Chapter 5

Lighting*

5.0. INTRODUCTION

The lighting system provides many opportunities for cost-effective energy savings with little or no inconvenience. In many cases, lighting can be improved and operation costs can be reduced at the same time. Lighting improvements are excellent investments in most commercial businesses because lighting accounts for a large part of the energy bill—ranging from 30-70% of the total energy cost. Lighting energy use represents only 5-25% of the total energy in industrial facilities, but it is usually cost-effective to address because lighting improvements are often easier to make than many process upgrades.

While there are significant energy-use and power-demand reductions available from lighting retrofits, the minimum lighting level standards of the Illuminating Engineering Society (IES) should be followed to insure worker productivity and safety. Inadequate lighting levels can decrease productivity, and they can also lead to a perception of poor indoor air quality.

Used as a starting place for an energy management program, lighting can attract immediate employee attention and participation, since everyone has ideas about lighting. Lighting is also seen as a barometer of the attitude of top managers toward energy management: if the office of the president of a company is an example of efficient lighting, then employees will see that energy management is taken seriously. A lighting retrofit program can be a win-win proposition for the business owner and the employees as it can improve morale, safety, and productivity while reducing life-cycle costs. This chapter provides a brief description of lighting systems, their characteristics, and retrofit options.

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5.1 COMPONENTS OF THE LIGHTING SYSTEM

A lighting system consists of light sources (lamps), luminaires (or fixtures), and ballasts. Each component will affect the performance, energy use and annual operating cost of the lighting system. This section discusses each of these components, and provides the basic information on lighting technology needed to successfully accomplish lighting Energy Management Opportunities (EMOs).

5.1.1 Lamp Characteristics

Lamps are rated a number of different ways and each characteristic is a factor to consider in the lamp selection process. The basic ratings include: luminous efficacy (lumens/watt); color temperature (Kelvins); color rendering index (CRI); cost ($); rated life (operation hours); and labor required for relamping. Lamps should carry recognizable name brands and should be purchased from a reputable vendor. Some off-brand lamps, particularly those from some foreign countries, have low light output and short lives.

5.1.1.1 Luminous Efficacy

The luminous efficacy of a lamp is an estimate of the light output (lumens) divided by the electrical power input (watts) under test conditions. Lamps operating outside their design envelope may suffer reduced efficacy. For example, 34-watt energy-saving fluorescent lamps should not be used in environments with temperatures below 60°F; at lower temperatures, they are prone to flickering, their light output is low, and they have short lives. Table 5.1 presents lamp data on many commonly used lamps. More data is available from lamp manufacturers and the IES Lighting Handbook [1].

5.1.1.2 Color Temperature

The color temperature of a lamp describes the appearance of the light generated compared to the perceived color of a blackbody radiator at that temperature on the absolute temperature scale (i.e., Kelvin scale). For example, a daylight fluorescent lamp rated at 6300 Kelvins appears bluish, while a warm-white fluorescent lamp rated at 3000 Kelvins appears yellowish. Figure 5-1 shows the color temperatures of commonly used fluorescent lamps.

The energy manager should be sensitive to lamp color when recommending lighting changes and should not recommend changing lamp color unless nearly everyone is in favor of the proposed change. Understanding the color needs of the facility is important too. Some merchan-

Table 5.1. Light Source Characteristics [ref 2, Table 13.4]

