DELTA
LIGHTING SOLUTIONS

A Delta Group Company

GUIDEBOOK ON APPLICATIONS, DESIGN AND IMPLEMENTATION OF DELTA LIGHTING CONTROLS

Delta Controls Inc. Canada

17850 - 56 Ave, Surrey, BC V3S-1C7
Phone: 604.574.9444
deltacontrols.com

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A Delta Group Company

Delta Controls is the benchmark for controls manufacturers, being one of the most respected organizations in our industry. We pride ourselves on our integrity, reliability, innovation and track record of our products and partners. At the root of our success is our people who use technology to create products that are simple, yet powerful enough to last, and we never compromise on quality. We care for the world around us, and we are proud to be a part of the integration upon which infrastructures and businesses are built.

17850 56th Avenue
Surrey BC Canada V3S 1C7
Phone: 604.575.9444

E-mail:
dbelkowska@deltacontrols.com

deltacontrols.com

1. A HUMAN-CENTRIC APPROACH TO LIGHTING

A HUMAN-CENTRIC APPROACH TO LIGHTING

In North America and Europe, people now spend close to 90 percent of their time indoors. This has led to a growing focus on healthy buildings, with lighting playing a key role. Lighting has long been an essential part of making buildings more energy efficient, but designers are increasingly recognizing its importance in promoting occupant health, well-being, and productivity.

This human-centric approach to lighting has grown out of recent research into the non-visual effects of light on the human body, which has shown that light conditions in the built environment can significantly influence biological rhythms, emotional health, and cognitive performance.

To realize the beneficial effects of light, indoor lighting must be dynamic and tunable, with lighting controls adjusting exposures and color characteristics throughout the day. Advances in LED technology and lighting controls are now making this possible.

HOW LIGHT AFFECTS THE HUMAN BODY

Our body's biological clock, located in the brain, regulates our daily circadian rhythms: when we sleep and wake, when we feel alert, when we feel drowsy, and so on.

In the absence of external time cues, our circadian rhythms repeat approximately every 24.2 hours. Daily light/dark patterns on the retina—the amount of light that reaches the back of our eyes—synchronize (or "entrain") our circadian rhythms to the 24-hour solar day. When local light/dark patterns and our biological clock are out of alignment, circadian disruption occurs, which can lead to poor sleep and performance. If you've ever experienced jet lag or worked night shifts, you know how this feels. Circadian disruption has also been associated with increased risk of diabetes, obesity, cardiovascular disease, and cancer.

Morning light resets our biological clocks. Daylight is the ideal light source for circadian entrainment, as it provides the right amount, spectrum, duration, and timing of light to the eye. Lighting characteristics affecting the circadian system differ from those affecting vision. Compared to the visual system, the circadian system requires more light to be activated; is most sensitive to short-wavelength (blue) light; and needs a longer duration of light exposure (several minutes rather than a few milliseconds). The timing of the light exposure is also important. Light applied before the minimum core body temperature is reached (approximately 1.5–2.5 hours before one naturally awakens) delays the biological clock, while light applied after the minimum core body temperature is reached advances it.

Without access to daylight, or to LED lighting providing comparable characteristics, health and well-being may be compromised. Exposure to natural-quality light, on the other hand, can elevate moods, improve cognitive functions, and increase overall health.

TUNABLE WHITE LIGHTING

Advances in LED technology have transformed the lighting landscape in recent years. In commercial buildings, LED-based lighting has begun replacing fluorescent lighting as the light source of choice due to its efficiency, durability, and controllability. As solid-state devices, LED lamps are more efficient in converting

electricity to light than other types of lighting and have extremely long lifetimes. In addition to being energy-efficient and cost-effective, LED lighting now offers the additional benefit of improving health and well-being.

Until tunable LED lighting became available, electric lighting was unable to create natural light conditions indoors. Traditional incandescent and fluorescent lighting at the standard indoor light levels of 50–500 lux could only operate on the visual system. It allowed us to see where we were going and what we were doing, but it could not reproduce the effects of daylight on the non-visual system. Tunable white lighting, on the other hand, can entrain our circadian rhythms by automatically changing the intensity and color temperature of the light throughout the day, mimicking the dynamic characteristics of daylight from sunrise to sunset.

Color temperatures are typically described using correlated color temperature (CCT) values. Expressed in degrees Kelvin (K), CCT is a measure of the “warmth” or “coolness” of the white light emitted by an electric light source. Most commercially available light sources have a CCT between 2700 K and 6500 K. Lamps with lower CCT values (2700 K to 3000 K) provide light that appears yellowish or warm, while lamps with higher CCT values (4000 K to 6500 K) provide light that appears bluish or cool.

Cool-toned light emitting from a tunable white lighting system, especially at high intensity, suppresses the hormone melatonin (which prepares the body for sleep), stimulates alertness, and improves cognitive function. Warm-toned light, on the other hand, encourages melatonin secretion and helps us relax. Exposure to amber light before bed can help us get a good night's sleep. By adjusting the coolness or warmth of the white light, a space can also appear to be cooler in hotter climates and warmer in colder climates.

HEALTHCARE APPLICATIONS

At present, most lighting in hospitals, rehab facilities, assisted living facilities, and nursing homes is designed only for illumination. But that is starting to change. For example, the calming and alerting effects of tunable white light are starting to be used to treat dementia and to reduce aggressive behavior.

Healthcare facilities where tunable white lighting has been installed have reported a number of positive outcomes, including:

- a sharp reduction in dementia behaviors
- significantly fewer patient falls, especially among those who are elderly
- better circadian alignment of the internal biological clock rhythm
- improved sleep and overall health
- more calmness
- less need for psychotropic and sleep medication

Tunable lighting systems can be beneficial in any space where patients, visitors, or caregivers spend large amounts of time, but special consideration should be given to patient rooms, hallways, neonatal intensive care units (NICU), and post-acute care units (PACU).

While most patient rooms in hospitals and long-term care facilities have windows, beds are sometimes not close enough to the windows to receive the full circadian effect of daylight. Hallways typically get even less natural light, despite being a high foot-traffic area for patients. Tunable lighting systems can also help premature newborns in NICUs and PACUs set their internal clocks and increase their recovery times.

Other areas that can benefit from tunable white lighting include lobbies, cafés, emergency departments, and visitor lounges.

OFFICE APPLICATIONS

According to the U.S. Environmental Protection Agency, Americans spend, on average, approximately 90 percent of their time indoors. Much of that time is spent at work, reportedly in discomfort. A survey by the American Society of Interior Design found that 68 percent of employees complained of the lighting situation in their office. The Mayo Clinic lists glare and bright light as the leading cause of eyestrain, and the National Headache Foundation lists fluorescent lighting as a primary trigger for migraine headaches.

Color temperatures, and their effect on our internal sleep/wake cycle, have a huge impact on how we do our jobs—in how we feel physically and emotionally, how we think, and how we react to situations. Having the right temperature of light, in the right office space, at the right time of day, has proven effective in helping occupants improve their concentration and cognitive functions; elevate their moods; increase their overall health; and reduce disruptions to their circadian rhythms, helping them to feel more refreshed the next day.

A more confrontational meeting, such as a contract negotiation, on the other hand, might work better with a "calm" preset with a low CCT (2700 K) and low illuminance (200–300 lx).

The commercial real estate firm JLL developed a famous formula to quantify the value of productivity improvements called the 3/30/300 rule. Actual figures vary depending on various factors (such as location), but in general, according to this rule, organizational expenses per square foot, per year break down as follows:

- $3 for utilities
- $30 for rent/mortgage
- $300 for payroll

According to the U.S. Energy Information Administration, the average commercial building is a little over 15,000 square feet. Using the 3/30/300 proportions, annual spending for a business in an average building should break down to approximately $45,000 on utilities, $450,000 on rent, and $4.5 million on employees. Reducing utility costs by 50 percent would save a company $22,500 annually. Improving space utilization by 10 percent would save $45,000. And increasing employee productivity by 5 percent would save a staggering $225,000. This formula illustrates how even a small change in the employee category can have a major impact on a company's bottom line.

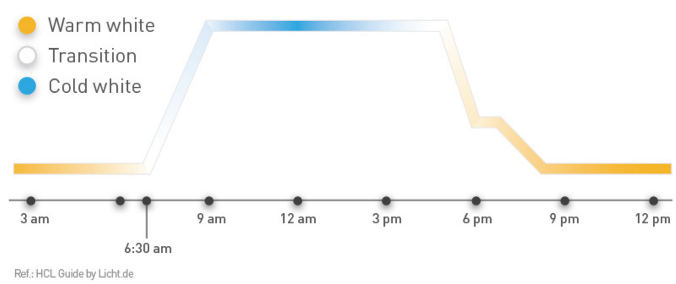
Studies have shown that poor office lighting can contribute to inadequate sleep, drowsiness, fatigue, stress, anxiety, and even to seasonal affective disorder, a type of depression. Providing optimal lighting, on the other hand, promotes the health, happiness, comfort, and productivity of employees. The 3/30/300 rule shows why everything in the office environment should contribute towards the goal of employee productivity, lighting included.

