Technology Position Paper

Integrated Daylighting and Electric Lighting in Non-residential Buildings

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Contents

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This position paper provides an overview of the lighting technologies market for non-residential buildings, outlining its importance, potential, and development. It addresses issues for policy- and decision-makers and other stakeholders aiming to support the implementation of energy-efficient, sustainable, and integrated and integrative lighting solutions. It concludes by highlighting existing challenges and the actions needed to best exploit energy efficiency and decarbonization opportunities.

1 Introduction and Relevance

Lighting accounts for **5% of global CO_2 emissions**. In addition to its carbon footprint and impact on global warming, as the world transitions to primarily all electricity-based energy systems, lighting is in strong competition with other existing and new consumers (e.g., e-mobility, heat pump systems, etc.) as it consumes **15% of the global electricity consumption** (Figure 1). Plus, taxed CO_2 emissions, rising electricity prices, and power shortages are related phenomena requiring more efficient use of lighting. Aside from the direct impact on the consumption of electric lighting, daylighting – when appropriately utilized in trade-off with solar gains – can have a positive impact on managing heating and cooling loads in today's highly engineered buildings. Furthermore, embodied energy for electric and daylighting technologies is playing a growing role on a relative scale and needs to be taken into account. On these bases, to support the sustainability of buildings, it is urgently necessary **to widen the design perspective of lighting solutions embracing a more holistic view of its impact on CO_2 emissions**, encompassing the whole life cycle (the 'lighting value chain)' also in the context of regional energy markets aspects, interaction with other building trades, etc. This goes far beyond implementing strategies focusing uniquely on LED lamp-driven energy efficiency gains.

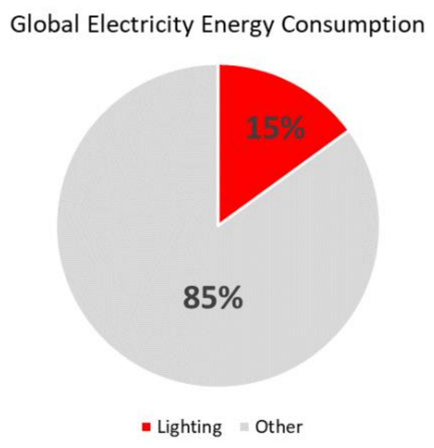

Figure 1. Lighting accounts for 15% of global electricity consumption[1].

The users and their needs are of paramount relevance: **lighting has to be made for the people. Humans receive 80 to 90% of information from their surrounding environment through their eyes** (Figure 2)**.** This shows how important the visual environment is for comfort, well-being, and performance. To achieve an optimal lighting

[1] Data Source: UNEP Report, Accelerating the Global Adoption of ENERGY-EFFICIENT LIGHTING, 2017.

scenario, designers must consider personal needs and the environment in which individuals work. Tailor-made solutions, today, should always encompass an appropriate combination of electric lighting and daylight. The interface to new and, possibly, more complex lighting controls (Human-machine interface, HMI) needs to be properly addressed, as they can raise issues of interaction and acceptance. Still, they could finally unleash substantial energy savings.

From a user perspective, it is now understood that lighting solutions have to consider not only the visual but also the non-visual effects (or non-image forming, NIF) of the luminous radiation received by the eye. This renewed design paradigm strengthens the role of daylight as the basis for indoor lighting. However, implementing **efficient, comfortable, healthy, and widely acceptable lighting installations is a multi-criteria task.**

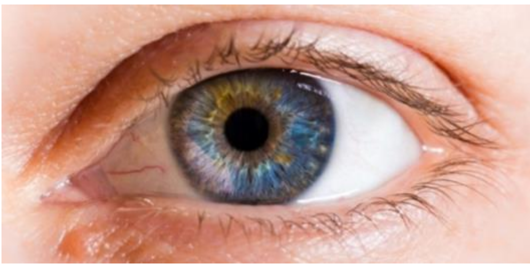

Figure 2. Humans receive 80 to 90% of information from their surrounding environment through their eyes. Therefore, lighting must be made for the people.

2 Current Status

To address user needs and be energy efficient, integrated lighting is driven by architecture and building design practice. It employs technologies from three sectors: the façade industry, electric lighting, and building automation (Figure 3).