	Incandescent, Including Tungsten Halogen	Fluorescent	High-Intensity Discharge: Mercury Vapor (Self-Ballasted)	High-Intensity Discharge: Metal Halide	High-Intensity Discharge: High-Pressure Sodium (Improved Color)	Low-Pressure Sodium
Wattages (lamp only)	15-1500	15-219	40-1000	175-1000	70-1000	35-180
Life[a] (hr)	750-12,000	7500-24,000	16,000-15,000	1500-15,000	24,000 (10,000)	18,000
Efficacy[a] (lumens/W) lamp only	15-25	55-100	50-60 (20-25)	80-100	75-140 (67-112)	Up to 180
Lumen maintenance	Fair to excellent	Fair to excellent	Very good (good)	Good	Excellent	Excellent
Color rendition	Excellent	Good to excellent	Poor to excellent	Very good	Fair (very good)	Poor
Light direction control	Very good to excellent	Fair	Very good	Very good	Very good	Fair
Source size	Compact	Extended	Compact	Compact	Compact	Extended
Relight time	Immediate	Immediate	3-10 min	10-20 min	Less than 1 min	Immediate
Comparative fixture cost	Low: simple fixtures	Moderate	Higher than incandescent and fluorescent	Generally higher than mercury	High	High
Comparative operating cost	High: short life and low efficiency	Lower than incandescent	Lower than incandescent	Lower than mercury	Lowest of HID types	Low
Auxiliary equipment needed	Not needed	Needed: medium cost	Needed: high cost	Needed: High cost	Needed: High cost	Needed: high cost

[a]Life and efficacy ratings subject to revision. Check manufacturers' data for latest information.

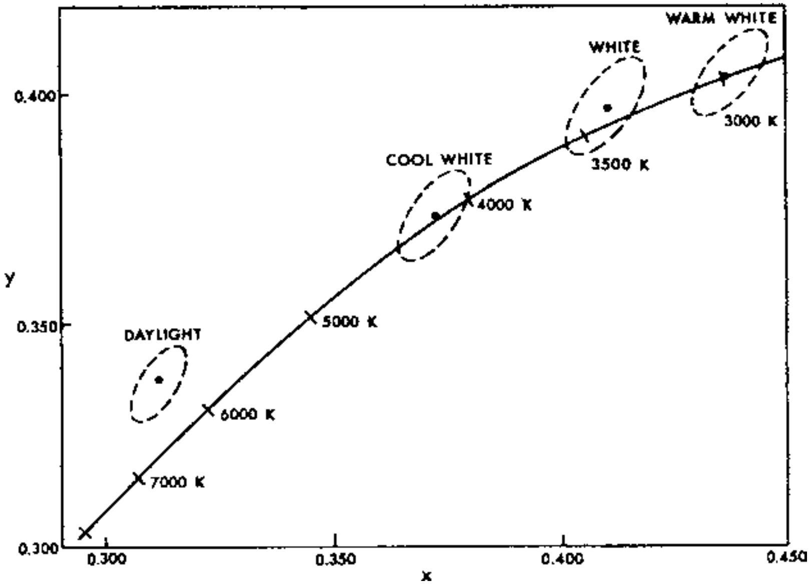


Figure 5-1. Fluorescent Lamp Color Temperatures [ref 1, Figure 5-17]

dise looks better at a particular color temperature. Example: meat in grocery store looks more appealing under warm lamps which accentuate the reds hues. The same meat in a meat-packing facility can be illuminated with lamps of a higher color temperature because visual appeal is not a factor.

5.1.1.3 Color Rendering Index

The color rendering index (CRI) is a relative indication of how well colors can be distinguished under the light produced by a lamp with a particular color temperature. The index runs from 0 to 1; where a high CRI indicates good color rendering. Many commonly-used lamps have poor CRIs (e.g., the CRI of a typical warm-white fluorescent lamp is 0.42, the CRI of a typical cool white fluorescent lamp is 0.67).

Rare earth elements in the phosphors of high-efficiency lamps increase light conversion efficacy and color rendition. Light sources such as metal halide lamps have better color rendering abilities than high pressure sodium lamps. The need for accurate color rendering depends on the particular task. Matching colors in a garment factory or photo laboratory will require a much higher CRI lamp than assembling large machine parts.

The color rendering abilities of commonly used lamps are described in Table 5.2.