HOW TO LIGHT OFFICES TO INCREASE PRODUCTIVITY

To maximize productivity, you will need to consider such variables as brightness (illuminance), color temperature, time of day, and location in your lighting setup. In most office settings, a schedule that mirrors the activity of the sun will work best. For example, you will want to schedule light that stimulates wakefulness and alertness early in the workday but not at the end of the workday. A general tunable white lighting schedule for a normal work in an office open from 9 a.m. to 5 p.m. might look something like the example below:

Time of day	CCT	Illuminance (lux)
9 a.m. – 11 a.m.	5500–6500 K (cool white)	500–1000 lx
11 a.m. – 1 p.m.	3000–4000 K (warm white)	250–700 lx
1 p.m. – 2 p.m.	5500–6500 K (cool white)	500–800 lx
2 p.m. – 5 p.m.	3000–4000 K (warm white)	250–500 lx

A dynamic lighting scenario for human-centric lighting for daytime use space might therefore look like the following:



Changes in light settings should be smooth. Start the general office lighting with cool light in the morning and warm up gradually toward lunchtime to maximize morning productivity. After lunch, reset the cycle with a blast of blue light to fight the mid-afternoon slump. Then warm up again gradually toward the end of the day to prepare employees for sleeping at night. Spaces that aren't used for work, such as bathrooms or break rooms, can be kept at a CCT below 3000 K.

A good way to manage controls for offices is to leverage presets in different rooms and areas. With presets, users can choose from a range of color temperatures and intensities for different purposes to temporarily override the system. For example, a brainstorming meeting might work better under a "focus" preset with a high CCT (6500 K) and high illuminance (500–1000 lx). better with a "calm" preset with a low CCT (2700 K) and low illuminance (200–300 lx).

It's also a good practice to put dimmers on the fixtures. If dimmers cannot be installed on all lights, they should at least be considered for individual task lighting. Current controls make LEDs more flexible and versatile than any other light source. By changing nothing in a space or room other than the light using a simple control, the occupant can change the visual environment for different activities: focused workspace in the morning, relaxed lunch time with a team, intensive meeting, or training in the afternoon.

Even a slight increase in employee satisfaction and productivity due to better office lighting can have a huge impact on a company's returns, often bringing higher profits than other popular savings measures. A few years ago, the real estate company CBRE installed time-controlled, circadian-friendly lighting in its offices in Amsterdam. High illuminance levels and cool, indirect white light were used in the morning and early afternoon hours, and lower light levels and warmer white light were used at midday and in the late afternoon hours. Employees were then surveyed over a 7-month period via questionnaires and interviews. The results showed that:

- productivity increased 18%
- work accuracy improved 12%
- 76% of employees felt happier
- 71% of employees felt they had more energy
- 50% of employees felt healthier

This example underscores how recent advances in LED technologies and controls are making it easier than ever to design workspaces that produce happier, healthier, and more productive employees.

Further Reading: More on the topic in UL standard "Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People" https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=36592.

Sources: Amerlux Blog, Amerlux Webinars eLUMENNATION, LEDs Magazine, Rensselaer Polytechnic Institute's Lighting Research Center, Lux Review Magazine, Buildings Smarter Facility Management Magazine.

Do it **right.**

2. STANDARDS AND REGULATIONS


EXIT

STANDARDS AND REGULATIONS

Several national and international standards pertain to indoor lighting, covering such things as fixtures, lighting quality, energy efficiency, and communication technology. These standards incorporate guidelines and requirements for both new construction and major renovation projects. This chapter discusses standards and regulations relating to energy and green building initiatives that directly affect lighting controls applications.

DESIGN RECOMMENDATIONS

When designing a new building, you can specify lighting, HVAC, and other systems as standalone control systems, or you can specify a single whole-building solution that offers seamless interoperability. The benefits of the latter approach are clear. Integrating lighting controls and daylight harvesting with a building automation system (BAS) allows for comprehensive data and hardware sharing, which produces cost efficiencies otherwise not reachable by decentralized standalone systems. In addition to providing significant energy savings, integrated controls also make the building more responsive to occupants.

RECOMMENDED LIGHT LEVELS BY IES

Responsible body: The Illuminating Engineering Society (IES), formerly the Illuminating Engineering Society of North America (IESNA), is an industry-backed, not-for-profit, learned society that was founded in New York City on January 10, 1906. The IES's stated mission is "to improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefit the public." The IES is credited with over 100 publications, approved by an American National Standards Institute (ANSI), in The Lighting Library (TLL).

The following titles from The Lighting Library provide lighting guidance for specific commercial verticals:

- RP-1-20 Recommended Practice: Lighting Office Spaces
- RP-2-20 Recommended Practice: Lighting Retail Spaces
- RP-3-20 Recommended Practice: Lighting Educational Facilities
- RP-9-20 Recommended Practice: Lighting Hospitality Spaces
- RP-29-20 Recommended Practice: Lighting Hospital and Healthcare Facilities

PB-324-08 Lighting Controls Handbook with practical description of major lighting controls types and how to apply them for achieving relevant energy savings, as well as supporting occupant visual needs and preferences

All these publications are gathered in the ANSI/IES TLL Standard. Other publications, like ASHRAE standards, include recommended practices for a variety of specific lighting applications, such as office, sports, healthcare, and outdoor lighting. The National Institute of Standards and Technology (NIST) references several IES publications for Optical Radiation Calibrations.

The following tables provide recommended light levels from the ANSI/IES TLL Standard. The required light levels are indicated in a range because different tasks, even in the same space, require different amounts of light. In general, low contrast and more detailed tasks require more light, while high contrast and less detailed tasks require less light. Illuminance levels must not fall below the maintenance values in the visual task area. If the precise location is not known, the limit should be applied to the whole room or a specific working area.

The first table also lists Lighting Power Density (LPD) levels from the IECC 2021 (using the Space-By-Space Method for calculations). The LPD represents the amount of power used by lighting per unit of building area, taking into account all power consumed by light fixtures, ballasts, controls, transformers, and so on. The U.S. General Services Administration provides lighting levels and LPDs for U.S. government buildings, which can be used as a guide for other types of buildings. LPD levels should continue to drop with subsequent codes and as LED lighting becomes more energy efficient.

Recommended lighting levels by room type:

Room Type	Light Level (Foot Candles)	Light Level (LUX)	IECC 2021 Lighting Power Density (Watts Per SF)
Cafeteria - Eating	20 - 30 FC	200 - 300 lux	0.40
Classroom - General	30 - 50 FC	300 - 500 lux	0.71
Conference - Room	30 - 50 FC	300 - 500 lux	0.97
Corridor - General	5 - 10 FC	50 - 100 lux	0.41
Corridor - Hospital	5 - 10 FC	50 - 100 lux	0.71
Dormitory - Living Quarters	20 - 30 FC	200 - 300 lux	0.50
Exhibit Space (Museum	30 - 50 FC	300 - 500 lux	0.31
Gymnasium - Exercise / Workout	20 - 30 FC	200 - 300 lux	0.90
Gymnasium - Sports / Games	30 - 50 FC	300 - 500 lux	0.85
Kitchen / Food Prep	30 - 75 FC	300 - 500 lux	1.09
Laboratory (Classroom)	50 - 75 FC	500 - 750 lux	1.11
Laboratory (Professional)	75 - 120 FC	750 - 1200 lux	1.33
Library - Stacks	20 - 50 FC	200 - 500 lux	1.18
Library - Reading / Studying	30 - 50 FC	300 - 500 lux	0.96
Loading Dock	10 - 30 FC	100 - 300 lux	0.88
Lobby - Office / General	20 - 30 FC	200 - 300 lux	0.84
Locker room	10 - 30 FC	100 - 300 lux	0.52
Lounge / Break room	10 - 30 FC	100 - 300 lux	0.59
Mechanical / Electrical room	20 - 50 FC	200 - 500 lux	0.43
Office - Open	30 - 50 FC	300 - 500 lux	0.61
Office - Private / Closed	30 - 50 FC	300 - 500 lux	0.74
Parking - Interior	5 -10 FC	50 - 100 lux	0.15
Restroom / Toilet	10 -30 FC	100 - 300 lux	0.63
Retail Sales	10 - 30 FC	200 - 500 lux	1.05
Stairway	5 -10 FC	50 - 100 lux	0.49
Storage Room - General	5 - 20 FC	50 - 200 lux	0.38
Workshop	30 - 75 FC	300 - 750 lux	1.26

Recommended lighting levels by occupants' activity:

Activity	Illumination (lux, Lumen/m²)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, homes, theatres, archives	150
Easy office work, classes	250
Normal office work, pc work, study library, groceries, show rooms, laboratories	500
Supermarkets, mechanical workshops, office landscapes	750
Normal drawing work, detailed mechanical workshops, operation theatres	1000
Detailed drawing work, very detailed mechanical works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

These tables do not fully represent every environment, and specific needs may require further research. Also, be sure to check local codes for additional requirements.

Further reading: https://store.ies.org/?product_cat=&s=lighting&post_type=product.

ENERGY STANDARDS

Control of the lighting system is one of the most significant ways to reduce global energy consumption. In the U.S., commercial and residential lighting accounts for as much as 22% of all energy generated. To promote ongoing reductions in electrical energy use, local, state, and federal energy codes are becoming increasingly restrictive. Savings can be achieved by using automatic shutoff control in unoccupied spaces, multilevel dimming, and daylight harvesting. Lighting controls need to be based on control sequences that encompass the whole system and environment, taking into account the character of the space and how it is used. For example, does the building have an open or private office plan? Does it have skylights or large windows? How are the reception areas, corridors, stairwells, meeting rooms, and lobby areas lit?