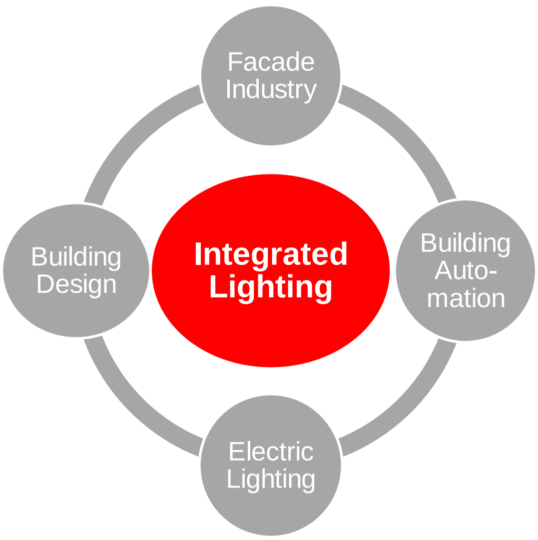

Figure 3. Efficient lighting driven by building design and technologies from three sectors: façade industry, electric lighting, and building automation.

Architecture & building design

Indoor daylight availability strongly depends on architectural parameters like floor plans, façade layout, and neighborhood density. These inherently structural features are established (or given) at the very early stages of design. Building performance is a function of these parameters along the life of the building, so errors made at this stage are difficult to address later. Conversely, systems like electric lighting and other building services have shorter use expectancies and are typically replaced several times over a building's lifespan[2]. **Therefore, building design usually plays the most important role in securing quality daylighting. Clearly, nowadays, this must be contextualized more with the increasing densification of urban settings.**

The proper implementation of daylighting strategies requires specific training of designers. This also encompasses the role of the architect or designer to respond to the client's expectations, the building's technical requirements, and interactions with its urban surroundings. In professional practice, this is often accompanied by guidelines, ordinances, and private partnership agreements, also including sustainability certificates. **To reach an appropriate level of design definition, larger architecture companies often employ automated, parametric software-driven design processes.** This means they are varying under given constraints, for instance, the window size in the façade design to achieve sufficient daylight penetration. In some advanced cases, the arrangement of floor plans or the distribution of lighting over large surfaces (e.g., stadium design) is modified parametrically by **algorithms that can reduce design and simulation time by a factor of 5.** Advanced software tools are starting to indicate untapped energy-saving potentials throughout the design process directly.

New standards like **EN 17037, "Daylight in Buildings,"** now offer guidelines to designers **by introducing new criteria, such as a classification of daylight autonomy, risks of daylight glare, sunlight exposure, and views to the outside**. In practice, this standard can significantly improve daylight quality and daylight-driven energy efficiency. Initial experiences in practice show the need for some adaptations while not questioning the general feasibility of the methodology.

Façade technology

The global façade market has grown significantly in the last decades. Today, **around 1.3 billion square meters of glazed facades (the equivalent of the area of the city of London) are built every year.** Innovation in glazing has significantly improved the thermal properties by using new coating techniques and multilayer systems. In recent years, 3-pane glazing systems have become the standard option in many countries despite their reduced visual transmission. Advances in matched coatings for sun protection glazing show **favorable LSG (light-to-solar-gains) close to 2**, therefore offering sun protection while still providing an acceptable ingress of daylight. In terms of solar protection, the 1990s saw the development of diverse advanced (complex) fenestration systems offering simultaneously good shading and daylight potential. From the wide variety of systems developed, only a few have had a lasting impact on the market, partly due to technical drawbacks but mostly linked to economic reasons. Among these, **electrochromic switchable glazing is expecting a boost as its color**

[2] Typical lifespan of fenestration systems is 30-50 years, whereas electric lighting is now around 10-15 years.

rendering properties improve, particularly when used at large scales. For these switchable elements, costs nevertheless are still a multiple of the costs of conventional solutions, which are made up of standard glazing units combined with mechanical glare and or sun protection. The architectural trend of fully glazed facades is generally still prevalent. Another tendency consists in integrating active solar systems (photovoltaic and thermal collectors) directly within the façade. These solutions must be paired with the need to provide sufficient daylight supply in the adjacent indoor spaces. **Daylight provision should not be reduced in conflicts of goals.**

Electric lighting and building automation technology

LED lamp efficiency has come close to the **theoretical maximum of around 230 lm/W**[3], so no further significant improvements are expected (Figure 4).

