Innovative Photonics

Illumination Technologies

Energy Efficient LED Lighting Systems

Lighting systems represent up to 40% of the total commercial building energy consumption in the United States (versus only about 15% in residential settings). And of all the areas where potential commercial energy savings may be attained, lighting systems represent the area with the largest incremental potential. While the total savings far outweigh the higher initial capital costs, there has generally been a financial disconnect between the motivating factors of lighting contractors versus building owners/managers.

It is the purpose of this white paper to educate building owners/managers about recent trends in high quality, efficient, ***LED lighting systems*** that are being developed specifically for the commercial building sectors. Upon completion, the reader should be able to quantitatively understand and calculate the overall cost savings, the total reduction in energy consumption, and the reduction in environmental impact including mercury (Hg) and greenhouse gas (GHG) emissions for any specific project.

Fluorescent Lamps

Fluorescent lamps use only about 25% of the energy required by incandescent lamps, and they last up to 10 times longer. For this reason, they currently dominate the commercial lighting landscape. Emerging as a significant commercial lighting technology in the late 1930's, the fluorescent system utilizes a gas-discharge lamp that uses electricity to excite mercury vapor which then produces ultraviolet light. This ultraviolet light then causes a phosphor to fluoresce, producing visible light.

Figure 1: Standard 24" x 48" Fluorescent Drop-Ceiling Lighting Fixture

Although the lamps and ballasts required for this technology are significantly more expensive than incandescent lamps, this technology converts electrical power into useful light about 4 times more efficiently than an incandescent lamp, and therefore over time provides considerable savings. The workhorse of the commercial office setting is the standard 2' x 4' fixture (typically called a "troffer") that integrates seamlessly with standard drop ceiling panel systems. These fixtures are typically outfitted with four (4) T12 lamps which are powered by electronic ballasts.

The standard T12 lamp (12/8" or 1.5" diameter) draws 40W, so that these systems typically draw 160W per fixture, not including ballast efficiency which is typically as low as 80%. Therefore, these lamp fixtures typically draw about 200W of electrical energy and are designed to provide uniform illuminance of approximately 500 lux (~50 foot-candles) at a distance of 2 meters (the average distance from the ceiling tile to the surface of a desk). This is the recommended level of illuminance required in a well-lit office setting where detailed work is to be performed over long periods.

These 24" x 48" fixtures are the *de facto* standard in most United States commercial settings. There are currently more than 300 Million of these fixtures installed[1], and according to the US DOE about 60% of them are using the T12 standard[2]. Over the last 20 years there has been a concerted effort to increase the efficiency of these 4-foot fluorescent tubes, resulting in the development of the T8 standard (8/8" or 1" diameter) and the even newer T5 standard (5/8" diameter). Several generations of T8 based systems have improved both lamp and ballast efficiencies, with 5th generation systems delivering up to 40% energy savings. There are now more than 75 commercially available T8 lamps, and the number of different high efficiency ballasts exceeds 350[3].

Despite all of these improvements, as of 2008 only 30% of installations had implemented the more energy efficient T8 standard. Part of this is due to rate of change for new versus existing installations and the higher capital cost for retrofit conversions (40-50% increase in capital costs). At about the same time, two important disruptive events occurred. First, public opinion for the technology began to sour as the mercury hazardous waste issue began to surface. This sentiment rapidly evolved, even though the use of high efficiency fluorescent systems provides a net reduction in total environmental mercury release (significantly more mercury is released into the ecosystem by coal power plants than is released by fluorescent lamp disposal). While these new lamps have much lower mercury levels, the technical inability of these lamps to completely eliminate mercury from their product offerings has cast a shadow over the entire technology. At about the same time, LED (Light Emitting Diode) technologies made huge technical advances and successful commercial debuts. Together, these two concurrent factors raised serious doubts as to whether fluorescent systems would remain as the dominant lighting technology over the long-term.

[1] Modification of the Hazardous Waste Program: Hazardous Waste Lamps, Final Economic Assessment, Final Document., Post-OMB Review, Economics, Methods and Risk Analysis Division, Office of Solid Waste, U.S. EPA, March 11, 1999
[2] Consortium for Energy Efficiency, High Performance Commercial Lighting Systems Initiative, January 2008, p. 3
[3] Consortium for Energy Efficiency, High Performance Commercial Lighting Systems Initiative, January 2008, p. 5

The primary factors which determine precisely when LED technology will overtake fluorescent lighting in commercial market segments rely on three key issues:

1) STANDARDIZATION	*LED systems must be standardized (lamps and ballasts) so they may be installed in the same manner as existing fluorescent systems*
2) ENERGY SAVINGS	*LED systems must exceed the overall energy savings of the most efficient T8 systems*
3) COST	*LED systems must reduce initial capital costs and provide a clear advantage in reduced cost of ownership over their lifetime.*

After several years of R&D, Illumination Technologies (**IT**) has successfully designed and manufactured next generation LED lighting systems for the commercial market that address these three critical issues.

