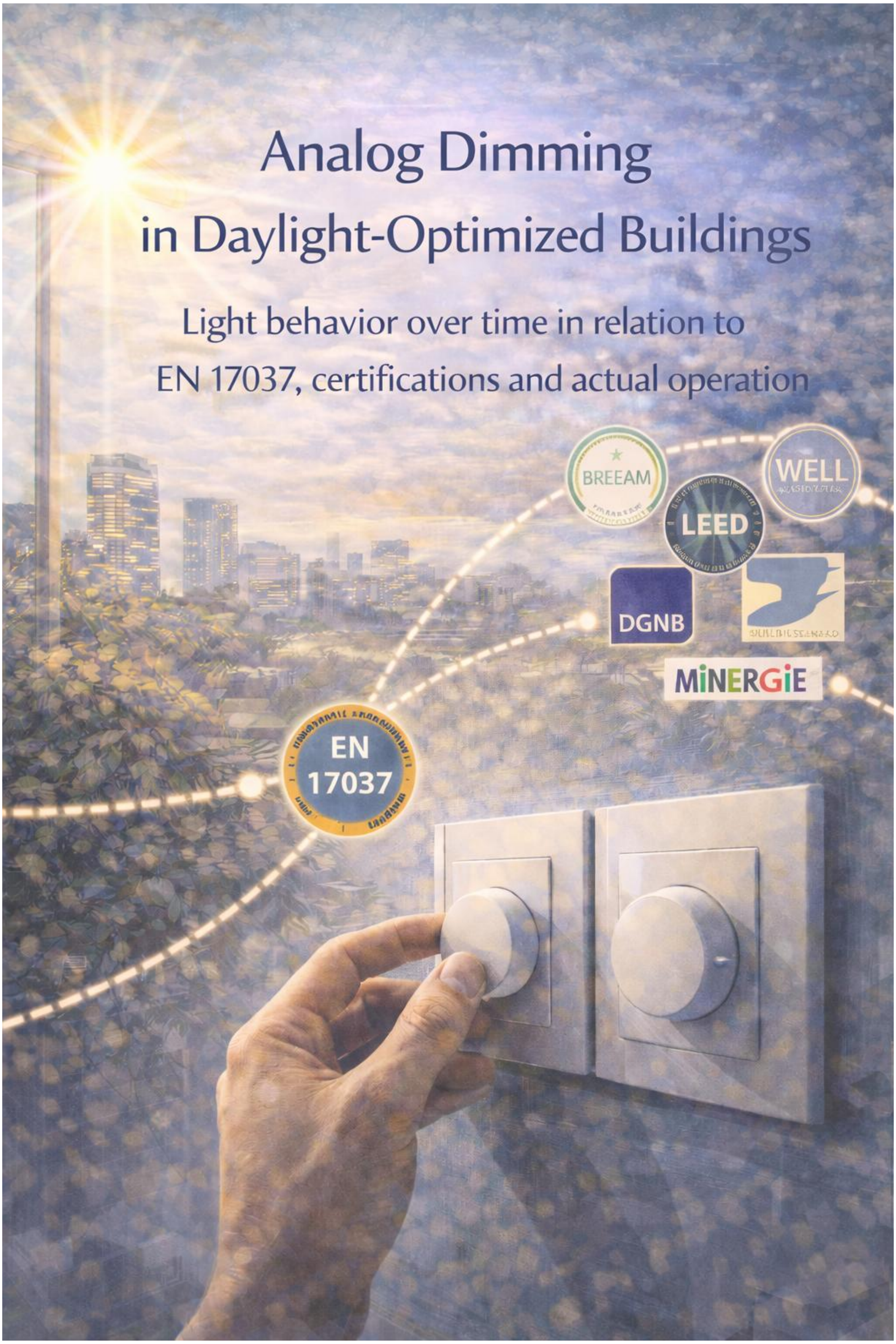

Analog Dimming in Daylight-Optimized Buildings

Light behavior over time in relation to EN 17037, certifications and actual operation

WHITEPAPER

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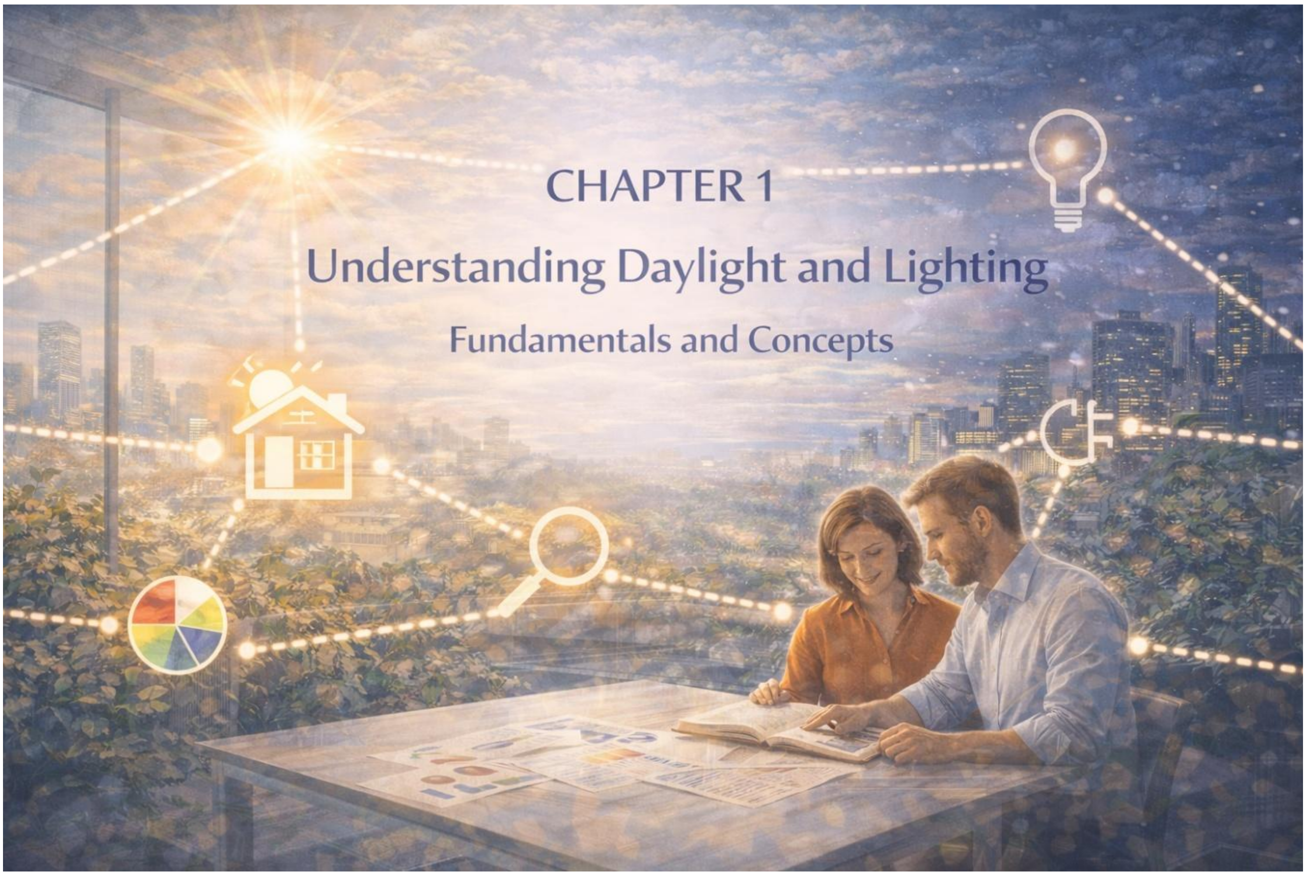
WHY OPTOGA IS TRANSITING FROM PWM TO DIGITALLY CONTROLLED ANALOG DIMMING AND WHAT IT MEANS FOR THE LIGHTING ENVIRONMENTS OF THE FUTURE



1. EXECUTIVE SUMMARY

The role of lighting in modern buildings is changing.

Daylight is no longer treated as a fixed design parameter, but as a dynamic condition that influences comfort, energy performance, and long-term building operation. At the same time, regulatory frameworks, standards, and certification systems increasingly evaluate buildings based on real behaviour in use rather than static, calculated values.

This shift places new demands on electric lighting.

To function effectively in daylight-optimised buildings, lighting systems must deliver:

- stable and predictable dimming at low light levels
- flicker-free operation
- linear and measurable energy behaviour
- reliable interaction with sensors, control systems, and building automation

Traditional LED dimming approaches, particularly PWM-based solutions, struggle to meet these requirements consistently in practice.

Optoga addresses this challenge through a hybrid approach combining digital control with analogue dimming at the LED module level. By separating control precision from light generation, this approach enables lighting that behaves in a continuous, stable, and predictable manner over time.

The result is lighting that:

- integrates naturally with daylight variation
- supports daylight harvesting and energy reporting
- reduces technical risk in certified and regulated projects
- preserves visual comfort and design intent throughout the building lifecycle

Across standards such as EN 17037, regulatory frameworks such as EPBD, and certification systems including BREEAM, LEED, DGNB, WELL, and Minergie, a common direction is clear: lighting behaviour in real operation matters.

Solutions that offer stability, transparency, and verifiable performance over time are increasingly favoured, while technologies that introduce flicker, non-linear energy behaviour, or unpredictable control responses become harder to justify.

In this context, lighting is no longer defined only by output and efficiency, but by how it behaves, interacts, and performs throughout the life of the building.

1.1 HOW THIS DOCUMENT IS INTENDED TO BE USED

This whitepaper is intended to serve as a shared reference document in projects where daylight, energy performance, certifications, and long-term operational reliability are critical factors.

It is not a product datasheet and not a specification list. Instead, its purpose is to provide a coherent understanding of how modern requirements related to daylight, control systems, and energy performance influence lighting technology choices and how these requirements are addressed in practice.

For Luminaire Manufacturers

This document can be used as:

- a basis for technical decision-making when developing luminaire platforms
- support in procurement processes involving certifications and energy frameworks
- a common reference between engineering, sales, and project management teams

For Architects and Lighting Designers

This document can be used as:

- a reference for how electric lighting should interact with daylight
- support in discussions related to visual comfort, stable dimming, and light behaviour over time
- technical background for requirements linked to EN 17037, daylight harvesting, and certification-driven projects

For Property Owners and Facility Managers

This document can be used as:

- decision support when selecting lighting solutions with a focus on operation, energy, and lifecycle performance
- a reference when evaluating energy performance and certification compliance
- a shared language between technical, operational, and sustainability stakeholders

For Consultants, Procurement Specialists, and Certification Experts

This document can be used as:

- an overarching framework describing how lighting relates to EN 17037, EPBD, BREEAM, LEED, DGNB, WELL, Minergie, and national regulations
- support when formulating requirements related to daylight-responsive control, energy monitoring, and operational behaviour
- a reference for technical comparison between different lighting and control principles

DOCUMENT STRUCTURE

Chapters 1-2 provide background and context on the evolving role of daylight in buildings

Chapters 3-6 cover lighting control and dimming in daylight-optimised environments

Chapter 7 addresses how these requirements materialise in procurement and competitive evaluation

Chapters 8-11 cover standards, certifications, and daylight metrics in practice

SCOPE AND LIMITATIONS

This whitepaper focuses on light behaviour, controllability, and energy logic in relation to daylight and regulatory frameworks. It does not cover detailed luminaire design, optics, or specific product configurations.

