REPORT

Advanced Lighting Technologies

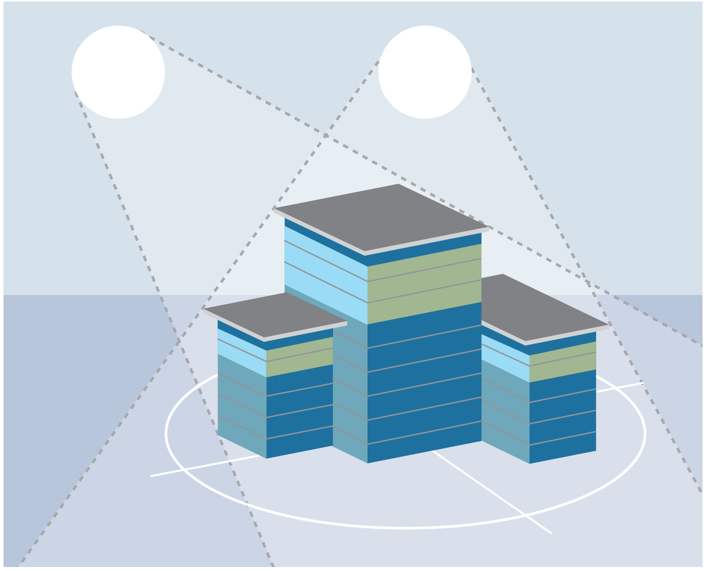
Throughout the history of lighting, few periods have experienced such rapid evolutionary changes as have occurred during the past few years. Technological advances, primarily in the realm of LED technology, and the rediscovery of time-tested lighting design principles have created a lighting renaissance for the building industry. Such advances are further propelled by increasingly aggressive federal and state targets to reduce energy—some buildings are subject to the goal of "net zero," which means that buildings will soon need to produce as much energy as they consume. The DOE is advocating through various codes (ASHRAE 90.1 / IECC / Title 24) to adopt energy saving techniques through load reduction, lighting technologies, and controls.

Building designers, owners, and managers now have the opportunity to select from many new options, as well as to reassess many status quo lighting approaches that may no longer be the most efficient or effective in accomplishing lighting goals and may therefore be candidates for replacement. This overview is provided to help building operators and energy professionals navigate the swiftly changing landscape of advanced lighting.

LIGHTING STRATEGIES

Daylighting: *Rediscovering Naturally Abundant Light*

The oldest source of light is our sun and, prior to the advent of electric lighting, daylight was the primary source of light serving buildings. The long history of daylighting in the 19th century indicates that natural daylight possessed the color spectrum and light qualities that electric lighting only attempted to achieve. But as building footprint densities grew in the 20th century, electric light became a more viable means to illuminate darker interiors and the sun became an increasingly ignored option for illuminating commercial spaces. There is a modern lighting renaissance today, however, that features a re-exploration of daylighting as a practical solution for buildings and a renewed appreciation for daylighting's excellent qualities, efficiency, health, and productivity benefits.



The goal of daylighting efforts is to identify how natural light can meet indoor lighting needs while controlling adverse glare, and how it is able to work in harmony with supplemental electric lighting. Daylighting strategies need to be developed during the planning stages of new building design and existing building upgrades since implementing them almost always impacts the fundamental components of construction. The following considerations can help guide the process:

- **Building orientation** is a determining factor in applying successful daylighting strategies. The preferred building orientation is north-south. North-facing windows will have a sun-free view of the sky and typically do not require additional glare management. South faces can be managed by vertical overhangs for summer months and also require additional shading in the low-sun months of the winter. Long east-west exposures create the need for dynamic shade control in the morning and evening, respectively.
- **Window-to-wall ratio** is of particular importance as energy codes become more stringent about wall construction and associated heat loss, thereby restricting window area. Orientation and other shading strategies can minimize overheating, but the "glass box" (i.e., many faces of windows) as a design concept has fallen out of favor.
- **Daylight penetration** strategies involve skylights, light wells, and products specifically designed to harvest available daylight. Daylight tracking technologies can be expensive and often do not produce significant volume of daylighting to justify a reasonable return-on-investment (ROI).
- No matter how effective the daylighting strategy, all buildings need to supplement with electric light for evening, night, and early-morning hours.

