Alternatives to Standard HID Lighting in Industrial Facilities

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ABSTRACT

Traditionally, a large percentage of industrial facility lighting has been performed by standard high intensity discharge (HID) fixtures, including metal halide and high-pressure sodium. Recent developments have led to lighting technology innovations that can profoundly reduce energy consumption while improving illumination quality from industrial facility lighting systems. Pulse start metal halide fixtures have been available for several years and can provide the same light output and color rendering as traditional metal halide fixtures, but with dramatic reductions in power input and significant improvement in starting times. New controllable HID ballasts, combined with automatic control technologies, allow for further energy savings. These ballasts can be controlled manually, by occupancy sensing, with astronomical timing panels, or any combination of the above. High performance fluorescent fixtures allow even greater energy savings through enhanced control strategies, as well as dramatically enhanced color rendering and lumen maintenance. Fluorescent fixtures utilizing standard and high-output (HO) T-8 lamps are a frequently overlooked viable alternative to HID lighting systems. A new generation of compact fluorescent fixtures, as well as T-5 HO fixtures provide exciting alternatives allowing a level of optical control previously unavailable with fluorescent lighting. Design and control strategies focused on performed tasks can often offer energy savings and lighting performance advantages that are even greater than those offered through simply changing to new light source technologies. These topics will be discussed at length in this paper.

Introduction

Traditionally, a large percentage of industrial facility lighting has been performed by standard high intensity discharge (HID) fixtures, including metal halide and high-pressure sodium. Recent developments have led to lighting technology innovations that can profoundly reduce energy consumption while improving illumination quality from lighting systems in industrial facilities.

Pulse-start metal halide fixtures have been available for several years and can provide the same light output and color rendering as traditional metal halide fixtures, but with dramatic reductions in power input and significant improvement in starting times. This step is only the first in the improvement of industrial lighting. New controllable HID ballasts combined with automatic control technologies allow for multi-level and continuous dimming of HID fixtures. These ballasts can be controlled manually or automatically with occupancy sensing, astronomical timing panels, daylight sensors, or any combination of the above.

High performance fluorescent fixtures allow even greater energy savings through enhanced control strategies, as well as dramatically enhanced color rendering and lumen maintenance. Although fixtures utilizing standard and high-output (HO) fluorescent lamps have become standard practice for commercial lighting, they are frequently overlooked as a viable alternative to HID lighting systems for industrial applications. A new generation of compact fluorescent fixtures, as well as T-5 HO fixtures provide exciting alternatives, allowing a level of optical control previously unavailable with fluorescent lighting.

Design approaches have also advanced to allow lighting to be tailored to the workstation, rather than the entire room or facility. Design and control strategies focused on the performed tasks can often offer energy savings and lighting performance advantages that are even greater than the advantages offered through simply changing to new light source technologies.

In this paper we will discuss the latest innovations in lighting systems and design approaches that are applicable to industrial facility spaces. All of the above listed technologies will be described at length. The paper will also discuss significant factors in assessing the quality of lighting for industrial process spaces.

Standard HID Fixtures

HID lighting has been a standard in industrial lighting since the 1960's. At the time of introduction, HID lighting offered many dramatic advantages over the various incandescent light sources that were the standard for industrial applications. The improved efficacy of HID lamps allowed fewer fixtures of lower wattage to be installed, and longer lamp life greatly reduced maintenance costs.

All HID lighting fixtures share a number of basic design features. Each type features an electric-discharge lamp powered by a magnetic or electronic ballast. The lamp relies on a light-producing arc that is stabilized by the lamp's wall temperature. HID lamps include the lamp groups mercury vapor, metal halide, and high-pressure sodium.

Lamp Types

Mercury vapor. An HID source in which the major portion of the light is produced by radiation from pressurized mercury vapor. Mercury vapor lighting was once the standard for color correct HID lighting. It has now been replaced by metal halide lighting for most applications.

Metal halide. An HID source in which the major portion of the light is produced by radiation of metal halides, often in combination with metallic vapors such as mercury. Metal halide is often used for industrial lighting not involving critical tasks. Pulse-start is one type of metal halide lighting.

High-pressure sodium. An HID source in which light is produced by radiation from pressurized sodium vapor. High-pressure sodium lighting is very popular for outdoor site lighting, but is also used in low-bay and high-bay storage areas. It is now the opinion of most lighting designers, including the authors, that because of poor color rendering, high-pressure sodium is not a good choice for illuminating industrial areas where work is routinely performed.

Problems Associated with Standard HID Lighting

Glare. Direct and indirect glare are both significant problems in the workplace. Direct glare is associated with the discomfort experienced when bright light fixtures enter the worker's field of view. Indirect glare is caused when direct glare is reflected off working surfaces, paper, floors, and walls.