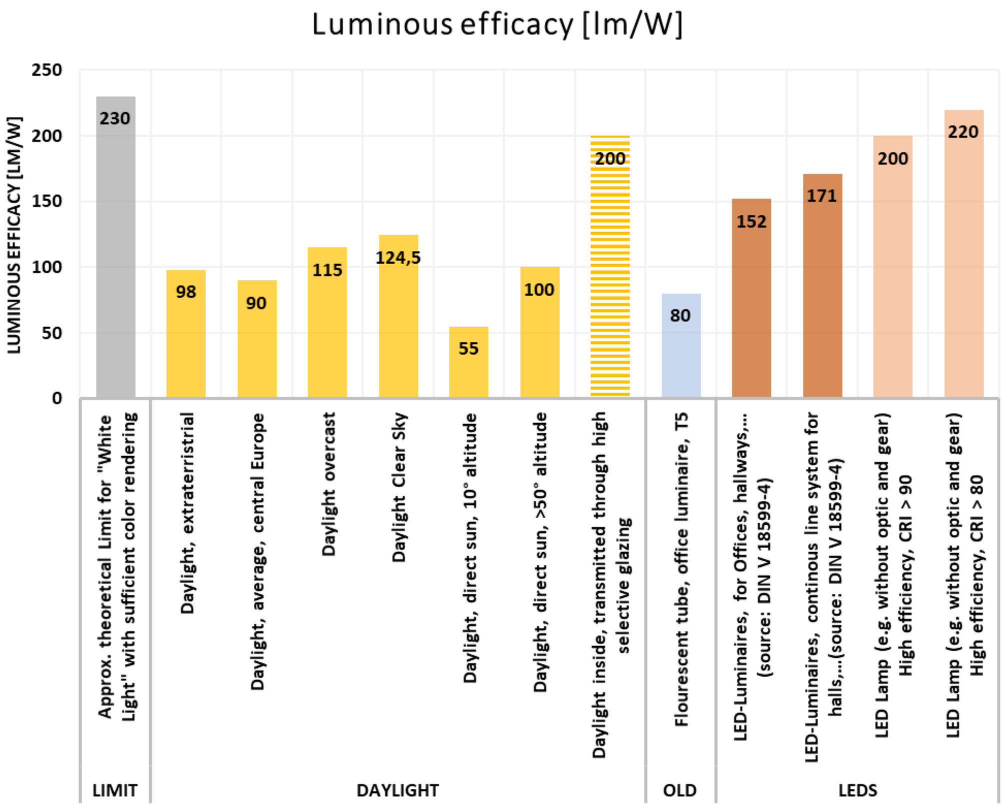

Figure 4. Luminous efficacies: Theoretical limit for white light, selected efficacies of daylight, and LED luminaires and lamps.

In current practice, **luminaire efficacies of a minimum of 150 lm/W should be the benchmark**. Recent advances in LEDs lie in the field of better color rendition with so-called full spectrum LEDs, which offer more balanced luminous emission. From an economic perspective, LED lamps (which cost well under 2€/1000 lm) are no longer the driving factor in selecting lighting solutions. Instead, the fixtures with optics, housing, and control gear determine the final prices of installation. But also, in this case, significant effects of economy of scale are observable for standard fixtures. This goes along with persistently stronger integration of additional features, e.g., sensor and

[3] Higher efficiencies would lower acceptable color rendering for premises like offices.

network functionality, as known for other integrated semiconductor products following the principle of “more for less.”

In its now-published strategic vision, *‘Technology and innovation pathways for zero-carbon-ready buildings by 2030,’* **the IEA promotes LED implementation as one of the possible fast-working contributions in lowering carbon emission in the built environment** (https://www.iea.org/reports/targeting-100-led-lighting-sales-by-2025). Regulations, as in the European Union, taking fluorescent lamps almost entirely out of the market support this transition process.

