Industrial Lighting Guidelines
Best Practices for Efficiency

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Drafted by

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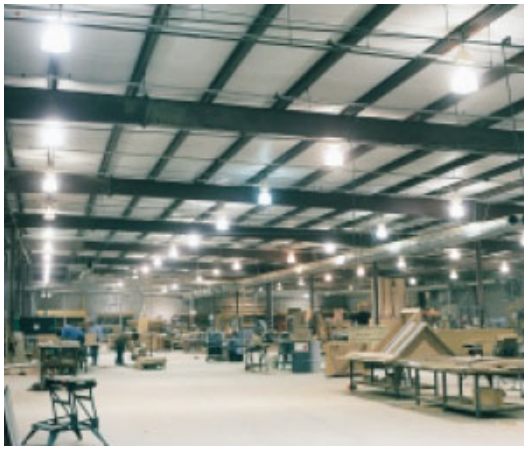
Commissioned by

UI and CL&P



Photos: Acuity Brands, Inc.

Introduction

Industrial lighting is where the necessity of light meets the challenges of environment, dirt and practicality. Mounting and ceiling heights vary from close-in task lighting to out-of-the-way locations 20 to 30 feet or more, above the floor. Moreover, lighting costs are critical, and there is an expectation of efficiency in every way. While hardly glamorous, industrial lighting is a demanding design problem.

Advances in state-of-the-art lighting technology can significantly reduce energy use and costs while providing light levels and quality recommended by the Illuminating Engineering Society of North America. In order to ensure compliance with applicable energy codes, achieve typical lighting energy levels substantially less than the energy code allowance, and contribute to regional energy and demand management, the following guidelines for lighting are strongly recommended. Note that these guidelines generally provide substantial benefits from utility incentive programs and through LEED and other certification programs and may offer significant tax deductions and other benefits.

Facilities Affected

These Guidelines are intended to be used by contractors, architects, engineers, and others responsible for designing, specifying and/or building new lighting systems, including new buildings, tenant fit-out, remodeling, and/or energy-upgrade initiatives.

In general, these Guidelines should be applied to the following:

- Factories
- Warehouses
- Manufacturing and assembly areas
- Service areas
- Vocational training

Facilities Less Affected

These Guidelines are not necessarily intended to address any of the following space types.

- Foundries and similar heavy industry
- Spaces with hazardous or explosive gases or fumes
- Field Houses

However, these facilities have similarities, and principles of cost effective, energy efficient design expressed by these Guidelines should be employed in these or other space types whenever possible.

Implicit Considerations

These Guidelines were developed in consideration of applicable codes and standards in the U.S., including the following:

- Standards of the Illuminating Engineering Society of North America, including IESNA/ANSI RP-7-01, American National Standard for Lighting Industrial Facilities. IESNA Standards apply in the USA, Canada and Mexico

- Standards of Underwriters Laboratories.
- Energy efficiency standards of the States of Connecticut, Massachusetts, and IESNA/ASHRAE/ANSI 90.1-2001.

Understanding the area-by-area code requirements of 90.1 with respect to industrial facilities is important. The 90.1-1999 and 90.1-2001 standards were much more generous for industrial lighting; in 90.1-2004, the allowances were reduced dramatically, as follows:

Activity	***90.1-2001***	***90.1-2004***
Workshop	2.5	1.9
Garage service/repair	1.4	0.7
General low bay	2.1	1.2
General high bay	3.0	1.7
Detailed	6.2	2.1
Equipment room	0.8	1.2
Control room	0.5	0.5
Warehouse – fine material	1.6	1.4
Warehouse –medium and bulky	1.1	0.9

In general, the 90.1-2004 values are probably more realistic, which makes improving upon 90.1-2001 and 1999 relatively easy.