Direct glare. Direct glare is caused by excessive brightness at the light fixture compared with the surrounding area. An extreme example of direct glare is the discomfort from an oncoming automobile's high beams on a dark stretch of road. Lighting fixtures that produce a concentrated amount of light in a small area with little or no shielding produce the most amount of glare. Since all HID lighting is "point-source" lighting of high intensity, they are the most glare prone fixture style commonly used in industrial environments. Open fixtures with opaque reflectors produce the most amount of direct glare, whereas fixtures with prismatic lenses and/or transparent reflectors tend to reduce direct glare somewhat. Indirect HID fixtures often produce the least glare of the various HID fixture types.

Indirect glare. Indirect glare is closely associated with direct glare. However, indirect glare is much more dependant on the working surroundings and the work subject/s. For instance, a highly polished light-colored floor will produce much more indirect glare than a dull gray floor, although more light will also be reflected into the working environment. The object being worked on also has a dramatic impact on indirect glare. For example, a worker assembling white fiberglass boat hulls will experience much more indirect glare from HID fixtures than the same worker would experience assembling "battleship gray" boat hulls. It is important to consider the task when considering the effects of indirect lighting.

Long lamp starting time. All HID lighting relies on the striking of an electrical arc that in turn excites a pressurized vapor. It takes a significant amount of time (generally up to 10 minutes) for the lamps to reach an illumination level that is near full brightness. This start-up time is further lengthened when the lamps are restarted when warm, such as following a brief power outage. This problem creates a situation where the lighting is continuously illuminated whether a space is actively in use or not. It is not uncommon to encounter industrial spaces illuminated with "efficient" 400-watt HID fixtures 24 hours per day to support 4 hours of actual "occupied" working time. Energy could be saved in such a space by replacing the "efficient" HID fixtures with "inefficient" 1,000-watt incandescent fixtures that are illuminated only when needed.

Traditional HID fixtures are difficult to control. A problem that is closely associated with long lamp start-up problems is that HID fixtures are difficult to control. As discussed above, they cannot be manually turned on as needed. This same factor means they are not compatible with occupancy sensors that are used to automatically control fluorescent and incandescent lighting sources. In addition, the light output of traditional HID fixtures cannot be varied through Hi/Low or continuous dimming.

Slow restrike. As mentioned in the discussion on slow lamp start-up, HID lamps are especially slow to restart (re-strike) after they have been off for a brief period and the lamps are still warm. This is a serious safety issue, especially in areas that commonly experience brief power outages (even outages as brief as a fraction of a second triggers a re-strike). This problem is usually dealt with by installing a second incandescent (usually quartz) light source in a portion of the fixtures. This second source is designed to be illuminated only during a re-strike situation.

Poor color rendering. According to the Illuminating Engineering Society (IES), color rendering is "the general expression for the effect of a light source on the color appearance of objects in conscious or subconscious comparison with their color appearance under a reference light source." To express it more simply, color rendering is the ability of artificial lighting to render colors accurately. This ability is measured on a (0-100) scale called the Color Rendering Index (CRI). Lighting that provides poor color rendering is difficult to work under because work-piece contrast is reduced, and the eye/brain is constantly attempting to correct for color. High-pressure sodium lighting suffers from particularly poor color rendering abilities. Table 1 illustrates the color rendering capabilities of various HID and fluorescent light sources.

Table 1. Color Rendering Abilities of Popular Lamp Types

Lamp Group	Lamp Type	CRI	Notes
HID	High Pressure Sodium	21-25	
	Color Corrected High Pressure Sodium	60-85	Decreased life and light output
	Mercury Vapor	20-45	
	Metal Halide	65-70	
	Color Enhanced Metal Halide	75-80	Decreased life and light output
	Pulse Start Metal Halide	65-70	
Fluorescent	4' T-12 34 watt Lamp	50-62	
	4' T-12 34 watt Lamp "Color Enhanced" Lamp	70-80	
	4' T-8 700 Series Lamp	72-75	
	4' T-8 800 Series Lamp	82-85	
	4' T-8 900 Series Lamp	90-94	Decreased light output
	8' T-8 Lamp	72-85	
	8' T-8 H.O. Lamp	72-85	
	40" T-5 H.O. Lamp	80-85	
	40 watt compact fluorescent lamp	82-85	

As the table illustrates, standard HID lighting, and in particular high-pressure sodium and mercury vapor lighting, provide poor color rendering when compared with modern fluorescent options. Enhanced or "corrected" HID sources can rival fluorescent sources, but with their improved color rendering comes decreased light output and decreased lamp life.