Daylight-dependent control of electric lighting is a technology that **has proven to work efficiently and lead to substantial energy savings.** Nevertheless, its **actual implementation rate is still low, as** in Germany with an estimated 20% of new installations. Façade control technology can now be easily integrated into building management systems. Available functionalities also include cut-off controls for shading systems, which provide a good compromise between solar protection, daylight penetration, and views to the outside. Integrating façade control and occupancy detection technologies into electric lighting control schemes can lead to additional energy savings. Finally, designing control systems to accommodate energy-efficient user behaviors, for example, by **introducing energy saving default settings for shading and lighting, can further reduce energy demand.**

The number of lighting fixtures equipped with electronics, such as sensors for daylight-dependent lighting control, occupancy detection, and communication components, is increasing. This integration of functionalities is helping to lower costs for more effective use of daylight. **Integrative lighting** (often referred to as ‘human-centric lighting’), **which aims to elicit a human circadian response**, is currently **driving innovations in lighting technology.** A wider implementation of integrative lighting – whereas electric lighting installations can supplement daylight to address non-visual requirements – can be expected as the knowledge advances in this field.

3 Potential

The energy demand for lighting can drastically be reduced due to the combined effect of more efficient light sources, advances in controls, and raised awareness about the integration of daylighting and electric lighting. As SHC Task 61 / EBC Annex 77 on Integrated Solutions for Daylighting and Electric Lighting has shown, **annual lighting energy use as low as 3-4 kWh/m² for spaces like offices is now possible**. **But this is still far from being the standard in typical projects, where the range of energy demands is often around 10-20 kWh/m².**

Substantial energy-saving potentials can be achieved by replacing the large stock of old installations with state-of-the-art lighting technologies. Nevertheless, replacement decisions based on investment costs can present a significant barrier. Instead, **approaches based on the total cost of ownership** should be adopted. These recognize long-term benefits of effective daylighting use. As a result, replacements of installations with high operating times become highly favorable.

As the focus shifts from pure energy performance optimization to a more holistic view of general resource use efficiency, decarbonization aspects – particularly embodied energy – will come stronger into play. The IEA SHC TCP is planning to address this issue in depth in the new IEA SHC Task on Low Carbon, High Comfort Integrated Lighting.

Products

Whereas in electric lighting, the **transition to LEDs at the lamp level is already largely achieved**, this shift is **yet to be fully realized at the luminaire level**. Potentials for decreasing the embodied energy lie, for instance, in:

a) **Modular luminaire architectures** including exchangeable optics, programmable lumen outputs, smart use of 3D printed parts, recyclable components, and
b) **Direct integration** of light **into building components** (e.g., allocation as heat sinks for the lamps) and architecture (e.g., with new slim optical systems).

In daylighting technology, the embodied energy is dominated by façades.

a) **Micro-optics for light redirection** can be obtained for **1/5 of the plastic mass** employed compared to standard solutions.
b) New, **electrochromic glazing systems** with **better color rendering** combined, for example, **with vacuum glazing**, are making conventional glare protection and sun shading devices obsolete while allowing much lighter solutions than closed cavity systems.
c) At the laboratory level, diverse **lighting control schemes** are being tested **to better integrate daylighting and electric lighting as perceived by the users directly at their workplace**. Nevertheless, the increasing use of sensor hardware and bigger standby losses need to be addressed for controls.

Planning/design

This stage has a long-lasting impact as a decisive lever on the usage phase, which usually dominates the overall lifetime costs and resources used. Numerous inefficiencies are known in lighting design. For example, erroneous design processes result in over-installations. Trade association's findings are that the majority **of installations are not properly designed (or are not designed at all). This needs to be significantly improved.**

Architectural and design constraints demand answers like offering good (day) light supply in dense urban environments – inside and outside (also understanding the external impacts of façades at an urban level). **Lighting must find its place in a strive for optimal functionality within a limited building envelope surface – daylight vs. active solar vs. facade greening**, difficulties meeting requirements, as in EN 17037 or workplace regulations. 'Daylight mimicking' is a recurrent theme. When electric lighting is the only luminous source available, it relies on the use of variable spectra and intensities following, to a certain degree, the dynamics of daylight. In some cases, this approach can be considered more resource efficient as a whole. Yet, despite soaring energy prices and the high efficiency of LEDs, the feasibility of the approach is still questioned. Potentials need to be better understood under variable boundary conditions throughout the world.