The document is intended to function as a technical and strategic framework for decision-making and dialogue across disciplines. This document does not attempt to rank or certify dimming technologies, but to describe how different dimming principles affect light behaviour in daylight-optimised buildings.

CONTENT

2. BACKGROUND: THE CHANGING ROLE OF DAYLIGHT IN BUILDING DESIGN

Daylight has shifted from being an architectural added value to becoming a governing design parameter in contemporary buildings. Today, daylight influences not only architectural expression, but also energy performance, regulatory compliance, and indoor environmental quality. This change is clearly reflected across modern standards, certification systems, and energy frameworks.

A central example of this development is EN 17037, the European standard for daylight in buildings. In contrast to earlier, static daylight factor (DF) based approaches, EN 17037 introduces a fundamentally different perspective. Rather than asking *whether* a space receives sufficient daylight at a single point in time, the standard focuses on *how daylight performs over time* and how it contributes to the overall usability of the space.

EN 17037 therefore addresses daylight in relation to:

- its availability throughout the day and year,
- how deeply it penetrates into the space,
- visual comfort, including glare and contrast,
- and its interaction with electric lighting.

This temporal and experiential approach represents a decisive shift. Daylight is no longer treated as a fixed quantity, but as a dynamic resource that varies continuously and must be supported rather than counteracted by artificial lighting.

In parallel, environmental certification systems such as BREEAM, LEED, and DGNB have reinforced the role of daylight as a key instrument for reducing energy use and improving indoor environmental quality. These systems increasingly rely on climate-based daylight metrics such as Daylight Autonomy (DA), Spatial Daylight Autonomy (sDA), and Useful Daylight Illuminance (UDI) which explicitly assume that electric lighting responds proportionally and predictably to daylight availability.

The WELL Building Standard adds another dimension by emphasising visual comfort, flicker-free lighting, and the impact of light on human health and well-being. Here, the quality and stability of light over time are as important as absolute light levels.

At the regulatory level, EPBD and national energy frameworks require lighting systems to be measurable, controllable, and verifiable as part of the building's overall energy performance. This introduces additional demands on how lighting behaves in real operation, particularly in relation to energy logging, control accuracy, and long-term stability.

Across all these frameworks, a common assumption emerges:

Electric lighting must be capable of adapting dynamically, accurately, and stably to changing daylight conditions.

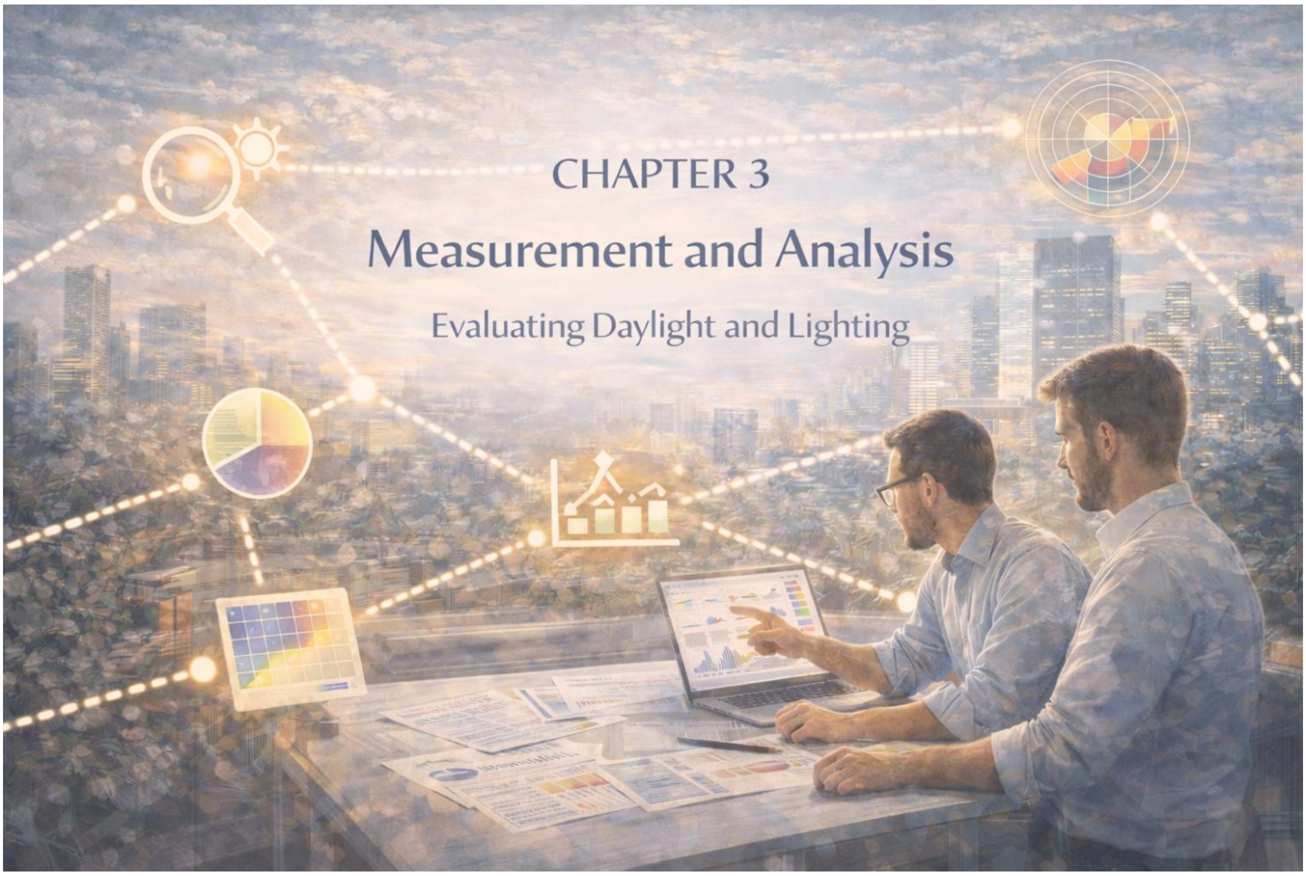
This assumption has far-reaching technical consequences. It is no longer sufficient for a lighting system to be dimmable in principle. Instead, it must behave predictably at low output levels, support smooth transitions, maintain visual comfort, and provide reliable energy data over time. These requirements form the foundation for the technical discussion that follows in this document.

As daylight becomes a governing parameter rather than a supplementary one, the demands placed on electric lighting change fundamentally. Standards and certification systems no longer evaluate lighting as a static installation, but as a dynamic system that must perform reliably over time, in continuous interaction with daylight, sensors, users, and control systems.

This shift exposes an important gap between regulatory intent and technical implementation. While standards such as EN 17037, and frameworks like BREEAM, LEED, WELL, and EPBD clearly describe *what* the lighting system is expected to achieve, they are largely technology-agnostic when it comes to *how* this should be realised.

As a result, different dimming and control technologies may formally comply with the same requirements, yet behave very differently in real operation. The critical question therefore becomes not whether a lighting system can be dimmed, measured, or controlled in theory, but how it behaves in practice, particularly at low light levels and during continuous daylight-responsive operation.

Chapter 3 examines how these standards, certifications, and energy frameworks converge toward a common set of technical requirements for electric lighting and why the choice of dimming principle becomes decisive for achieving stable, predictable, and comfortable lighting behaviour in daylight-optimised buildings.



3. THE RELATIONSHIP BETWEEN STANDARDS, CERTIFICATIONS, AND TECHNICAL REQUIREMENTS

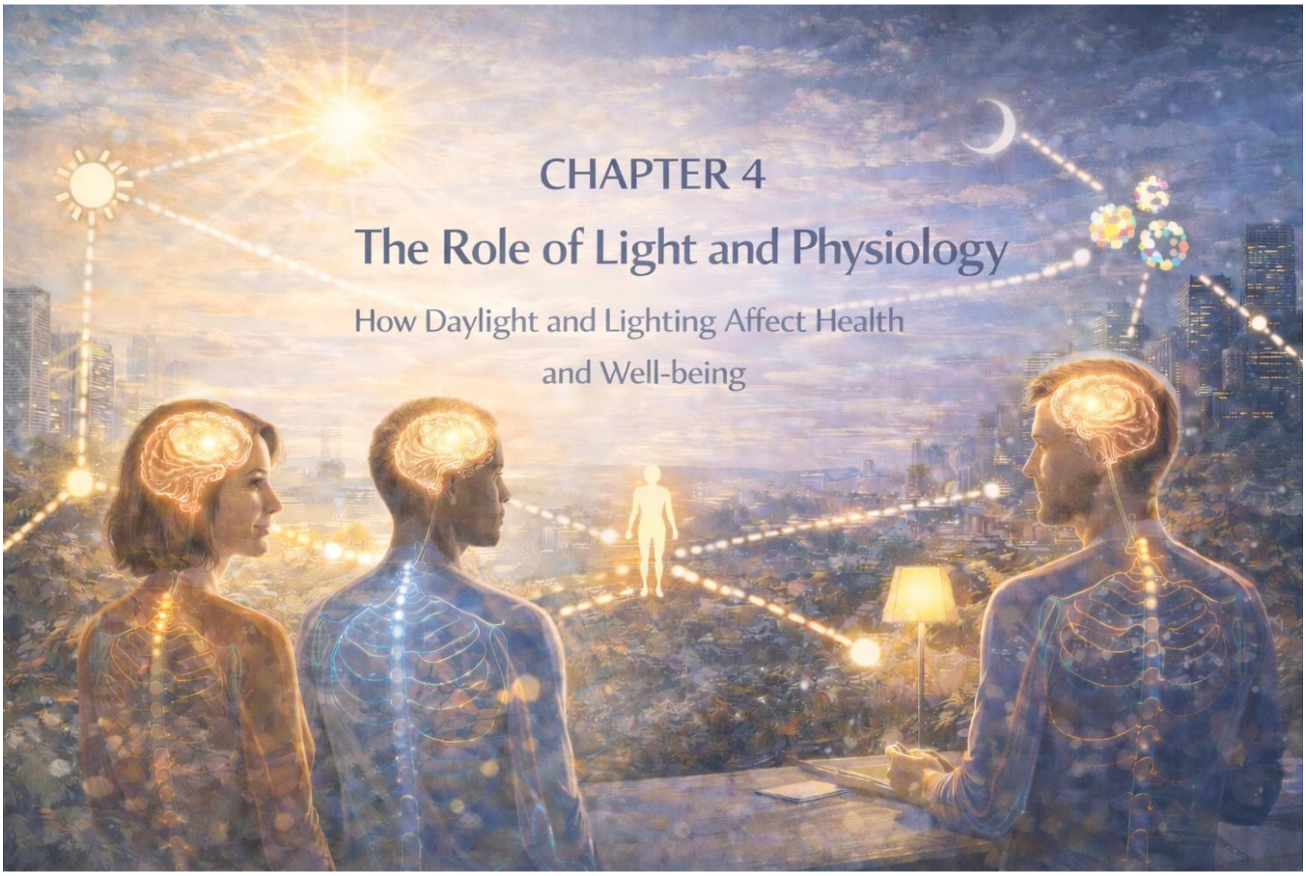
Although EN 17037, BREEAM, LEED, DGNB, WELL, and EPBD use different terminology and methodologies, they point towards the same technical implications for lighting systems.
Daylight is intended to serve as the primary light source, while electric lighting is expected to complement it in an energy-efficient and visually comfortable manner.

To clarify this relationship, Table 1 on next page illustrates how standards, certifications, and energy frameworks converge towards common technical requirements for electric lighting.