Lamp flicker. With very few exceptions, HID lamps are powered by magnetic ballasts. Magnetic ballasts create lamp flicker at a factor of two times the operating electrical frequency. In the United States, the frequency is 60 Hertz, creating a lamp flicker of 120 times per second. The flicker is barely noticeable to the human eye, but can become bothersome when lamps and/or ballasts are near the end of their useful life. Some people are bothered by lamp flicker even from new lamps and ballasts, and some behavioral scientists claim that all humans are adversely affected by lamp flicker. Studies are now underway to determine if lamp flicker, along with poor color rendering, contribute to "sick building syndrome."

For most work environments, lamp flicker is considered an annoyance. But in a production environment, it can create a dangerous situation called sympathetic stroboscopic flicker. Sympathetic stroboscopic flicker occurs when the lamp flicker sympathizes with a rotating work piece, making the work piece appear to be static. This phenomenon can also occur with fluorescent fixtures operating on magnetic ballasts, but electronic ballasts are now much more common in fluorescent lighting sources.

Limited vertical illumination: Simple lighting design usually concerns itself mainly with the amount of light (illumination) delivered to a surface. This surface is usually an imaginary work plane 2 ½ feet from the floor. HID lighting, especially in areas with high ceilings, is one of the most efficient fixture types for the delivery of horizontal illumination. However, in an industrial environment, it is often equally important to illuminate the vertical working surfaces (vertical illumination). An example of this is illuminating an aisle in an active warehouse. Shelves of goods are typically stacked almost to the ceiling with 5'-10' wide aisles for order picking. Ceiling heights are usually 20-40 feet, but can sometimes reach 75 feet. Metal halide fixtures with a full opaque reflector delivering a concentrated light beam are often utilized to deliver the most amount of light for the least amount of energy at the imaginary work-plane. When this strategy is used, one result is that the upper shelving is very poorly illuminated because most of the light is being projected straight down. Specially designed HID fixtures, such as "aisle-lighters", can be used to reduce this effect, but fluorescent lighting is also an effective strategy for the improvement of vertical illumination.

New Options to Traditional HID Lighting

Pulse Start Metal Halide

Although low wattage metal halide lamps (under 150 watts) have always used pulse start technology, the extension of this technology to higher wattage metal halide lighting is quite recent. All HID lamps incorporate an arc tube where an electrical arc discharge is created to excite the vapor to produce light. In an effort to produce shorter start times, metal halide lamps with formed arc tubes have been developed. Formed body arc tubes do not have room to accommodate the starter electrode in the pinched body arc tube lamps, so a separate igniter powered by a special pulse start ballast is employed. The igniter is a low current/high voltage generating device that provides enough voltage across the main electrodes to cause an arc, starting the lamp. This starting voltage is called a "pulse" and the lamp indeed starts and warms-up much faster (approximately 60% faster) than their standard metal halide counterparts.

Table 2 presents a comparison of standard metal halide lamps and their pulse start alternatives.

Table 2. Comparison Between Standard Metal Halide and Pulse Start

Lamp Type	*Ballast Type*	*System Wattage*	*Mean Lumens*	*Rated Life*	*Lamp Type*	*Ballast Type*	*System Wattage*	*Mean Lumens*	*Rated Life*
175W Metal Halide	CWA*	205	10,500	10,000	150W Pulse Start	Linear Reactor	172	11,300	15,000
						CWA*	190	11,300	15,000
					175W Pulse Start	Linear Reactor	190	14,000	15,000
						CWA*	208	14,000	15,000
250W Metal Halide	CWA*	295	17,000	10,000	200W Pulse Start	Linear Reactor	218	16,800	12,000
						CWA*	232	16,800	12,000
					250W Pulse Start	Linear Reactor	265	21,000	15,000
						CWA*	288	21,000	15,000
360W Metal Halide	CWA*	430	26,000	10,000	320W Pulse Start	Linear Reactor	345	27,200	20,000
						CWA*	365	27,200	20,000
400W Metal Halide	CWA*	455	28,800	12-18,000	350W Pulse Start	Linear Reactor	375	30,400	20,000
						CWA*	400	30,400	20,000
					400W Pulse Start	Linear Reactor	430	35,200	20,000
						CWA*	455	35,200	20,000
750W Metal Halide	CWA*	825	50,000	10,000	750W Pulse Start	Linear Reactor	805	No Data	No Data
1000W Metal Halide	CWA*	1,075	88,000	10,000		CWA*	850	No Data	No Data

Although pulse start lamps still present the same glare, vertical illumination, and control problems, the combination of the "pulse" current and the formed arc tube does provide several other advantages:

Greater efficacy (lumens per watt). Because the shape of the arc tube allows more halides to be pulled into the arc stream, pulse start lamps produce more light than their equivalent standard metal halide lamps. At most wattages, pulse start lamps produce approximately 20% more light than their standard counterparts.

Improved lumen maintenance. The formed arc tubes tend to allow less buildup of carbon on the arc tube allowing for better lumen maintenance (the lamps stay brighter over their useful life). Some manufacturers claim that lumen maintenance is improved by as much as 40%, although this figure is probably optimistic.

