

Basics of Quality Lighting  
 Energy Effective Lighting  
 Luminaire Efficacy Rating (LER)  
 General Workspace Layouts

Tasklighting for Manufacturing  
 Active Highbay Storage Layouts  
 Lighting Fixture Specifications  
 Lighting Controls for Industrial Buildings



HIGHBAY INDUSTRIAL LIGHTING

# knowhow

## INTRODUCTION

Industrial buildings, like all workplaces, require well-planned lighting systems to support various activities. Appropriate

quantities of light are essential, but quality issues are just as important in providing a comfortable and safe working atmosphere. When the lighting meets both quantity and quality needs, it adds measurably to worker performance and productivity.

This guide will give you the *knowhow* to provide energy effective lighting for spaces designed for light manufacturing and assembly tasks which require average light levels. While this guide is designed primarily to assist the specifier or electrical contractor for smaller warehouse and highbay industrial spaces, the principles outlined here apply to industrial buildings of all sizes.

Industrial tasks that require higher light levels, such as cleanrooms or assembly of fine materials, are discussed in the Lowbay Industrial *knowhow*. Daylighting in industrial buildings is covered in the Warehouse Skylighting *knowhow*.



Photo courtesy of General Electric Co.

Research studies show that improvement in productivity as low as 4% justifies doubling the investment to upgrade the lighting.

The **Quality Chart** below shows important criteria and their relevance to typical industrial tasks. In the following pages, fixture and lamp types are compared, control strategies identified and sample lighting

layouts are shown. Safety concerns are discussed and economic and quality issues are weighed to assist in planning energy effective and reliable lighting systems that promote optimal productivity and a safe place to work.



Too often lighting is the “step-child” during planning and construction. The effect of the lighting system on the productivity of the workers is often not considered. It is essential to a continued growth of the economy.

John Fetters  
 Lighting Engineer

## QUALITY ISSUES FOR INDUSTRIAL LIGHTING

	Material Processing	Component Production	Assembly	Computer Viewing	Storage, Inactive	Storage, Active	Shipping/Receiving
Fixture location related to workers	●	●	●	●	●	●	●
Light on walls and ceilings	○	●	●	○	○	○	○
Control of direct and reflected glare	◐	●	●	●	◐	◐	◐
Light patterns, uniformity vs. shadows	◐	◐	●	◐	○	○	◐
Control of source flicker and strobe effect	○	◐	NA	NA	NA	NA	NA
Daylight integration and control	◐	◐	◐	◐	○	◐	◐
Modeling of objects and faces	◐	●	○	○	○	○	◐
Color rendering and color temperature	○	○	○	◐	●	●	○
Appearance of space and fixtures	○	○	○	○	○	○	○

● Very Important   ◐ Important   ○ Somewhat Important   NA - Not Applicable

\* Adapted from the Lighting Design Guide. IESNA Lighting Handbook, 9th Edition

# basics of quality lighting

## INDUSTRIAL QUALITY ISSUES

Quality lighting contributes to the comfort and productivity of warehouse and manufacturing personnel. It also contributes to their safety, especially around moving machinery. Glare control, balanced brightness ratios and reduced lamp flicker or strobe effect must be taken into account to ensure safety and security in the work space.

### BRIGHTNESS, CONTRAST AND REFLECTANCE

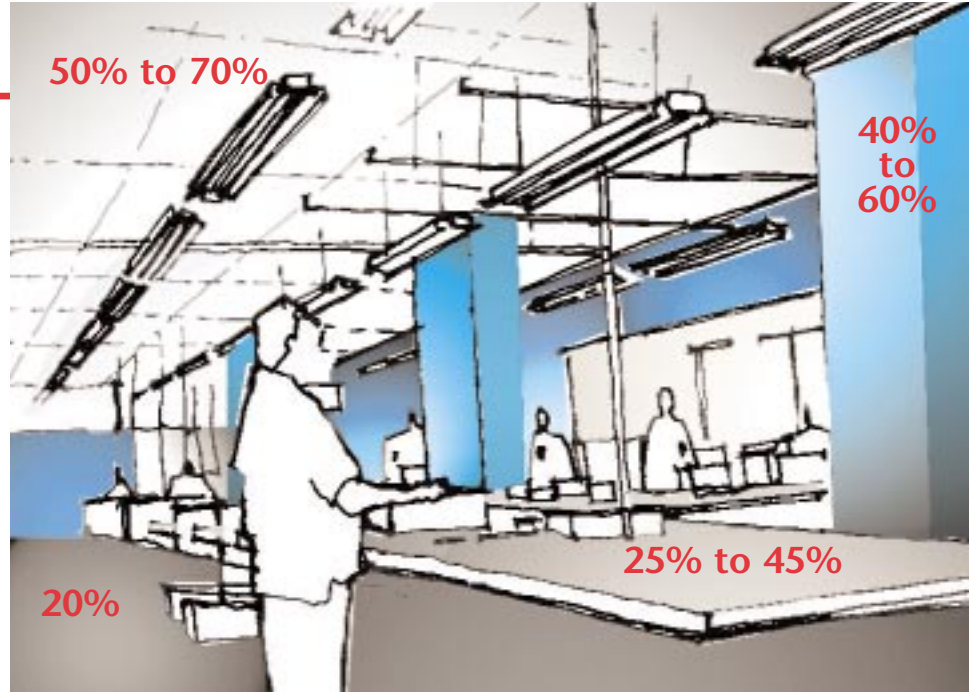
The ability to see detail is dependent on good contrast. When the task blends with the background it is difficult to see. If contrast is too great people may experience adaptation discomfort when looking from bright surfaces to very dark surfaces. People are most comfortable when the visual environment is relatively uniform. The following ratios are recommended by the IESNA for areas where reflectance of the work area can be controlled, and where control of the remote surroundings is limited.

