition API,” and “Lighting API.” The names of the menu items correspond to the application’s settings options. Additionally, the relevant conditions of the ISO standard 9241-110 have been taken into account, contributing to a clear menu navigation and counteracting the complexity of the application.

Figure 1: lixl lights.

Lights API

The application was primarily developed for use with “lixl” lights, with a focus on creating an API connection that is as open as possible to enable integration with other systems. However, the additional effort required for entering API commands poses a disadvantage. To address this, suggestions for the standard body of the “lixl” API have already been incorporated. Theoretically, it is possible to control a vanory “Estelle” or Philips Hue light with the API.

The subsections “Lighting API settings” and “Brightness and color settings” are solely for inputting the corresponding API body. Additionally, in the “Lighting API Settings” subsection, there is a button that sends a test API call. This allows the connection to be tested immediately after input, and any errors in the API call can be corrected. In the “Brightness and color settings,” such a button is omitted, as the relevant functions can already be triggered and verified independently through the buttons in the “Music to Light” menu.

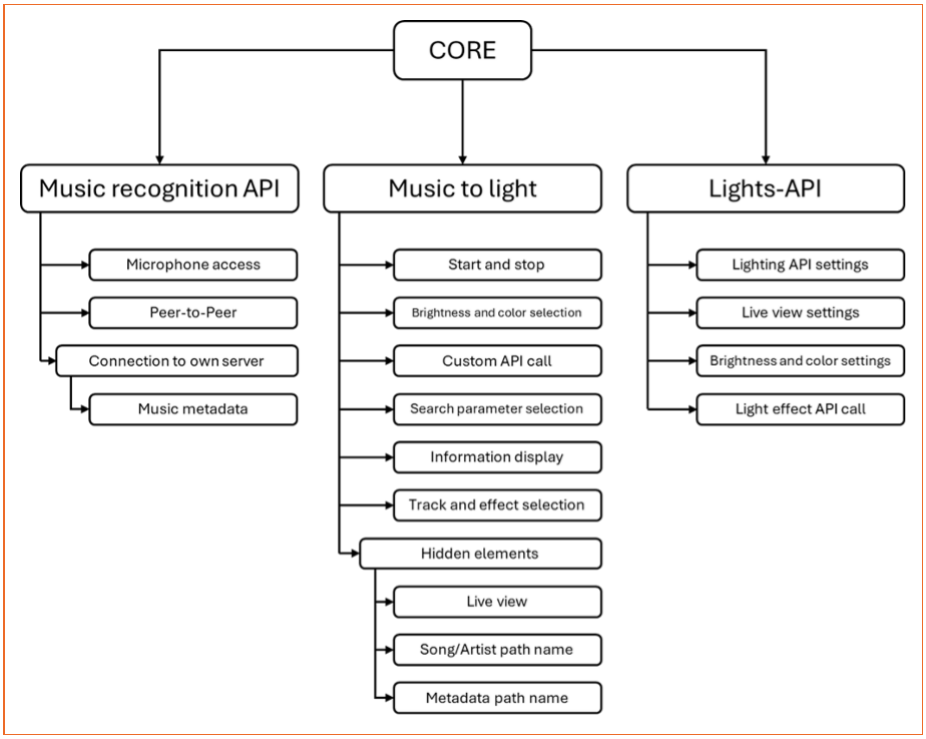

Figure 2: Schematic structure of the app and its functions.

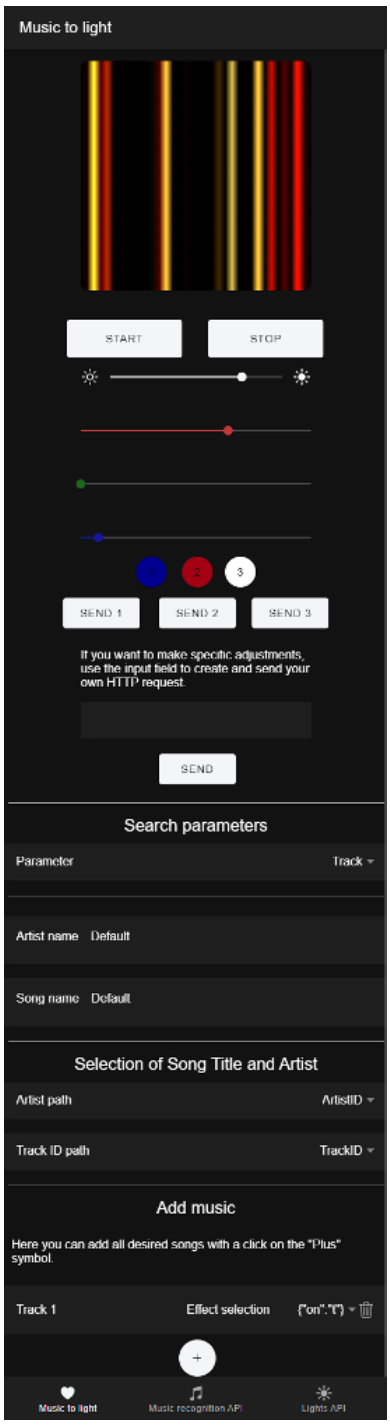

Figure 3: Home page of the app.

If a real-time view of the light is required or desired, the “liveview” function can be activated. However, this requires a separate API call. If the function is not used or not supported by the light, it can simply be turned off. The bottom section, “Effect,” is a list that stores the JSON commands for triggering the effects. The elements of the list are unordered, as the commands do not follow a sortable structure. These are simply commands that are executed by the corresponding light. Additionally, each element in the list can be deleted individually, enhancing ease of use.

Music Recognition API

This section addresses the API for music recognition and the corresponding servers. The application is designed to be used with its own AI or algorithm. It would have been possible to tailor everything to a specific AI or algorithm, but that would limit the user’s options. In addition to providing the API URL for querying the server, the user must specify the storage location for the relevant information. This is defined in the section “Connecting to own Servers.” An individual identification token can also be added to the API call here.

In this context, the question arises as to how the corresponding server gains access to the audio data for analysis. The transmission of audio data is done through a peer-to-peer connection. To launch the application on an Android smartphone, microphone access must first be granted. Once confirmed, the microphone is rechecked, and the audio signal is played through the speakers. This feature is also available in the PC version, where the PC primarily serves as a receiver for the peer-to-peer connection. Access to all transmitted audio data is handled via the computer’s standard output system. This allows for the creation of a server on the PC with the corresponding algorithm or AI by capturing the standard audio output signal.