Longer lamp life. Many pulse start lamps are rated for 15,000 hours, whereas most standard metal halide lamps are rated for 12,000 hours. This increase in useful life is also due to the decreased buildup of carbon on the arc tube surfaces.

Color uniformity. Metal halide lamps tend to "color-shift", leading to differing lamp "colors" within the same fixture array. Although pulse start lamps offer the same nominal color temperature and color rendering as standard metal halide lamps, they tend to offer more stable color balance.

Fluorescent Alternatives

With the introduction of metal halide lighting during the 1960's, fluorescent lighting began to lose market share for industrial lighting, especially for facilities with ceiling heights of 20' or more. Metal halide offered better lamp efficacy (lumens per watt) than the T-12 fluorescents of the 1960's. With fewer fixtures needed, they were cheaper to install. In addition, compared with fluorescent technologies of the 1960's, metal halide offered the same color rendering as standard fluorescent sources. With the much lower electric prices of the 1960's, there was little concern that long warm-up times would lead to lamps being left on for long time periods.

Many changes have taken place since the 1960's in regards to both lighting technologies and energy costs. Many of these changes have brought fluorescent technologies back into a very competitive situation with metal halide lighting. Some of the changes that have been most influential in the comeback of industrial fluorescent lighting include the following.

- Dramatic increase in electrical rates, encouraging the turning off of lighting in temporarily unoccupied spaces.
- Improvements in the output of fluorescent lamps.
- Improvements in the color rendering abilities of fluorescent lamps.
- The development of T-8 and T-5 lamps that allow fluorescent lighting fixtures to be designed for more projection.
- The development of electronic ballasts for fluorescent lamps, allowing for greater lamp efficacy and the elimination of lamp flicker.
- The development of occupancy sensing lighting controls that interface well with fluorescent, but not HID, sources.

Premium T-8 fluorescent lighting. With the increase in electric rates experienced in the 1970's, the first attempts at reducing the consumption of fluorescent lighting were in the development of low energy versions of standard T-12 lamps. These lamps, sold under such trade names as "Econo-Watt" and "Watt-Mizer" save about 15%-20% of the energy consumed. Unfortunately to accomplish this reduction, a corresponding 10%-15% loss of lumen output is also experienced. Similarly, the first generation of energy saving ballasts also reduced energy consumption and light output by corresponding factors.

When T-8 lamps were developed during the 1980's in Europe, they managed to improve on the energy consumption of T-12 lamps while also increasing light output. The T-8 fluorescent lamps are a family of 1" diameter linear tube lamps manufactured in some of the same lengths as T-12 lamps. The smaller diameter makes it economical to use the more efficient and more expensive rare-earth phosphors. The smaller diameter also allows better optical control through the design of fixtures that more efficiently reflect the illumination to where it is needed. This advantage is important, as fluorescent lighting is a diffuse form of lighting that is hard to shape and project.

Although T-8 lamps can be operated on certain line-frequency rapid-start ballasts, they are specifically designed to operate on high-frequency electronic ballasts, allowing for improved lamp efficacy and the elimination of all lamp flicker.

The first T-8 lamps offered color rendering performance of approximately 72 CRI, only a slight improvement over metal halide. However, the development of 800 series T-8 lamps increased light output by about 10% while boosting color rendering to 85 CRI (see

Table 1). The 800 series lamps in industrial fixtures with integral reflectors are preferred over metal halide low bay fixtures in areas with ceiling heights of 20 feet or less.

T-8 high output fluorescent lighting. At ceiling heights greater than 20' and in areas requiring high illumination levels, it becomes difficult to design effective lighting utilizing standard output T-8 lamps. T-12 high output lamps suffer from poor lumen maintenance. For this reason, along with all the reasons given for the development of standard output T-8 lamps, high output T-8 lamps were developed. These lamps offer the same efficacy and color rendering abilities as their standard output counterparts, but output, along with energy consumption, has been boosted by approximately 50%. High output T-8 lamps teamed with electronic ballasts and efficient industrial fixtures are an excellent choice for industrial areas with ceiling heights ranging from 14' to 30'.

T-5 fluorescent lighting. Just as T-8 lamps offer an advantage in optical control over T-12 lamps, T-5 fluorescent lamps, in turn, offer an optical control advantage over T-8 lamps. T-5 fluorescent lamps are a family of 5/8" diameter linear tube lamps employing tri-phosphor technology. Currently available only in metric lengths, T-5 lamps provide a higher source of concentrated brightness than T-8 lamps, allowing improved optical control. T-5 lamps are designed to operate solely on electronic ballasts. The lamps provide optimum light output at an ambient temperature of 35°C (95°F) rather than the more typical 25°C (77°F), allowing for the design of very compact lighting fixtures. High-output versions of T-5 lamps are also available providing approximately twice the lumens of standard versions.