INTERNATIONAL DOCUMENTS

ASHRAE 90.1 Standard

Responsible body: American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Founded in 1894, ASHRAE is a global professional association committed to advance heating, ventilation, air conditioning and refrigeration (HVAC&R) systems design and construction.

The American National Standards Institute (ANSI), American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), and the Illuminating Engineering Society (IES) jointly sponsor the ANSI/ASHRAE/IES 90.1-2019 Energy Standard for Buildings Except Low-Rise Residential Buildings. Designed to reduce energy consumption, this standard provides minimum energy-efficient requirements for design and construction of new or existing buildings and their systems, as well as criteria for determining compliance. The standard requires the use of advanced lighting controls to synchronize light levels with daylight, occupancy, and multilevel control capability. The standard covers interior building spaces, exterior lighting powered through building electrical service, and interior space lighting alterations where 20% or more of the connected lighting is altered. It does not cover emergency lighting off during normal operation, lighting within dwelling units, lighting required by health or life safety, and gas lighting.

ASHRAE/ANSI/IES 90.1-2019 has strict rules on interior lighting power allowances and ties commissioning activities to a series of building commissioning activities. It also attempts to simplify compliance for certain building types. While it may be some time before the standard is adopted, it is a good idea to begin familiarizing yourself with its requirements.

The following table is for informational purposes only and shows multiple options for meeting the lighting and receptacle control requirements. For specific requirements, refer to ASHRAE 90.1–2019.

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
On-Off Control													
Local Control (Switch, Dimmer, Scene Control)	9.4.1.1 (a)	One or more readily accessible manual lighting controls in the space that controls all lighting in the space (can see lighting controlled from local device). If the space is 10,000 sq. ft. or smaller, the smallest control area must be equal to or smaller than 2,500 sq. ft. If the space is bigger than 10,000 sq. ft., the smallest control area must be equal to or smaller than 10,000 sq. ft.	Remote control device is permitted for reasons of safety or security provided it has a status pilot light and is labeled to identify the controlled lights.	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Continued:

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
On-Off Control													
Manual On or Partial Auto On	9.4.1.1 (b) 9.4.1.1 (c)	Lighting shall be either manual or auto on to maximum of 50% of the general lighting.	Where full auto on is permitted, manual on or partial auto on is not required. Where manual on would endanger safety or security, only full auto on is permitted.	✓	✓	✓	✓			✓		✓	
Full Auto On	9.4.1.1	Automatic-ally controlled spaces are allowed to turn on to full: corridors, stairwells, restrooms, lobbies, electrical/ mechanical rooms, storage rooms <50 sq. ft., healthcare facilities	Where full auto on is permitted, manual on or partial auto on is not required. Where manual on would endanger safety or security, only full auto on is permitted.					✓	✓		✓		

Continued:

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
On-Off Control													
Auto Partial Off (via Occu-pancy Sensor or Time-clock)	9.4.1.1 (g)	General lighting power shall be automatically reduced by a least 50% within 20 minutes of all occupants leaving the space. Auto full off also complies. This type of control is required for the following spaces: corridors (not manufacturing), classroom labs, lobbies, stairwells, library stacks, warehouses, storage rooms > 1,000 sq. ft.	The following conditions must be met: LPD no more than 0.8 W per sq. ft. Spaces lit by HID lamps Light power reduced by ≥ 30% within 20 minutes after leaving					✓	✓			✓	

Continued:

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
On-Off Control													
Auto Partial Off (via Occupancy Sensor or Time-clock)	9.4.1.1 (g)	All lighting shall be automatically shut off within 20 minutes of all occupants leaving the space. Control device shall control an area no larger than 5,000 sq. ft. This type of control is required for the following spaces: classrooms, training rooms, lounge/break rooms, locker rooms, lecture halls, fitting/dressing rooms, restrooms, conference/meeting rooms, copy/print rooms, offices ≤ 250 sq. ft., multipurpose rooms, storage rooms ≥ 50 to ≤ 1,000 sq. ft.	The following conditions must be met: • LPD no more than 0.8 W per sq. ft. • Spaces lit by HID lamps • Light power reduced by ≥ 30% within 20 minutes after leaving					✓	✓			✓	

Continued:

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
On-Off Control													
Scheduled Shut-off and Off During Non-Business Hours	9.4.1.1 (i) 9.4.1.1 (j)	All lighting shall be automatically shut off during periods when the space is scheduled to be unoccupied using a time-of-day operated control. A signal from another automatic control device or alarm/security system complies. Required for spaces not already controlled by auto full off (9.4.1.1(h)). Control area ≤ 25,000 sq. ft. but not more than one floor Override ≤ 2 hours and area ≤ 5,000 sq. ft.	Lighting for patient care where auto off would endanger safety or security Lighting for 24/7 operation	✓			✓	✓	✓	✓		✓	✓

Continued:

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
Light Level Control													
Bi-Level Lighting Control	9.4.1.1 (d)	Besides on and off, lighting is either continuously dimmed or controlled with at least one step between 30% and 70% of full lighting power (bi-level switching).	Atriums < 20 ft ht, loading docks, corridors, restrooms, electrical/ mechanical rooms, lobbies, storerooms	✓	✓			✓	✓			✓	
Bi-Level Lighting Control	9.4.1.1 (d)	If the general lighting load is 150 W or greater in the primary Side-lighted or top-lighted areas, or 300 W or greater in the primary and secondary side-lighted areas, daylight control is required and general lighting in these areas shall be controlled by multistep (at least one step between 50-70% and a second step between 20-40% or lowest dimmed level) or continuous dimming photo-controls. Automatic daylight responsive control turns off all controlled lighting. Side-lighting – Two independent zones: primary and secondary. Top-lighting – Single primary zone under skylights and monitors.	Side-lighting: Adjacent structure obstruction, glazing < 20 sq. ft., retail spaces Top-lighting: Obstruction > 1,500 hrs/ year, skylight visual transmittance < 0.4, climate zone 8 and lighting < 200 W	✓	✓			✓	✓	✓	✓	✓	

Continued:

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Additional Controls													
Auto Receptacle (Plug Load Control)	8.4.2	At least 50% of all receptacles, and 25% of branch circuit feeders installed for modular furniture, shall be automatically turned off by an occupancy sensor within 20 minutes of all occupants leaving the space (20 minute off delay), a time-of-day schedule (≤ 2 hour override, control area ≤ 5,000 sq. ft.), or a signal from another automatic control device or alarm/ security system. Required for the following spaces: private offices, conference rooms, print/ copy rooms, break rooms, individual workstations, classrooms.	Equipment operating 24/7 Where auto control would endanger safety or security	✓	✓	✓							

Continued:

Control Type	ASHRAE Code Reference	Description	Exceptions	Open Office (>250 sq. ft.)	Private Offices, Meeting, Conference, Break Room, Multipurpose Spaces, Classroom, Training Room, Lecture Hall	Guest room	Restaurant Cafeteria, Retail	Lobby, Corridor	Stairwell	Gymnasium, Fitness Center	Restroom	Warehouse, Storage Room, Library Stacks	Parking, Garage
Additional Controls													
Parking Garage Lighting Power Setback	9.4.1.2 (b)	Automatic lighting shut off per 9.4.1.1(i). Parking garage lighting control shall automatically reduce lighting ≥ 50% when no activity is detected within 20 minutes and with the area controlled ≤ 3,600 sq. ft. Vehicle entrances and exits have separate controls to reduce lighting ≤ 50% from sunset to sunrise. Within 20 ft of perimeter wall openings, it shall automatically reduce lighting power in response to daylight.	Equipment operating 24/7 Where auto control would endanger safety or security										✓
Guestroom Control	9.4.1.3 (b)	Auto-off all lighting and switched receptacles within 20 minutes of occupants leaving.	Lighting and switched receptacles controlled by a captive key system			✓							
Guestroom Bathroom Control	9.4.1.3 (b)	Guestroom bathrooms have separate control to auto-off bathroom lighting within 30 minutes of occupants leaving.	Nightlights up to 5 W per bathroom.			✓							

A status of ASHRAE 90.1 energy code adoption in U.S. can be tracked here:
https://www.energycodes.gov/status-state-energy-code-adoption.

Further reading:
https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_90.1_2019,https://901portal.ashrae.org/?token={TOKEN_VALUE}&Site=ashrae

IECC CODE

Responsible body: International Code Council (ICC). Founded in 1994, the ICC develops model codes and safety standards for buildings covering product evaluation, accreditation, technology, training, and certification. The ICC family of solutions includes the ICC Evaluation Service (ICC-ES), S.K. Ghosh Associates, the International Accreditation Service (IAS), General Code, ICC NTA, ICC Community Development Solutions, Alliance for National & Community Resilience (ANCR), and Progressive Engineering Inc.

The International Energy Conservation Code IECC 2018 is a building code created by the International Code Council in 2000. IECC addresses minimum regulations for the design of energy-efficient commercial building envelopes and the installation of energy-efficient mechanical, lighting, and power systems through requirements emphasizing performance. It is a model code adopted by many states and municipal governments in the United States, member nations of the Caribbean Community (CARICOM), Mexico, Saudi Arabia, and Abu Dhabi, for the establishment of minimum design and construction requirements for energy efficiency. This standard closely follows ASHRAE 90.1, with few exceptions. Beyond energy savings, the IECC plays a critical role in promoting safer, more resilient buildings.

Further reading: https://www.iccsafe.org/

ISO STANDARDS

Responsible body: International Organization for Standardization (ISO). Founded in 1947, the ISO is an international standard-setting body composed of representatives from various national standards organizations.