Standard / Framework	Primary Focus	Technical Implications for Lighting
EN 17037	Daylight availability, distribution, and visual comfort over time	Stable and continuous dimming, flicker-free operation, smooth interaction between daylight and electric lighting
BREEAM	Energy efficiency, daylight (sDA/UDI), visual comfort, BACS	Accurate dimming response, daylight harvesting, linear energy logic, reliable energy measurement
LEED	Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), energy performance	Predictable light regulation, stability at low output levels, accurate energy calculation
DGNB	Holistic sustainability, user quality, and life-cycle performance	Robust light regulation, verifiable energy performance over time, high operational stability
WELL Building Standard	Visual comfort, health, and well-being	Flicker-free dimming, smooth light regulation, stable light levels without visual artefacts
Minergie	Energy-efficient operation, comfort, system performance in real use	Demand-controlled lighting, stable dimming, linear energy logic, reliable energy measurement
EPBD (EU)	Energy performance, measurement, control, and reporting of building energy use	Linear and measurable energy logic, continuous energy monitoring, predictable controllability
National building regulations and energy frameworks	Energy efficiency and compliance with local requirements	Reliable dimming, accurate energy data, compatibility with daylight and control systems

Overview of how daylight standards (EN 17037), environmental certifications (BREEAM, LEED, DGNB, WELL), and energy frameworks (EPBD, national building regulations) converge towards common technical requirements such as flicker-free operation, stable dimming at low output levels, linear energy logic, and predictable controllability.

As illustrated in Figure 1, it is not a single standard that drives this development, but the combined interaction of multiple frameworks. The differences often lie in measurement methodology rather than in the technical requirements placed on lighting systems in practice.



4. WHY PWM DIMMING IS NO LONGER SUFFICIENT

The role of light behaviour in physiology, perception, and well-being

Light is not only a visual stimulus; it is a biological signal that affects human perception, comfort, alertness, and well-being. Daylight, in particular, provides a continuous, stable, and rhythmical light environment to which the human visual and circadian systems are naturally adapted.

Beyond visual perception, light also plays a role in regulating non-visual responses, including alertness and circadian rhythms. These effects are influenced not only by spectrum and intensity, but also by temporal stability and continuity of light over time.

Lighting that introduces rapid modulation, instability, or temporal artefacts particularly at low output levels may interfere with both visual comfort and non-visual responses. For this reason, standards and guidelines increasingly emphasise stable, flicker-free light behaviour as a prerequisite for healthy and comfortable indoor environments, rather than focusing on spectral metrics alone.

As daylight has taken on a more central role in architecture and lighting design through standards such as EN 17037 and certification systems like BREEAM, LEED, WELL, and Minergie, the expectations placed on electric lighting have changed fundamentally. Electric light is no longer evaluated solely on illuminance levels or efficiency, but on how it behaves over time, how it interacts with daylight, and how it supports human comfort in real operation.

In this context, the limitations of PWM dimming become evident. While PWM has long been an accepted technical solution for LED control, its pulsed nature introduces temporal artefacts that can affect visual stability, perceived comfort, and the physiological experience of light particularly at low output levels where daylight-responsive systems operate most of the time.

For architects and lighting designers, the question is therefore no longer whether light can be dimmed, but whether it behaves in a way that aligns with human perception, spatial intention, and the biological expectations shaped by daylight.

4.1 FLICKER AND INSTABILITY AT LOW OUTPUT LEVELS

PWM dimming regulates light by switching the current on and off in rapid pulses. At high output levels, this behaviour is rarely perceived as problematic. However, in daylight-optimised buildings, a significant share of operation takes place in the range of 1-10% light output, precisely where PWM behaviour becomes most pronounced.

This is the range in which architects and lighting designers work with subtle conditions such as transitions between daylight and electric light, low-intensity ambient scenes, and spaces where light should be present without drawing attention to itself. At these levels, PWM pulses become extremely short, increasing the risk of temporal artefacts in the emitted light.

These artefacts may manifest as subtle but perceptible visual flicker, micro-flicker affecting cameras, sensors and digital environments, and a general sense of instability in otherwise calm and carefully designed spaces. Beyond visual perception, such temporal instability may also influence non-visual responses to light, including alertness and circadian regulation, which are sensitive not only to light level and spectrum, but also to temporal consistency.

Research and emerging guidance increasingly indicate that stable, continuous light behaviour over time is a prerequisite for both visual comfort and physiological well-being, particularly in environments where occupants are exposed for long periods. Lighting that fluctuates or modulates rapidly, even when technically compliant, may therefore undermine both spatial experience and human comfort.

For the lighting designer, this means that the light begins to follow its own technical logic rather than the intended design intention. Instead of supporting calm transitions and spatial coherence, the lighting system risks introducing a subtle but persistent layer of disturbance visually, perceptually and physiologically.

4.2 NON-LINEAR ENERGY LOGIC

During the design phase and at the point of delivery, a PWM-controlled lighting system may appear to perform satisfactorily. At fixed light levels and under static conditions, its behaviour is often difficult to distinguish from more refined control strategies.

The limitations become apparent in real operation, where light is no longer static but continuously responding to changing conditions. In daylight-optimised buildings, electric lighting must constantly adapt to variations in daylight, sensor input, occupancy patterns, and gradually changing scenes. It is precisely under these dynamic conditions that the non-linear nature of PWM becomes problematic.

PWM does not provide a linear relationship between control signal, light output, and energy consumption. Small adjustments in the control signal can result in disproportionate or unpredictable changes in both perceived brightness and power use. As a result, lighting behaviour may appear inconsistent or unsettled, even when control systems are operating as intended.

In practice, this leads to several challenges. Daylight harvesting systems become more difficult to calibrate and fine-tune, as sensor feedback does not translate into stable and predictable light levels. Energy data may no longer correspond to the visual experience in the space, complicating energy reporting, performance verification, and optimisation over time.

For architects and lighting designers, this creates a fundamental disconnect between intention and outcome. The light that is specified, simulated, and approved during design is not necessarily the light that users experience in daily operation. Instead of supporting a coherent spatial experience, the lighting system risks becoming a variable technical layer that subtly undermines both visual comfort and design intent.

4.3 INSUFFICIENT INTERACTION WITH DAYLIGHT CONTROL

In daylight-responsive buildings, lighting control systems depend on continuous and accurate feedback from daylight sensors. These sensors form the basis for balancing daylight and electric lighting, with the intention of maintaining stable light levels while minimising energy use.

PWM-based dimming can disrupt this interaction. Because the light output is delivered in pulses rather than as a continuous signal, sensor readings may be influenced by the temporal structure of the light itself rather than by actual illuminance conditions in the space. This can lead to unstable control behaviour, including fluctuating signals, difficulties in achieving reliable calibration, and delayed or oscillating responses in hybrid systems combining daylight and electric lighting.

In practice, this results in lighting systems that are constantly correcting themselves instead of responding smoothly to changing daylight conditions. Rather than following the natural rhythm of daylight, the system may introduce subtle but perceptible irregularities in light output.

For architects and lighting designers, this behaviour undermines the intended spatial experience. Instead of a gradual and intuitive transition between daylight and electric lighting, the system risks revealing its technical operation through visible or perceptible disturbances.

As daylight becomes a primary design parameter rather than a secondary consideration, these limitations become increasingly critical. Lighting systems are no longer expected to operate as isolated technical installations, but as coherent components of the architectural environment supporting spatial quality, visual comfort, and continuity over time.

4.4 WHY THIS IS NO LONGER ACCEPTABLE IN MODERN PROJECTS

With standards such as EN 17037 and certifications including BREEAM, LEED, DGNB, WELL, and Minergie, the focus has shifted towards the experience of light over time, visual comfort, energy performance in real operation, and the interaction between daylight and electric lighting.

Within this framework, PWM dimming represents a legacy from an earlier generation of LED lighting developed to function technically, but not to interact spatially.

For architects and lighting designers, this marks a clear shift.
It is no longer sufficient for light to be dimmable.
It must behave like light.

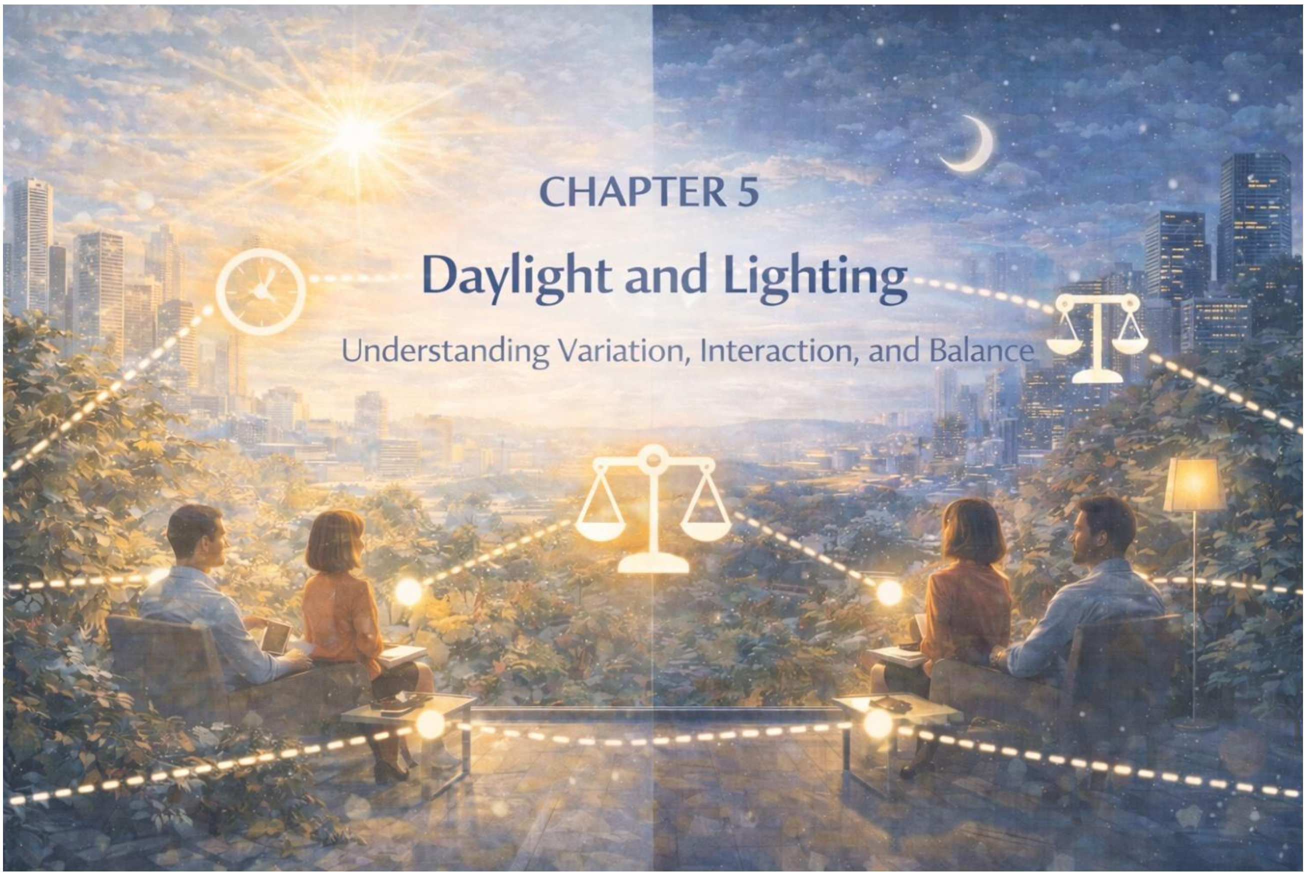
As daylight becomes a primary design parameter rather than a secondary consideration, these limitations become increasingly apparent. Beyond questions of visual artefacts and control stability, the temporal behaviour of light has also gained importance from a human perspective. Growing attention is being paid to how light supports alertness, well-being, and circadian stability throughout the day, particularly in buildings where occupants spend extended periods of time.