STANDARDIZATION of Commercial LED Luminaires

As mentioned, the primary standard for commercial office lighting is the 2'x4' light fixture that fits with standard US drop-ceiling panel systems. Therefore, **IT** has developed a simple drop-in replacement for these standard US fixtures. The UBerLED *LitePanel*™ is a single integrated unit that is only ½" thick (13mm) and weighs just under 21 lbs (9.5 kg). These long-lifetime panels provide extremely pleasing, high intensity light in the most energy efficient manner to date. And they offer a host of additional advantages.

Figure 2: UBerLED *LitePanel*™ for Commercial Office Settings

The design of these panels is such that contractors may use industry standard installation techniques, making the LED *LitePanel*™ an easy to integrate solution for any drop-ceiling project, including new installations and existing renovation/retrofits.

ENERGY SAVINGS for Commercial LED Luminaires

Figure 3 provides a simple efficacy comparison between these alternative technologies, and highlights the disruptive technology trajectory which has made these new LED alternatives commercially viable[4]. The peak efficacy obtainable by fluorescent lamp technology is about 100 lumens per watt, while the theoretical limit of white LEDs is nearly 300 lumens/watt. Within the past year, commercial white LEDs have been manufactured that exceed 150 lumens/watt, closely approaching the DOE's long-term R&D goal of producing cost-effective 160 lumens/watt devices by 2025. These factors have contributed to the rapid interest in adopting LED based systems as the technology platform for green energy initiatives.

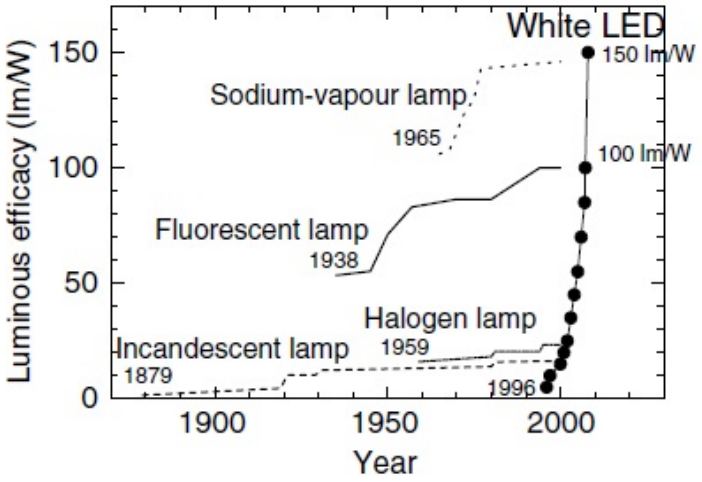

Figure 3: Efficacy of Various Light Conversion Technologies

Lamp efficacy is only one factor to consider when calculating energy savings. Ballast efficiency and luminaire efficiency (efficiency with which light is delivered to the working surface) also are major contributors. To understand the energy impact, one needs to compare the total power required of each lighting system to provide uniform illuminance (500 lux) at a distance of 2 meters. Typical results of these comparison tests[5] of are shown in Figure 4, and are consistent with the latest CALiPER findings published by the US DOE[6].

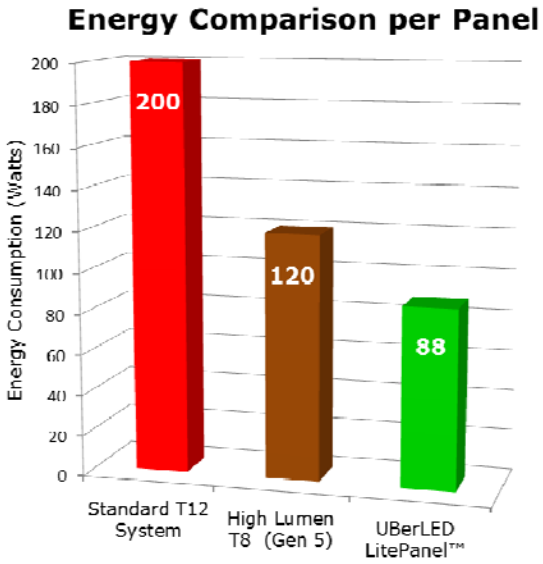

Figure 4: Energy Comparison in Commercial Office Settings

[4] Yukio Narukawa, et al., Journal Applied Physics D, 43, August 2010
[5] Illumination Technologies Testing Laboratories, October 2011
[6] Commercially Available LED Product Evaluation and Reporting http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/troffer_benchmark_01-09.pdf January 2009