The advantage of the peer-to-peer connection is the possibility of a serverless connection. This can save server costs and ensure independence from third parties. In the final menu item, titled “Music metadata,” users can configure settings for music metadata. Here, there is the option to integrate an online database of their choice to retrieve additional information about an artist or their song.

Music to Light

“Music to light” is the home screen of the application. Using the “Start” and “Stop” buttons, the application can be launched in the background. If the option “Connecting Custom Servers” has been selected and configured in the “Music recognition API” menu, requests are now automatically sent to a server at regular intervals, which analyzes the audio data. These requests sent from the application to the server include, for example, the song title and artist name. The drawback of this polling method is that requests are sent to the server repeatedly over a user-defined period. Processing these requests requires corresponding computational resources from the server. However, the user can set the time interval in such a way that the requests do not overload the system. An advantage is the ease of switching and replacing servers.

The functions for adjusting brightness and color selection differ in that the API call for changing brightness is sent with the movement of the slider. For color selection, this is not the case. Instead, colors are first mixed using the RGB sliders. When a number is clicked, the button will appear in the selected color, and a preview of the color is displayed. The color can then be sent via the buttons, and up to three RGB color spaces can be transmitted. This is the maximum number that can be processed by the “lixl” software as an API call.

Below the RGB sliders is an additional function that allows the user to send a custom body. This makes it possible to send API calls that are not covered by the app.

Next, the search parameter is selected. The criteria that change the lighting effects are set by choosing a song title or artist. If metadata analysis is activated, these can also be selected. Information such as the artist’s name and song title can be displayed in the information view.

For the main function of the application, the search parameter data is stored in a list. Here, an effect can be assigned to the song title parameter. When the algorithm or AI recognizes the song, the application queries it and triggers the corresponding effect. The API call, along with the corresponding body, is sent to the light. The aforementioned information view serves as an error check. If the displayed song title is not available, this is indicated in the information view, and the query is canceled. The user can then add the missing title. Since the list contains search parameters such as song titles or artist names, it makes sense to sort it. This provides better clarity and allows the use of a binary search algorithm [8].

The hidden elements are functions only needed on demand, such as the “liveview” feature. Song/artist path and metadata path settings are used to define the path for the relevant information. Since each interface differs in how it transmits information, the user can choose a custom path to access the desired data. However, this requires the user to be familiar with the corresponding interfaces.

Functional Testing

To ensure the proper functioning of the application, a comprehensive evaluation and analysis of the application delay and stability of the app is conducted. Application delay refers to the latency that exists between music recognition and the control of the lighting.

Approach

To conduct both tests, a database of 95 randomly selected songs is created. The individual songs differ in terms of sound quality and duration. For the test scenario, it is assumed that the corresponding server is operated by a private user at home. Regarding the total duration of the music, it is noted that it amounts to 5.34 hours, which is significantly above the average music consumption of 2.11 hours for purchased music data/physical media, as outlined in the "Musikindustrie in Zahlen" study by the Bundesverbandes Musikindustrie eV. from 2023 [9]. For the purposes of this work, it is simplistically assumed that all music data from the various media are also available as MP3 files and can be used to create a music fingerprint. Streaming services are not considered here, as the file must be physically present to create a fingerprint.

To avoid errors due to the network, the corresponding devices are pinged before the two tests to ensure error-free data transport and to determine any existing network latencies. Network latency refers to the time taken for the transport of individual data packets between sender and receiver. This information is necessary for the later evaluation of latency measurements.

Continuous Run
The present test is designed to evaluate the stability of the application in connection with the music recognition algorithm and the lighting API. To this end, a server is used that handles both the music recognition and the querying of music data. Additionally, it acts as the API interface for the light. A real light controlled via the API is not used. If there were an error in such a light or the API, it would not be possible to determine whether the error is due to the app or the light because of the closed system. Furthermore, automating the testing process allows for efficient execution.

The music pieces are played three times in succession. This increases the total duration of the test and, thus, the number of queries made by the app. For the application, only the change of the music piece is relevant. Only then does the search algorithm and the lighting API come into play. Therefore, the music pieces are only played for thirty seconds before starting the next piece. In the first run, the music recognition algorithm is started with the beginning of the corresponding song. The second run takes place in the middle of the song. In a final sequence, the last five seconds of each music piece are played. Afterward, detection and processing of the music piece take place through the application. If the music recognition algorithm mistakenly recognizes the wrong song but the application responds correctly to the incorrectly recognized song, this will not be counted as an error of the application. Ultimately, the application fulfills its function.

Latency Measurement
The second test aimed to capture the delay between the information retrieval by the app and the control of the lights. For this purpose, the same server was used that had already been employed in the stability test. Once a GET request is made by the app, it is displayed in the console along with the corresponding time. This includes the hours, minutes, and milliseconds when the request occurs. For the test, only the seconds and milliseconds are relevant. The deviation here is less than one millisecond and can therefore be neglected. The same applies to the POST request of the lights API. The difference between the first GET request and the sending of the POST request, minus the average network latency, subsequently results in the application's latency.

Test Setup

The server is a computer running Ubuntu version 22.04. A condenser microphone has been connected to it via Universal Serial Bus (USB). The microphone was operated at a sample rate of 192 kHz and is positioned one meter away and at the same height as the speakers. The originally intended use of the smartphone microphone via WebRTC was flawed, as the network connection was interrupted on the server side after establishing the peer-to-peer connection. The speakers are the Teufel CINEBAR PRO operating in stereo mode. The volume of the speakers at a distance of one meter is 64 dB.

The application was installed on a Google Pixel 6 Pro, which is connected via a wireless connection. The server was connected to a router, specifically the Fritzbox 6660 Cable, via a 1,000 Mbit/s LAN connection.

Results of the Continuous Test

During the continuous test, a total of 285 successful queries were executed by the application. The processing of all queries and the identification of the corresponding effect for the detected music piece were successfully carried out and subsequently forwarded to the simulated light API. No errors were found in the application, nor were there any crashes or other impairments. In contrast, several misassignments by the fingerprint algorithm were noted. Group 1 represents the first run, where both the song and the fingerprint were started simultaneously. The recognition probability for the first 5 seconds was 71.25%. In Group 2, the algorithm had the highest hit rate at 74.1%. However, in the final run of Group 3, only a recognition rate of 43.7% was achieved (**Figure 4**).