Further alignment with user expectations is of great importance at the design stage – integrative lighting, including visual and non-visual effects, is driving innovation in lighting technology[4]. However, **if not properly integrated with daylight,** this comes with **the risk of energy rebounds, that is, more delivered lumens and lower luminous efficacies, as shown in SHC Task 61 / EBC Annex 77.** Here, tools and knowledge for designers to implement daylight in integrative lighting schemes are available but need to be put into practice more often. Their application could be increased by widening their scope to include methods for appropriate LCA analysis of lighting and lighting's role in building rating schemes.

Construction/commissioning/usage/end-of-life

These phases can only be as performant as product quality and design processes allow. **Commissioning and maintenance processes need to be improved and become standard practice. Otherwise, efficiency might be jeopardized.** The better a product and architectural solution (e.g., durable, recyclable components), the lower the impact at the end-of-life stage. SHC Task 61 / EBC Annex 77 has shown that (re) commissioning and maintenance (monitoring, validation) are central to achieving good, energy-efficient performance over the usage period. **However, this is far from standard practice, unlike other HVAC trades, where appropriate commissioning and maintenance procedures are long established.**

Digitalization

Cross-cutting for an effective design and technical implementation is digitalization on all levels: 1) next-level design tools (parametric, automated, VR/AR) and robust processes relying, among others, on basic work from previous IEA SHC Tasks (digital façade models, energy rating algorithms) and 2) transfer of design data into the commissioning, predictive maintenance, and grid integration in a seamless data integration. **Digitalization is a critical success factor for low-carbon lighting and goes hand in hand with profitable future business models.**

4 Actions Needed

To support the implementation of energy efficient, sustainable, and at the same time integrated and integrative lighting solutions, the table below highlights some of the existing challenges, and the actions needed to address them. **The targeted stakeholders are governments, industry and their trade associations, designers, and building owners.**

[4] Also, in standardization as EN 12464 "Light and lighting - Lighting of work places - Part 1: Indoor work places."

Challenge	Action needed
Harvest 'low hanging fruit' in electric lighting	• Replace old lighting installations with **LED** technology. • Request **luminaire efficiencies >150 lm/W.** • Refocus from decisions based on pure investment costs to **total cost of ownership.**
Strengthen the role of daylighting	• **Recognize daylight** – which nowadays can be sufficiently quantified as a substitute for electric lighting – **a "renewable energy source"** – allowing for **inclusion in subsidy programs** as known from other market sectors (PV, wind, etc.). • **Use sustainability certificates** to promote daylighting, if not included, or revisit existing certificates and update. • Demand **a minimal window to floor area ratio,** e.g., in central Europe between **1/8 and 1/10**. • **Revise ordinances** to demand technical and economical advantageous daylighting solutions, such as: - **Daylight-supportive combinations of glazing and sun shading/glare protection** devices - **Light redirecting** fenestration, and - Daylight and occupancy sensitive **electric lighting controls** also integrated with facades (i.e., visual comfort driven when occupied, solar gain driven when unoccupied).
Widen the rating perspective of lighting	• Put lighting into the perspective of its **impact on decarbonization**. • **Foster LCA approaches** for rating integrated lighting.
Rethink products	• Make **product architectures**[5] more **sustainable.** • Push product design based on **micro-optics** for LED luminaires and façades applications. • Support development and implementation of disruptive façade technologies like **electrochromic glazing systems** (or other switchable technologies), ideally **in combination with vacuum glazing,** to drastically lower a façade's embodied energy.
Improve design processes	• Make **planning** of lighting installations **mandatory.** • Foster **employment of new available integrated design and rating tools**, which in part automatically indicates not yet allocated potentials. • Introduce processes **ensuring** certain **daylight quality levels** (e.g., parametric, automated design tools. • Use **design strategies** that prompt **energy efficient behaviors**. • Support the **deployment** of concepts from **new daylighting and electric lighting standard** (e.g., EN 17037 "Daylight in Buildings" and EN 12464 "Lighting of indoor workplaces").
Foster commissioning and maintenance	• Make **commissioning and maintenance** procedures mandatory avoiding rebound effects - as already done in other HVAC trades for years. • Practically integrate lighting into regular **electrical safety check procedures** in commercial buildings.

[5] Product architecture is the organization (or chunking) of a product's functional elements.