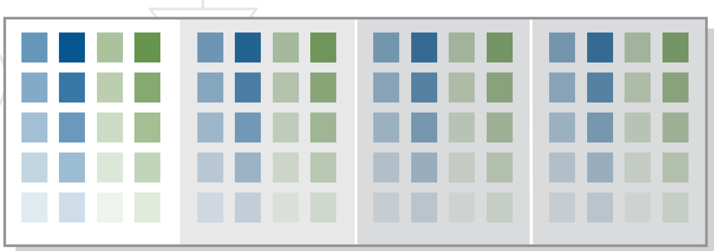
Electric Lighting: *Technological Solutions Abound*

This section offers a current state of the market for

electrical lighting. While the incandescent lamp was one of the earliest forms of electric lighting, today it is one of the most inefficient forms of lighting available. That said, society became accustomed to its light quality, which other lamp types now strive to mimic.

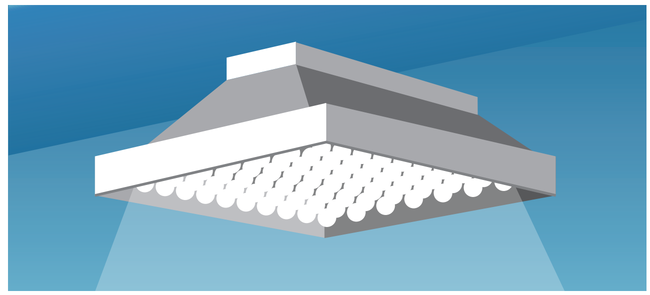
Light Quality Metrics

Color Rendering Index (CRI) is a measure of how colors look under light. An incandescent lamp is considered "perfect" on this scale, represented as 100. At this level,



all colors illuminated by the source will be ideally displayed, but at lower CRIs, deep blues or reds often look washed out.

Correlated color temperature (CCT) is the perceived color of the lamp as measured in degrees Kelvin. Incandescent lamps are described as "warmer" at around 2700 K while daylight is said to be "cooler" at nearly 6000 K.



Advanced Lamp Technologies

LED Lamps:

The light emitting diode (LED) was created in the early 1960s and has been used mainly in small digital applications, such as indicator lights, for several decades. It was not until the mid-1990s that practical lighting applications of LEDs were made possible by the creation of the blue LED. The effects of the blue LED on the lighting industry were revolutionary and even awarded the Nobel Prize in Physics 2014.[1] The technology is still in its infancy but developing at a rapid rate—approximately every 6 months, a new generation of brighter LED is being created.

Currently, bare LEDs are tested at 400 lumens/watt, but fixture efficiencies typically range between 80 and 120 lumens/watt. This number has been rising and is expected to iterate higher approximately every 6 months for the foreseeable future. As efficiencies increase, it opens the possibility for more optical management. Fixtures are expected to not only b more efficient, but also to have better control over their highly directional illumination properties.

"White" LEDs are blue LEDs that are phosphor coated in much the same way fluorescent lamps are. The difference is that the phosphor coating filters the blue light into green, yellow, and red, a mixture that the human eye perceives as white. LEDs create a significant amount of heat for their size, requiring thermal management to protect lamp life. The steady-state nature of LEDs means that the lamp itself has no active components to fail.

1 The Nobel Prize had three winners that each contributed to creating difficult-to-produce blue LEDs. Two of this year's prize winners, Isamu Akasaki and Hiroshi Amano, worked together on producing high-quality gallium nitride, a chemical that appears in many of the layers in a blue LED, in such a way that they would emit light efficiently. The third prize-winner, Shuji Nakamura, figured out why gallium nitride semiconductors treated with certain chemicals glow. http://www.popsci.com/article/technology/why-blue-led-worth-nobel-prize

However, they tend to slightly decrease in light output over their lifetimes, as rated by an LM70 test.[2] A more common failure of commercial fixtures is their drivers and power supplies. Commercial LED fixtures still require maintenance to these drivers and power supplies analogous to the maintenance required for the fluorescent ballast. LEDs typically have lives over 5 years of continuous 24/7 use or 15 years of 12 hour days in a commercial application. As with any semiconductors, failures before that are expected within the first 90 days.

CRI is dependent on the phosphors used in the LED. Currently, the CRI of LEDs is often in the mid 80's, similar to fluorescent technologies, however, some high quality LEDs can reach as high as the mid 90's. CCT is dependent on a process called "binning," a process that sorts LEDs into "bins" based on their color. Tight binning processes are required for LED sources to appear a consistent color, which is important to maintain consistency across multiple fixtures. "Dynamic White" is a new technology that allows LEDs to be tuned from warm to cool (2700-6000 K).