The low recognition rate in Group 3 can be explained by the fact that some of the music tracks end prematurely, meaning that there is no sound in the last five seconds. Consequently, the algorithm cannot analyze the audio data. To reduce this error, an ambient recording could be made while no music is playing. This would then serve as a baseline and would not result in any modification of the effect.

Another factor contributing to the poor performance of the fingerprint algorithm is the poor audio quality or bitrate of the unrecognized music tracks. The majority of the unrecognized tracks have a bitrate of less than 64 kBit/s. Furthermore, it should be noted that the music tracks are further degraded by being played and recorded through the microphone, making them more susceptible to interference. To avoid this problem, the music tracks used should have a higher quality/bitrate to ensure better detection.

Results of Latency Measurement

The latency of the application is calculated by subtracting the measured latency value between the first GET request from the app and the receipt of the POST call at the simulated light, as well as subtracting the average network latency. For each request, half of the network latency is deducted since the times were determined through the server using the API.

(Arrival time of POST call) – (Arrival time of GET request) – Network latency = Latency of the app

Thus, the average latency of the application is:

Latency of the app = 604 ms – 76.6 ms = 527.4 ms

When examining the values of graph 5, with a corresponding minimum value of 195.4 ms and a maximum value of 746.4 ms, it is noticeable that the application has very few outliers. The two values that are above average can likely be attributed to network latencies, as they do not correspond to the theoretical maximum value of the binary search algorithm. The minimum value corresponds to the theoretical minimum of the binary search algorithm, where the first value checked is the direct hit. Ultimately, it can be said that the application, as a closed system, exhibits relatively consistent latency, which is desirable. Another crucial factor for practical application is the query interval of the application. In the present measurement, the query occurs every 600 ms. This implies that, ideally, the fingerprint algorithm recognizes the song, and the query follows immediately afterward. In the worst-case scenario, the GET query occurs just before the algorithm recognizes the music piece and hands it over to the server. Consequently, the duration of the query interval is added to the app latency, resulting in a total latency of approximately 1,127.4 ms. Depending on the network and server conditions, the query interval can be individually adjusted via the app UI, potentially reducing this value further in the best case (**Figure 5**).

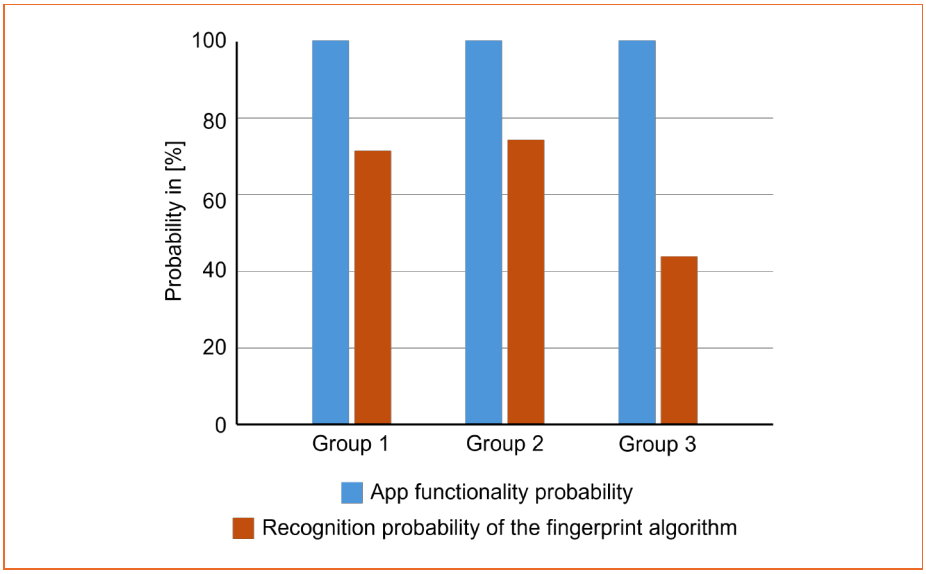

Figure 4: Comparison of the recognition probability of the algorithm (orange) and the functionality probability of the app (blue).

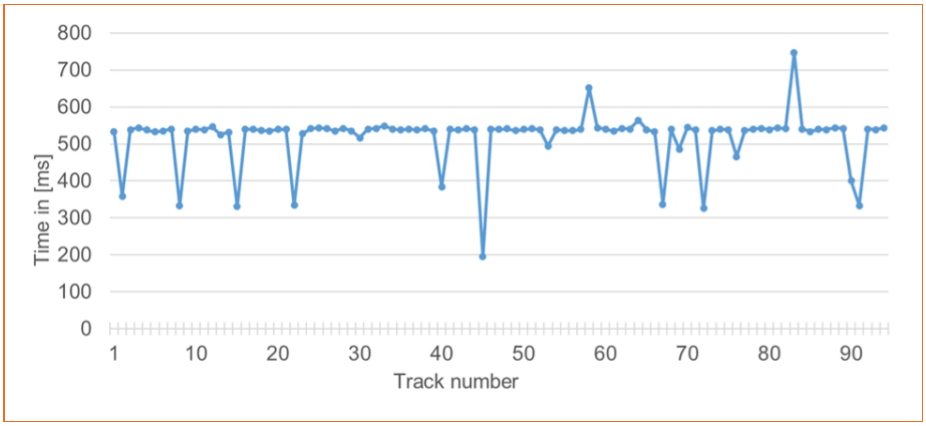

Figure 5: Latency of the application between the server query through a GET request and a POST call to the simulated lighting interface.

Outlook and Recap

As part of this master's thesis, a comprehensive system for synchronizing music and lighting was developed and evaluated. The main goal was to create an application that allows an AI or algorithm, using a server, to adjust the lighting of "lixl" lights in real time to match the music. A web application was designed and developed for this purpose, with the "lixl" lights' web interface serving as a template for the UI design. The menu navigation was also adapted to meet the relevant ISO standard.

Various IT components were integrated to ensure functionality. Among other things, a search algorithm was implemented that can efficiently find and search for the relevant effect data in a list. Additionally, a connection to a REST API was integrated for communication and the retrieval of additional metadata. A peer-to-peer connection for real-time audio transmission was also included.