ISO/CIE 20086:2019 Light and Lighting - Energy Performance of Lighting in Buildings specifies the methodology for evaluating the energy performance of lighting systems for providing general illumination inside non-residential buildings and for calculating or measuring the amount of energy required or used for lighting inside buildings.

ISO 8995-1:2002 Lighting of Work Places - Part 1: Indoor provides quantitative lighting requirements for indoor workplaces that are meant to ensure visual comfort, visual performance, and visual safety for workers throughout the work period. The main body of the standard consists of tables with specified values for work plane illuminance (the horizontal plane on which a visual task is usually done), surrounding area illuminance, glare limitation, and color rendering for 31 different types of indoor workspaces, each with different visual tasks.

ISO/TS 21274:2020 Light and Lighting - Commissioning of Lighting Systems in Buildings specifies requirements for the commissioning of lighting systems in buildings to meet design specifications and can be applied to new installations of non-residential buildings and public spaces of multi-residence buildings.

Further reading:
https://www.iso.org/standard/28857.html

DLC INITIATIVE

Responsible body: Design Lights Consortium (DLC). Founded in 1998, DLC is a nonprofit organization dedicated to accelerating the use of high-performing commercial lighting solutions. It establishes product quality specifications that promote high-quality, energy-efficient lighting solutions.

DLC's Networked Lighting Controls (NLC) program provides tools and resources to enable the widespread adoption of networked lighting controls in commercial buildings. Lighting controls manufacturers can qualify their products and systems against specific technical requirements that focus on interoperability, energy monitoring, and energy management. DLC created the NLC Qualified Products List (QPL) for products and systems that prequalify for incentives and rebates from utilities across North America, providing access to the energy efficiency program market.

Further reading:
https://www.designlights.org/lighting-controls/

EUROPEAN REGULATIONS

Responsible bodies: European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC), European Telecommunications Standards Institute (ETSI). European (EN) standards take precedence over any national standards, so EN compliance gives manufacturers access to the entire European market.

The following standards apply to lighting control systems:

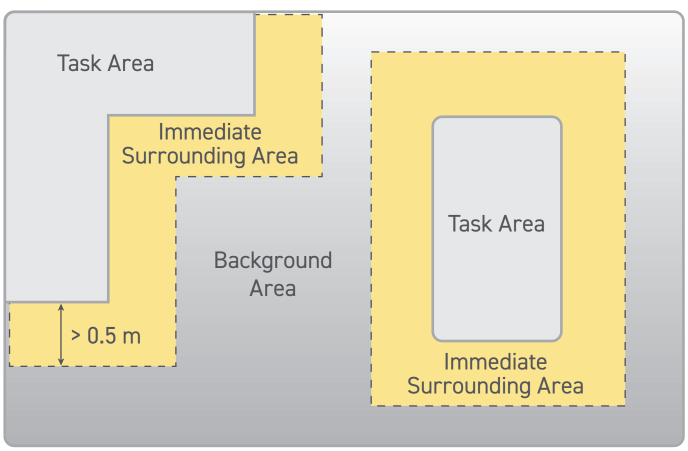
EN 15193 Energy Performance of Buildings provides requirements for lighting. It predicts lighting energy use in buildings and emphasizes the use of lighting controls to reduce energy consumption.

EN 12464-1 Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places specifies the lighting design requirements for indoor workplaces and recommends the use of controls where necessary. It provides recommended lighting levels for spaces and tasks and also identifies illuminance ratios in the immediate vicinity of the task area to improve visual comfort and performance.

Examples of lighting requirements for spaces and tasks:

Space	Illuminance (1x)
Areas with Traffic and corridors	100
Stairways, escalators, and travelators	100
Lifts	100
Loading bays	150
Coffee-break rooms	200
Technical facilities	200
Storage spaces	100
Electronics workshops, testing and adjustments	1500
Ball-mill areas and pulp plants	200
Offices and writing	500
Check-out areas	500
Waiting Rooms	200
Kitchens	500
Parking areas	75
Classrooms	300
Auditoriums	500

Single-person task area, immediate surrounding area, and background area, as used in European standards:



Illuminance ratios for a task area and its immediate vicinity:

Illuminance in the task area E_{task} (1x)	Illuminance in the immediate vacinity of the task area (1x)
≥ 750	500
500	300
300	200
200	150
150	E_{task}
100	E_{task}
≤ 50	E_{task}

Further reading:

https://lumenlightpro.com/wp-content/themes/lumenlightpro/assets/EN_12464-1.pdf

Regional Examples

CALIFORNIA TITLE 24

Responsible body: California Building Standards Commission (CBSC). Established in 1953 by the California Building Standards Law, the CBSC manages and oversees processes relating to the development, adoption, approval, publication, and implementation of California's building codes.

California Title 24, the California Building Standards Code, is a set of codes designed to reduce wasteful and unnecessary energy consumption, with a target of zero net energy by 2030. Title 24 applies to all newly constructed or altered commercial and residential buildings, and requires modifying, moving, replacing, or disconnecting and reconnecting at least 10% or 40 light fixtures in a room (luminaire alteration). Currently, projects in California must comply with the 2019 standard, including all the mandatory lighting control requirements. Routine maintenance does not trigger Title 24 compliance.

Further reading:

https://www.iso.org/standard/28857.html

Lighting control requirements generally apply to spaces over 100 square feet using more than 0.5 watts of lighting per square foot. Every applicable space must have lighting controls based on the fixture type.

Fixture Type	Control Requirements
• Line voltage incandescent and halogen • Low voltage incandescent an halogen systems • LED lamps and LED systems	Continuous dimming 10% to 100%
• GU-24 sockets rated for fluorescent (CFL) > 20 W • Pin-based compact fluorescent > 20 W	Continuous dimming 20% to 100%
• GU-24 sockets rated for fluorescent <= 20 W • Pin-based compact fluorescent (CFL) <= 20 W • Linear and U-bent fluorescent <= 13 W	Minimum of one reduction step between 30% to 70% (Stepped dimming, continuous dimming, or switching alternate lamps in a fixture)
• Linear and U-bent fluorescent <= 13 W	Minimum of four steps of light levels at: 20% to 40% 50% to 70% 80% to 85% 100% (Stepped dimming, continuous dimming, or switching alternate lamps in a fixture)
• Track lighting	Minimum of one reduction between 30% and 70% (Stepped dimming, continuous dimming or switching alternate track circuits)
• HID > 20 W and induction > 25 W • Other light sources	Minimum of one reduction step between 50% and 70% (Stepped dimming, continuous dimming, or switching alternate lamps in a fixture)

If the luminaire alteration is done and the permit has been pulled, the watts per square foot (Lighting Power Density - LPD) and the lighting controls in the space must meet current Title 24 requirements.

Scenario	Solution
Less than 85% of the maximum allowed watts per sq. ft. (LPD) are used for the space	Rooms must be separately switched *and* Either two-level lighting control or the interior lighting control requirements must be met
Between 85% and 100% of the maximum allowed watts per sq. ft. (LPD) are used for the space	Rooms must be separately switched *and* Daylight controls must be used where applicable *and* Either two level lighting control or the interior lighting control requirements must be met
More than the maximum allowed watts per sq. ft. (LPD) are used in the space	Rooms must be separately switched *and* Daylight controls must be used where applicable *and* Demand response controls must be used *and* Either two level lighting control or the interior lighting control requirements must be met

Further reading:
https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards, https://ww2.energy.ca.gov/2018publications/CEC-400-2018-020/CEC-400-2018-020-CMF.pdf

SOCIETY OF LIGHT AND LIGHTING

Responsible body: Chartered Institution of Building Services Engineers (CIBSE). Founded in 1976, the CIBSE is a professional engineering association that represents building services engineers (mechanical, electrical, architectural, technical) with headquarters in London. It is a full member of the Construction Industry Council and is consulted by government on construction, engineering, and sustainability matters. The Society of Light and Lighting (SLL) was launched in 1999 as a part of the CIBSE, focusing on lighting design and application.

SLL Code for Lighting (2012) provides information on the effects of lighting on task performance, behavior, safety, perception, and health, as well as its financial and environmental costs. It covers recommendations for both interior and exterior lighting in normal conditions. The following table lists examples of recommended illuminance by activity and room type.

Illuminance (lux)	Activity	Area
100	Casual seeing	Corridors, changing rooms, stores
150	Some perception of detail	Loading bays, switch rooms, plant rooms
200	Continuously occupied	Foyers, entrance halls, dining rooms
300	Visual tasks moderatley easy	Libraries, sports halls, lecture theatres, classrooms
500	Visual tasks moderatley difficult	General offices, kitchens, laboratories retail shops
750	Visual tasks difficult	Drawing offices, meat inspection, chain stores
1000	Visual tasks very difficult	General inspection, electronic assembly, paintwork, super-markets, examination and treatment rooms in healthcare
1500	Visual tasks extremely difficult	Fine work and inspection, precision assembly
2000	Visual tasks exceptionaly difficult	Assembly of minute items, finished fabric inspection

SLL Lighting Handbook (2018) covers design aspects of lighting, lighting technology, and specific applications in the field of interior and exterior lighting.

LG14: Control of Electric Lighting (2016) incorporates chapters on lighting control products and techniques, design of lighting control systems, human interaction with the system, lighting control techniques for visual comfort (addressing circadian lighting), integrated systems, and energy reduction through lighting control.