In this context, lighting systems that rely on pulsed modulation at low output levels risk introducing subtle physiological and perceptual disturbances, even when average light levels appear correct. As standards and certification frameworks increasingly emphasise comfort, usability, and performance over time, temporal light stability becomes a fundamental quality criterion rather than a secondary technical detail.

This reinforces the shift in expectations: electric lighting must not only meet technical requirements, but behave in a way that supports both spatial experience and human well-being throughout the day.

Together, these limitations highlight a fundamental mismatch between how many lighting systems are technically implemented and how light is expected to behave in daylight-optimised architecture. As daylight becomes a governing design parameter, the performance of electric lighting is increasingly judged by its temporal stability, predictability, and ability to support both spatial experience and human well-being.

Addressing these challenges does not require more complex control systems, but a reconsideration of how control precision and light generation are combined. This shift forms the basis for Optoga’s approach, where digital control is used where information is handled, and analogue regulation is used where light is actually formed.



5. OPTOGA’S SOLUTION: DIGITAL CONTROL COMBINED WITH ANALOGUE DIMMING

Light that follows variation, interaction, and spatial intention

Daylight and electric lighting are not static phenomena. They vary continuously over time, interact with each other, and shape how spaces are perceived throughout the day. In daylight-optimised buildings, good lighting design is therefore less about fixed levels and more about balance: between natural and artificial light, between control and perception, and between technical precision and human experience.

As shown in the preceding chapters, many conventional lighting solutions struggle in this context. When daylight becomes a primary driver, the limitations of pulsed dimming, non-linear behaviour, and unstable control become increasingly apparent not only technically, but spatially and experientially.

In response to these challenges, Optoga has developed a hybrid approach in which digital control precision is combined with analogue light regulation. The objective has not been to introduce yet another control system, but to enable electric light that can vary, interact, and balance itself with daylight in a way that remains meaningful within architecture and lighting design.

5.1 HOW THE SOLUTION OPERATES WITHOUT DISTURBING THE LIGHT EXPERIENCE

Optoga’s solution is based on two clearly separated functions:

- Digital control via DimIn, with an update frequency of 10 kHz
- Analogue current regulation inside the LED module, where the light output is actually formed

For the lighting designer, this means that the digital complexity of the control system never becomes visible in the light itself. There are no pulses, no steps, and no discontinuities in the light output, only a continuous change in light level.

5.2 WHAT THIS MEANS IN THE SPACE

By separating how the light is controlled from how the light is generated, the resulting light behaviour:

- dims smoothly and continuously, remaining stable even at very low output levels
- behaves predictably over time and interacts naturally with daylight
- avoids revealing the underlying control technology

For architects and lighting designers, this means that light can be used as a spatial material, enabling subtle transitions, low-level operation, and consistent visual experience rather than appearing as a technical artefact.

5.3 WHEN THE BENEFITS ARE MOST APPARENT

The advantages of digitally controlled analogue dimming are most evident in environments where the light:

- changes gradually throughout the day and operates close to daylight levels
- is used to shape atmosphere, spatial perception, and visual comfort rather than maximum brightness
- must remain stable, predictable, and unobtrusive over long periods of operation

Typical applications include schools and educational environments, healthcare and care facilities, offices with daylight-responsive lighting, hotels, restaurants, cultural spaces, as well as museums and exhibition environments.

In these contexts, the behaviour of light over time is more critical than peak light output.

5.4 WHY THIS APPROACH ALIGNS WITH MODERN STANDARDS

Modern standards and certification systems such as EN 17037, BREEAM, LEED, DGNB, WELL, and Minergie increasingly converge around a common understanding of what good lighting performance means in practice. The emphasis is no longer placed solely on calculated values or nominal performance, but on how light is experienced and performs over time in real buildings.

Across these frameworks, three recurring priorities can be identified:

- visual comfort and the avoidance of disturbance
- daylight as a primary driver for lighting design and control
- energy performance verified in actual operation rather than theoretical scenarios

Optoga's approach addresses these priorities by enabling flicker-free and stable dimming without reliance on extreme PWM frequencies, by supporting precise and robust daylight harvesting, and by providing a linear and predictable relationship between control signal, light output, and energy use. This creates smooth transitions between daylight and electric lighting and allows lighting systems to meet both experiential and regulatory expectations simultaneously.

As a result, the original lighting design intent can be maintained even in projects subject to high technical, certification, and compliance requirements.

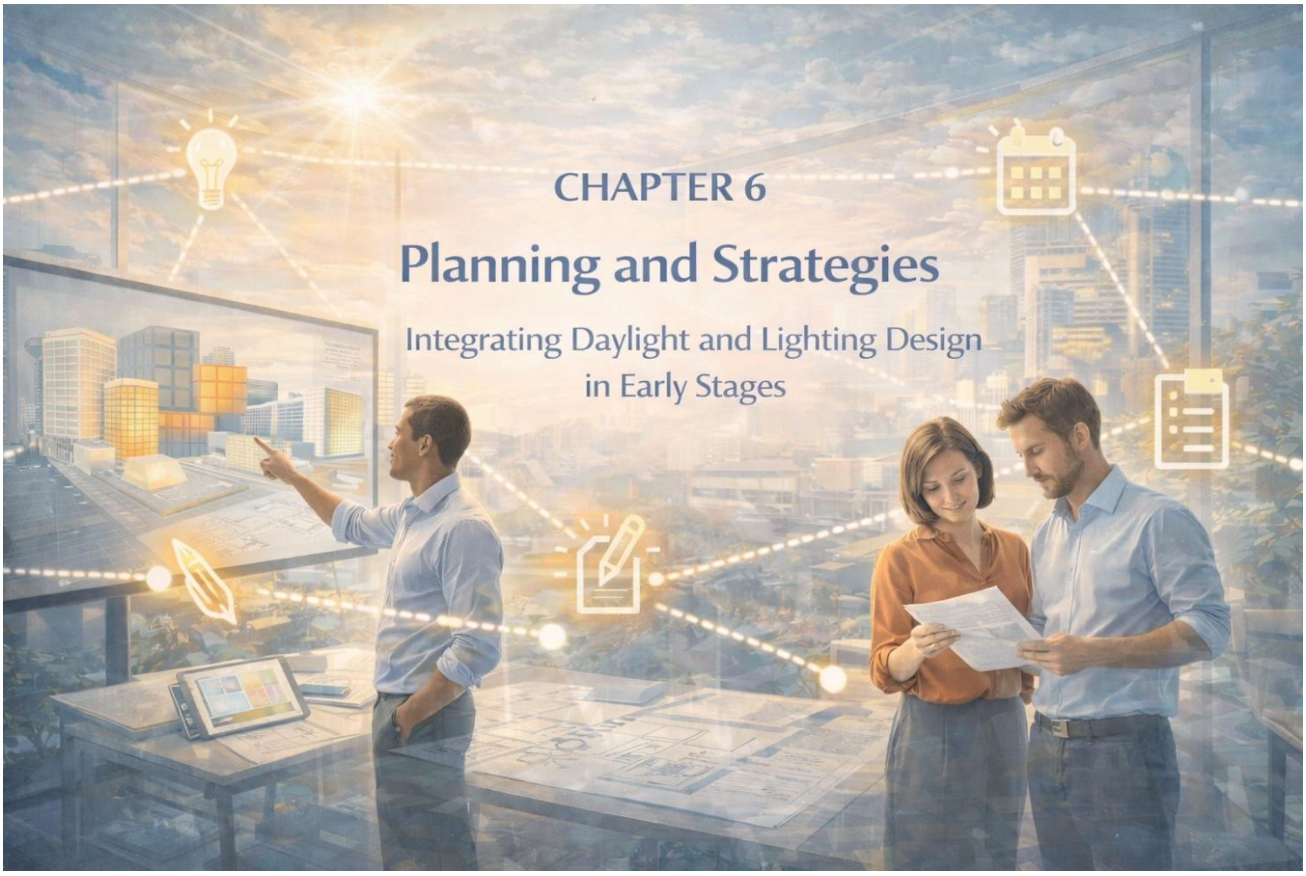
5.5 SUMMARY: FROM CONTROL SYSTEM TO LIGHT EXPERIENCE

At its core, Optoga's hybrid solution is based on a clear separation between control logic and light formation. Digital precision is applied where accuracy, communication, and responsiveness are required, while analogue regulation is used where the light itself is shaped and perceived.

This results in a lighting behaviour that can be summarised as:

- continuous and stable across the full dimming range
- predictable and consistent over time
- aligned with both spatial intention and operational reality

The outcome is light that is perceived as natural, supports architectural storytelling, and behaves in real operation as expected from simulations and design intent. Rather than forcing designers to adapt their concepts to technical constraints, this approach allows the technology to adapt to the needs of architecture and lighting design.



6. BENEFITS IN DAYLIGHT-OPTIMISED PROJECTS WHEN LIGHT FOLLOWS TIME, SPACE, AND PEOPLE

The behaviour described in this chapter is not an operational afterthought. It is a direct consequence of early planning decisions where daylight, lighting strategy, and dimming behaviour are considered together from the outset.

In daylight-optimised buildings, maximum light output is rarely the defining parameter. Instead, the quality of the lighting environment is shaped by how light evolves over time in response to daylight, occupancy, and use. Standards and calculation methods such as EN 17037, Daylight Autonomy (DA), and Useful Daylight Illuminance (UDI) are based on this understanding, treating light as a dynamic resource rather than a static condition. In such projects, the behaviour of electric lighting becomes decisive not only for energy performance, but for spatial coherence, visual comfort, and the human experience of the space.

6.1 WHEN ELECTRIC LIGHT MEETS DAYLIGHT

Daylight is inherently dynamic. Its intensity, direction, and spectral character change continuously throughout the day, influenced by weather, season, orientation, and surrounding context. For electric lighting to support rather than disrupt this dynamic condition, it must be capable of responding with equal subtlety.

Analogue dimming enables electric light to follow the rhythm of daylight by allowing light levels to change gradually and continuously, without steps, pulses, or abrupt transitions. This makes it possible for electric lighting to remain present without drawing attention to itself, particularly in the critical low-output range where daylight and artificial light overlap.

In practice, this means that electric light can:

- change smoothly in response to daylight variation
- remain stable and usable at very low output levels
- transition imperceptibly between daylight-dominated and electric-light-dominated conditions

For architects and lighting designers, this creates a lighting environment that maintains a coherent visual expression throughout the day. The result is reduced visual stress for occupants and spaces that feel calm, balanced, and consistent even when lighting is actively regulated. In this way, electric lighting becomes a natural extension of daylight rather than a competing layer.

6.2 STABILITY IN VISUALLY SENSITIVE ENVIRONMENTS

In environments where people spend long periods of time, or where light quality plays a critical role in perception, well-being, and orientation, stability becomes a fundamental requirement. Even subtle disturbances in light behaviour can affect comfort, concentration, and the overall experience of the space.

This is particularly relevant in environments such as schools and educational facilities, healthcare and care buildings, offices with activity-based workspaces, as well as cultural settings including libraries, museums, and exhibition environments. In these applications, daylight-responsive lighting systems frequently operate in the lower part of the dimming range for extended periods.