The main outcomes of the thesis include the successful implementation of a robust and flexible application for controlling various lighting effects using a server, where a user-defined AI or music recognition algorithm can be employed. The tests conducted show that the application runs without errors or crashes. Furthermore, the latency of the application was measured and found to be within an acceptable range, allowing for quick and appropriate adjustments to the lighting effects.

A key aspect of the system is the open architecture of the developed application, which enables the control of other lighting systems via API and the use of different backend servers. This provides a foundation for further research and development in the field of controlled lighting systems. In the future, various promising possibilities for further development arise from this work. For example, the application could be extended to include a feature that integrates a music streaming service account, allowing the direct retrieval of all relevant data from the streaming service. The advantage of this approach is that no algorithm or AI is needed for music recognition, and the lighting effects can be synchronized with the streamed music without any delay. The necessary logic for this is already implemented in the application—only the account query and the streaming service's API would need to be added. Additionally, it would be of interest to adapt an algorithm or AI for fast and accurate music recognition. In this context, special attention should be paid to music transitions and avoiding unwanted false detections.

The application could also be used beyond music recognition. Due to its open design, it is conceivable to use a speech recognition AI to analyze verbal expressions and the associated emotions. The informa-

tion could then be provided to the app by a server via an API, enabling the lighting mood to be adjusted to match the emotions of the conversation participants. The peer-to-peer connection ensures the transmission of audio, meaning only a corresponding server with AI would be required.

In conclusion, the application provides a logic that supports a wide range of use cases beyond the synchronization of light and music. It can be used on stage, in a private living room, or in relevant research projects. ■

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The Karlsruhe Institute of Technology (KIT) is both a technical university and a national research center within the Helmholtz Association. It is one of Germany's Universities of Excellence. As "The Research University in the Helmholtz Association," KIT creates and shares knowledge for the benefit of society and the environment. Its mission is to make significant contributions to global challenges in the fields of energy, mobility, and information.

Tim Köbel, M.Sc.

From October 2021 to October 2024, **Tim Köbel** pursued a Master of Science in Electrical Engineering and Information Technology, specializing in micro-, nano-, and optoelectronics, at the Karlsruhe Institute of Technology (KIT), Karlsruhe. His master's thesis focuses on "Automated Server-Based Lighting Control Through Music Metadata." Prior to that, from October 2016 to September 2021, he completed a Bachelor of Science in Electrical Engineering and Information Technology at KIT, with his bachelor's thesis titled "Dynamically Calculated Runtime Light Effects." In terms of practical experience, since November 2021, Tim has been employed as a working student at vanory GmbH in Karlsruhe, where his responsibilities include prototype construction, software and hardware development, and the design and development of dynamic and static light effects. Additionally, from October 2020 to March 2021, he completed an internship at Mercedes-Benz AG in Sindelfingen, where he worked on the conceptualization and programming of various tools and tail light animations, as well as the development of a tool for calculating WLTP consumption.

Dr.-Ing. Chris Herbold

Chris Herbold is one of the founders of vanory GmbH, a company that emerged as a spin-off from the Lighting Technology Institute at KIT and has been developing and manufacturing smart lighting systems since early 2017. He completed his studies in Electrical Engineering and Information Technology with a focus on high-power UV-LED modules. In the following years, he conducted research during his doctorate at the Lighting Technology Institute in Karlsruhe, focusing on efficient thermal management for LED systems. During this time, he combined his passion for innovative technology and high-quality product design, a passion that is now reflected in the projects of his own development studio, kary.studio. The studio creates systems that integrate the latest lighting technology with innovative controls to deliver exceptional product experiences. Products from the studio have already been recognized with awards, including the "German Design Award for Excellent Product Design in Lighting" and the "International Design Award Baden-Württemberg."

Professor Dr. Cornelius Neumann

Cornelius Neumann studied Physics and Philosophy at the University of Bielefeld, Germany. After his PhD, he worked for the automotive supplier Hella in the advanced development for Automotive Lighting. During his time at Hella he was responsible for signal lighting, LED application and acted as a director of the L-LAB, a laboratory for lighting and mechatronics in public private partnership with the University of Paderborn, Germany. In 2009, he became Professor for Optical Technologies in Automotive and General Lighting and one of the two directors of the Light Technology Institute at the Karlsruhe Institute of Technology, Germany.

Understanding UV LED Specifications: A Selection Blueprint

Dr. Pratibha SHARMA, Director of Applications Research and Development and Saya HAN, Director Business Development at Violumas

Ultraviolet light-emitting diodes (UV LEDs) have gained significant popularity in the past decade and are being used in many diverse applications, from water and air disinfection to curing and horticulture [1]. However, the choice of a suitable UV LED is application-driven and can be challenging due to the numerous sets of specifications which need to be examined when designing a system. This article aims to provide a guideline to system designers to select LEDs using technical specifications and make informed decisions based on their application.

Understanding UV Wavelengths

Commercial UV LEDs are primarily available in three wavelength bands: UVA, UVB and UVC. The longer wavelengths between 314 nm and 400 nm fall under the UVA band. The UVB category is composed of ≈ 280–315 nm light while UVC represents 100–280 nm UV light.

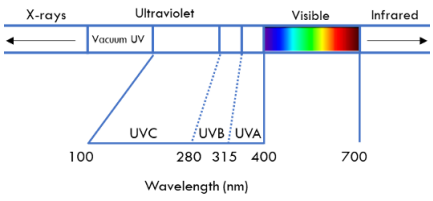

Figure 1: Ultraviolet light wavelength bands.

While popular applications of UVA LEDs include curing, fluorescence spectroscopy, forensic science, photocatalysis, security and authentication, more recent applications include phototherapy, visible light disinfection, and art conservation [2].

UVB LEDs are primarily employed for phototherapy (for skin conditions), analytical chemistry (fluorescence spectroscopy), and plant growth [3]. UVC LEDs with shorter wavelengths are known to reduce microbial loads by denaturing microbial DNA. Hence, these LEDs offer a promising solution for various disinfection applications, specifically in water/air treatment, food safety, and medical device disinfection [4].