There has been a lot of misinformation concerning T-5 lamps, including common claims that they offer better lamp efficacy and better color rendering than T-8 lamps. These claims are untrue, as these performance factors are almost identical to 800 series T-8 lamps. However, the improved optical control and the ability to use shallower fixture depths offers real advantages in designing efficient lighting fixtures for industrial facilities. There is an extremely active move in the lighting industry to design compact T-5 fixtures for industrial and sport lighting applications in high ceilings areas.

Compact fluorescent high and low bay fixtures. Compact fluorescent lamps (CFLs) were originally designed to be direct replacements for conventional 25- to 100-watt incandescent lamps. However, with recent advances in CFL lamp and fixture design, this lamp type includes sizes that replace conventional fluorescent lamps as well as HID lamps.

Presently, compact lamp sizes include wattages from 5 to 55 Watts. It is only the high power versions (28 watts and above) that are of interest for industrial lighting design. Because of the high power density in these lamps, high-performance phosphors are used extensively in order to enhance brightness, lumen maintenance, and color rendering ability.

Until very recently, lighting designers would never have recommended compact fluorescent lighting for industrial applications. Many lighting designers have been highly skeptical about the use of CFL technology for industrial lighting applications. However, the recent introduction of multi-lamp, electronically ballasted, high and low bay fixtures offers a new viable alternative for industrial environments.

Since fluorescent lighting is not "point-source" lighting, it is difficult to focus and project to the desired surface. Like the T-5 linear lamps (most CFLs are "folded" T-5 tubes), the compact nature of the lamp makes it easier to design lighting fixtures that provide improved optical control.

There are several advantages offered with advanced CFL technologies.

- ❑ **Better Lumen Maintenance:** High wattage compact fluorescent T-8 and T-5 lamps paired with electronic ballasts lose about 15-20% of their initial output during their lifespan. Metal halide lamps lose as much as 40%.

- ❑ **Reduced Glare**: Because metal halide and mercury vapor are point source lamps, they create more direct and reflected glare than do diffuse sources such as fluorescent.

- ❑ **Better Vertical Illumination:** Metal halide projects light very well to a surface. However, at levels between the fixture and the working plane, the light becomes more variable the closer you get to the fixtures. This is because of the pronounced cone effect of projected light. Fluorescent sources can do a better job of illuminating the vertical plane.

- ❑ **Lamp Burnout is Not as Critical**: With metal halide lighting, each fixture contains one lamp. If a lamp burns-out, immediate replacement may be necessary. Fluorescent industrial fixtures typically contain from 1 to 8 lamps and a single lamp burnout is much less noticeable.

- ❑ **No Lamp Flicker:** All lamp flicker is eliminated when fluorescent lamps are paired with electronic ballasts.

- ❑ **Better On/Off Controllability:** With virtually none of the warm-up time associated with HID lighting, fluorescent lighting can be turned on and off as needed, either manually or with automatic controls.

- ❑ **Multi-Level Lighting**: With metal halide lighting, only one or two lighting levels are possible. The typical 8-lamp CFL fixtures allow up to four different lighting levels without the use of dimming ballasts.

Listed below are some of the disadvantages and limitations encountered with using advanced fluorescent lighting technologies.

- ❑ **Poor Cold Environment Operation:** HID lighting is often utilized in cold ambient temperature industrial environments such as loading docks and food storage areas. For areas that experience temperatures below 50F, ballast and lamp combinations must be carefully chosen. Fluorescent lamps and ballasts not designed for colder environments may fail to start, or may be slow to start and operate poorly. Slow lamp starting is a common cause of shortened lamp and ballast life.

- ❑ **Limited Lamp Life:** Although there are exceptions, HID lamps generally have a longer operating life than fluorescent lamps. Most popular metal halide lamps are rated for an average life of 20,000 hours, while most 8' T-8 lamps and high wattage CFLs are rated for 15,000 – 18,000 hours. Of course the shorter lamp life can often be offset if the greater controllability of the fluorescent lighting allows it to be turned off for longer time periods.

- ❑ **Limited Optical Control for Projection:** Although there is ongoing design improvement affecting the ability of fluorescent lighting to be controlled and projected, HID and incandescent lighting remain as the light sources providing the best opportunity to control beam spread and projected light.
- ❑ **Higher Initial Investment Cost:** Standard HID lighting, as well as pulse start lighting, has been slowly coming down in price. Many HID high-bay fixtures are available in the $100-$175 price range. High performance fluorescent options are more expensive, with most fixture types ranging from $200 - $350. In addition, it is often necessary to install a greater number of fluorescent fixtures than HID fixtures.