#### RECOMMENDED MAXIMUM BRIGHTNESS RATIOS

Tasks to adjacent darker areas	3 to 1
Tasks to adjacent lighter areas	1 to 3
Tasks to more remote darker areas	20 to 1
Tasks to more remote lighter areas	1 to 20
Between light fixtures or windows and the surfaces next to them	20 to 1

### LAMP COLOR MATTERS

Outdated fluorescent and HID lamps such as cool white and mercury are inferior at coloring rendering and are associated with noisy ballasts that often produced flicker in fluorescent lamps. All light sources recommended in the layouts on pages 5 and 6 and in the Fixture Specifications on page 7 are high color rendering sources, and if used consistently, will allow people to see color accurately and work in a comfortable and safe environment.



### RECOMMENDED SURFACE REFLECTANCE VALUES

Dark colors absorb light and light colors reflect light. To achieve comfortable brightness ratios, encourage the building owner to select reflectance values for equipment and room surfaces based on the values shown above. Many paint and ceiling material manufacturers publish reflectance values for their products.

Based on IESNA BSR RP-7-00-Recommended Practice for Lighting Industrial Facilities.

### GLARE CONTROL

When the brightness ratios exceed maximum recommended values, disturbing or debilitating glare can result. To minimize glare-producing conditions, consider the following:

- Use more lower wattage fixtures to reduce individual lamp brightness while maintaining required light levels.
- Locate control panels and computer screens facing away from windows or bright light fixtures. If these elements are fixed, adjust the lighting fixture locations and shade the windows.
- Raise bright fixtures above normal field of view.
- Direct some light toward the ceiling to balance space brightness ratios and reduce contrast between the ceiling and fixtures.



Photo courtesy of Kurt Versen Co.

**Avoid glare by locating computer screens facing away from bright light sources.**



### Quality = Increased Profits

Employees are a company's single largest investment. It pays in bottom line dollars and worker satisfaction to optimize the lighting for their comfort.

*Carol Jones  
Lighting Researcher and Designer*

### SEEING AND PRODUCTIVITY

Ability to see well is based on several conditions including the age of the worker. A 40-year-old person generally requires twice as much light to perform a task as a 20-year-old. The size of the task and the amount of time available to see it, dramatically affects the need for light. For example, small font text, moving rapidly past a reader and out of sight, needs a significant amount of light for comprehension. Large, stationary objects are easier to see in lower light levels.

# energy effective lighting

## LUMINAIRE EFFICACY RATING (LER)

When choosing luminaires for small industrial projects, look for catalog information indicating that each selected fixture meets or exceeds minimum LER values. This standard was developed to provide uniform practical metrics for evaluating the energy efficiency of luminaires (fixtures). The following formula is used for calculating LER.

$$\frac{\text{Total Rated Lamp Lumens} \times \text{Ballast Factor} \times \text{Luminaire Efficiency}}{\text{Input Watts}}$$

Input Watts = Total published rated input wattage of the ballasts.

Ballast Factor for HID ballasts is assumed to be 1.0, fluorescent ballasts - .95.



LER gets to the core of what energy efficiency is all about – to get more energy service using less energy.

Francis Rubinstein  
Staff Scientist LBNL



Photo courtesy of Lithonia Lighting

**If surfaces are painted with highly reflective (light) colors instead of dark colors, a higher percentage of the light will be made useable by being reflected back into the room.**

are shown in the example layouts and in the Fixture Specifications on page 7. See types C and D. Twin-tube alternates for fixture such as Types A and E are also available but are not illustrated in this guide.