Analogue dimming ensures that, even under these conditions, the light:

- remains free from flicker and pulsing
- retains the same visual character as it is dimmed
- is perceived as equally stable at very low levels as at higher output

This level of stability is central to visual comfort and directly supports the intentions of EN 17037, where consistent and comfortable light conditions over time are considered more important than peak illumination levels.

6.3 PREDICTABILITY FOR SIMULATION, DESIGN, AND OPERATION

Calculation methods such as **Daylight Autonomy (DA)** and **Useful Daylight Illuminance (UDI)** are used to simulate how often and how effectively daylight provides sufficient illumination in a space. For these simulations to be meaningful, the electric lighting must be capable of reproducing the same behaviour in real operation.

Analogue dimming provides a linear relationship between control signal, light output, and energy use, combined with a stable response free from PWM-related deviations. This enables control systems to regulate light levels accurately in relation to daylight availability, to calculate energy savings reliably, and to avoid mismatches between sensor data and the perceived lighting condition in the space.

This predictability is particularly important in projects where daylight simulations are used as a basis for design decisions, certification, or procurement. When the behaviour of the installed lighting matches the assumptions made during simulation, the risk of deviation between expected and actual performance is significantly reduced.

For the lighting designer, this creates a direct link between simulation, specification, and reality: the light that is modelled and intended during design is also the light that is experienced when the building is commissioned and occupied.

6.4 ALIGNMENT WITH EN 17037'S VIEW OF LIGHT OVER TIME

EN 17037 emphasises that daylight should not be assessed at a single moment, but over time, with a focus on usability, comfort, and variation. This temporal perspective fundamentally changes how electric lighting is expected to perform in daylight-responsive environments.

Analogue dimming supports this approach by allowing continuous adaptation to changing daylight conditions, while maintaining a stable light experience even when artificial lighting operates at very low levels. By reducing the need for abrupt adjustments or compensatory control strategies, electric lighting can fulfil the role assumed by the standard: supporting daylight rather than replacing it.

In this way, electric lighting becomes an integrated part of the daylight concept rather than a separate technical layer.

6.5 SUMMARY - LIGHT THAT WORKS IN REAL OPERATION

In daylight-optimised projects, quality is not defined by more light, but by the right light at the right time. As daylight varies continuously, electric lighting must be able to respond in a manner that feels natural, stable, and unobtrusive rather than technical or corrective.

The value of analogue dimming lies in its ability to deliver smooth transitions, maintain stability at low output levels, and provide predictable energy performance without introducing visual disturbance. This supports a lighting environment that remains comfortable and coherent throughout the day, even as conditions change.

As a result, the lighting behaves as intended both visually and operationally, aligning simulation, design, and real-world use. This makes the approach particularly well suited to projects guided by **EN 17037**, **DA**, and **UDI**, where the behaviour of light over time is considered just as important as the quantity of light itself.

7. WHEN DAYLIGHT, TECHNOLOGY, AND PROCUREMENT MEET - WHAT MATTERS IN PRACTICE

In many modern building projects, the choice of lighting solution is no longer determined solely by light quality or theoretical system performance. Instead, it is increasingly driven by how well a solution can be verified, compared, and defended during procurement and how reliably it performs during operation.

This becomes particularly evident in projects where established suppliers compete with new market entrants, where certifications and energy frameworks form part of the procurement requirements, and where developers and property owners seek low technical risk over the building's lifetime.

In such contexts, the concept of *real performance in operation* becomes a tangible and decisive factor.
In daylight-optimised projects, many of the conditions that define lighting quality in operation are established long before the building is occupied. Decisions made during early planning stages such as window placement, spatial depth, daylight targets, and control strategies directly influence how electric lighting must perform later on.

When daylight and electric lighting are considered together from the outset, lighting strategies can be developed that support both architectural intent and operational stability. In this context, the ability of electric lighting to respond smoothly, predictably, and continuously to daylight variation becomes a prerequisite not only for good performance in use, but for reliable design decisions in the early stages of the project.

The following sections describe how these strategic choices translate into tangible benefits once the building is in operation.

7.1 WHAT PROCUREMENT BODIES ACTUALLY EVALUATE

Although procurement documents rarely specify dimming technology in detail, evaluation criteria increasingly reflect expectations related to real operational behaviour rather than isolated technical specifications.

In practice, procurement bodies often assess whether a lighting solution can deliver predictable and stable behaviour under conditions that reflect everyday use. This includes performance at low output levels, interaction with daylight control systems, and the ability to document energy use in a transparent and verifiable manner.

Particular attention is paid to situations where lighting operates continuously in response to sensors, where small deviations in behaviour may accumulate over time. In such cases, differences between control methods that appear negligible on paper can become clearly visible in operation.

As a result, procurement decisions are frequently influenced not by whether a solution can technically meet minimum requirements, but by how confidently its performance can be explained, compared, and defended after commissioning.

7.2 REAL OPERATION AS A COMPETITIVE PARAMETER

When certifications such as **BREEAM**, **LEED**, **DGNB**, **WELL**, or **Minergie** are used as part of the selection process, evaluation increasingly extends beyond compliance at handover. The focus shifts towards how lighting systems behave once the building is in use.

This includes how the system responds to changing daylight conditions over time, how reliably sensors and control algorithms operate, and how consistently energy data reflects actual lighting behaviour. In these contexts, robustness becomes a competitive parameter in its own right.

Solutions that rely on non-linear relationships, pulsed behaviour, or complex interpretation of energy data may introduce uncertainty, even if they are technically approved. Such uncertainty can be perceived as risk during procurement, particularly in projects where long-term operation, reporting, and follow-up are part of the contractual framework.

7.3 IMPLICATIONS FOR LUMINAIRE MANUFACTURERS

For luminaire manufacturers, this development represents a clear shift in focus. Rather than optimising isolated product parameters, increasing importance is placed on system behaviour over time.

From a procurement perspective, solutions are favoured that:

- are easy to document, simulate, and verify
- can be used across both standard projects and certified projects without redesign
- maintain consistent behaviour regardless of control strategy or operating conditions

This favours technical platforms where dimming remains stable even at very low output levels, where energy behaviour is linear and measurable, and where control logic is clearly separated from the light-generating function.

7.4 A COMMON LANGUAGE IN PROCUREMENT

When daylight standards, energy frameworks, and certification systems are applied in parallel, procurement increasingly functions as a point of translation between different perspectives. Architectural intent, lighting design simulations, operational requirements, and verification criteria must all be aligned within a single decision-making process.

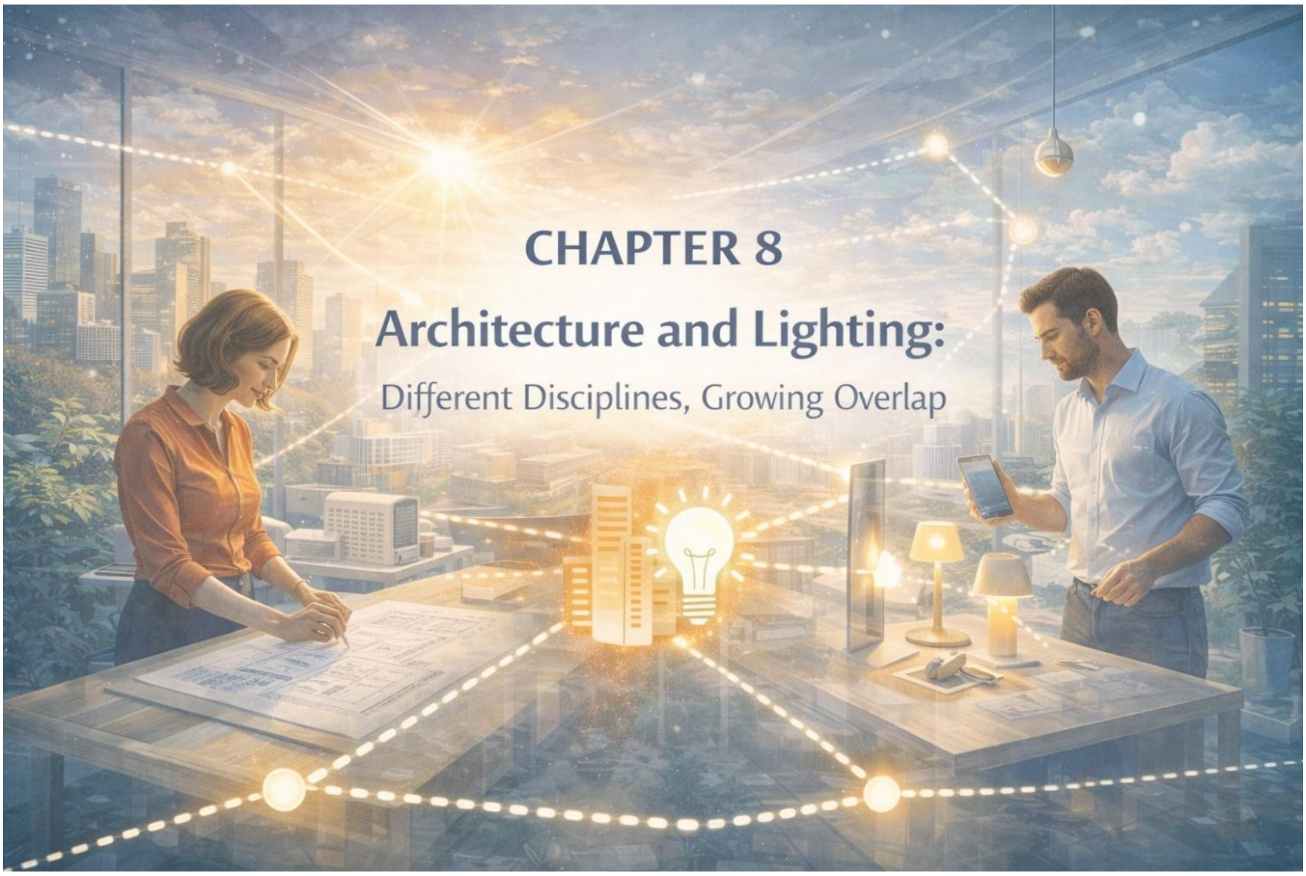
In this situation, lighting solutions that behave consistently across design, simulation, commissioning, and operation help establish a shared reference point between stakeholders. This reduces the need for project-specific explanations, assumptions, or compensatory measures later in the process.

From a procurement perspective, such consistency simplifies comparison between alternatives and strengthens confidence that the selected solution will perform as expected throughout the building's lifecycle.

7.5 CONCLUDING REFLECTION FROM A PROCUREMENT PERSPECTIVE

In today's projects, competitiveness is no longer defined solely by high efficiency figures or advanced control features. Instead, value lies in the ability to demonstrate stability over time, predictable energy performance, and a clear correspondence between design assumptions and real operation.

As a result, the behaviour of light has become a strategic procurement parameter not merely a technical detail.



CHAPTER 8

Architecture and Lighting:

Different Disciplines, Growing Overlap

8. WHEN DESIGN, OPERATION, AND DOCUMENTATION CONVERGE

In contemporary building projects, certifications and energy frameworks are no longer separate from architecture and lighting design. They influence how buildings are designed, how lighting is controlled in operation, and how performance must be verified over time.

For architects and lighting designers, this represents a clear shift:
lighting quality is no longer assessed solely by visual impression, but also by measurability, stability, and consistency in real-world use.

In this context, the behaviour of light over time rather than its maximum output becomes decisive for user experience, operational reliability, and regulatory compliance.

Historically, architecture, lighting design, and building operation have often been treated as distinct disciplines, each with its own tools, responsibilities, and evaluation criteria. Daylight was addressed primarily through architectural form, while electric lighting was developed and assessed largely as a technical system added later in the process.