General Design Requirements

All designs must comply with applicable codes and ordinances. Note that in general, the following requirements will result in lighting designs that demand less power (watts per square foot floor area) than mandated by the energy code. The energy cost savings realized by this practice will often pay back the incremental cost for the more efficient system within 3 years. Additionally, in many cases the first cost of lighting may be less than traditional designs because these Guidelines optimize the amount and type of lighting equipment than can be used.

Lighting Systems

In order to comply with this Guideline, a complete lighting design for the affected spaces must be provided with connected power density equal to or less than the following:

Activity	***Criterion***
Workshop	1.4
Garage service/repair	0.6
General low bay	0.9
General high bay	1.3
Detailed	1.5
Equipment room	0.9
Control room	0.5
Warehouse – fine material	1.4
Warehouse –medium and bulky	0.6

Compliance Documentation

Designs shall be certified using COM-CHECK 3.1 release 1 or higher. For the Code to be used, select ASHRAE/IESNA 90.1-2004. If these guidelines are followed closely, the resulting designs should achieve approximately 25-35% better than 90.1-2004 and 40-70% better than 90.1-2001. NOTE: Achieving performance significantly better than these target values is very difficult and not recommended without design involving considerable expertise.

Design Approach

As an overarching consideration, try to use a task-and-ambient approach for illuminating any task requiring more than 30 footcandles. With modern lighting systems, general lighting can achieve 30 footcandles at 0.6 watts per square foot in all but the most dirty or difficult environments. Local task lighting is almost always better, with the exception of work on large objects. In other words, the primary lighting system should provide between 25 and 35 footcandles of general lighting with a high degree of uniformity. For areas requiring high light levels throughout, increase the lighting power density to 0.9 w/sf and light levels will be around 50 footcandles, average.

Another primary consideration is luminaire distribution. Industrial and warehousing facilities often have areas of stacks for storage for which stack lighting systems with long, thin distribution patterns are preferred. For open areas, wide symmetric beams of light are preferred, overlapping to illuminate each area with at least four light sources. As a general rule, ensure that the structure is painted white and permit some uplight; this will reduce the tendency of the light sources to create harsh shadows and will make for a better working space.

Task lighting should be oriented to address the visual characteristics of the work, with consideration for shadowing, angle, and elimination of stroboscopy. As a general rule, use very high CRI light sources (>80) for detailed work, and consider 5000-7500K lamps for fine detail and exacting visual discern and discrimination.

Encourage daylighting as much as possible. In addition to its energy efficiency, daylight's spectral qualities are superb, especially for fine work.

General Lighting Systems

For open work and assembly spaces, designers should employ either of the two pattern lighting layouts illustrated below. Spacing measurements are taken from the plan view center of the luminaire. Luminaires should be mounted at least 1/3 of the indicated mounting distance away from any ceiling-high partition. For stack areas, two alternative patterns are also provided.

Other Common Lighting Systems

Most associated spaces benefit from the use of simple, durable lighting systems employing modern fluorescent technology. Consult these and other Guidelines for suggestions for efficient solutions. In general, do NOT use incandescent lighting, halogen lighting, or track lighting systems of any kind or voltage of operation.

Principal Lighting Systems

There are two primary choices: HID and fluorescent. In some cases, a third possible choice, induction, may be viable.

HID Systems

Photo courtesy of Acuity Brands, Inc.

HID lamps have been used for decades to illuminate high bay spaces. Having good energy efficiency and acceptable color, for many years HID lamps presented the only economically viable alternative for big spaces. But in order to compete with fluorescent lighting systems, significant improvements were called for and recently have been made available.

Historically, industrial lighting focused on economy, and for many years high pressure sodium lighting was used for industrial spaces. But recent discoveries about human vision demonstrate that high pressure sodium is an inferior source that may detract from visual performance, and for modern industrial lighting, white light sources with CRI>60 are essentially required.