Given the variety in the wavelength types, it is important to understand application requirements to select the most optimal UV LED wavelength. It is important to note that UV LEDs emit in a band of wavelengths, mostly ranging around 10–12 nm, centered around a peak wavelength (λ_p). So, the peak wavelength must be chosen in alignment with the spectral requirements of the application. For example, for a disinfection system, a 265 nm peak wavelength LED will perform better than a 365 nm LED, as the DNA action spectrum aligns with the 265 nm peak. While for some applications, this choice may be straightforward, others benefit from using a higher efficiency LED with a different peak wavelength.

Package Types

Commercially available UV LEDs come in several different package types. The suitability of the package depends on the application. Most popular package types include:

- **Transistor-Outline-Can (TO-Can):** TO-cans are available in metal cans with or without lenses, mostly in hermetic packages. UV LED TO-cans typically have low optical outputs and are most commonly used in optical sensing applications.
- **Surface-Mount Technology (SMT):** SMT devices are ideal for applications requiring multiple LEDs, as surface mount devices (SMD) can be directly soldered onto PCBs, offering design flexibility and enabling countless applications. Well-suited for mass production, SMTs offer competitive pricing.
- **Chip-on-Board (COB):** COB packages feature single or multiple LED chips directly mounted on a common substrate, providing high optical output and customization options for large-area applications. Unlike SMDs, COBs are 'plug-and-play' solutions, eliminating the need for additional PCB design and configuration. Manufacturers offer COBs in various forms, such as rings, rectangles, and linear bars, to accommodate diverse application needs.

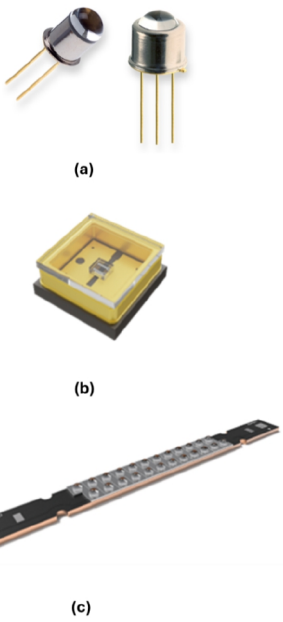

Figure 2: Example of a (a) TO-Can package [5], (b) an SMT package [6] and (c) a COB package [6].

The choice of package type may depend on the optical output needs, thermal performance, mechanical constraints, and lifetimes.

Comprehending Optical Characteristics

Optical output, often referred to as "*radiant flux*" in technical specifications, is the total amount of light emitted by a UV LED in all directions and is typically measured in milliwatts (mW) or watts (W). This value is directly influenced by the LED driving current and affects system performance, system design, and development costs and therefore needs to be evaluated precisely.

Radiant flux values are typically measured in an integrating sphere and act as a metric for comparison with LEDs from different manufacturers. However, lack of standardized sensors and testing protocols can cause ambiguity and discrepancy in values across manufacturers leading to 2–10× the error [7]. Thus, designers must seek information on how the optical output is measured or perform their own measurements before finalizing an LED. In addition, since the light emitted is measured in all directions, side emissions would be included in these values but may not be applicable for applications in which the emitted light is directed down to a certain target area. Therefore, while radiant flux values may give an initial reference point for selection, irradiance values measured at specific throw distances may give a better idea of the intensity received on a target area.

Optical simulations can greatly aid in estimating irradiance values without developing prototypes and performing actual measurements. **Figure 3** shows irradiance maps generated using optical simulation of a 365 nm UVA LED at different throw distances.

Beam angle control: Engineering the irradiance distribution of an LED is viable by using specific optical components to focus light on certain areas. Beam angles refer to the angular spread of light emitted by an LED. Typically measured in degrees, it is mostly defined in datasheets numerically or by means of a polar plot, the full-width half maximum of which is defined as the *beam angle*. Bare die LEDs spread light over 130 to 140 deg. angles and so high irradiances over a small target area may be difficult to achieve with this broad distribution. It is also important to look at uniformity and throw distance considerations when selecting optical components. While narrow beam angles are necessary to focus light over longer throw distances, wider beam angles promise a more uniform distribution at shorter throw distances. Applications such as UV spot curing and 3D printing often require narrower beam angles to focus

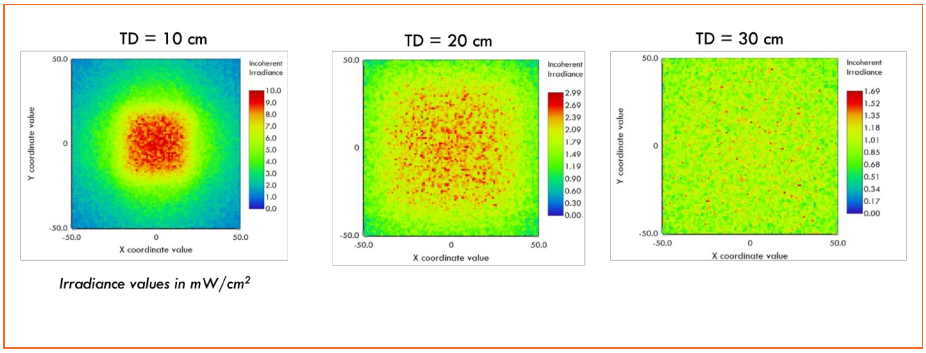

Figure 3: Irradiance maps generated using optical simulations of a 365nm UVA LED at different throw distances. Irradiance values in mW/cm^2

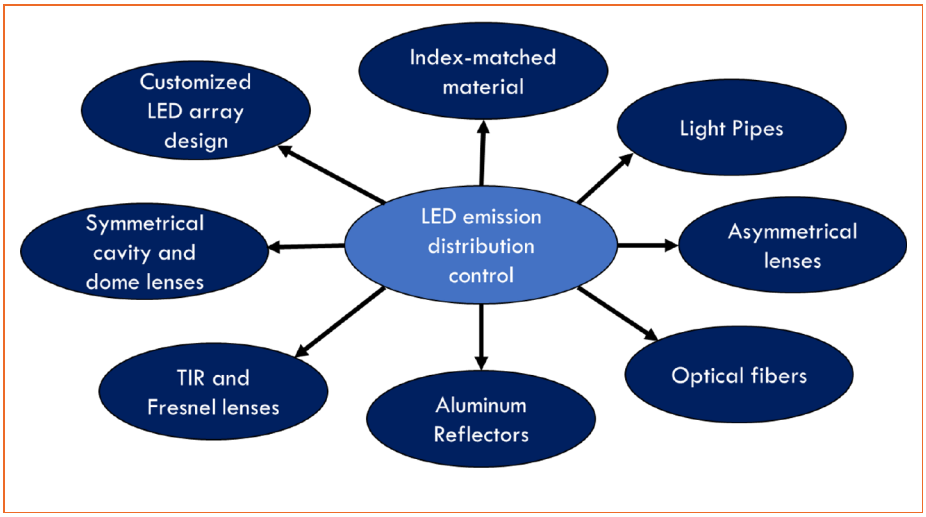

Figure 4: Commercially available methods to optimize LED emission characteristics.

light on a tight spot, but applications such as disinfection and horticulture can work with more distributed sources.