Today, this separation is increasingly difficult to maintain. As standards, certifications, and energy frameworks place greater emphasis on performance over time, the boundaries between architecture, lighting design, operation, and documentation are beginning to overlap. Decisions made in one domain now have direct and measurable consequences in the others.

This growing overlap requires a shared understanding of how light behaves in real buildings not only as a design element, but as a system that must remain stable, measurable, and consistent throughout its lifecycle.

8.1 EN 17037 - DAYLIGHT AS PART OF THE SPATIAL EXPERIENCE

EN 17037 is the European daylight standard that shifts the focus from how much light a space receives to how daylight is actually experienced over time.

Rather than defining static minimum values, the standard describes daylight as a dynamic architectural element, where variation, distribution, and spatial relationship are central. It considers how daylight enters a space and changes throughout the day and year, how it contributes to visual comfort and reduces the need for artificial lighting, and how view, glare, and direct sunlight influence the perception of place.

For architects and lighting designers, EN 17037 provides a framework that supports spatial quality, narrative, and design intent rather than constraining them. It encourages daylight to be treated as an active design material, supported by artificial lighting that can adapt smoothly, precisely, and without visual disturbance.

In projects where daylight is allowed to play a leading role, EN 17037 therefore places indirect but clear requirements on electric lighting: it must dim stably and flicker-free, function reliably at very low levels, and follow the rhythm of daylight rather than compete with it.

This establishes a fundamental principle: electric light should support daylight as part of the architectural experience, not dominate it.

8.2 BREEAM - BALANCING DAYLIGHT, COMFORT, AND ENERGY PERFORMANCE

BREEAM sets requirements for flicker-free lighting and visual comfort (HEA), daylight and daylight harvesting, and documented energy performance (Ene).

In practice, this means that lighting systems must perform reliably in environments where daylight, sensors, and control systems interact continuously. Digitally controlled analogue dimming enables flicker-free regulation even at very low output levels, precise and stable interaction with daylight control, and linear energy logic that delivers reliable energy data.

For lighting designers, this allows lighting quality to be preserved even when systems are optimised for energy efficiency, without compromising the visual experience or introducing unwanted artefacts.

8.3 LEED - DAYLIGHT-DRIVEN CONTROL AND VERIFIABLE PERFORMANCE

LEED uses metrics such as Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) to assess the effectiveness of daylight and the need for artificial lighting.

For these calculations to remain meaningful, electric lighting must be capable of smooth and predictable regulation, real operational light levels must correspond to those assumed in simulations, and energy use must be trackable without systematic deviation.

Analogue dimming creates a direct link between simulation, specification, and real-world operation, strengthening the technical credibility of LEED projects. In practice, both BREEAM and LEED favour solutions that behave consistently under dynamic conditions, where daylight variation, occupancy, and energy control occur simultaneously.

8.4 DGNB - VERIFIABLE QUALITY OVER THE BUILDING LIFECYCLE

DGNB places strong emphasis on lifecycle performance, robust technical systems, and verifiable quality over time.

Unlike frameworks that primarily assess compliance at completion, DGNB focuses on how systems actually perform throughout the building's lifespan. It is not sufficient for a lighting system to function at handover - it must remain stable in everyday use, easy to monitor, and predictable even as building usage evolves.

By avoiding PWM-related variation and non-linear energy behaviour, analogue dimming enables lighting systems that are easier to document, evaluate, and defend over time.

8.5 WELL - LIGHTING AND HUMAN WELL-BEING

The WELL Building Standard focuses on how buildings affect human health and well-being. Within lighting, visual comfort, a stable light environment, and the absence of flicker are central considerations.

Analogue dimming supports these objectives by eliminating pulsed light behaviour, creating calm and consistent lighting environments, and enabling smooth adaptation to daylight without abrupt changes.

Here, the absence of visual disturbance is not a technical detail, but a prerequisite for environments that support concentration, recovery, and long-term comfort.

8.6 MINERGIE - FOCUS ON REAL OPERATION AND COMFORT

Minergie, which is well established in Switzerland and parts of Central Europe, places strong emphasis on energy-efficient operation in real use, combined with high comfort for building occupants.

For lighting, this translates into requirements for daylight-responsive control, stable and predictable dimming behaviour, correct and linear energy logic, and systems that perform equally well in everyday operation and during verification.

In Minergie projects, technical simplicity, operational reliability, and measurable outcomes are often valued more highly than theoretical optimisation, making stable light behaviour a key quality factor.

8.7 EPBD AND BACS - FROM LIGHTING TO A DATA-DRIVEN SYSTEM

EPBD requires lighting to be considered part of the building's energy system rather than an isolated installation. This entails requirements for continuous energy monitoring, data-driven control, and integration with other building automation systems (BACS).

Analogue dimming provides a linear relationship between light level and energy use, more reliable energy logs, and improved conditions for prediction and optimisation. As a result, the lighting system becomes an active and trustworthy component of the building's overall energy strategy.

8.8 NATIONAL ENERGY REGULATIONS - CONSISTENCY AND COMPLIANCE

National building codes and energy regulations differ in detail but share common objectives: energy efficiency, verifiable performance, and the ability to follow up over time.

By offering stable dimming behaviour and correct energy logic, lighting systems become easier to adapt to local requirements, more robust during inspection and verification, and less dependent on project-specific special solutions.

In this context, light behaviour becomes part of the compliance strategy rather than a technical compromise.

8.9 SUMMARY - A SHARED LANGUAGE BETWEEN DESIGN AND REGULATION

Despite differences in terminology and structure, certification schemes and energy frameworks converge on the same fundamental requirements: stable light regulation, flicker-free operation, linear and measurable energy performance, and predictable behaviour over time.

By avoiding PWM-related deviations and instead applying digitally controlled analogue dimming, lighting systems can perform consistently across multiple frameworks, support both design intent and regulatory requirements, and reduce the gap between specification and real-world operation.

In this way, light becomes a shared language between architecture, technology, and regulation rather than a point of conflict between them.

8.10 FRAMEWORKS AND CERTIFICATIONS - SCOPE AND LIGHTING IMPLICATIONS

Although the frameworks differ in scope, terminology, and legal status, they converge on the same practical expectations for lighting systems: stability, predictability, measurable performance, and compatibility with daylight-driven operation.

For lighting designers, architects, and system suppliers, this convergence highlights that compliance is less about adapting to individual standards, and more about ensuring that light behaves consistently, comfortably, and verifiably in real operation across different regulatory and certification contexts.

Framework / Standard	Geographical application in Europe	Status	Implications from a lighting perspective
EN 17037 - Daylight in buildings	Entire EU and EEA (including Norway)	Harmonised European standard	Used as a reference or requirement in design. Focuses on daylight availability, distribution, and visual comfort over time. Influences requirements for daylight-responsive control and stable, continuous dimming.
EPBD - Energy Performance of Buildings Directive	All EU member states	Legal requirement (EU directive, implemented nationally)	Requires energy-efficient lighting, measurement, control, and reporting. Drives the need for linear energy logic and data-driven lighting control.
BREEAM	Strong presence in the UK, Netherlands, Nordic countries, Central Europe	Voluntary certification	The most widely used environmental certification in Europe. Sets requirements for daylight (sDA/UDI), daylight harvesting, flicker-free operation, and energy performance.
LEED	Applied across Europe in international projects	Voluntary certification	Primarily used in international and commercial developments. Similar to BREEAM, but based on US methodologies (sDA/ASE).
DGNB	Germany, Austria, Switzerland, Central Europe	Voluntary certification	Technically detailed certification with a strong focus on lifecycle performance, user comfort, and verifiable operational quality.
WELL Building Standard	Growing adoption across Europe	Voluntary certification	Applied where health and well-being are prioritised (offices, schools, healthcare). Requires flicker-free lighting and a stable visual environment.
Minergie	Switzerland (occasionally in neighbouring regions)	National voluntary standard	Highly established in Switzerland. Focuses on real energy-efficient operation, comfort, and demand-based control, indirectly imposing high requirements on lighting regulation.
National building codes and energy regulations (BBR, DIN, SIA, TEK, etc.)	Country-specific	Legal requirement	Implement EPBD and supplement it with national requirements. May include daylight criteria, energy limits, and control requirements for lighting systems.

9. BENEFITS FOR ARCHITECTS AND LIGHTING DESIGNERS - CREATIVE FREEDOM

For architects and lighting designers, light is not a technical parameter but a design medium. It defines spatial hierarchy, supports orientation, shapes atmosphere, and influences how architecture is perceived over time. Light contributes to how a place feels in the morning, how it settles during the day, and how it transitions into evening.

As buildings have become increasingly automated and performance-driven, lighting design has often been forced to adapt to the limitations of control systems rather than the needs of space and experience. In many projects, technical constraints subtly dictate design decisions.

Digitally controlled analogue dimming reverses this relationship.
Here, technology adapts to design not the other way around.

As expectations on buildings continue to evolve, this relationship is beginning to change. Lighting is no longer evaluated only at handover, but over years of use, adaptation, and change. This requires design approaches and technical solutions that remain relevant beyond current project constraints.

A forward-looking approach to lighting design therefore focuses not only on how light looks at a given moment, but on how it behaves over time across changing daylight conditions, user needs, and operational requirements.

9.1 LIGHT THAT BEHAVES LIKE LIGHT, NOT ELECTRONICS

One of the most common challenges in contemporary projects is maintaining the natural character of light while using advanced control and automation systems. PWM-based solutions may function technically, but they can introduce subtle artefacts that disturb the spatial calm and make the presence of technology perceptible.

These effects are rarely dramatic. Instead, they appear as a sense of restlessness, slight instability, or an indefinable “technical feeling” in spaces that were otherwise carefully designed.

With analogue dimming, light changes continuously and fluidly. Its character remains consistent even at very low output levels, and dimming is perceived as a natural transition rather than a technical function. The light does not pulse, step, or break rhythm.

For the lighting designer, this restores an intuitive relationship with light. Light can once again be treated as a material within the space something shaped, refined, and composed, rather than as a signal constrained by control logic.

9.2 FULL CONTROL IN THE MOST SENSITIVE LIGHTING CONDITIONS

The quality of a lighting concept is often decided at the lower end of the dimming range. This is where atmospheres are formed, where daylight gradually takes precedence, and where the identity of the space becomes most apparent.

These moments are also where many control systems struggle.

Analogue dimming maintains stability even at 1-2% light output, without pulses, flicker, or abrupt changes. This enables designers to work confidently with subtle transitions and restrained light levels in environments such as hotels and restaurants, museums and exhibition spaces, cultural heritage settings, as well as offices and educational buildings with high comfort requirements.

Light can remain low, calm, and understated without ever feeling fragile or technically uncertain.

9.3 A CLEARER CONNECTION BETWEEN INTENTION AND REALITY

A recurring frustration in many projects is the gap between what is simulated and specified, and what is ultimately experienced once the building is in use. Even when calculations are correct, lighting behaviour in operation can diverge due to non-linear dimming, sensor interactions, or control artefacts.

Analogue dimming with linear energy logic significantly reduces this gap. Lighting behaviour becomes predictable, repeatable, and easier to model accurately. The same relationships assumed during simulation are preserved during installation and daily operation.

For architects and lighting designers, this creates confidence. The lighting concept presented to the client is not an idealised scenario, but a realistic representation of how the space will actually feel once occupied.