The **Lamp Comparison** chart below shows the difference between light output at the beginning of a lamp's life (initial lumens) and when 40% of the lamp's rated life is over, (design lumens). Fluorescent lamps have better lumen maintenance as the lamps age, compared to metal halide.

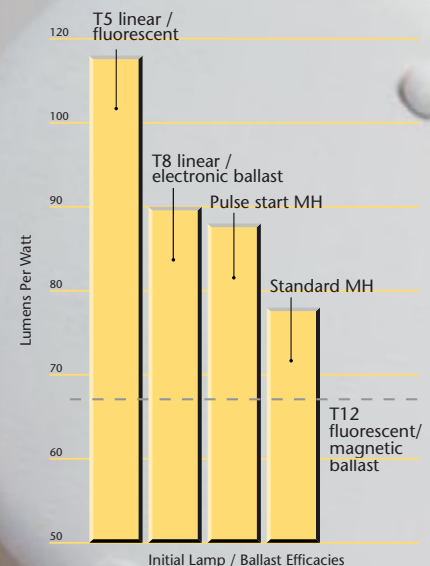
### LAMP EFFICACY IS NOT THE WHOLE STORY

400 Watt metal halide is currently the standard practice in industrial buildings in the Northeast. Newer, pulse-start metal halide is 20% more efficient than standard metal halide. Both MH lamps are initially more efficient than fluorescent, but close comparison to fluorescent sources show that because MH light output degrades rapidly (lumen depreciation) after a few months of use, fluorescent may be a better choice. Both twin-tube and linear fluorescent fixture equivalents to HID fixtures are available. In this guide T-8 and T-5 linear fixtures

### NEW LIGHT SOURCES

In this guide, standard high intensity discharge (HID) metal halide is compared to newer pulse-start metal halide. T-8 fluorescent lamps are compared to metal halide choices and to T-5 high output fluorescent lamps. Each of these four lamp types are used in the example spaces. Other HID sources such as high pressure sodium or mercury vapor have not been recommended because of inherently poor color rendition.

### Initial Lamp/Ballast Efficacies



Values from E SOURCE document # ER-00-1, "New High-Intensity Fluorescent Lights Outshine Their HID Competitors."

LAMP COMPARISON	Rated Input Watts	Rated Life (Hours)	Initial Lumens	Initial Lumens/ Watt	Lumens @ 40% of Rated Life	% of Initial (Design Lumens)	Design Lumens/ Watt
Metal Halide — Standard	400	20,000	40,000	100	26,000	65%	65
Metal Halide — Standard	250	10,000	20,500	82	13,500	66%	54
Metal Halide — Pulse Start	400	20,000	44,000	110	31,000	70%	78
Metal Halide — Pulse Start	250	10,000	23,800	95	16,000	67%	64
Fluorescent T-8 Standard	32	20,000	2,950	92	2,800	95%	88
Fluorescent T-5 High Output	54	20,000	5,000	93	4,740	95%	88
Fluorescent T-5 Twin-tube	38	20,000	3,300	87	2,970	90%	78

# general industrial workspace lighting

## Making an informed choice

The light fixture layouts on pages 5 and 6 give options for providing the right amount of light, while meeting or exceeding the requirements of national and local energy codes. These layouts apply to general factory and warehouse lighting for typical highbay fixture mounting heights between 25 and 35 feet above the floor. Lower mounting heights are addressed in the Lowbay Industrial Lighting *knowhow* guide.

Layout 1 on page 5, illustrates the use of Type A, 400 Watt metal halide highbay open metal reflector fixtures. This fixture type is most commonly used in the New England area. Using Fixture Type B in the same layout achieves better uniformity with slightly lower light levels.

Layout 2 shows more fixtures at 250 Watts instead of 400 Watts used in Layout 1, increasing uniformity and comfort by lowering individual fixture brightness.

Layout 3 compares two types of fluorescent lamps on the same spacing layout. The fixture cost of types C and D are similar, but Type C uses twice as many lamps, but the nominal lamp cost is less, so the total cost of Type C is somewhat higher than Type D. All of these costs vary with different manufacturers, so the comparisons are made in percentage of increase over the Standard - Layout 1.



Photo courtesy of General Electric Co.

## FLICKER AND STROBE EFFECT

Fluorescent lamps using magnetic ballasts, pulse at 60 cycles per second and cause a perceptible flicker. This effect may be irritating to some people, and can be eliminated using electronic high frequency ballasts.

HID ballast cycles can create a stroboscopic effect, and can cause a potentially dangerous condition where rotating machinery appears to be not moving.

## PHASE ROTATION

HID “strobe effect” can be minimized by connecting adjacent fixtures to different phases of a three phase power system, as shown by the numbering system in Layout 1 shown to the right on page 5.