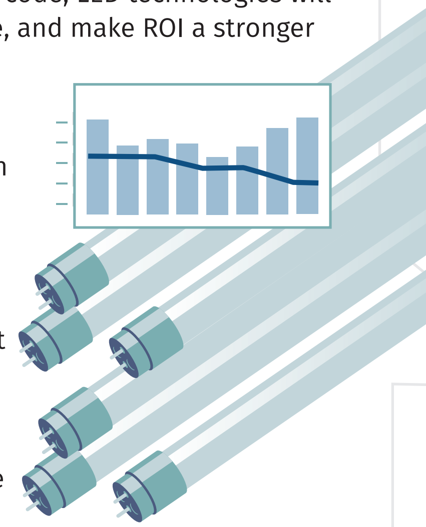
It is often challenging to justify LED retrofits over fluorescents when considering capital cost and energy savings payback. Typical ROI is approximately 10 years for replacement when utility or government rebates are unavailable, but as efficiencies increase and costs decrease, ROI will improve. As new LED applications are explored (e.g., dimming), the costs of LEDs become even more comparable to those of fluorescents.

LEDs are a directional source by their nature. LEDs work great as downlights because the directional source matches the directional application, but LEDs are not an ideal for applications that require 180-360 degree illumination. Thus, LEDs are not yet a perfect replacement for linear fluorescent lamps, where light distribution accounts for reflected light. LEDs in similar applications can create bright spots below fixtures and dark spots between them.

LED fixtures create a high visual luminance (light measured over an area). This could be problematic as fixtures emit more light and get smaller. The contrast between areas of high and low visual luminance can often create glare or the perception of too much brightness. Source management techniques (e.g., louvers or other optical cutoff) can address this shortcoming and will become more prevalent in the coming years.

LEDs dim by a process called Pulse Width Modulation (PWM). By rapidly turning the LED on and off above the perception range of the human eye, the process is observed as dimming. This has sometimes proven problematic in video conferencing or similar applications when a digital camera is required, where images are observed as flickering. The solution often requires higher than normal filtration to "clean" the power regulation of LEDs. As this issue does not have a clear solution yet, LEDs are not recommended for these types of applications.

Despite minor technology hurdles, LEDs are a revolutionary light source that has the potential to make most other light sources obsolete. As lighting controls become more commonplace and required by code, LED technologies will become more cost-competitive, and make ROI a stronger factor in purchase decisions.



Fluorescent Lamps:
Fluorescent lamps are a proven technology with a long history. Until approximately the year 2000, fluorescent lamps were the go-to energy efficient alternative to the incandescent lamp in the commercial market. The compact fluorescent lamp was created featuring a smaller form factor to the typical style lamp and quickly became the main energy efficient alternative in commercial and residential applications. Fluorescent's peak 80 lumens/watt efficiency was the theoretical maximum for non-HID (high-intensity discharge) sources until LEDs met and surpassed that benchmark a few years ago.

The forecast for commercial fluorescent lamps is not promising, as they have reached the peak of their design and despite small, incremental steps every few years with regard to electrode development and lamp life, revolutionary changes are no longer expected. The CFL will become completely irrelevant as LED technology becomes price-comparable. Linear florescent lamps are at a tipping point—once LEDs can overcome their cost and distribution hurdles, the linear fluorescent lamp will be redundant and should phase out steadily.

HID Lamp
High Intensity Discharge or HID lamps were created concurrently with fluorescent technologies. Unlike fluorescent, their application fits a more high-output source where quantity of lighting is favored over quality of lighting. These lamps require warm-up and cool-down periods

[2] Lumen maintenance is a prediction of the number of hours an LED will operate before it fades below a useful level of intensity. Currently, lumen maintenance reporting assumes that dropping below 70% of initial lumen output is the end-of-life for the emitter. Hence, L70 predicts when the LED reaches 70% of initial lumen output. http://www.liton.com/webcatalog/brochures/wp_makingsense.pdf

which make them impractical for emergency applications without additional equipment. These start-up and cool-down periods also make controls via occupancy sensors impractical with this lamp source. Dimming is possible through a stepped process but it is limited and not often available in all applications.

Sodium Lamps (high or low pressure) use sodium gas as the illuminated medium. These lamps are highly effective from a lumens/watt standpoint but have an extremely low CRI and CCT, making it difficult to differentiate colors. This makes the lamp source impractical for areas where security and/or visual aesthetics are a concern. Often these technologies can be replaced with a lower quantity of light (footcandles) if the CRI and CCT are more in-line with common lighting applications.