9.4 LIGHT OVER TIME, A DESIGN PRINCIPLE SUPPORTED BY EN 17037

A central idea in EN 17037 is that daylight should not be assessed at a single moment, but over time, with a focus on usability, comfort, and variation throughout the day and year. This perspective aligns closely with how architects and lighting designers already work with light in practice.

Rather than defining quality through static light levels, EN 17037 treats light as a dynamic element of architecture, something that changes, responds, and interacts with space and use. In this context, artificial lighting is expected to support daylight where it is insufficient, without disrupting the spatial experience.

This places implicit demands on electric lighting to behave predictably, adapt continuously, and remain visually stable even at low output levels. When artificial light can follow daylight's rhythm without introducing visual artefacts or abrupt transitions, it becomes a natural extension of the architectural concept rather than a technical overlay.

For architects and lighting designers, this reinforces a design approach where light is conceived as part of the spatial narrative over time, not as a fixed condition, but as an evolving quality that supports both function and experience.

9.5 LIGHT AS PART OF A STORY OVER TIME

Daylight is never static. It changes throughout the day, across seasons, and in response to weather and surroundings. When artificial lighting can follow this rhythm without disrupting the experience, light becomes part of a coherent spatial narrative.

Analogue dimming allows artificial light to fade in and out gently, supporting daylight rather than competing with it. Lighting scenes evolve slowly and naturally, reinforcing the sense of continuity within the space.

This enables a design approach where light supports architectural intention, strengthens the identity of a place, and enhances the user's experience over time not just at a single moment.

9.6 FEWER COMPROMISES, GREATER CREATIVE FREEDOM

When lighting design no longer needs to account for flicker concerns, unstable dimming behaviour, sensor interference, or unpredictable system responses, creative focus is freed.

Designers can concentrate on spatial quality, human perception, and experience rather than technical mitigation. Technology has become quiet enabler, supporting design decisions without demanding attention.

9.7 SUMMARY - TECHNOLOGY THAT RESPECTS THE DESIGN PROCESS

Digitally controlled analogue dimming provides architects and lighting designers with light that behaves naturally, remains stable in the most demanding conditions, and delivers consistency between concept, design, and real operation.

Most importantly, it allows light to be treated as a temporal and spatial material one that evolves over time and supports architectural storytelling.

Instead of forcing design to adapt to technical constraints, the technology respects and reinforces the original design intention.

10. FROM TECHNOLOGY CHOICE TO A FUTURE-PROOF LIGHTING STRATEGY

The way buildings are designed, certified, and operated has changed fundamentally. Daylight standards, energy frameworks, and sustainability certifications no longer treat lighting as a static technical installation, but as a dynamic system that must perform reliably over time, in real operation, and in close interaction with daylight.

With EN 17037, EPBD, BREEAM, LEED, DGNB, WELL, Minergie, and national energy regulations shaping contemporary projects, lighting is increasingly evaluated not only by what it delivers at commissioning, but by how it behaves throughout the life of the building.

In this context, it is no longer sufficient for lighting simply to be dimmable.
It must be predictable, stable, measurable, and visually comfortable, even in the most sensitive lighting situations.

In this context, lighting decisions increasingly shape a building's long-term performance rather than just its initial specification. Choices made at the level of dimming behaviour, control logic, and system architecture determine how well a building can adapt to future requirements, new regulations, and changing patterns of use.

A future-proof lighting strategy therefore prioritises predictable behaviour, long-term stability, and compatibility with evolving standards rather than short-term optimisation or isolated technical features.

10.1 A SHIFT FROM INSTALLATION PERFORMANCE TO BEHAVIOUR OVER TIME

Historically, electric lighting has been assessed primarily through static parameters: installed power, nominal efficiency, compliance at handover. Control systems were often added later, and their impact on the spatial and perceptual qualities of light was treated as a secondary concern.

In daylight-optimised buildings, this approach is no longer viable. Lighting is now expected to respond continuously to changing daylight conditions, user behaviour, and operational strategies. As a result, the value of a lighting solution is increasingly defined by its behaviour over time rather than its peak performance.

This mirrors the shift described in Chapter 9 from the designer's perspective: the quality of light is not defined in a single moment, but in how consistently it supports the space, the user, and the architectural intention throughout the day, the year, and the building's lifetime.

10.2 WHY DIMMING STRATEGY BECOMES A STRATEGIC DECISION

In many projects, dimming is still treated as a secondary technical function. However, when lighting is required to support daylight harvesting, energy monitoring, user comfort, and regulatory compliance simultaneously, the choice of dimming principle becomes a strategic decision.

Digitally controlled analogue dimming addresses this by separating control complexity from light generation. Digital systems handle communication, logic, and data, while analogue current regulation defines the actual luminous output. This results in light that behaves continuously and predictably, without revealing the technical processes behind it.

From a strategic perspective, this approach aligns the needs of multiple stakeholders:

- designers seeking spatial continuity and visual comfort
- operators requiring stable systems and reliable energy data
- regulators demanding verifiable performance in real operation

Rather than optimising for one requirement at the expense of others, the lighting system becomes a stable platform that supports all of them simultaneously.

10.3 ALIGNING DESIGN INTENT WITH REGULATORY REALITY

A recurring challenge in contemporary building projects is the gap between design intent, technical implementation, and regulatory evaluation. Architectural concepts and lighting simulations may express a clear vision, yet this vision can be compromised in operation by control artefacts, unstable dimming, or non-linear energy behaviour.

By adopting a lighting approach that behaves consistently across simulation, commissioning, and operation, this gap can be significantly reduced. When light output follows control input in a linear and predictable manner, simulated scenarios remain meaningful, energy calculations remain valid, and the realised lighting experience matches the original intention.

This creates a shared reference point between architects, lighting designers, engineers, clients, and authorities. Lighting becomes easier to specify, defend, and verify, not because it is simplified, but because its behaviour is coherent and transparent.

10.4 FROM TECHNICAL SYSTEM TO LONG-TERM LIGHTING PLATFORM

As buildings become more adaptive and data-driven, lighting increasingly forms part of a broader operational ecosystem. It interacts with building automation systems, energy management strategies, and user-centred comfort models. In this context, lighting solutions must be resilient to future changes rather than optimised solely for current requirements.

A future-proof lighting strategy therefore prioritises:

- stability under varying daylight and usage conditions
- compatibility with evolving regulatory and certification frameworks
- predictable energy behaviour that supports long-term monitoring and optimisation
- light qualities that remain relevant as architectural use evolves

This mirrors the creative freedom described in Chapter 9: when lighting technology does not impose limitations on behaviour, it allows both design and operation to evolve without fundamental reconfiguration.

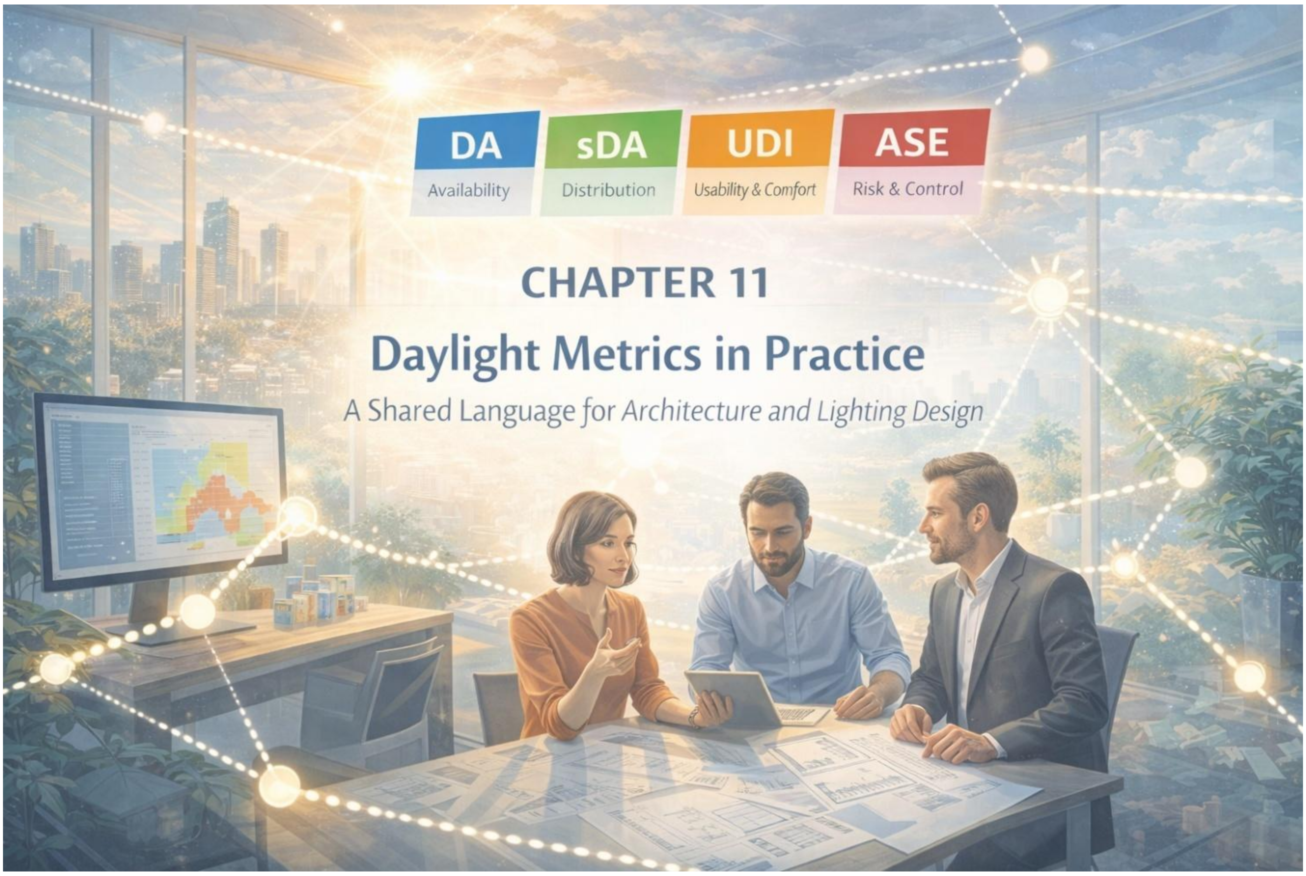
10.5 LIGHTING AS A STRATEGIC ASSET, NOT A CONSTRAINT

Ultimately, the choice of lighting technology influences more than visual output. It affects how buildings are perceived, how comfortably they are used, how efficiently they operate, and how convincingly they meet regulatory and sustainability goals.

When lighting behaves as light rather than as an electronic artefact, it supports architectural intention, enhances user experience, and reduces operational risk. In this sense, dimming strategy becomes a foundational element of the building's long-term quality.

The transition from technology choice to lighting strategy reflects a broader shift in the industry: from systems that merely function, to systems that support design, regulation, and human experience simultaneously. This is where lighting moves from being an installation to becoming an integral part of the building's identity and future readiness.

If lighting strategy is about choosing how light should behave over time, daylight metrics are the tools used to describe, test and verify that behaviour in practice.