## IT PAYS TO USE TASKLIGHTING

Relying on the general lighting system to provide adequate light for detailed tasks could result in high energy costs and less than comfortable lighting. Locating light close to the task can provide higher light levels and eliminate shadows created by machinery or the workers themselves. For example, if general factory lighting is planned for 30 footcandles, and 40% of the area requires 50 FC, to provide the higher level from ceiling mounted fixtures would require .24 Watts per square foot additional power and cost 58% more than using localized tasklighting. This example is shown in the Comparison Chart, based on Layout 1. See fixture types G or H on page 7, for examples of tasklights.



Photo courtesy of General Electric Co.

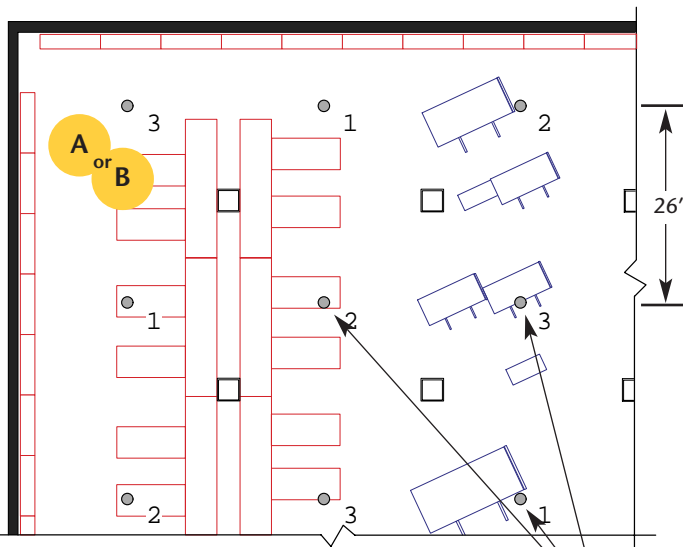
## POWER LIMITS FOR INDUSTRIAL SPACES\*

Whole Building Method	Watts / Sq. Ft.
<b>Manufacturing Facility</b>	<b>2.2</b>
<b>Warehouse</b>	<b>1.2</b>
Space Method	Watts / Sq. Ft.
<b>General Lighting High-bay</b>	<b>3.0</b>
<b>Active Storage/Bulky</b>	<b>1.1</b>
<b>Transition/Corridors</b>	<b>0.7</b>
<b>Equipment Room</b>	<b>0.8</b>
<b>Workshop</b>	<b>2.5</b>
<b>Control Room</b>	<b>0.5</b>

\* From ASHRAE/IESNA Standard 90.1-1999

## RECOMMENDED QUANTITY OF LIGHT (FOOTCANDLES)

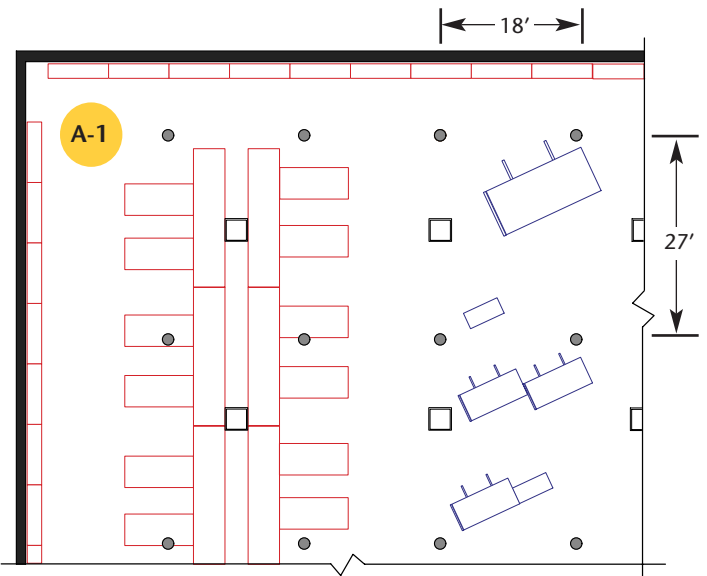
Material Processing	Course	10 FC
	Medium	30 FC
Component Production	Large	30 FC
	Medium	50 FC
Assembly	Simple	50 FC
Shipping and Receiving		50 FC
Control Panel/Computer Viewing		30 FC vertical



LAYOUT 1 – **STANDARD PRACTICE**

Fixture type A is Standard Practice based on research of current practices in New England. Type B, with a prismatic reflector can be used in the same layout with slightly lower footcandle levels but higher uniformity and comfort. See comparison schedule on the next page.