Automatic Lighting Controls

Automatic lighting controls can have a tremendous impact on the overall savings of a properly designed efficient lighting system. There are control options available for both HID and fluorescent lighting technologies.

Automatic Lighting Controls for HID Lighting

As previously stated, HID lighting does not lend itself to automatic on/off controls because of lengthy warm-up times. However, there are some relatively new control options that can help reduce the energy consumption of HID lighting systems.

Occupancy controlled high/low bi-level HID systems. Recently developed HID fixtures and retrofit kits allow metal halide and high-pressure sodium lamps to operate at two distinct lighting levels. Typically, the bi-level fixture will operate at the normal full nominal output as well as operate at 50% of the system wattage. Depending on the actual ballast and lamp combination, the lamp delivers 25-35% of full illumination when operating at 50% wattage.

The ballasts in standard HID fixtures are controlled by single-pole capacitors. The bi-level systems incorporate a dual pole capacitor within the ballast box. This dual pole capacitor is the primary component in bi-level retrofit kits.

Either pole of the capacitor could be selected manually in order to select the proper light level. Typically, however, the selection is done with an occupancy sensor that "ramps" the fixture up to full bright upon space occupancy and returns it to 50% power shortly after the space is vacated.

This type of bi-level system is very useful in warehouse situations where each aisle can be controlled, allowing only occupied aisles to operate at full wattage/brightness.

Daylight harvesting high/low bi-level HID systems. This type of system utilizes the exact same bi-level ballast system as the above-described occupancy-controlled system. However, the occupancy sensor is replaced by a daylight harvesting sensor that senses the amount of available daylight and reduces the fixture wattage to 50% when an adjustable daylight threshold is obtained. This system is very effective in buildings that incorporate skylights or monitors for daylighting. The proper placement and adjustment of sensors is critical for the successful implementation of this approach.

Daylight harvesting continuous dimming systems. These systems use the same type of daylight harvesting sensor as the bi-level system. Instead of reacting to a lighting threshold, the fixture is "dimmed" over a predetermined range as it reacts to the input from the daylight sensor. The dimming range is usually around 30-100% of system wattage. As with the high/low systems, there are efficiency losses at the dimmed settings causing the lumen output to be lower as a ratio of full output than the wattage is as a ratio of full wattage. These systems are significantly more expensive than high/low systems. As such, they have not been very successful in the marketplace.

Automatic Control Systems for Fluorescent Lighting Systems

As previously discussed, one of the prime advantages of fluorescent lighting is its compatibility with automatic control systems. Because of the rapid warm-up times, fluorescent lighting systems are much more adaptable to automatic controls than are HID systems. Many different options are available for automatic control of fluorescent lighting. Some of these options require the use of special ballasts; some do not.

Occupancy controlled on/off systems. Occupancy sensors can control entire lighting circuits or any portion of a lighting circuit. They are available in many versions, from simple line voltage wall switch replacements to low voltage remote mounted sensors that interface with an energy management system. Only ceiling/remote mounted occupancy sensors are appropriate for industrial lighting situations.

Ceiling mounted occupancy sensors are available in three general versions: passive infrared, ultrasonic, and a hybrid of both of these types known as "dual-technology" sensors. Passive infrared sensors work best in large open areas where few solid walls are available for the reflection of sound waves. For walled areas, dual technology sensors are usually the most reliable choice.

All occupancy sensors incorporate field adjustable time delays so that the lights will not immediately turn off when someone leaves the area. This prevents unnecessary cycling of the lighting and will allow a worker in areas "hidden" to the sensor to finish their task before the lights turn off. In addition, most sensors incorporate field adjustable sensitivity so that the "reach" of the sensor will not turn the lights on when there is movement in an adjoining area.

On/off occupancy sensors should not be relied upon for lighting control in areas where worker safety is a primary concern. These spaces primarily involve production space, which is usually too frequently occupied for on/off occupancy sensing.

Secondary industrial spaces such as warehouse, storage, break rooms, and production offices are often perfect candidates for occupancy sensing. 25-50% energy consumption savings are not uncommon.

Occupancy controlled multi-level lighting. This control type uses exactly the same type of sensors for the same space types as the on/off occupancy system. However, this system does not turn off all the lights in each fixture upon vacancy. This scenario is usually accomplished by installing more than one ballast per fixture. A typical example is a three-lamp fixture with a one-lamp ballast and a two-lamp ballast. The occupancy sensor would turn off two of the lamps upon vacancy, leaving one lamp lit for security or safety reasons. Multi-level switching ballasts are also available that can switch individual lamps in response to a signal from the occupancy sensor.