Commissioning Code: Lighting (2018) advises on the stages required to commission lighting installations, which may include luminaires, emergency luminaires, lighting controls, and interfaces with other services.

LG02: Lighting for Healthcare Premises (2019) presents modern lighting practice and illustrates ways of lighting the modern hospital environment. Illumination recommendations have been aligned with European lighting standards.

LG05: Lighting for Education (2011) offers guidance on the lighting of educational spaces, including lecture theaters, teaching rooms, conference rooms, special-purpose rooms (art rooms, dance studios), and multipurpose rooms. In addition to providing guidance on the lighting equipment and its positioning, the guide also considers the positioning of lighting controls and access doors.

LG07: Office Lighting (2015) emphasizes the need to minimize energy use while maintaining a good visual environment for occupants. It keeps a balanced approach to design options, covering (where ceiling heights allow it) direct/indirect lighting, and, for spaces with lower ceilings, recessed down-lighting. It also details task lighting and daylighting techniques.

Further reading:
https://www.cibse.org/society-of-light-and-lighting-sll/lighting-publications

GREEN BUILDING AND SUSTAINABLE DEVELOPMENT INITIATIVES

Many countries have developed green initiatives in recent decades. In this section, we will look at internationally recognized requirements, standards, and best practices around sustainable buildings.

IgCC CODE

Responsible body: International Code Council (ICC), in collaboration with the American Institute of Architects (AIA), ASHRAE, the U.S. Green Building Council (USGBC), and the Illuminating Engineering Society (IES).

The International Green Construction Code (IgCC) is a comprehensive code that applies a whole-systems approach to the design, construction, and operation of buildings, with criteria for energy efficiency, resource conservation, water safety, land use, site development, indoor environmental quality, and building performance.

The first code to be developed cooperatively by ICC and ASHRAE, 2018 IgCC is a voluntary code for new and retrofit constructions in residential, commercial, institutional, and healthcare sectors which are powered by ANSI/ASHRAE/ICC/USGBC/IES Standard 189.1. It delivers a comprehensive, sustainable solution for high-performance buildings that provides measurable benefits.

Below are several lighting strategies recognized in IgCC:

- Lighting systems that must remain operational, even when the lighted area is unoccupied, must be reduced to a step between full power and OFF to save energy during unoccupied periods (unless the application is specifically exempted).
- Automatic daylight harvesting controls and plug load controls are required in certain spaces.
- If a power provider offers a demand response program, and the building does not produce its own on-site renewable energy to satisfy 20% or more of its electrical demand, then lighting in certain office spaces must be capable of reducing the total connected lighting load by at least 15% (with a few exceptions).
- Tenant-occupied buildings must provide individual metering per tenant and collect, categorize, and report the meter data.
- Lighting controls must be calibrated by the system installer or commissioning agent, and recalibrated after 18 to 24 months. Operations and maintenance documentation must be turned over to the owner for all lighting systems.
- Daylight harvesting controls in daylight zones are required.

For more information, visit www.iccsafe.org/,https://www.ashrae.org/File%20Library/Technical%20Resources/Bookstore/2018-IgCC_preview_1102.pdf,https://www.ashrae.org/technical-resources/bookstore/standard-189-1

LEED RATING SYSTEM

Responsible body: U.S. Green Building Council (USGBC). Founded in 1993, the USGBC is a membership-based nonprofit organization that promotes sustainability in building design, construction, and operation. It cooperates with Green Business Certification Incorporation (GBCI), which administers the LEED certification program and the LEED professional credentialing program.

The Leadership in Energy and Environmental Design LEED Green Building Rating System provides a framework for healthy, highly efficient, cost-saving green buildings and is the most widely adopted green building rating system in the world for all building types. It offers scientific performance criteria and a point system for green building project certification, culminating in one of four benchmark levels: Certified, Silver, Gold, or Platinum.

Lighting controls contribute towards achieving LEED rating points by incorporating the following items into the system and control strategy:

- Dimming, switching, and occupancy sensors
- High-end task tuning
- Maximizing daylight harvesting
- Integrated sun blinds controls
- Personal controls of light environment
- Low energy consumption

LEED is used on a large scale outside the US. The following table lists the 10 best-performing countries in terms of LEED certifications.

Ranking	Country/Region	Number of Projects	Gross Square Meters*
1	China	1,494	68.83
2	Canada	3,254	46.81
3	India	899	24.81
4	Brazil	531	16.74
5	Republic of Korea	143	12.15
6	Turkey	337	10.9
7	Germany	327	8.47
8	Mexico	370	8.41
9	Taiwan	144	7.3
10	Spain	299	5.81
**	United States	33,632	441.6

* Gross square meters are reported in millions. Data: December 2018.

** The United States, where LEED originated, is not included on the list, but remains the world's largest market for LEED.

The USGBC is promoting LEED as a competitive edge as well as a selling point for prospective tenants. Buildings with LEED certification tend to have:

- Higher lease rates
- More tenants
- Lower energy and operating costs
- Greater resale values
- Healthier indoor spaces
- Greater levels of productivity by workers inside

Further reading: https://www.usgbc.org/leed

BREEAM METHOD

Responsible body: Building Research Establishment (BRE). Founded in 1921, and privatized in 1997, the BRE is a center of building science in the UK.

The Building Research Establishment Environmental Assessment Method (BREEAM) was initially published in 1990 and is the first sustainability assessment method for buildings. Currently, BREEAM can be used for the voluntary assessment of buildings of various uses (offices, hospitals, schools, etc.) at various stages of their lifecycle, and has six certification levels, with Outstanding being the highest. In this method, the performance of a building is quantified using several criteria that extend across a range of environmental issues.

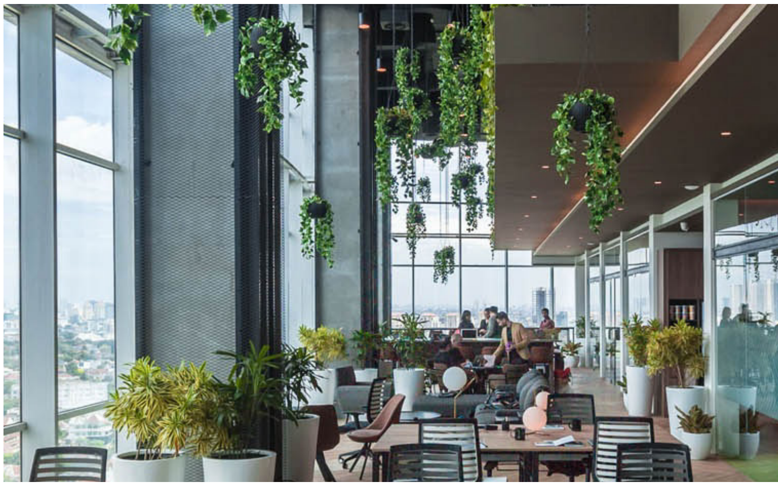
The BREEAM Assessment Method recommends internal lighting be zoned to allow for occupant control, providing specifics for different verticals.

- In office areas, zones may include no more than four workplaces.
- Workstations adjacent to windows/atria and other building areas are to be separately zoned and controlled.
- In classrooms, separate zoning of whiteboard and display screen areas is recommended.
- In seminar and lecture rooms, separate zoning of presentation and audience areas is recommended.
- In auditoriums, separate zoning of seating areas, circulation spaces, and lectern areas is recommended.
- In library spaces, separate zoning of stacks, reading areas, and counter areas is recommended.
- In dining spaces, separate zoning of server and seating/dining areas is recommended.
- In retail spaces, separate zoning of display and counter areas is recommended.
- In bars, separate zoning of bar and seating areas is recommended.
- In healthcare facilities, separate zoning of treatment areas, waiting areas, and circulation spaces is recommended, with controls accessible to staff.

Certification requires that manual controls be provided. Light switches or controls for each zone shall be accessible to the occupant(s) of that zone. Such controls should be located within, or close to, the zone or area that they control.

BREEAM is used in more than 70 countries, with over 550,000 certified buildings. There are country-specific versions of BREEAM in the Netherlands, Spain, Norway, Sweden, and Germany.

Further reading: https://www.breeam.com/



DGNB CERTIFICATION

Responsible body: German Sustainable Building Council (DGNB). Founded in 2007, the DGNB introduced green building certification in 2009 together with the German Federal Ministry of Traffic, Construction and Urban Development.

DGNB CERTIFICATION has three benchmark levels, Bronze, Silver, and Gold, based on the following criteria:

- Performance
- Life cycle assessment
- Holistic sustainability (ecological, economic, and sociocultural impacts are all considered)

In terms of lighting control, the DGNB system is focused on the following areas:

- Availability of and exposure to daylight
- Shading and glare protection
- Light levels and color rendering
- Artificial light control

DGNB certification is voluntary and is based on German codes and standards (DIN and VDI). It is regarded as more comprehensive than BREEAM or LEED, as it also incorporates economic aspects (for example, assessing the associated Life Cycle Costs and Value Creation of the building).

DGNB is used in 30 countries, with 5,900 constructions planned and built according to the principles of this certification.

Further reading: https://www.dgnb.de/en/

WELL STANDARD

Responsible body: International WELL Building Institute (IWBI). Founded in 2013, the IWBI is a public benefit corporation whose mission is to improve human health and well-being through the built environment. It cooperates with Green Business Certification Inc (GBCI), formed in 2008, which also administers the LEED certification program and the LEED professional credentialing program. WELL certification has three benchmark levels: Silver, Gold, and Platinum.