**PHASE ROTATION**



LAYOUT 2 – **BETTER**

**FIXTURES**

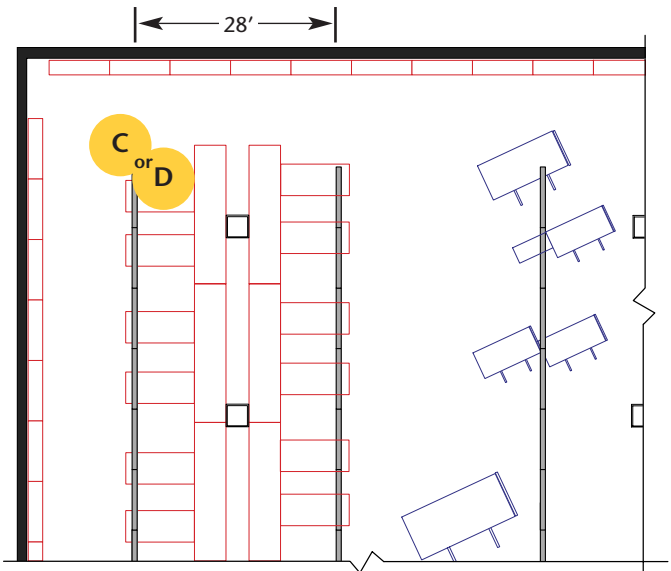
**TYPE**

- A: 400W Metal Halide, Open Metal Reflector
- A-1: 250W Metal Halide, Open Metal Reflector
- B: 400W Metal Halide, Prismatic Reflector
- C: 4' 2 lamp T-8 Fluorescent, Pendant Reflector
- D: 4' 1 lamp T-5 HO Fluorescent, Pendant Reflector



We always make sure to plan ahead for our customers by installing spare branch circuits for future lighting expansion, and scheduling future group relamping and cleaning to make sure the lighting is always at its best.

*Miguel Velez-Rossi, Contractor*



LAYOUT 3 – **BETTER YET**

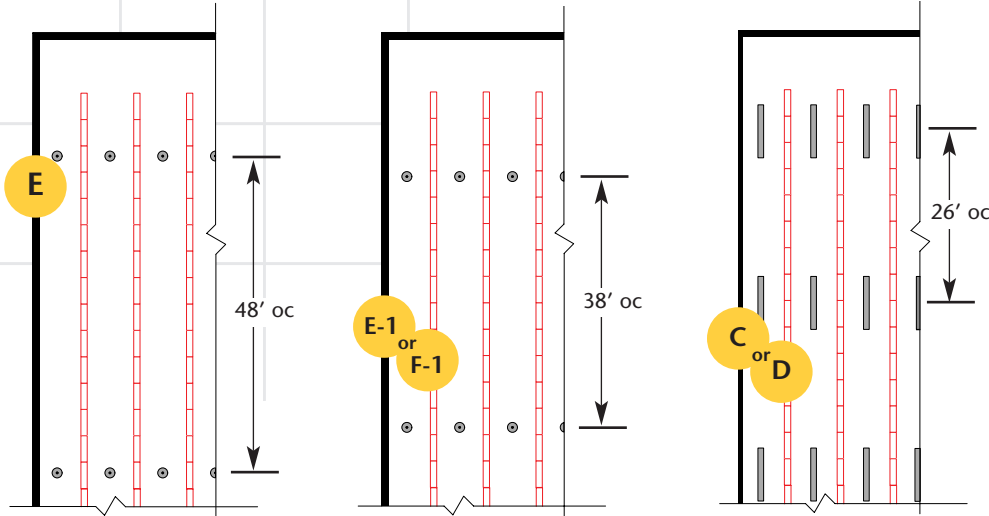
**COMPARISON CHART FOR GENERAL LIGHTING AND CLOSE WORK**

	Material Processing — Medium - 30 FC					Material Processing — Close Work - 50 FC	
	Layout 1		Layout 2	Layout 3		Based on Layout 1	
Fixtures	Type A	Type B	Type A-1	Type C	Type D	Type A task/ ambient 50 FC	Type A - 30 FC general w/ 40% Type G tasklighting
Uniformity	★★	★★	★★★	★★★★	★★★★	★★★	★★★
Comfort & Quality	★★	★★★	★★★	★★★★	★★★	★★	★★★
Maintained Footcandles (FC)	30	27	25	29	33	48	50
Power Density (Watts per/sq. ft.)	0.66	0.66	0.52	0.51	0.43	1.16	0.92
First Cost Increase (material & labor)	base case	60%	32%	162%	139%	58%	base case
<b>OVERALL VALUE</b>	★★	★★	★★★	★★★	★★★★	★★	★★★

Comparisons are based on research of current lighting practice in the New England region and illustrated in layout 1 based on 400 W metal halide open reflector fixtures.