Appropriate HID lighting systems employ state of the art, high color rendering metal halide lamps. In most cases, the ideal lamp watts are between 250 and 400. There are two types of suitable lamps: quartz pulse-start metal halide lamps (QMH), and ceramic metal halide pulse-start lamps (CMH). As a basic design guide, high color rendering index QMH lamps tend to favor high color temperatures (5000K+) while CMH lamps with high CRI favor neutral color temperature (4000K). All of these lamps have CRI>80, assuring good visual task performance for almost all work.

In order to achieve the performance required by this Guideline, use of suitable electronic ballasts is required. In addition to less internal loss than magnetic ballasts, electronic ballasts significantly improve the lamp's lumen maintenance. This permits electronically ballasted metal halide lighting systems to operate at 20-30% less power than comparable magnetic systems, including pulse start. Note that the ballast must be matched to the lamp; CMH and QMH lamps operate at different frequencies. Because of electronic ballasting, stroboscopy is much less than that from any magnetically ballasted HID.

Many current electronic ballasts have noteworthy built-in features including

- Dimming
- Relay for quartz auxiliary
- Switch selected lamp wattage (250-320-350-400)

Advantages of the HID system include superior luminaire appearance, better optical control, and reduced audience glare. The principal disadvantages are warm up, restrike and limited dimming range. HID systems are best in spaces where use is constant, there is little or no daylight, and mounting heights are generally over 20 feet. A lens or cage may be required to protect the lamp from errant flying objects.

Fluorescent Systems

Aisle lighter

General purpose with reflector and uplight

General purpose high bay

Economy strip with reflector

Fluorescent lighting has always been important for industrial lighting, especially in spaces with mounting heights less than 20 feet. In fact, there are a number of fluorescent lamps developed principally for industrial applications. But with increasing emphasis on energy efficiency, modern fluorescent lamps and ballasts are the way to go.

While there have been a number of HID luminaires designed for "low bay" use, in fact fluorescent lighting is more efficient and usually better quality light. The principal reason is source efficacy; HID lamps with electronic ballasts less than 250 watts are typically rated less than 75 mean lumens per watt, while practical T8, T5 and T5HO fluorescent lamps with electronic ballasts are now over 100 mean lumens per watt.

Also, specular reflectors now make it possible to "throw" fluorescent light better. One of the most important new products is the "high bay fluorescent". These luminaires typically use with 4 to 6 T5HO lamps, generating the same amount of light as 250-400 watt metal halide lamps. The high performance reflector can be designed for narrow, medium or wide distributions, making these fixtures useable as high as 30-40 feet. Another high performance luminaire is the fluorescent aisle lighter, which is superior to HID aisle luminaires in most respects.

Fluorescent lighting systems have the advantage of being instant-on, instant restriking. Each fixture can use 2 ballasts making multi-level lighting systems easy and inexpensive without requiring dimming ballasts. Ballast choices include

- Instant start ballasts, which offer the greatest energy efficiency but should not be frequently switched
- Program start ballasts, which permit frequent switching and very good energy efficiency
- Dimming ballasts, which permit tuning, daylighting, and other advanced control techniques.

At lower mounting heights, consider T8 lamps (both 4' and 8') with modern white powder-coat painted reflectors. As a general rule, always employ a reflector to direct the light downward. Reflectors with uplight are a good idea when the ceiling is painted a light color. Select from many luminaire choices including open, enclosed, and those designed for specific uses.

Induction Systems

There is a growing interest in the use of induction lamps in high bay applications. Historically, high costs of lamp and ballast systems have been an impediment, but recent advances have suggested that induction systems might compete. One huge advantage of induction lighting is the superior lamp life, with most lamps rated 100,000 hours. In industrial situation where lamp maintenance is difficult, consider induction lamps.

Induction lamps are a form of fluorescent lamp that uses RF induction, rather than an electric arc, to excite the internal gas and emit light. Induction lamps offer many of the advantages of other fluorescent lamps, including instant starting, instant restriking, and dimming. However, the key limitation to induction lamps is that while both lamp and fixture are efficient, it is difficult to control the candlepower, making these sources optically challenging to control. This tends to limit mounting heights for which this is a good choice. Note: even under ideal conditions, induction lighting systems not more efficient than the HID or fluorescent systems described above. When evaluating induction lighting options, make certain that the advantages of induction lighting are called for.