Optics such as different types of lenses, light pipes, and reflectors enable a variety of beam angles allowing for many unique distributions using the same LED die. Optical output may be boosted using index matched materials in combination with specific lens types. Additional secondary optics (not a part of the LED package) may also be used to obtain a specific beam profile. However, wavelength-dependent material properties must be taken into consideration when selecting such optics. If a secondary optic is used, the transmission losses must be considered, and cost trade-offs must be evaluated (**Figure 4**).

Designing for Electrical Characteristics

UV LED specification sheets typically include detailed electrical characteristics, such as forward voltage and recommended driving current. These devices operate on direct current (DC), and so mostly require an external power supply unit (PSU) to convert AC wall power to a constant-current DC supply. Even for multiple UV LEDs, a single PSU might suffice. However, the designer must carefully analyze series/parallel circuit configurations to ensure:

- **Voltage Compatibility:** The total forward voltage of the LED array should fall within the PSU's output voltage range. UV LEDs may be categorized by forward voltage bins, and the designer should select appropriate PSUs to meet the requirement of the different bins.
- **Safety Limits:** For safety reasons, it is recommended that the circuit configuration should not typically exceed a total voltage of 60VDC.
- **Current Protection:** The drive current flowing through each individual UV LED must never exceed the manufacturer's specified "absolute maximum".

The dimensions and weight of the PSU may also be considered if there are any mechanical design restrictions.

There may be applications where the LED needs to be run at a lower power than the typical values. In those cases, dimming en-

abled PSUs must be used. Optical output of UV LEDs is typically directly proportional to the drive current. So, it is important to look at the optical output vs. drive current curve, usually included in datasheets to see how the LED can be dimmed. Analog dimming options include resistive control or 0-10V control.

Another method of dimming is by using pulse width modulation (PWM) which allows for greater granularity and accuracy in dimming. The frequency and duty cycle of a PWM signal can be varied to dim at different current levels. Note that some PSUs may provide a PWM option for dimming but may not be using the PWM signal in the true form to vary the current. Instead, the output current to the LEDs may be constant but proportional to the PWM signal. Operating the LED using a PWM signal may also help in lowering the operating temperature [8].

Evaluating Thermal Characteristics

Due to their material composition and high sensitivity to temperature, UV LEDs are particularly susceptible to the detrimental effects of heat. Proper thermal management is crucial for successful integration of UV LEDs into various systems.

Important metrics to consider when evaluating thermal characteristics include:

- **Junction Temperature** is the temperature at the active, light-emitting region of the LED chip. Elevated junction temperatures can significantly shorten lifespan and compromise reliability. Junction temperature directly influences both radiant flux (light output) and LED lifetime. Therefore, accurate estimation of system junction temperatures is essential when interpreting radiant flux values. While direct measurement of junction temperature is challenging, many manufacturers provide a test point (Tc) on the device itself to measure the chip temperature. System designers can request manufacturers to validate the relationship between Tc and junction temperature (Tj) to enable more accurate estimations.
- **Thermal resistance** defines how effectively heat can be extracted out of the LED. Junction temperatures can be reduced significantly if the thermal resistance is minimized. Specification sheets often list thermal resistance values, facilitating comparisons between different LED package types. Some packages may offer an additional thermal pad which reduces the overall thermal resistance and allows for efficient heat extraction [6]. These values can be used to estimate thermal budgets for a system and select appropriate passive or active cooling solutions (**Figure 5**). Thermal simulations of the system can greatly assist in estimating junction temperatures, potentially reducing development costs and timelines.

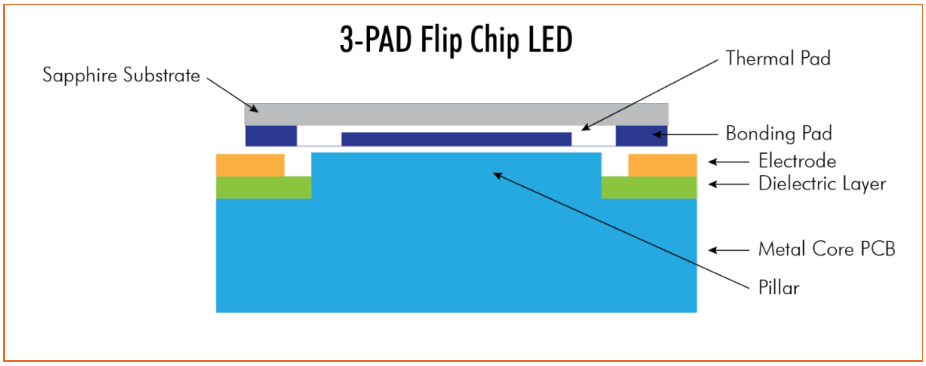

Figure 5: Example of a 3-PAD LED package which allows for efficient heat extraction at the package level.

Comparing LED Lifetimes

LED lifetime is typically calculated as the operating time at which the LED optical output at a specific wavelength drops to 70% of the initial value (L70). While long-lasting LEDs are desirable, it is important to examine the specific operating conditions under which these lifetimes were measured. Higher junction temperatures (Tj) and increased current densities can potentially shorten LED lifetimes. For instance, a manufacturer might advertise a 20,000-hour lifetime for a particular LED, but this figure might be based on testing at a Tj of 45°C and a drive current of 350 mA. While this data offers a general guideline, it is insufficient for estimating lifetimes for systems with operating conditions such as a Tj of 60 °C and a drive current of 500 mA. Thus, in-house lifetime testing at the intended operating conditions is highly recommended.