# active storage

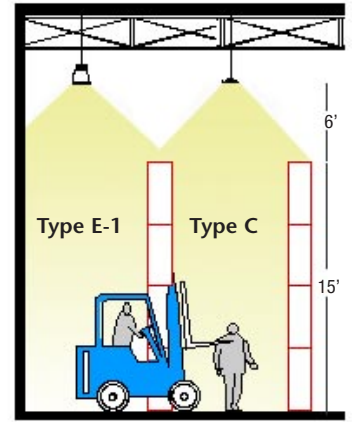
## narrow aisle – 8 ft. width



LAYOUT 1  
**STANDARD**

LAYOUT 2  
Type E-1 or F-1 – **BETTER**

LAYOUT 3  
Type D – **BETTER YET**



**Storage stacks, narrow aisle**

For optimum uniformity, distance from the fixture to the shelf top should be at least 40% of the height of the shelves.

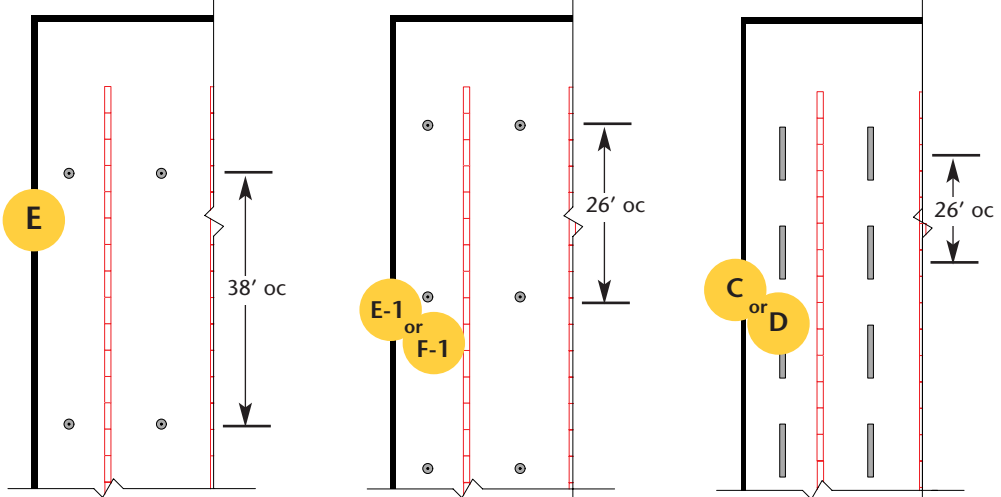
### RECOMMENDED QUANTITY OF LIGHT (FOOTCANDLES)

Active Storage	10 FC vertical
Inactive Storage	5 FC vertical

## Layout comparisons

Comparisons are based on research of current lighting practice in the New England region and illustrated in layouts 1 and 4 based on 400 W metal halide open reflector fixtures. Types E-1, F-1 and C layouts are rated better choices over the base cases because of increased comfort and quality. Type D layouts for both Narrow and Wide Aisle Storage are considered a Better Yet option because of increased quality over the base cases with less cost increase than Type C options.

## wide aisle – 16 ft. width



LAYOUT 4  
**STANDARD**

LAYOUT 5  
Types E-1 or F-1 – **BETTER**

LAYOUT 6  
Type D – **BETTER YET**

## COMPARISON CHART FOR ACTIVE STORAGE – 10 vertical FC required

	Narrow Aisle					Wide Aisle				
	Standard 1	Layout 2		Layout 3		Standard 4	Layout 5		Layout 6	
Fixtures	Type E	Type E-1	Type F-1	Type C	Type D	Type E	Type E-1	Type F-1	Type C	Type D
Uniformity	★	★★	★★★	★★★★	★★★★	★	★★	★★	★★★★	★★★★★
Comfort & Quality	★	★★	★★★	★★★★★	★★★★	★	★★	★★★	★★★★★	★★★★
Maintained Vertical Footcandles (FC)	14	14	13	14	12	14	13	13	12	10
Power Density (Watts per/sq. ft.)	1.03	0.97	0.97	0.57	0.48	0.88	0.74	0.74	0.41	0.34
Mounting Height Range	25-40'	25-40'	25-40'	20-35'	20-35'	25-40'	25-40'	25-40'	20-35'	20-35'
First Cost Increase (material & labor)	base case	59%	99%	136%	115%	base case	41%	77%	97%	80%
<b>OVERALL VALUE</b>	★	★★	★★	★★★★	★★★★★	★	★★	★★	★★★★	★★★★★

# lighting fixture schedule

These fixture specifications include fixtures that ensure a balance of performance, energy savings, comfort, lighting quality and ease of maintenance, at a cost-effective price. Many standard products meet these generic specifications. For those fixtures for which a Luminaire Efficacy Rating (LER) has been established, those values are given in the description. Luminaires for special applications such as hazardous areas, or using automatically switched quartz standby circuits or any fixtures under 150 input Watts, do not have LER values.