Lighting Patterns

Patterns 1a and 1b: the HID Solution

To meet this guideline, design the high bay metal halide lighting system as follows:

- High efficiency luminaire, preferably with qualities that reject dirt accumulation. Depending on the environment, choose among open, ventilated fixtures and totally enclosed fixtures. With open fixtures use protected lamps.
- Proper candlepower shape for the space. Use standard spacing criterion to determine candlepower based on mounting height.
- Luminaire efficiency should be at least 80% with CU >.75 at RCR = 2.0 and reflectances 50/30/20.
- High CRI QMH lamp with high frequency electronic ballast, or high CRI CMH lamp with low frequency electronic ballast

- Choice of lamp between 250 and 400 watts (with appropriate ballast) matching the lamp+ballast input power to the proper power density. See Table A for approximate spacing recommendations,

Patterns 2a and 2b: the High Bay T5HO Fluorescent Solution

To meet this guideline, design the high bay fluorescent lighting system as follows:

- High efficiency luminaire, preferably with qualities that reject dirt accumulation. Luminaires designed to manage lamp and ballast case temperatures should be selected.
- Proper candlepower shape for the space. Use standard spacing criterion to determine candlepower based on mounting height.
- T5HO non-amalgam lamps
- Luminaire efficiency of at least 75% with a minimum CU of 0.75 at RCR = 2.0 with reflectances 80/50/20.
- Electronic ballasts matching project conditions. Instant start ballasts are the most efficient and least costly, but can negatively affect lamp life if switched more than 2-3 times per day. Program start ballasts offer good lamp life with a power penalty of about 1.5 watts per lamp. Dimming ballasts are more expensive, but allow greatest flexibility. Choose ballasts designed for the application and rated for the temperatures to be encountered in the application.

Patterns 3a and 3b: the Low Bay T8 Fluorescent Solution

To meet this guideline, design the low bay fluorescent lighting system as follows:

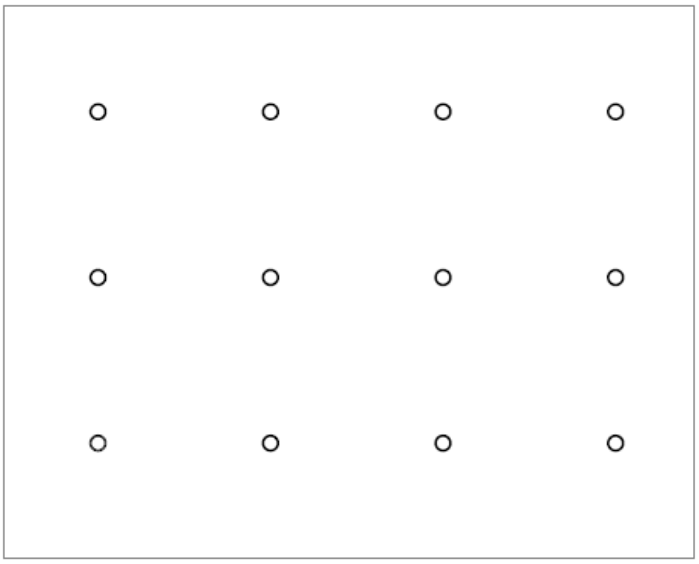
- High efficiency luminaire, preferably with qualities that reject dirt accumulation. Luminaires designed to manage lamp and ballast case temperatures should be selected.
- Proper candlepower shape for the space. Use standard spacing criterion to determine candlepower based on mounting height.
- T8 high performance (“super T8”) lamps and high performance electronic ballasts
- Luminaire efficiency of at least 85% with a minimum CU of 0.65 at RCR = 2.0 with reflectances 50/30/20.
- Electronic ballasts matching project conditions. Instant start ballasts are the most efficient and least costly, but can negatively affect lamp life if switched more than 2-3 times per day. Program start ballasts offer good lamp life with a power penalty of about 1.5 watts per lamp. Dimming ballasts are more expensive, but allow greatest flexibility. Choose ballasts designed for the application and rated for the temperatures to be encountered in the application.