These results suggest a 55% reduction in energy consumption when replacing the installed base of T12 systems (our primary target market space with an installed base of 180 Million troffers). The current energy consumption for all existing installed T12 based is approximately 34.5 Million kW-hrs/year (34.5 TW-hrs/year)[7]. Assuming that all these T12 systems were replaced with UBerLED *LitePanels*™ the annual impact would be as shown in column 2. The third column provides the value for a single panel (multiply the numbers in this column times the number of panels to be installed to estimate the environmental impact of any specific project).

	Annual Reduction (totals for US Market)	**Annual Reduction** (per panel)
Electrical Energy Savings	19 Million kW-hrs	290 kW-hrs
Operating Cost Savings ($0.10 per kW-hr)	$1.9 Trillion (USD)	$29
Green House Gas Emission (.61 metric tons/megawatt-hour)[8]	11.6 Billion Metric Tons	176 kg
Reduction in Mercury Release (21mg/lamp, 4-year lamp life)[9]	3,780 kg	21 mg

CAPITAL COST Comparison for Commercial LED Luminaires

There are many factors which can affect the capital cost of these 2' x 4' troffers. For the sake of approximate comparison, a 'typical' uninstalled system, complete with lamps and ballasts are given below:

2'x4' Troffer System (4-lamp/500 lux @ 2m)	**Typical System Cost** (1 piece, w/Lamps & Ballasts)	**Payback Period** (in years, upgrade from T12 system, 2600 hrs/yr operation)
T12 System	$200	-
T8 System	$250	2.4
T5 System	$350	5.2
UBerLED *LitePanel*™	$450	8.5

These conservative estimates illustrate why purely economic factors have not been the primary motivating factor for conversion to these more efficient standards. In the case of the UBerLED *LitePanel*™, the higher entry cost is due to the new nature of the technology and the relatively low production volume. We expect this pricing to follow a "Moore's Law" type of trajectory as increased demand drives production economics.

[7] US Lighting Market Characterization Study, Volume I: National Lighting Inventory and Energy Consumption Estimate, Office of Energy Efficiency and Renewable Energy U.S. Department of Energy 2002

[8] Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation, Energy Information Administration, Office of Integrated Analysis and Forecasting, Energy Information Administration, U.S. Department of Energy, April 2002

[9] Mercury Emissions from the Disposal of Fluorescent Lamps, Final Report, Office of Solid Waste, U.S. Environmental Protection Agency, Table 2-2, 1997

LIFETIME

The lifetime of LED based systems is generally much longer than that for fluorescent systems. A properly designed LED panel system has a lifetime in excess of 50,000 hours (20 years under normal office conditions, 70% lumen maintenance). While some of the newest fluorescent tubes have a 20,000 hour specification, they age much more rapidly when switched ON and OFF frequently. The reduction is caused by cathode erosion during the start of each lamp cycle, and can reduce lamp lifetime by factor of 2 or 3. LED based systems experience no deleterious effects from turning ON or OFF. Additionally, fluorescent tubes eventually fail to start and must be replaced. Under normal life, LEDs continue to degrade in output, but may still provide up to 50% of their initial lumen output at for more than 100,000 hours.

ADDITIONAL ENERGY CONSIDERATIONS – SMART CONTROL

Unlike fluorescent systems, LED systems may be cycled and dimmed without any negative effect. In fact, dimming these LED devices provides enhanced lifetime and even further energy savings. Turning systems off completely when no inhabitants are in an office or space can further improved energy saving and systems lifetimes.