## INDUSTRIAL LIGHTING EQUIPMENT

The types of fixtures used in industrial spaces are limited compared to the vast array of equipment available for other work places. Appropriately applied, however, they can help to create a comfortable and energy effective environment.

**Linear Fluorescent Fixtures** with slotted reflectors are designed to minimize accumulation of dirt by allowing upward air-flow. Lenses or diffusers are uncommon for this reason. Where airborne particles call for greater protection, dust-tight covers are used. In damp locations, diffusers with vapor-tight gaskets are necessary. Improvements in fluorescent lamp technology, with the introduction of high output T-5 lamps, have made fluorescent an attractive alternative to more commonly used HID fixtures.

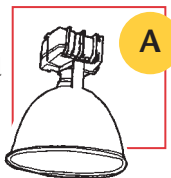
**High Intensity Discharge (HID) Fixtures** designed for metal halide lamps is often categorized as highbay or lowbay distribution. The light distribution of highbay fixtures is usually symmetrical, and is often adjustable to produce narrow to medium wide (44 - 60 degrees) with spacing criteria values of 1.0 or less. This light distribution is meant to concentrate light on horizontal work surfaces from lofty mounting heights of 25 feet or more.

**Aisle-lighting Fixtures** designed with asymmetric light distribution to specifically solve the unique requirements of this kind of area. In two directions, perpendicular to the stacks, the light distribution is high and broad to light the stored material top to bottom. Parallel to the aisle, light distribution is narrow so that workers are not disturbed by high angle light as they travel down the aisles.

*Both twin-tube and linear fluorescent fixtures equivalent to HID are available; typically these have better color rendering properties.*

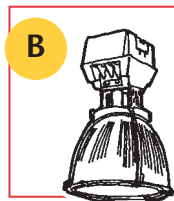
### A. Metal Halide, Open Metal Reflector, Standard Practice

LAMP: Type A, (1) Standard 400W Metal Halide  
Type A-1, (1) Pulse-start 250W Metal Halide  
DESCRIPTION: Pendant mounted open clear anodized metal housing with interior multi-faceted specular reflector, direct distribution. Field adjustable light pattern for concentrated to medium to wide light distribution for various ceiling height.  
LER Type A: 50; Type A-1: 40



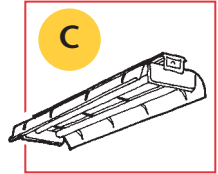
### B. Metal Halide, Open Prismatic Glass Reflector

LAMP: Type B, (1) Standard 400W Metal Halide  
DESCRIPTION: Pendant mounted open metal housing with interior faceted specular reflector for direct distribution. Approximately 25% uplight. Field adjustable socket position for medium to wide light distribution suitable for various mounting heights.  
LER Type B: 50



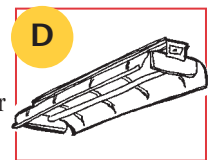
### C. T-8 Fluorescent, Pendant Industrial Reflector

LAMPS: (4) 32W T8  
DESCRIPTION: Pendant mounted fluorescent fixture in 8 foot lengths, 2 lamps in cross section, 4 lamps total. White baked enamel finish. Reflector slotted for 20% uplight. Optional "V" shaped center baffle (not shown) provides 30 degree glare shielding.  
LER 68



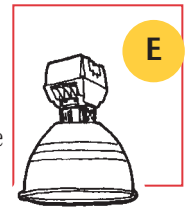
### D. T-5 Fluorescent, Pendant Industrial Reflector

LAMPS: (2) 54W T5 HO  
DESCRIPTION: Pendant mounted fluorescent fixture in 8 foot lengths, 1 lamp in cross section, 2 lamps total. White baked enamel finish. Reflector slotted for 20% uplight.  
Not rated for LER



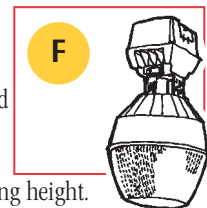
### E. Metal Halide, Open Reflector, Aisle-lighting

LAMPS: Type E, 400W Metal Halide  
Type E-1, 250W Metal Halide  
DESCRIPTION: Pendant mounted open clear anodized metal housing with interior multi-faceted specular reflector, direct distribution. Field adjustable light pattern for concentrated to medium to wide light distribution for various ceiling height.  
LER Type E: 50; Type E-1: 40



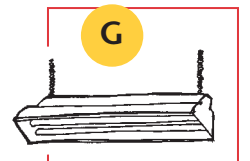
### F. Metal Halide, Prismatic Glass Reflector, Aisle-lighting