Alternate Solution: Induction Lighting

Induction lamps have limitations, but also offer tremendous potential. To meet this guideline, use high efficiency luminaires and modern high wattage induction lamps. Evaluate luminaires using both the round globe-style induction lamps and the square loop tubes as shown in the illustration above.

TABLE A –Lighting Systems

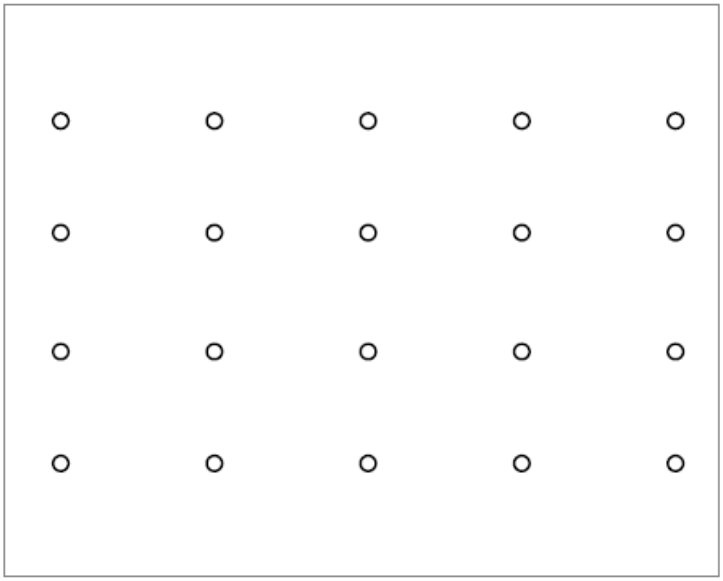
Applications	*Lighting Systems*	*Lamp Watts (Fixture input watts)*	*Spacing Area (approx grid)*	*Note*
PATTERN 1a HID general lighting 30 footcandles	CMH or QMH metal halide lamp with proper electronic ballast. Note: high frequency electronic for QMH, and low frequency electronic for CMH	250 (275) 320 (345) 350 (370) 400 (425)	458 (21’ x 22’) 575 (23’ x 25’) 617 (24’8” x 25’) 708 (27’3” x 26’)	Mounting height at least 20’ AFF Set lamp height to proper spacing criterion (<1.3)
PATTERN 1b HID general and task lighting 50 footcandles	CMH or QMH metal halide lamp with proper electronic ballast. Note: high frequency electronic for QMH, and low frequency electronic for CMH	250 (275) 320 (345) 350 (370) 400 (425)	306 (17’ x 18’) 383 (19’ x 20’) 411 (20’6” x 20’) 472 (21’6” x 22’)	Mounting height at least 20’ AFF Set lamp height to proper spacing criterion of (<1.1)
PATTERN 2a High Bay Fluorescent T5HO. General lighting 30 footcandles	T5HO with high bay reflector system and ballast designed for at least 60 degree C ambient temperature and 80 degree C case temperature in a properly designed luminaire with spacing criterion of <1.3	(4) T5HO with BF=1.0 IS ballast (226 watts) (6) T5HO with BF=1.05 IS ballast (344 watts)	377 (19’ x 19’8”) 575 (23’ x 25’)	Mounting height at least 20’ AFF. Choose reflector for proper spacing criterion (<1.3)
PATTERN 2b High Bay Fluorescent T5HO. General and task lighting 50 footcandles	T5HO with high bay reflector system and ballast designed for at least 60 degree C ambient temperature and 80 degree C case temperature in a properly designed luminaire with spacing criterion of <1.3	(4) T5HO with BF=1.0 IS ballast (226 watts) (6) T5HO with BF=1.05 IS ballast (344 watts)	251 (16’ x 15’9”) 382 (19’ x 20’)	Mounting height at least 20’ AFF. Choose reflector for proper spacing criterion (<1.1)
PATTERN 3a Low Bay Fluorescent T8. General lighting 30+ footcandles	(2) T8 lamps and high light output ballast with white reflector	(2) F32T8 with BF=1.15 IS ballast (72 watts) Tandem 8’ fixture (144 w)	120 (10’ x 12’) 240 (15’ x16’)	Mounting height 10-20’ AFF. Mounting height at least 12’
PATTERN 3b Low Bay Fluorescent T8. General and task lighting 50+ footcandles	(2) T8 lamps and high light output ballast with white reflector	(2) F32T8 with BF=1.15 IS ballast (72 watts) Tandem 8’ fixture (144 w)	80 (10’ x 8’) 160 (11’ x 14’)	Mounting height 10-20’ AFF. Mounting height at least 12’