While the LEED standard covers all phases of building development, design, and construction, and provides requirements on how a sustainable building can be operated, maintained, and retrofitted, the WELL Building Standard is interested in the people who use the building. WELL is designed to work harmoniously with and complement the LEED Green Building Rating System.

WELL is grounded in a body of medical research that explores the connection between buildings (where people spend, on average, 90% of their day) and the health and wellness of their occupants.

WELL Certified spaces and WELL Compliant core and shell developments can help create a built environment that promotes better nutrition, fitness, and sleep, improves concentration and productivity, and reduces stress and depression. Ensuring a healthy exposure to light by creating an environment that is optimal for physical and emotional health tops WELL's list of lighting requirements.

WELL's light concept is broken down into eight subcategories:

- Making sure occupants have proper exposure to light
- Providing visual comfort and enhanced acuity for all age groups
- Providing the right levels of light to maintain circadian health
- Minimizing light glare
- Supplying more daylight-quality light in indoor spaces
- Ensuring contrast levels between rooms and spaces do not vary too greatly
- Reducing flickering lights
- Providing occupant-controlled lighting

Controlled tunable white LED lighting checks off every WELL lighting requirement. This is why the technology is a key component of WELL's philosophy of occupant health and wellness.

Further reading: https://www.wellcertified.com/

NET ZERO ENERGY CERTIFICATION

Responsible body: International Living Future Institute (ILFI). The ILFI is a nonprofit organization that, in 2006, established an international sustainable building certification program called the Living Building Challenge.

The Living Building Challenge includes several types of certifications, among them the Net Zero Energy (NZE) certification. To be certified, a building must supply 100% of its net annual energy demand through on-site renewable sources, without combustion. In other words, it needs to produce as much energy as it uses over the course of a year.

To meet this requirement, the following lighting solutions can be used to decrease energy demand:

- Occupancy sensors
- Integration of controllable sunblinds
- Daylight harvesting
- Dimming and switching systems
- Astronomical time clock scheduling
- High-end task tuning
- Occupant-enabled controls with set maximum light levels
- Demand-responsive controls with individual circuit and fixture control to shed load uniformly throughout a building

Other strategies that can provide substantial energy savings to help achieve NZE certification include implementing energy-efficient LED fixtures; decreasing Lighting Power Density in connection with tuning light levels to specific tasks; integrating lighting and sunblind systems; and using a combination of scheduling, motion detection, and light level sensors for daylight harvesting.

Further reading: https://living-future.org/

Interesting achievement: In July 2017, Delta Americas Headquarters, located in Fremont, California, achieved full net-zero operation, with its solar energy generation surpassing consumption.

Interesting building: Taipei 101, a 508 m (1,667 ft) skyscraper in Taiwan's capital city, is the tallest and largest LEED Platinum certified green building in the world since 2011.

Interesting study: Roger Ulrich concluded that access to views and natural light in healthcare facilities can reduce stress, decrease pain, and shorten hospital stays. See Roger S. Ulrich, "Effects of interior design on wellness: theory and recent scientific research," Journal of Health Care and Interior Design 3 (1991): 97–109.

Do it Right.

Sources: All the above-mentioned standards and guides, Illuminating Engineering Society, Lighting Controls Association, Amerlux Blog, CIBSE, Wout van Bommel, Interior Lighting: Fundamentals, Technology and Application (Springer Nature Switzerland AG 2019).

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Delta Controls Inc. Canada

17850 - 56 Ave, Surrey, BC V3S-1C7
Phone: 604.574.9444
deltacontrols.com

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3. SMART LIGHTING CONTROLS

- INTRODUCTION: SMART LIGHTING CONTROL
    - ENERGY SAVING
    - SYSTEM OPERATIONS
    - BALLASTS AND DRIVERS
- CONTROL STRATEGIES
    - ZONE AND GROUP CONTROL
    - SCHEDULING
    - HIGH-END TASK TUNING
    - DIMMING
    - PRESENCE DETECTION
    - CONSTANT LIGHT CONTROL
    - COLOR TEMPERATURE CONTROL
    - LIGHTING SCENES
- THE FUTURE OF LIGHTING CONTROLS

SMART LIGHTING CONTROLS

Smart lighting technology uses collected data to optimize space usage and automate room control, improving energy efficiency, security, and comfort. A smart lighting system takes into account such factors as the availability of natural light, user preferences, activities and movements in controlling light intensity and color. Although upfront costs are higher, smart lighting systems can reduce energy costs by up to 60 percent thanks to sophisticated sensors and controls.

As energy regulations become more stringent, and energy incentives more attractive, the demand for smart lighting will only increase. Smart lighting systems are ideal for new constructions but can also be implemented in modernized older buildings.

Currently, two main types of smart lighting systems are preferred in projects:

- **Scalable panel systems** use low-voltage, mechanically-held, single- and double-pole latching relays and centralized control with panel-based systems to oversee lighting for large areas or entire buildings. This allows the building administrator to monitor and control the lighting for each floor from one central location.
- **Modular, distributed networked systems** use an array of sensors, switches, and outputs to provide complete room-level or floor-level lighting control. Gateway modules also enable the use of lighting protocols, such as DALI, for luminaire control.

Delta Controls offers both types of systems with its DLS Lighting Relay Cabinet and O3-DIN Integrated Room Control offerings. The modular O3 system, especially, provides an excellent integration platform for accomplishing the smart lighting control strategies described in this chapter.

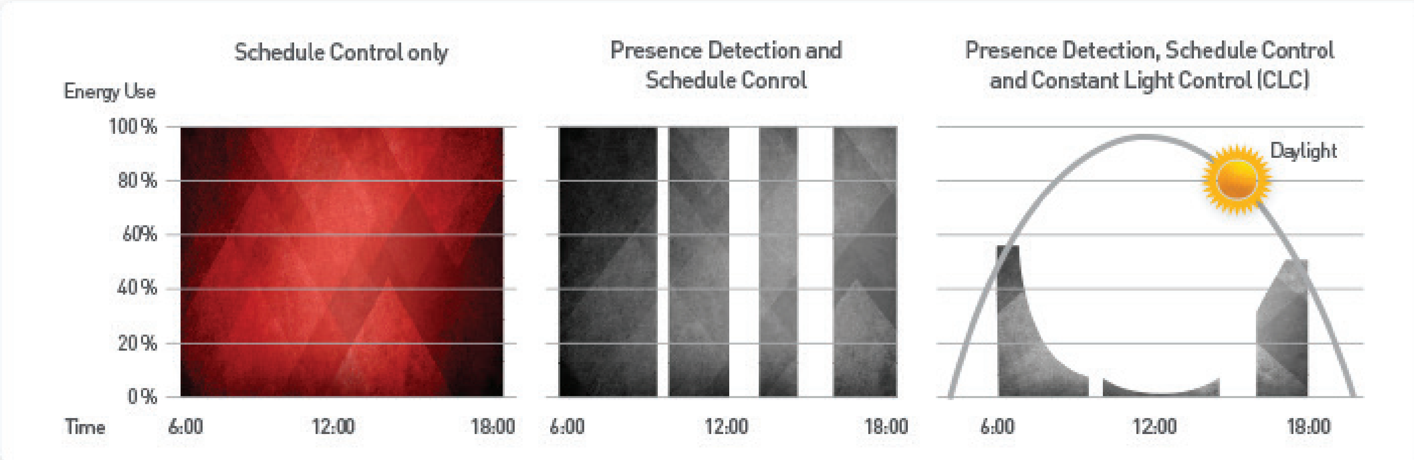
ENERGY SAVING

Lighting applications currently account for 19 percent of the world's energy use and 6 percent of all greenhouse emissions. In commercial buildings, lighting accounts for 40 percent of all energy use. Incorporating lighting control strategies into building automation management is therefore essential to achieving greener, more energy efficient buildings.

Smart lighting systems can help businesses reduce energy consumption, save money, and meet corporate sustainability goals. A recent study prepared by the Lawrence Berkeley National Laboratory (LBNL) found that lighting control techniques can reduce lighting energy use by 20 to 40 percent in commercial buildings. This was confirmed by another study, carried out by National Research Council Canada, which found that an automatic lighting system, including occupancy sensors and individual controls, can reduce lighting energy use by 32 percent compared to a conventional lighting system, even when the installed lighting power density of the automatic lighting system is 50 percent higher than that of the conventional system.

Even greater energy savings can be achieved by combining multiple lighting control strategies. For example, combining daylight harvesting (also called Constant Light Control) with occupancy control and scheduling can reduce energy usage by up to 60 percent. This can be implemented at no additional cost by using multi-sensors to detect occupancy, light intensity, and color levels.

Types of lighting system control. Constant Light Control (CLC) provides high quality of visual comfort with substantial energy savings.



SYSTEM OPERATIONS

A lighting controller processes information about room conditions and occupants' needs to make intelligent control decisions. The control logic should be structured to reduce energy costs in the building in terms of lighting and cooling, while simultaneously optimizing the levels and types of lighting for different uses of the space.

Artificial lighting levels can be reduced when there is enough natural light in the room through windows or skylights. Sunblinds should be positioned appropriately to reduce glare and protect the space against heat loads from daylight penetrating into the room, thus lowering cooling needs. Real-time coordination between light and sunblind control strategies should work to improve space management, energy efficiency, and occupant comfort.