The UBerLED *LitePanel*™ product line has several ballast offerings that can further reduce energy consumption in the following manners:

- Onboard Real-time monitoring of room illuminance values that adjusts panel power, allowing the luminaire to automatically dim to lower levels when natural lighting is at peak levels, thereby further reducing power consumption
- Onboard Real-time monitoring of room occupancy that controls panel power, allowing the luminaire to automatically turn OFF when there are no occupants present after a specified period, thereby further reducing power consumption.'
- Real-time interface for smart building management systems that can control ON/OFF timing and also perform smart dimming functions from central control facilities
- Internet protocol-addressable ballasts for remote system control in intelligent building management systems, with software-updatable capability for futures changes to features and/or operation
- Low power standby mode (~ 10 mW) using state-of the art buck buck power supply topology

COLOR & CHROMATICITY

Fluorescent systems come in a variety of color temperatures, depending on the phosphor blends used. LED based systems may also be specified to provide a range of correlated color temperatures from about 3000K to 6500K, although the lower color temperature devices are generally 10-15% less efficient than the 6500K devices used in the comparison within this document. For most commercial office settings, the 6500K provides a very productive and high brightness environment for performing typical office tasks. In applications where true color rendering is important (graphics, printing, publishing, etc.) a warmer correlate color temperature is usually desired (4000-5000K). These 'intelligent' lamps offer many additional functional opportunities including color-temperature control, color-mixing, power monitoring, end-of-life prediction, and occupancy response.

MANDATES & OPPORTUNITIES

Effective 1 July 2010 the US DOE fluorescent lighting mandate began restricting the production of the magnetic ballasts most commonly used for the operation of T12 lamps for all commercial and industrial applications. Beginning 1 July 2012The mandate further phases out many of the T12 lamps used in these systems. Once the DOE mandate becomes effective, it will become common practice to remove less efficient T12 systems, and this is our primary target market. Early adopter should include government offices, school districts, and military installations. There are a variety of State and Federal Energy Efficiency Fund incentive programs (some rebate up to 50% of the cost) that will support these commercial industrial T12 system retrofits. There are also many rebates available to building owners and operators when specifically installing LED fixtures, especially if these systems can demonstrate the ability to decrease energy demand at peak hours. The UBerLED *LitePanels*™ have the ability to dim in a very efficient manner, and also have occupancy sensing options.

SAFETY

Fluorescent lamps contain quantities of mercury sufficient to fail the Toxicity Characteristic (TC) and are regulated as hazardous wastes under the US Resource Conservation and Recovery Act (RCRA). Management and disposal of fluorescent light bulbs by commercial entities are regulated under Universal Waste Rule (UWR) and Subtitle C hazardous waste regulations. As a result, all fluorescent lamps are currently subject to manifesting and disposal requirements.

The Code of Federal Regulations (CFR) and the National Fire Protection Association (NFPA) both require that live parts of electric equipment operating at 50 volts or more be guarded against accidental contact by approved enclosures, locations, and partitions. Unlike fluorescent systems, the UBerLED *LitePanel*™ systems operate at 42VDC, and do not require any high voltage for start-up or operation.

ULTRAVIOLET RADIATION

Fluorescent lamps emit a small amount of ultraviolet (UV) light. A US study found that UV exposure from sitting under fluorescent lights for eight hours is equivalent to only one minute of sun exposure[10]. While this is only an issue for individuals with highly sensitivity to UV radiation, the levels are sufficient to affect sensitive paintings (especially watercolors) and many textiles. The white LEDs used in the UBerLED *LitePanel*™ product line emit no UV radiation.

OTHER FACTORS

In some circumstances, especially older T12 systems with magnetic ballasts, the fluorescent lamps may produce flicker at the mains frequency (50 or 60 Hz), which can be very annoying to many people. Flicker can also happen in many systems as the lamps age, and is caused as the cathode emission coating begins to degrade. The UBerLED *LitePanel*™ product line operates from precision current controlled ballast that provides DC current to the LED panel and therefore is very stable output with no flicker.

There are a lot of rebates available to building owners and operators to install LED fixtures, and a lot of that [motivation] is driven by decreasing their demand at peak hours. LEDs have the ability to dim in a very efficient manner and also to do occupancy sensing.

MILITARY APPLICATIONS

LED panels provide many options in military settings due to their high vibration and mechanical shock resistance. In addition, they may be easily designed to switch back and forth between white to red for a variety of battlefield and shipborne applications.

COLD WEATHER INSTALLATIONS

Fluorescent systems do not perform well in cold environments. The UBerLED *LitePanels*™ perform more efficiently the colder they are operated.

[10] Lytle et al., "An Estimation of Squamous Cell Carcinoma Risk from Ultraviolet Radiation Emitted by Fluorescent Lamps"; Photodermatol Photoimmunol Photomed (1993)