PATTERN 1a HIGH BAY

APPROX. 8000 SF

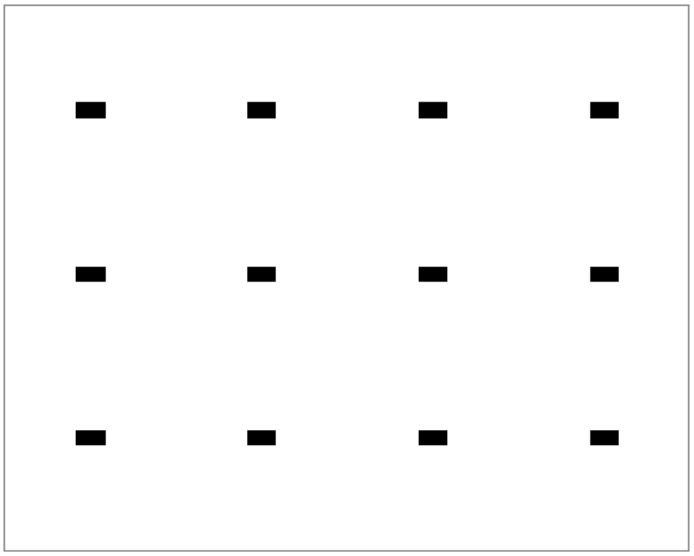
(12) 350 WATT CERAMIC METAL HALIDE FIXTURES
PRISMATIC GLASS WITH ALUMINUM SHROUD
ELECTRONIC BALLAST
30 FOOTCANDLES MAINTAINED AT 0.55 W/SF



PATTERN 1b HIGH BAY

APPROX. 8000 SF

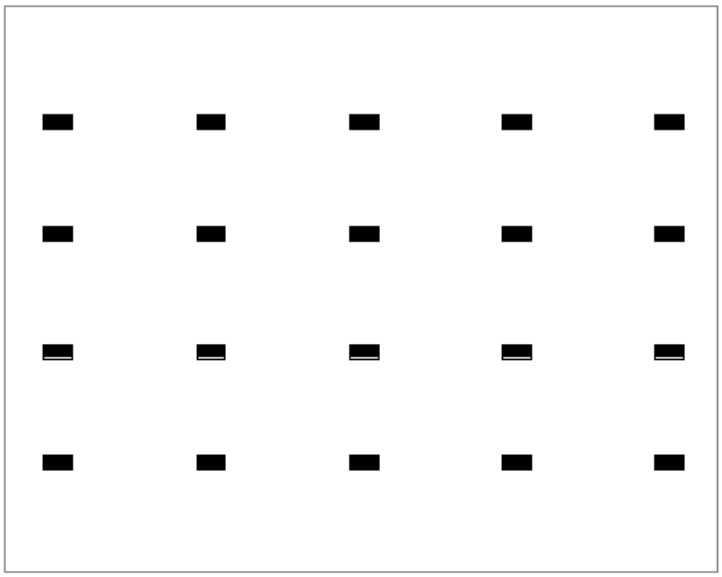
(20) 320 WATT CERAMIC METAL HALIDE FIXTURES
PRISMATIC GLASS WITH ALUMINUM SHROUD
ELECTRONIC BALLAST
50 FOOTCANDLES MAINTAINED AT 0.86 W/SF