In open office plans, the lighting of individual zones should be activated only when the zones are occupied and controlled separately within the larger space. This scenario can be further improved by synchronizing the sunblinds and lighting systems. For example, the lighting system should ignore rapid and temporary changes of the measured lux level due to movements of the blinds. Another improvement is to provide dimmed light to unoccupied zones that are adjacent to the occupied illuminated zone. This will reduce the contrast between the zones, increasing occupants' visual comfort and subjective sense of security.

Integrating the lighting system with the building management system over the open BACnet protocol allows the sharing of the operational schedules and occupancy information, providing a coordinated approach to energy saving strategies in real time. It also eases the work of the building operator and helps the facility manager access data on energy consumption and the state of the lighting fixtures, facilitating reporting and system maintenance.

The following factors should be considered when creating a smart lighting control system:

- Customer requirements and needs
- Usage patterns in each of the rooms or spaces
- Existing installations and systems in the room and in the building (lamp and ballasts types, shades, emergency lighting, building management system)
- Building orientation for daylight harvesting, as well as glare and reflections
- Required level of control by occupants (thermostats, touch panels, mobile app, PC, and/or manual control)
- The amount of multi-sensors required for Constant Light Control (CLC)
- System architecture and functional requirements and scenarios

The number of lighting fixtures and the distance between fixtures, controllers, and input devices (switches) is not an issue in smart lighting systems due to the network characteristics and scalability of the solution.

The lighting control system, which is based on sensors and logic algorithms, needs to provide lighting that matches the needs of occupants.

Therefore, it is important to make sure end users know how to interact with the system. For example, you may need to provide a graphical interface tailored to their needs.

In addition to reducing energy costs, smart lighting systems also facilitate management and maintenance of the lighting. Lighting automation offers, among other things, powerful visualization, trending, and alarming features. These allow facility managers to see energy and status reports, maintenance lists, and alarms in real time. They receive instant notification of lamp failures and monitoring the operating hours of the lamps enables them to plan maintenance cycles.

BALLASTS AND DRIVERS

Almost all lights come with a device to limit the amount of current in its electrical circuit, called a control gear. Two common types of control gear are ballasts and drivers.

Fluorescent lights operate by generating an arc between the anode and the cathode within the tube. Fluorescent light ballasts facilitate this by providing an initial spike of high voltage and then, once the light is on, acting as a current regulator. Even if the lamp is connected to a high power source, the ballast regulates the power to prevent a current rise. Metal halides, mercury vapor, and HID lamps are examples of lights equipped with ballasts.

Ballasts are a much older technology than drivers and consist mainly of inductors, a capacitor, and a series resistor. This was enough to run fluorescent lights but not enough to run high-efficiency lights like LEDs.

Modern LED drivers do most of the work of ballasts but much more efficiently.

LED lights typically require low-voltage DC current. Given that most locations supply higher voltage AC current, a device is needed to rectify this.

LED lights typically require low-voltage DC current. Given that most locations supply higher voltage AC current, a device is needed to rectify this. This is where the LED driver comes in. In addition to being self-contained power supplies, LED drivers regulate power for LEDs and shield them from voltage and current fluctuations. There are two main types of external LED drivers: constant-current and constant-voltage. There is also a third type, known as an AC LED driver. Each driver type is designed to light LEDs with different electrical requirements. Some LED lights, however, are designed to work with existing ballasts and do not require a driver.

CONTROL STRATEGIES

ZONE AND GROUP CONTROL

A control zone is created when one control output is in charge of several lighting drivers. The smaller the zones in a space, the greater the control flexibility and the greater the energy savings. For this reason, energy codes divide spaces into zones. In traditional lighting systems with mains voltage as a control signal or analog 0–10 V controls, zones are limited by wiring. However, newer systems, like those based on DALI standard, provide economical zoning that can be detailed to individual drivers.

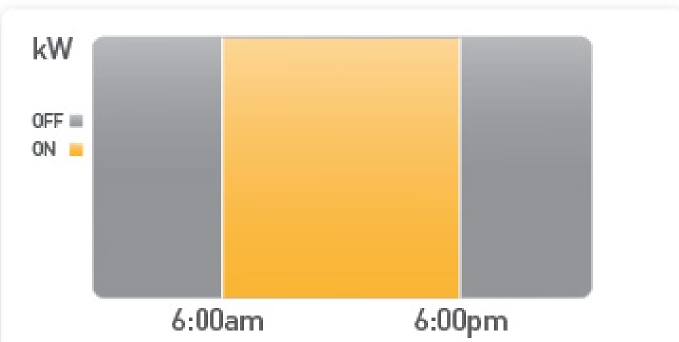
To create different lighting zones, the DALI system uses software instead of wiring to assign each fixture to its own functional group. A fixture can also belong to more than one functional group. The composition of these functional groups can be changed any time through the software. Functional grouping is not confined to one hard-wired lighting zone, but can be applied across multiple zones. For example, you could set up a functional group to control all lights in corridors, despite their being on separate lighting circuits.

A lighting system divided into zones and functional groups is more stable and secure than a centralized system, which is vulnerable to single points of failure. Zones and groups can be organized with regard to space characteristics, daylight availability, control needs, or even energy codes, as different areas of the building have different lighting needs. For example, in a large open office a hallway may have lights turned on for the whole working day but turned off at night to save energy according to the schedule. In periodically used spaces, like conference rooms, lights will be turned on only occasionally, when the space is occupied. Work spaces near windows will often require less artificial light.

SCHEDULING

Scheduling allows users to automatically adjust light levels and color temperature according to a calendar. The schedule can be set according to the room usage profiles and manage light levels based on time of day and day of the week, with a setting for peak and off-peak control. For example, a typical open office space or retail business might have all lights turned on during business hours and revert control to local vacancy detectors or switches after working hours. At certain times, according to the schedule, controlled lights will turn on, off, or dim to save energy or support changing uses of the space. According to the Berkeley Lab, lighting control strategies that combine calendar planning with presence detection can deliver energy savings of over 20 percent.

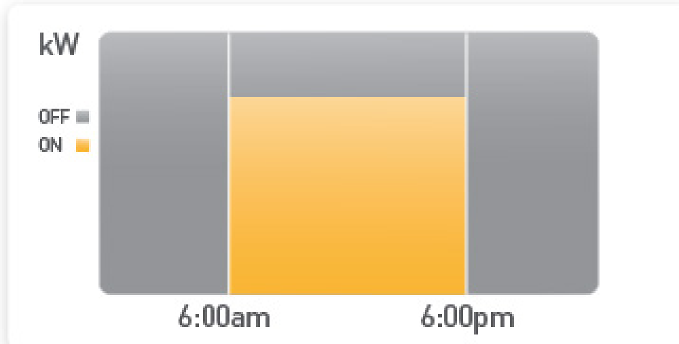
Scheduling is suitable for larger, open spaces that are regularly occupied, as well as for spaces that are occupied occasionally but where the lights must remain on all day for safety reasons, as in healthcare facilities. The building operator and the facility manager can make changes to the schedule to accommodate unforeseen events, special occasions, or guest visits. This type of control can also be used in conjunction with group or pattern (light scenes) control.



HIGH-END TASK TUNING

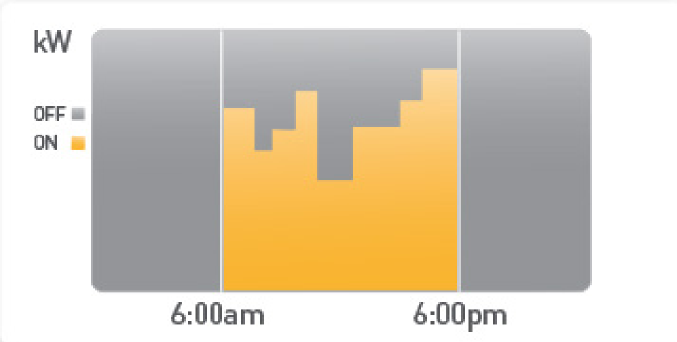
Commercial buildings are often over-illuminated, since most office work nowadays mainly done using self-lit computer screens. The aim of high-end task tuning—also referred to as institutional tuning or high-end trim—is to save energy by reducing light levels to a safe, comfortable level for the task or activity performed. This involves dimming the lights in areas where certain tasks are performed. According to the Berkeley Lab, task tuning can generate energy savings of over 30 percent.

Personal control is available through a mobile phone app, PC, or a hand-held wireless device like the Echoflex switches in our offer, which allows occupants to set a preferred light level for a specific activity performed, within the trimmed range (for example, 0–90%).



DIMMING

Dimming is a transition from one light level to another. The transition may be gradual across a dimming range (best for visual comfort) or stepped between multiple light levels. Control can be handled automatically by the system or by a manual switch or knob. The best option, however, may be to use a lighting network switch that can be programmed to provide occupants with various ways of dimming. Multi-way switching with networked switches, such as Delta Controls Ultra and Mystique products, can minimize cabling and simplify the installation and commissioning processes, as well as provide LED feedback. Manual dimming control is primarily driven by occupants' visual comfort, but can also be a significant source of energy savings. Regarding lighting fixtures, LED technology generally responds better to dimming control than fluorescent lighting.