Other trade-offs to be considered when selecting UV LEDs

- **Wavelength vs. Efficiency:** The conversion efficiency of UV LED devices can be expressed in the form of the wall-plug efficiencies (WPE) defined as follows:

$$WPE = \frac{P_{OUT}}{I \cdot V} \quad (1)$$

Where P_{OUT} is the optical output power, I is the forward current, V is the voltage of operation

Electrical efficiency increase may come at the cost of switching to a longer wavelength. However, if WPEs are comparable for two different wavelengths, it is better to use the wavelength that provides a higher overall performance. For example, between 280 nm and 265 nm systems, the 280 nm may have a marginally better WPE than the 265 nm LED. However, when used for a disinfection application, the 265 nm shows a much better log reduction as compared to the 280 nm and would be the LED of choice.

- **Uniformity vs. Cost:** Uniform irradiance distributions are highly desirable for most applications. In many applications such as curing, such metrics are a requirement. To ensure high uniformity, the LED count must be increased and the cost to develop such systems can be very high. In such cases, a trade-off between uniformity and cost must be carefully considered. However, by strategically adjusting factors like LED spacing, employing multiple lenses, and varying throw distances, it is possible to mitigate costs and reduce the required number of LEDs while maintaining acceptable levels of uniformity. Custom LED array design options can aid in achieving such targets.
- **Current density vs lifetime:** Higher drive currents imply higher junction temperatures. If thermal solutions are not optimized, high junction temperatures can reduce LED lifetimes. So, the target lifetimes must be considered when looking at high drive currents.
- **Spectral purity vs cost:** Some applications such as fluorescence spectroscopy, UV-visible spectrophotometry, and photodynamic therapy require a higher spectral purity (shorter wavelength emission range) than others which can add to production costs and can affect UV LED selection.

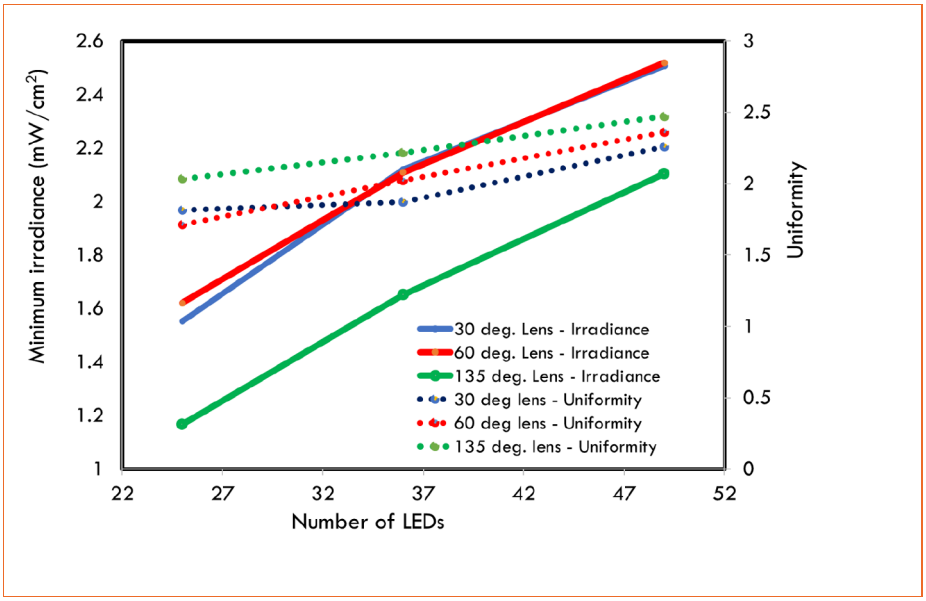

Figure 6: Comparison of various optics types for a disinfection device design with custom arrays using 265 nm LEDs [9].

The Need for Custom Arrays

While standard, commercially available UV LED products may suffice for certain applications, custom array design enables the development of niche products and provides greater flexibility and adaptability to produce tailor-made, application-specific solutions. Such solutions require clarity in terms of the application requirements, thoroughness on the system design aspect as well as a deeper understanding of how the LEDs would be integrated into the system/product. While SMDs and COBs may be suitable for prototyping needs, custom arrays are sought more often for final designs geared for production (**Figure 6**).

The Economics of Buying UV LEDs

Pricing of UV LEDs depends heavily on the emission wavelength, with UVC LEDs typically being significantly more expensive than UVA LEDs per milliwatt of optical power. In addition, system costs increase with the addition of optical elements, corresponding PSUs, thermal solutions as well as mechanical components. System designers, when evaluating costs should consider the system in its entirety as opposed to individual LED costs, although LED costs may be a dominant factor in the overall system costs. In addition to the initial costs, it is also important to factor in LED lifetimes as well as reliability depending on targeted system lifetimes. A steeper degradation curve would highlight a greater decay in the output over time. This means that the exposure times may have to be changed more rapidly, specifically for disinfection and curing applications, which could lead to a significant change in system design parameters. For visible LEDs, wall plug efficiency is usually a key factor in device selection. However, for UV LED systems, considerations like device lifetimes and overall system costs often take precedence over efficiency comparisons.

Conclusion

UV LEDs have made significant strides, reaching hundreds of milliwatts in optical output and finding applications across various industries. However, selecting UV LEDs remains challenging due to varying specification standards and characterization methods. System designers must carefully consider multiple factors, including optical output, efficiency, optical elements, and thermal solutions, to select LEDs based on their application. ■

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Expert Talks on Light – LUMINUS, Improving Life with Photons

Robert de Jonge, VP of Sales & Business Development for the EMEA region, presents the company and its products in three expert talks, explaining applications of the latest LED developments and technologies.

Talk#1: Company Overview

https://youtu.be/JCDNHgOOM6c

Luminus, a **photonics innovator**, offers **high-performance lighting** and **LED solutions** across sectors, utilizing **advanced technology** to impact markets like **health and well-being**, **metaverse applications**, **automotive**, and **consumer lighting**. Their targeted products support applications in **medical imaging**, **sanitation**, and **augmented reality**.

Backed by **San'an Optoelectronics**, Luminus maintains a **scalable supply chain** for efficient, high-volume production. Known for **market-leading innovations**, including the **brightest light sources** and **long-life products**, Luminus emphasizes **precise wavelength targeting** and **high photon density**. Their products meet **ISO certifications** and comply with **RoHS** and **REACH**, underscoring their **reliability** and **performance**.