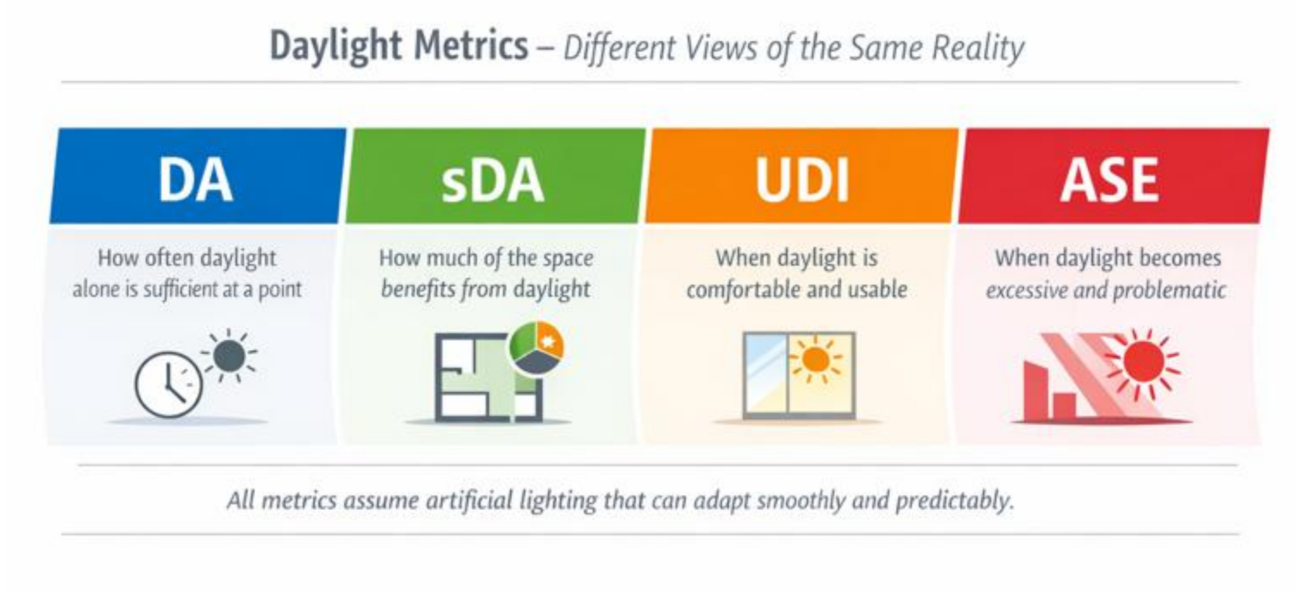


11. DAYLIGHT METRICS IN PRACTICE, A SHARED LANGUAGE FOR ARCHITECTURE AND LIGHTING DESIGN

In contemporary buildings, climate-based daylight metrics such as DA, sDA, UDI and ASE have become essential tools for understanding how daylight performs over time. Rather than describing a static condition, these metrics capture the dynamic relationship between daylight, space and use. For architects, lighting designers and building owners, they are not ends in themselves, but a shared framework for making informed design and operational decisions.

Used correctly, daylight metrics help translate architectural intentions into measurable performance. They support spaces that feel visually balanced, operate efficiently, and remain robust throughout the building's lifecycle. In this sense, they form a common language between design disciplines, technical consultants and building operators.

What all daylight metrics have in common is a fundamental assumption: daylight should be the primary light source whenever possible, and artificial lighting should act as a responsive complement rather than a competing system. This assumption places clear demands on electric lighting. It must be capable of adapting continuously, remaining stable at low output levels, and supporting the spatial and perceptual qualities established by daylight.



Each metric approaches the same underlying question from a slightly different perspective:

When, where and how often is daylight sufficient and when does electric light need to take over?

The differences between DA, sDA, UDI and ASE lie not in conflicting objectives, but in how reality is simplified and which aspects of daylight performance are prioritised. Some metrics focus on availability, others on usability or risk. Together, they provide a nuanced understanding of daylight that allows lighting design to move beyond static compliance and towards spaces that perform well both visually and operationally over time.

In contemporary buildings, climate-based daylight metrics such as DA, sDA, UDI and ASE have become essential tools for understanding how daylight performs over time. Rather than describing a static condition, these metrics capture the dynamic relationship between daylight, space, and use.

For architects, lighting designers, and building owners, they are not goals in themselves. Instead, they form a shared framework for translating architectural intention into measurable performance and long-term operational quality.

11.1 DA AND SDA - WHEN AND WHERE DAYLIGHT IS SUFFICIENT

Daylight Autonomy (DA) describes how often daylight alone provides sufficient illumination at a specific point in a room. **Spatial Daylight Autonomy (sDA)** extends this concept by indicating how large a portion of the room meets a daylight requirement for a defined share of time.

From an architectural perspective, these metrics support decisions related to window placement, room depth and spatial organisation. For lighting designers, DA and sDA provide guidance on how frequently artificial lighting is required and how low baseline light levels can be set. For building owners, high DA and sDA values indicate reduced reliance on electric lighting and long-term potential for lower energy consumption.

However, this potential can only be realised if the lighting system is capable of stable and predictable dimming in the lower output range, where daylight dominates. This is where analogue dimming becomes critical: light levels can be reduced to very low outputs without flicker or instability, allowing daylight to take precedence without compromising visual comfort.

In practical terms, DA answers the question *"How often is daylight sufficient at this point?"*, while sDA answers *"How much of the space benefits from sufficient daylight?"* Both rely on climate-based simulations that consider sun position, weather data and a defined illuminance threshold.

What does Daylight Autonomy (DA) measure? *How often is daylight sufficient?*	What does Spatial Daylight Autonomy (sDA) measure? *How much of the space receives sufficient daylight?*
Daylight Autonomy (DA) indicates the percentage of time (for example, occupied working hours over a year) during which daylight at a specific point in a room exceeds a defined illuminance threshold. **Example:** • DA300 = 55% → Daylight provides at least 300 lux during 55% of the time. **How is DA calculated?** DA is based on climate-based daylight simulations that take into account: • local climate data (sunlight and cloud cover) • the sun's position throughout the year • a selected reference point within the room • a fixed illuminance threshold (e.g. 300 lux) **When is DA used?** DA is commonly applied in: • early-stage daylight studies • EN 17037, as a fundamental daylight principle • comparisons between different rooms or design options	**Spatial Daylight Autonomy (sDA)** is an extension of Daylight Autonomy (DA) and measures the percentage of a room's floor area that meets a specified daylight criterion for a defined portion of the occupied time. **Example (commonly used in LEED):** • sDA300/50% = 60% → 60% of the space receives at least 300 lux for at least 50% of the occupied time. **How is sDA calculated?** sDA is based on the same climate-based daylight simulation methodology as DA, but: • the calculation is performed across many points distributed throughout the space • the result is expressed as an area-based metric rather than a single point value **When is sDA used?** sDA is commonly applied in: • LEED certification • BREEAM daylight credits • offices, schools, and large open-plan spaces

11.2 UDI - WHEN DAYLIGHT IS ACTUALLY USEFUL

While DA and sDA focus on sufficiency, **Useful Daylight Illuminance (UDI)** addresses usability. UDI evaluates when daylight levels are perceived as comfortable and beneficial, rather than merely adequate.

By distinguishing between too little, useful and excessive daylight, UDI reflects how spaces are actually experienced by users. For architects and lighting designers, this supports a focus on spatial quality and visual comfort. For building owners, it reduces the risk of occupants drawing blinds and switching on lights unnecessarily, which often leads to higher energy use and less predictable operation.

Because analogue dimming enables smooth transitions between daylight and artificial light, electric lighting can complement daylight without disrupting the overall balance of the space. This makes UDI particularly relevant in comfort-oriented projects, where user behaviour and long-term satisfaction are as important as calculated performance.

What does Useful Daylight Illuminance (UDI) measure?

When is daylight actually useful?

Useful Daylight Illuminance (UDI) evaluates when daylight levels are perceived as comfortable and usable, rather than simply sufficient. It divides daylight illuminance into three ranges:

Illuminance level	Interpretation
< 100 lux	Too little light
100-2000 lux	Useful daylight
> 2000 lux	Too much light (risk of glare and excessive solar exposure)

UDI indicates the percentage of time during which daylight levels fall within the useful range.

When is UDI used?

UDI is increasingly applied in:

- BREEAM assessments
- comfort-oriented building projects
- architectural and lighting design analysis

11.3 ASE - WHEN DAYLIGHT BECOMES A PROBLEM

Annual Sunlight Exposure (ASE) identifies the risk of excessive direct sunlight, which can lead to glare, overheating and visual discomfort. High ASE values often trigger compensatory measures such as permanently lowered blinds or increased artificial lighting, undermining both daylight strategies and energy performance.

From the perspective of all stakeholders, excessive ASE typically results in poorer visual comfort, higher energy use and reduced architectural quality. By combining thoughtful daylight design with artificial lighting that can be regulated continuously and without technical artefacts, the need for such compensations can be significantly reduced.

ASE is therefore not a measure to maximise, but a constraint to manage, particularly in buildings with large glazed façades or strong solar exposure.

What does Annual Sunlight Exposure (ASE) measure?

When does daylight become a problem?

Annual Sunlight Exposure (ASE) indicates the percentage of a space that is exposed to excessive direct sunlight, which may lead to glare, overheating, and visual discomfort.

Example (as used in LEED):

- ASE1000/250h ≤ 10%
  → No more than 10% of the floor area receives over 1000 lux of direct sunlight for more than 250 hours per year.

What is ASE used for?

ASE is used to identify the risk of:

- glare
- excessive solar heat gain
- frequent use of lowered blinds or shading devices
- degradation of the overall daylight strategy

When is ASE applied?

ASE is typically required in:

- LEED certification (mandatory in combination with sDA)
- projects with large glazed façades
- buildings located in highly sun-exposed environments

11.4 A PREREQUISITE FOR SIMULATIONS TO MATCH REALITY

DA, sDA, UDI and ASE are primarily used during early design stages to inform decisions. For these decisions to remain valid over time, the lighting system in operation must behave in line with the assumptions made during simulation.

Digitally controlled analogue dimming provides a linear relationship between control signal, light output and energy use, combined with stable behaviour even at very low levels. This ensures that sensor feedback remains reliable and that simulated scenarios translate into real-world performance.

As a result, architectural intentions are preserved, lighting scenarios function as designed, and building owners gain a system that is robust, energy-efficient and straightforward to monitor.

11.5 RELATION TO EN 17037 AND FUTURE REQUIREMENTS

EN 17037 emphasises daylight usability, variation and experience over time. In this context, DA, sDA, UDI and ASE can be seen as practical tools for implementing the standard's intent provided that artificial lighting is capable of adapting with the same continuity as daylight itself.

Analogue dimming is specifically suited to this role, enabling electric light to support daylight rather than replace it. This alignment becomes increasingly important as future standards and regulations continue to prioritise real-world performance over static compliance.

11.6 HOW THE METRICS WORK TOGETHER

Each daylight metric answers a specific question:

- DA: How often is daylight sufficient?
- sDA: How much of the space benefits from daylight?
- UDI: When is daylight actually comfortable and useful?
- ASE: When does daylight become excessive?

No single metric is sufficient on its own. Together, they form a framework for understanding daylight performance, not as an abstract target but as a basis for informed design decisions.

11.7 CONCLUDING REFLECTION - BETTER LIGHT OVER TIME

Lighting that truly cooperates with daylight must be able to change smoothly, remain stable in subtle conditions, and behave predictably in complex environments. Digitally controlled analogue dimming addresses these requirements by allowing technology to follow the nature of light, rather than imposing technical artefacts upon it.

This is not a promise of more light. It is a promise of better light over time.

Light that supports daylight, respects human perception, and behaves consistently across design, simulation, and real operation. In this way, daylight metrics become more than calculations they become tools for creating buildings that perform well, feel right, and remain relevant throughout their lifecycle.
The behaviour described in this chapter is not an operational afterthought. It is a direct consequence of early planning decisions where daylight, lighting strategy, and dimming behaviour are considered together from the outset.