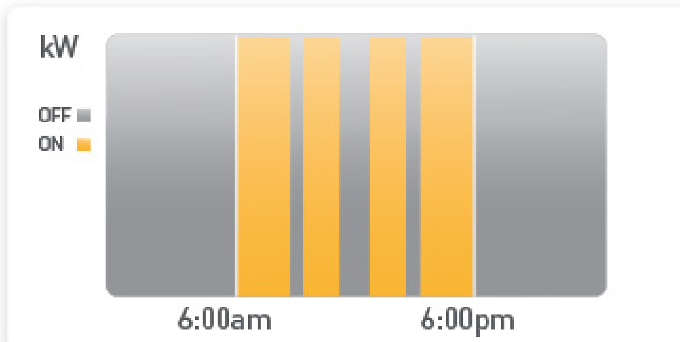
PRESENCE DETECTION

In a fully automatic environment, lights turn on when the area is occupied and turn off when no presence is detected for a specified period of time (this time delay can be adjusted). Occupancy detectors can be used to control the lighting system in smaller spaces that are occasionally occupied, such as copy rooms, closets, conference rooms, or bathrooms. For example, simple switching of the lights on and off with a rocker switch, but in conjunction with a vacancy detector, can be a powerful, inexpensive tool to reduce energy. For larger spaces, presence detectors can be networked to function as a zone control for specific areas, incorporating in the lighting scenario the influence of adjacent zones. According to the Berkeley Lab, control strategies in which lights are only turned on when a space is occupied can provide energy savings of over 20 percent.

In some systems, vacancy sensors serve as an input to automatically turn off the lights. Partial-on occupancy sensors can automatically turn lights on to a set level (for example, 50%), but require manual operation via a switch to turn the lights on to their maximum intensity. In a semi-automatic system, lights can be turned on manually and turned off automatically when the area becomes unoccupied.

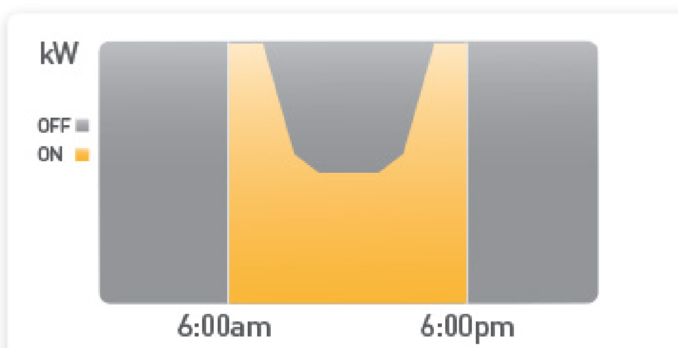
Control system accuracy can be increased by using a PC monitor's standby state as an input to turn off office lights when no presence is detected, or by using a multi-sensor with two-way presence detection. For example, Delta Controls' O3 sensor hubs determine occupancy with a PIR sensor that detects motion and a microphone that listens for low noises, such as typing and mouse clicks.

Occupancy information provided by sensors and collected in the lighting control system can be communicated to other building automation systems (HVAC, access control, etc.), where it can be used to turn off non-essential equipment or reduce equipment operation during unoccupied periods, generating even more energy savings.

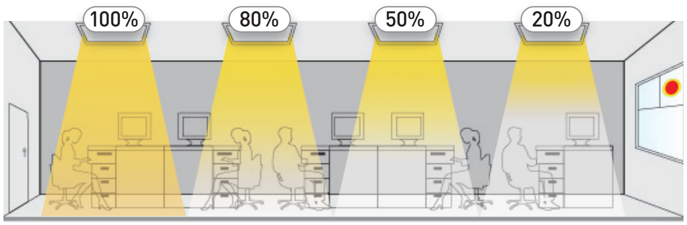


CONSTANT LIGHT CONTROL

Constant Light Control (CLC) is a strategy based on daylight harvesting. In this control strategy, a photosensor or photocell detects the light level in its field of view, and then uses this information to control the artificial lights, dimming or brightening them according to the available natural light. The control loop needs to ensure that the output to the luminaires does not cause the light level in the room to exceed the levels appropriate for the space (see Chapter 2. Design Standards and Codes for more details).



Daylight-responsive control is perfect for lighting zones adjacent to windows or skylights or other spaces with large glazed areas, and can lower energy costs by 20 to 30 percent.



During unstable weather conditions, and even on sunny days with fast moving clouds, rapid and frequent changes in the light levels can cause fixtures to switch on and off, which is highly undesirable as it disturbs occupants and can reduce the lamps' life. The key is to set the proper reaction times for the lighting system as a function of input changes from the sensor, as well as hysteresis of this reading. In PI control loops it is recommended to use a high proportional band (for example, 500 lux), a low integral rate (for example, 5% per minute), and a reasonable deadband (for example, 5 lux). Ensuring proper control loop operation will deliver constant light control that is unnoticed by occupants.

A CLC strategy has two main goals: to significantly reduce energy consumption when sufficient daylight is available, and to increase occupant comfort and well-being, as well as overall user satisfaction with the automation system when the required level of illumination is achieved.
This is accomplished through smooth transitions between natural and artificial lighting.

Sunblinds and shutters control can be added to the CLC system through integration with the lighting system. A combination of lighting and sunblinds control may be required in applications where a certain light level cannot be exceeded, such as in healthcare clinics or museums.

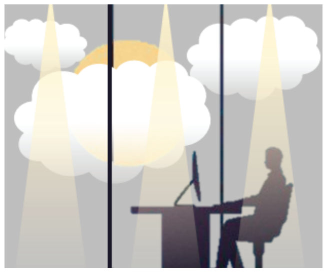
COLOR TEMPERATURE CONTROL

Tunable white lighting control can provide the control output for changing the CCT (Color Correlated Temperature) of an adjustable LED fixture. Color temperature defines the color appearance of a white LED, from warm (2700K) to cool (6500K). Color temperatures can significantly influence impressions of a space and even moods.

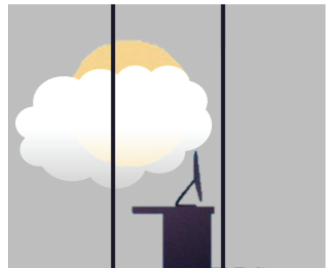
Delta Controls' modular O3 system, with options for 10 V, DALI, and wireless EnOcean communication, can deliver several interrelated control techniques to create a satisfactory light environment.
These include:

- Dim-to-warm technique where LED lamps dim to a very warm white similar to incandescent dimming
- Dynamic calibration across installed LED lamps to maintain an exact CCT for specific spaces and activities
- Changing and fine-tuning the light intensity and color temperature of LED fixtures to transform the appearance of spaces, displays, and objects
- Adjusting the CCT and light intensity according to room profiles and user preferences during different times of the day
- Supporting human circadian rhythms by automatically simulating the natural daylight color temperature and light intensity cycle and optimally blending it with actual daylight (see Chapter 1. Light and Human Perception for more details)
- Imitating the color appearance of popular traditional light sources

Sunny weather:
Enough light indoors, blinds partially covering direct sunlight to minimize the glare.



Clouds, rain:
Not enough light indoors, artificial lights are on, blinds are open.



Clouds, rain, occupant not present:
Artificial lights are off, blinds are open.

Sunny weather, occupant not present:
Artificial lights are off, blinds are covering direct sunlight to minimize cooling needs.

LIGHTING SCENES

A lighting scene controls a set of light fixtures, groups and/or zones with a single command, from a switch, touch panel, mobile phone app, voice command, or sensor. Lighting scenes with specific color and light intensity patterns can be developed for different scenarios. For example:

- Bright cool-white lighting for a training session or medical test
- Dimmed cool-white lighting with lamps turned off in front for a presentation
- Neutral lighting for business discussions and negotiations
- Bright warm-white lighting for an evening event
- Dimmed warm-white lighting for resting

Lighting scenes, which can be easily changed, allow commercial spaces to be reconfigured or repurposed for different users or tasks.

In the case of integrated systems like Delta Controls' building automation solution, control commands can be sent to many devices at once to transform the atmosphere of the room by changing the lighting color and intensity, the sunblinds position, the projector state, or audio settings with just one touch. Lighting scenes for specific events can also be included in the building schedule and recalled when the event starts by the automation system.

THE FUTURE OF LIGHTING CONTROLS

All building types can use smart lighting controls, whether they are new or existing buildings, or modern or vintage in style. These include:

- Private, commercial, government offices
- Healthcare facilities, clinics, senior homes
- Hotels and conference centers
- Retail and shopping malls
- Schools and universities
- Airports, railway stations, warehouses

To cut peak demand in these buildings and reduce stress on the electric power grid, many utilities offer load shedding or demand response programs in exchange for incentives or lower energy costs. Networked lighting control systems can take advantage of these programs by temporarily reducing light levels in response to a set energy level or a signal from the utility.

Connected lighting systems are the next natural step in lighting controls technology development, and businesses are increasingly considering lighting systems as the backbone for even smarter solutions—from sensors that collect building data, to cloud processing engines, to systems that can track people and equipment for occupancy analytics. Lighting systems are also moving towards learning user preferences by capturing occupants' decisions through an app or browser to create personalized comfort settings.

Internet of Things (IoT) multi-sensors, like the O3 Sense and O3 Edge, are now able to analyze all-inclusive lists of metrics about the indoor environment to reveal previously unseen operational cost savings, security insights, and returns on investment. Big data and cloud-based IoT analytics will offer facility managers and building operators unprecedented control over their infrastructure and the ability to enable optimizations in real time.

Do it **Right.**

Sources: Amerlux Energy Observer, Lighting Controls Association, Loytec Express.