Talk#2: Light for Living

https://youtu.be/8966w6jGLn4

Luminus is a **pioneering photonics company** focused on **specialty lighting** with high **flux density** and **color accuracy**. Their portfolio includes innovative **LED solutions** for diverse applications, such as **architectural lighting**, **directional lighting**, and **portable lighting**. Products like the **LUX COB LEDs** offer superior **color quality** and **high CRI**, while the **Robusto COB** series provides enhanced **reliability** and longevity.

Luminus's technology emphasizes **spectrum engineering**, with phosphor innovations and a wide range of **wavelengths**. Their **global supply chain** and partnerships ensure production scalability and performance. Compliant with **ISO certifications** and **RoHS/REACH standards**, Luminus products are trusted for applications demanding **quality light output**, thermal efficiency, and compact design across industrial, medical, and commercial sectors.

Talk#3: Light for Working

https://youtu.be/YlwRRQ-ngXQ

Luminus specializes in **high-intensity specialty lighting** solutions, with products that target diverse applications such as **medical imaging**, **3D printing**, **stage lighting**, **night vision**, and **horticulture**. Their offerings, including **high-power LEDs** and **lasers**, provide precise **wavelength targeting** and exceptional **flux density**, optimized for **thermal management** and long-lasting performance.

Luminus's **UVC and UVA LEDs** serve high-demand sectors like **sanitation** and **industrial curing**, while their **IR LEDs** support **biometrics**, **sensing**, and **night-vision**. The portfolio's **high CRI LEDs** ensure vivid color fidelity, critical for **studio lighting** and **medical applications**. Leveraging a **scalable supply chain** and in-house **chip technology**, Luminus remains a leader in durable, precision lighting solutions across specialized markets.

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Lighting Outlook

Innovations in Controls and Performance
The next issue of LED professional Review, LpR#107, features exclusive interviews with key leaders in the lighting sector. We dive into a discussion with a DALI Alliance expert on the latest advancements in DALI technology, with a focus on wireless communication. Another interview provides insights from a lighting industry representative on the opportunities and challenges for the coming year, exploring potential for groundbreaking innovations. This issue will include part two of Bartenbach's research study on energy efficiency. For the automotive sector, we highlight cutting-edge developments in control systems and chip design. In addition to all that, you can look forward to an in-depth article on DC systems in lighting architecture. And, as usual, we will be bringing you the latest updates from the global lighting industry, along with a commentary from a prominent figure in the field.

* *Subject to change without notice.*

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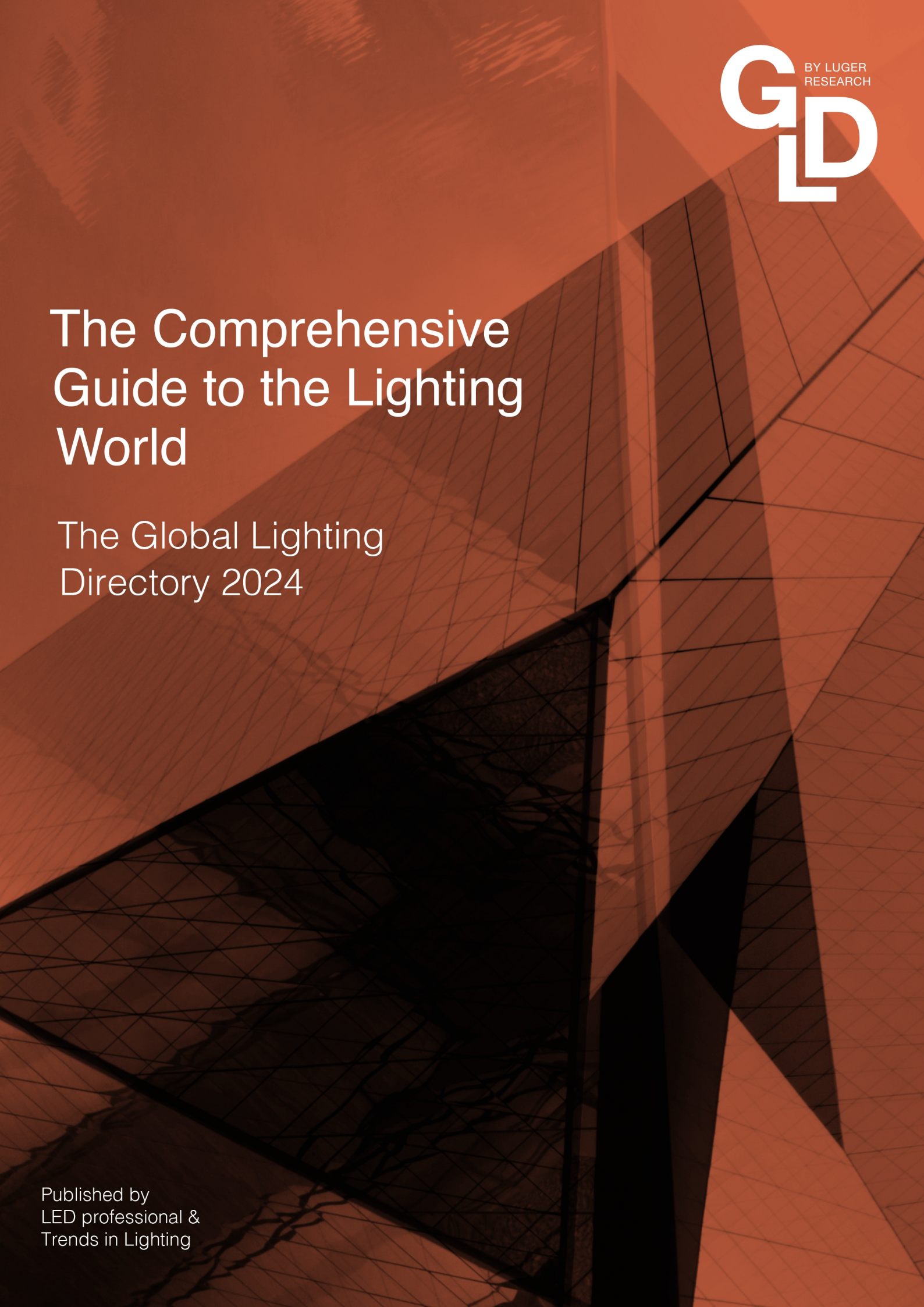

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