Ceramic Metal Halide lamps use a ceramic tube to suspend a gas. They are less effective than sodium lamps, but their CRI and CCT are more in-line with the more commonly used fluorescent lamps.

The plasma lamp is another variation and evolution of the HID technology. Lamps are 90 lumens per watt or more. However, they, like all HID sources, create enormous amounts of wasted energy in the form of heat. Practical applications of the plasma lamp have never seen much market share as the source's creation has been overshadowed by the potential of LED sources.

HID lamps are also expected to phase out. Currently their market share is dependent on their dominant output and high wattage packages for sports lighting or other similar applications. Almost all sight lighting has migrated toward LED. This is due to the controllability (dimmable, quick start-up/cool-down, long life), distribution, low wattage, and high CRI/CCT of this lamp source. Sports lighting applications are also migrating toward LED but have some obstacles to overcome (PWM & Output) before they become mainstream.

CONTROLS

The final component of modern advanced lighting options is the automation technology commonly referred to as "lighting controls." The most efficient light source is one that is turned off when not needed and automation controls are key to making this happen consistently. While lighting technologies are in a renaissance, controls technologies have not experienced much change throughout their relatively short history. The industry is still using essentially the same occupancy sensor technology that has been available since the 1980s. But the industry has learned a lot about how to apply controls, for example, meeting user needs with respect to zoning and dimming.

Technology Options

Passive Infrared (PIR)

Passive Infrared or PIR technology on a basic level will detect movement patterns through a sensor. The technology works by picking up the obvious activity of human-sized heat sources to determine space occupancy. It fares less well at tracking finer movements, such as a person typing at their desk, and only "sees" in a straight line-of-sight, which is a problem when people are obscured by walls or objects. PIR is ideal for corridors and stairwells, but less effective as the sole source of occupancy control for large, complex office spaces.

Ultrasonic & Microwave

Ultrasonic & microwave technologies work on the principle of the Doppler Effect by emitting a high frequency wave and then listening for its return. The advantage of this type of sensing is that it is not line-of-sight dependent and it can work with fine movement. The disadvantage is that it is prone to false detection. The industry has moved toward a dual technology sensor that uses PIR to turn the lights on and ultrasonic to keep it on.

Photocell

There are two types of photocell, closed loop and open loop, neither of which has experienced much change since its inception. Open loop will dim lighting based on the quantity of available daylight as measured outside the building. Open loop sensors are great for exterior applications such as parking lots and high daylit spaces like atriums. Closed loop sensors will dim lighting based on the total availability of daylighting and electric lighting inside the building. Closed loop sensing configurations are better applied where changes within the building, such as the deployment of blinds or shades, impact daylight distribution independent of the outdoor sky conditions; and thus an exterior sensor would not appropriately adjust the lighting.

Application Options

Wireless

The current high-visibility trend in lighting controls is "wireless," which is not a method of automation technology, but an application change in how existing sensing technologies are applied. For example, you can have wireless lighting controls, but they will still be either PIR or Ultrasonic technologies.

Vacancy Sensor

Vacancy sensors are occupancy sensors that require manual operation to turn on. This method eliminates false detection and gives tenants the option to turn off lights during occupancy (e.g., during a screen presentation). In the absence of a completely new and reliable automation technology, methods like vacancy sensing are expected to become more commonplace.

For much more information on advanced lighting, please visit the following sites:

Advanced Buildings	http://patternguide.advancedbuildings.net
Advanced Lighting Guidelines	https://algonline.org
Illuminating Engineering Society	http://www.ies.org
Integrated Design Lab	http://www.cidseattle.com/idl/technical-assistance
Lighting Controls Association	http://lightingcontrolsassociation.org
Lighting Design Lab	https://www.lightingdesignlab.com
Lightsearch.com	http://www.lightsearch.com

CONCLUSION

The rapidly evolving marketplace for lamp and controls technology in the past 40 years has changed the lighting industry. With so many options available, it is more important than ever to clearly understand what is desired to be accomplished by the lighting and then properly match the technologies to those goals. Coupling lighting functionality and energy goals with the aesthetic opportunities that currently available illumination alternatives can offer raises this understanding to an art form.

The goal for the future is to make the light sources work cohesively with maximized and controlled natural daylight. Electric lighting designs need to analyze the various lamp technologies and control methods to determine the right solution for the application. While LEDs are not yet a one-stop solution, with their rapid increase in intensity, color metrics, controllability, and reliability; soon they very well could be. These solutions show significant promise for saving energy and providing light that enhances our architecture and positively affects human productivity, comfort, and health.