PATTERN 2a HIGH BAY

APPROX. 8000 SF

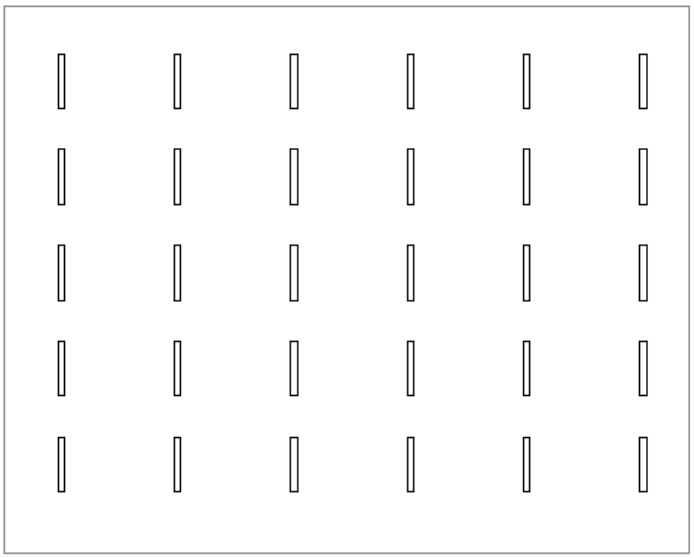
(12) FLUORESCENT HIGH BAY FIXTURES
EACH WITH (6) F54T5HO LAMPS
(2) OR (3) ELECTRONIC BALLAST TOTAL 360 WATTS
35 FOOTCANDLES MAINTAINED AT 0.54 W/SF

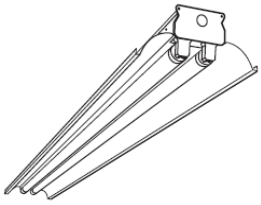


PATTERN 2b HIGH BAY

APPROX. 8000 SF

(20) FLUORESCENT HIGH BAY FIXTURES
EACH WITH (6) F54T5HO LAMPS
(2) OR (3) ELECTRONIC BALLAST TOTAL 360 WATTS
60 FOOTCANDLES MAINTAINED AT 0.90 W/SF