LAMP: Type F, (1) 400W Metal Halide  
Type F-1, (1) 250W Metal Halide  
DESCRIPTION: Pendant mounted open clear anodized metal housing with interior multi-faceted specular reflector, direct distribution. Field adjustable light pattern for concentrated to medium to wide light distribution for various ceiling height.  
LER Type F: 50; Type F-1: 45



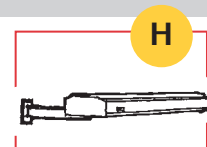
### G. Pendant Fluorescent Reflector

LAMPS: (2) 32W T-8 4' fluorescent  
DESCRIPTION: Cantilevered shelf mounted linear fluorescent tasklight.  
Not rated for LER



### H. Undershef Fluorescent Tasklight

LAMPS: (2) 32W T8  
DESCRIPTION: Cantilevered shelf mounted linear fluorescent tasklight.  
Not rated for LER



# lighting controls

## THE RIGHT AMOUNT OF LIGHT WHEN AND WHERE IT IS NEEDED

When an area is not in use, reduced light levels save energy and operating expense for the building owner. There are several ways of doing this including:

- Occupancy sensors
- Manual or equipment activated interval timer switches
- High/low switched ballasts
- Building time-switch or automated control systems

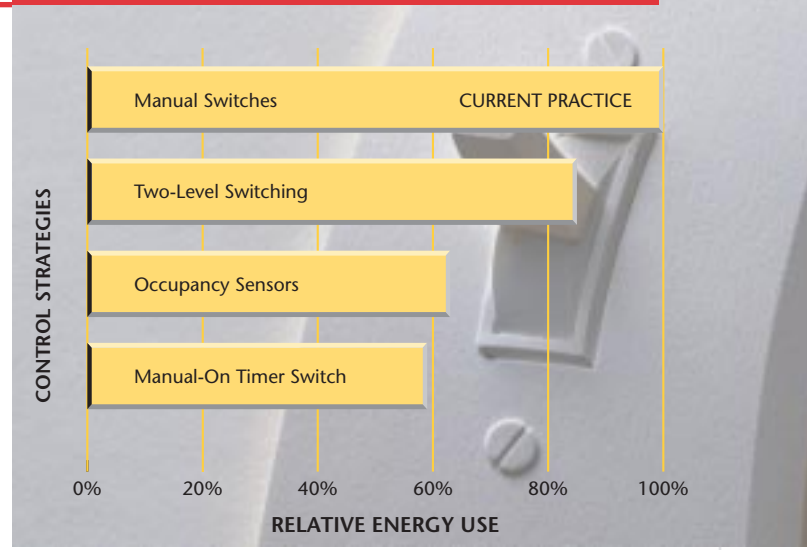
### MEDIUM ACTIVITY AREAS

The amount and type of control depends on the type of source and how often an area is used. Some light should be on in all areas of medium to heavy use when the building is occupied, especially in areas that are visible from other workspaces. Reduced light levels in unoccupied areas, instead of complete darkness, help to maintain acceptable contrast ratios.

### HIGH/LOW SWITCHING

Switching fixtures to a lower light level on an occupancy or operator activated system is a cost-effective energy saver in medium use areas. While switching may reduce lamp life hours, calendar life will be significantly longer. New “Programmed Rapid Start” ballast technology for fluorescent lamps significantly improve the life of lamps that are switched frequently.

Two level control also works well for metal halide systems because when the high level is switched on, the lamps ramp up quickly and return to optimum color and light output. In areas where abundant daylight is available for at least 25% of the time, the electric lighting energy usage can be reduced. Photo-sensor controlled fluorescent dimming systems or high/low metal halide



Energy savings are achieved by strategies which reduce both the connected load and the hours of operation. The bar chart compares energy consumed in a typical building space relative to current practice.

systems are effective and comfortable ways to optimize energy use in those areas.

### HIGH USE AREAS

In those areas where the space is in constant use or heavily trafficked, the lighting level usually should remain constant when the building is occupied.

### AUTOMATIC SHUT-OFF

A time-switch control or computer system can be programmed to assure that all non-essential lighting including tasklighting, is off during unoccupied hours. Automatic shut-off is a requirement of ASHRAE/IESNA Standard 90.1-1999.

### CONTROL CAUTION

- Be sure that reduced light levels do not cause dark areas in the worker’s immediate field of view.
- Metal halide lamps change color when wattage is reduced, to a Mercury type greenish blue. Occupants should be aware of and accept this change before a dual level system is installed.



### Controls Mean Energy Savings

Industrial space lighting systems can be optimized for comfort and energy savings by careful planning of automated controls.

*Earl Levin IALD, Lighting Designer*

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