Occupancy controlled dimming. Operation of this system is similar to that of the occupancy controlled multi-level system, except that the entire fixture dims in response to the sensor, rather than turning lamps off. This fixture type is particularly useful in situations where the space receives repeated occupied and vacant cycles throughout the day. In this situation, switching lamps on and off repeatedly causes shortened lamp life that diminishes any savings obtained through lower energy consumption. The dimming ballast has no adverse effect on lamp life. The lamps are usually dimmed to about 10-20% output upon vacancy.

Daylight harvesting on/off systems. As with daylight harvesting systems for HID lighting, a daylight-harvesting sensor senses the amount of available daylight. However, instead of reducing the fixture wattage, the lighting fixtures are turned off when an adjustable daylight threshold is obtained. An adjustable "lag" prevents the fixture from cycling quickly during variable daylighting conditions. Like the HID system, this system is also used in buildings that incorporate skylights or monitors for daylighting. Another efficient design using this system involves controlling lighting fixtures within 10' of glazed exterior walls, while the rest of the lighting fixtures in the space are controlled by other means.

Dimming daylight harvesting systems. Although it involves the use of relatively expensive dimming ballasts, this type of daylight harvesting system is usually preferable to the on-off systems. An adjustable daylight sensor (often called an ambient light sensor) sends a signal to the dimming ballasts. The ballasts, in turn, "ramp" the light intensity up or down to satisfy the illumination needs of the space. Lamp life is not affected as with on/off systems, but more importantly, workers are not distracted and/or concerned about light fixtures that are turned off.

Lighting Design for Improved System Efficiency

It is a mistake to think of lighting efficiency only in terms of lamp, ballast, and fixture efficiency. Often, more energy is saved through efficient space and lighting system design than through the selection of efficient equipment only.

A facility study that ***ERS*** recently performed for a New England paper mill provides an interesting example. The mill included a roll storage area for storing "overruns." The room was at the end of one building and was visited infrequently. The facility's lighting designer selected 400 watt high-pressure sodium (HPS) lighting for this space. Although it suffers from poor color rendering, HPS lighting is the most efficient type of light fixture used for storage areas. However, because of the long warm-up time, the fixtures remain on 24/7 even though the area is seldom occupied. Installation of 1000-watt incandescent lamps controlled by an occupancy sensing system would save large amounts of energy despite the fact that it would incorporate the least efficient lamp style (incandescent).

Lighting Design Issues to Consider

Following are some design issues to consider when specifying illumination for industrial spaces. Simply selecting the most energy efficient equipment will likely not result in the most efficient and effective lighting system.

Utilize task lighting for system efficiency. Industrial spaces rarely have the same illumination requirements throughout the space. Typically there is a certain amount of overall illumination that is needed, with added illumination necessary at certain machines or activity areas. It is all too common for the entire space to be illuminated to the levels required for the most critical task. Properly designed task lighting will allow for proper illumination of critical operations while saving large amounts of wattage throughout the remainder of the space. Care must be taken not to introduce excessive glare with task lighting. Because of its diffuse nature, fluorescent task lighting is usually preferable. The use of electronic ballasts will eliminate all lamp flicker.

Consider specially designed aisle lighting for warehouse areas. Often a large percentage of the lighting in warehouse spaces is uselessly illuminating the tops of boxes on the top shelves. Special fixtures are available that shape the light beam to more effectively illuminate the aisle and provide better vertical illumination. Choosing HID or fluorescent lighting fixtures that are designed to illuminate warehouse aisles will allow for increased fixture spacing and the resulting lower fixture count and energy consumption.

Space organization can be a valuable part of lighting design. In designing or redesigning industrial spaces, usually each discipline is unfortunately addressed in a vacuum. Because different tasks require different lighting levels, grouping tasks by type and size can save significant amounts of lighting dedicated wattage. A good example of this is warehouse space that contains both small and large items. The recommended lighting levels for warehousing small items might be 20 foot candles, whereas the recommended levels for the large items might be 10 foot candles. Without segregation by size, the entire warehouse would need to be illuminated to 20 foot candles. By dedicating one or two aisles to small items, some of the warehouse can be illuminated to 10-foot candles saving significant connected wattage.

Case Study – (Confidential) Furniture Manufacturer

Although we cannot directly mention its name, this confidential company is a Massachusetts based manufacturer of commercial furniture. The space this study addresses is an expansion of an existing facility and includes both manufacturing and warehousing/material handling areas. Similar areas at the facility are illuminated with 400 watt metal halide high-bay fixtures. Management was considering the installation of similar lighting in the expansion area. ***ERS*** was retained to consider and present alternative lighting designs.

The space is 66'x 125' with a 24' ceiling. Approximately 40% of the area was to be used for manufacturing and 60% was to be used for aisled product and supply storage. Anticipated operating hours were for two shifts with constant usage of the manufacturing area and intermittent usage of the warehouse aisles.

ERS considered the following lighting technologies for the manufacturing area.