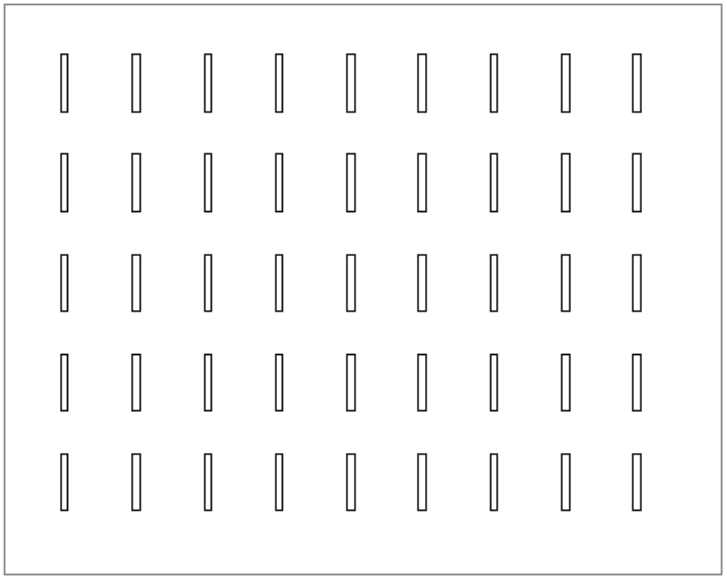


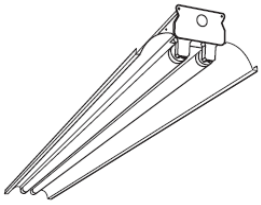


PATTERN 3a LOW BAY

APPROX. 8000 SF

(30) TANDEM FLUORESCENT LOW BAY FIXTURES
EACH 8' UNIT WITH (4) F32T8 LAMPS
(2) HIGH BALLAST FACTOR BALLASTS
40 FOOTCANDLES MAINTAINED AT 0.54 W/SF





PATTERN 3b LOW BAY

APPROX. 8000 SF

(45) TANDEM FLUORESCENT LOW BAY FIXTURES
EACH 8' UNIT WITH (4) F32T8 LAMPS
(2) HIGH BALLAST FACTOR BALLASTS
60 FOOTCANDLES MAINTAINED AT 0.81 W/SF

Aisle Lighting

IESNA recommends 10 vertical footcandles for most items medium and bulky items in storage aisles. For most aisles up to about 15' high, it's possible using modern stack luminaires to achieve these values at less than 0.35 w/sf; taller stacks, up to 0.50 w/sf. To achieve this efficiency, use either T8 or T5 lamps in single lamp continuous rows of luminaires.

Some aisles require reading and inspection of stored items. For aisles up to about 20' high, stack luminaires with a single T5HO lamp can provide 30 footcandles, vertical, at a power density of about .85 w/sf. For taller stacks or better uniformity, use a specialized two lamp stack luminaire with F28T5 or F32T8 lamps with power density up to about 1.0 w/sf. There may be situations where HID lighting is required, in which case employ luminaires with special stack optics at roughly the same power density.

In all cases in stacks consider the use of multi-level ballasts and motion sensors. Depending on the frequency of access, motion sensors can save huge amounts of energy by reducing lighting during periods when stack aisles are empty.

Task Lighting

As a general rule, lighting levels of up to 50 footcandles can be provided in most industrial spaces (Patterns 1b, 2b and 3b) and still meet the requirements of these Guidelines. But there are many industrial tasks that require lighting levels over 50 footcandles; IESNA recommends 100 footcandles for a variety of industrial tasks, such as very fine processing, fine manufacturing, difficult assembly, difficult inspection, and fine crafting. For most tasks, it's actually pretty easy to achieve 100 footcandles in the specific area of a task using basic industrial fluorescent luminaires. If the overhead lighting system is providing 30 footcandles (at about 0.6 w/sf) adding fluorescent task lights only at the task requires about 70 footcandles and around 1.2 additional w/sf for that area. For instance, take the pattern illustrated in Pattern 3b and **add** it to any of the patterns 1a, 2a, or 3a, but **only** for the area of tasks. Assuming 50% of the space is tasks, the result will be a space with general lighting levels of 30-40 footcandles and task lighting levels of 100 footcandles, with an average power density of 1.2 w/sf. This is well within the target of 1.5 w/sf set by these Guidelines.

There are a few tasks for which IESNA recommends 300 footcandles or more. These tasks should have very specific task lighting developed specifically for the task. Because the lighting is localized, the energy impact can generally be well within the Guidelines' limits.

Lighting Controls

Significant energy savings can be realized by using controls. Specific recommendations include:

- When using fluorescent systems, consider motion sensing. When covering a large area, use a number of sensors in parallel to prevent inactivity in one end of the space from affecting the rest of the space. Be sure to use sensors designed for high bay use.

- If skylights are employed, use daylight sensors. Dimming ballasts are preferred, but multi-level switching daylight sensing can also be employed. With skylights, open loop control systems are generally recommended.
- If the facility has a predictable schedule, employ a programmable time control system.
- Whenever possible, make it possible for light levels to be lowered when full lighting levels aren't required.