- ❑ 400-watt metal halide enclosed low bay fixtures
- ❑ 350-watt metal halide pulse start low bay fixtures
- ❑ 8' T-8 High Output Industrial Fixtures

Technologies considered for the warehouse areas include the following.

- ❑ 400-watt metal halide enclosed low bay fixtures
- ❑ 350-watt metal halide pulse start aisle lighting fixtures
- ❑ 350-watt metal halide pulse start aisle lighting fixtures with occupancy controlled high/low dimming
- ❑ 8' T-8 Industrial Fixtures with occupancy controlled on/off
- ❑ Multi-lamp compact fluorescent low bay fixtures with occupancy controlled multi-level switching

Table 3 illustrates the analysis of the lighting system alternatives for the two space types at this industrial facility.

Table 3. Analysis of Lighting System Alternatives

Manufacturing Area Fixture Type	QTY	Nominal Wattage	Connected kW	Total Annual operating hours	Unoccupied Hours	Control Type	Annual kWH	Annual Cost@ $.09/kWH	CRI	Lamp Maintained Lumens	Total Maintained Lumens	Lamp Life (hrs)	System Installed Cost
400W MH low bay fixtures	22	455	10.01	5,200	NA	NA	52,052	$4,685	70	28,800	633,600	20,000	$5,500
350W M.H. pulse start low bay	22	375	8.25	5,200	NA	NA	42,900	$3,861	70	30,400	668,800	20,000	$6,380
2L8'T8 HO Industrial Fixtures	44	160	7.04	5,200	NA	NA	36,608	$3,295	85	7,625	671,000	18,000	$8,800
Warehouse													
Fixture Type	QTY	Nominal Wattage	Connected kW	Total Annual operating hours	Unoccupied Hours	Control Type	Annual kWH	Annual Cost@ $.09/kWH	CRI	Lamp Maintained Lumens	Total Maintained Lumens	Lamp Life (hrs)	System Installed Cost
400W MH low bay fixtures	26	455	11.83	5,200	1,560	NA	61,516	$5,536	70	28,800	748,800	20,000	$6,500
350W pulse start aisle lighters	20	375	7.5	5,200	1,560	NA	39,000	$3,510	70	30,400	608,000	20,000	$6,900
350W P.S. High/Low aisle lighters	20	375/190	7.5	5,200	1,560	O.S. Hi/Lo	33,345	$3,001	70	30,400	608,000	20,000	$9,000
2L8'T8 HO Industrial Fixtures	52	160	8.32	5,200	1,560	O.S. On/Off	30,285	$2,726	85	7,625	793,000	18,000	$10,400
8-40W CFL Hi/Low - Low Bay	26	304/76	7.904	5,200	1,560	O.S. Hi/Lo	31,853	$2,867	85	2,840	590,720	15,000	$12,350

* Lifecycle cost includes initial installation, electrical consumption, and lamp replacement costs.

Case Study Conclusion

For both space types, the originally planned 400-watt metal halide fixtures offer the lowest installation cost. The pulse start fixtures were approximately $40 (this incremental cost is now approximately $25) per fixture more expensive to purchase, but that cost is easily made up in energy savings.

Manufacturing area. The eight-foot 2 lamp T-8 high output fixtures have several advantages for this application. A larger quantity of fixtures is needed, so the installation cost is higher, but the lower operating costs associated with the fluorescent fixtures makes them an attractive alternative to HID. In addition, as discussed previously, improved color rendering; elimination of lamp flicker; and improved lighting level uniformity are very important in the industrial work environment. Eight foot 2 lamp T-8 high output fixtures were installed in this area.

Warehouse. For the warehouse, aisle lighting fixtures offer a significant improvement over standard HID fixtures because of their ability to shape the light beam, which allows fewer fixtures to be used. Pulse start fixtures offer the same incremental savings as calculated for the manufacturing area. Because the warehouse aisles are only occupied an average of 70% of the operating hours, controllable fixtures offer added economic benefits. Bi-level dimmable pulse start fixtures allow the fixtures to be automatically dimmed to 50% wattage when an aisle remains unoccupied. The 2 lamp eight-foot fluorescent option offers almost the same long term costs with improved color rendering, but turning fixtures completely off in a warehouse environment can be unsettling to employees. The high/low option of multi-lamp compact fluorescent fixture offers significant savings with good color rendering. However, the pulse-start high/low option proved to be more cost effective. Because color rendering and lamp flicker are not as critical in warehousing spaces, the decision was made to install pulse-start, high/low, aisle-lighters controlled by remote mounted occupancy sensors.

Conclusion

This paper has presented comprehensive details on state-of-the-art lighting in industrial facilities. By using pulse start or advanced fluorescent lighting technologies, and on-off or dimming controls, considerable energy savings can be achieved. Finally, application of more effective design approaches will result in industrial lighting designs that are optimized for performance and energy efficiency.

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