Table 5.2 Color Rendition of Various Lamp Types

	Incandescent, high-intensity discharge lamps					
	Filament[a]	Clear Mercury	White Mercury	Deluxe White[b] Mercury	Multi-Vapor[b]	Lucalox[a]
Efficacy (lm/w)	Low	Medium	Medium	Medium	High	High
Lamp appearance effect on neutral surfaces	Yellowish white	Greenish blue-white	Greenish white	Purplish white	Greenish white	Yellowish
Effect on "atmosphere"	Warm	Very cool, greenish	Moderately cool, greenish	Warm, purplish	Moderately cool, greenish	Warm, yellowish
Colors strengthened	Red Orange Yellow	Yellow Green Blue	Yellow Green Blue	Red Yellow Blue	Yellow Green Blue	Yellow Orange Green
Colors grayed	Blue	Red, orange	Red, orange	Green	Red	Red, blue
Effect on complexions	Ruddiest	Greenish	Very pale	Ruddy	Grayed	Yellowish
Remarks	Good color rendering	Very poor color rendering	Moderate color rendering	Color acceptance similar to CW fluorescent	Color acceptance similar to CW fluorescent	Color acceptance approaches that of WW fluorescent

(*Continued*)

Table 5.2 Color Rendition of Various Lamp Types (*Continued*)

	Fluorescent lamps						
	Cool[b] White	Deluxe[b] Cool White	Warm[a] White	Deluxe[a] Warm White	Daylight	White	Soft White/Natural
Efficacy (lm/w)	High	Medium	High	Medium	Medium-high	High	Medium
Lamp appearance effect on neutral surfaces	White	White	Yellowish white	Yellowish white	Bluish white	Pale yellowish white	Purplish white
Effect on "atmosphere"	Neutral to moderately cool	Neutral to moderately cool	Warm	Warm	Very cool	Moderately warm	Warm pinkish
Colors strengthened	Orange Yellow Blue	All nearly equal	Orange Yellow	Red Orange Yellow Green	Green Blue	orange Yellow	Red Orange
Colors grayed	Red	None appreciably	Red, green blue	Blue	Red, orange	Red, green blue	Green, blue
Effect on complexions	Pale pink	Most natural	Sallow	Ruddy	Grayed	Pale	Ruddy pink
Remarks	Blends with natural daylight; good color acceptance	Best overall color rendition; simulates natural daylight	Blends with incandescent light; poor color acceptance	Good color rendition; simulates incandescent light	Usually replaceable with CW	Usually replaceable with CW or WW	Tinted source; usually replaceable with CWX or WWX

[a]Greater preference at lower levels.
[b]Greater preference at higher levels.
Source: General Electric Technical Pamphlet TP-I 19[3]. Reprinted with permission of General Electric Co.

5.1.2 Lamp Types

Lamps come in a variety of types and have a wide range of characteristics. Choosing the appropriate lamp type depends on the lighting task. Often, the least expensive lamp to buy is not the least expensive to operate. The energy manager should be familiar with the different options available for providing the desired lighting levels.

5.1.2.1 Incandescent Lamps

Incandescent lamps render colors well, are inexpensive to purchase, easily dimmed, small, and controllable which is useful for product display. However, they have relatively short lifespans, low efficacy and are susceptible to failure from heat and vibration. Incandescent lamps rated for long life or rough service have a correspondingly low efficacy. Some energy-saving lamps have a poorly supported filament and should not be used in environments with vibration or other mechanical stresses.

Most incandescent lamps tend to darken with age as tungsten is lost from the filament and deposited on the lamp walls. Figure 5-2 shows most of the commonly used lamps.

A Lamps, These lamps are low cost and commonly used in sizes of 20-1500 Watts. They project light out in all directions. In old industrial plants, look for large A-lamps in pendant fixtures where the lamps are left on most of the time. These are good candidates for replacement with HID lamps.

Reflector (R) Lamps. These lamps are usually more expensive than A-lamps and offer better control of the direction in which light is cast due to a reflective paint on the lamp wall. They have a focal point in back of the lamp, which results in the light from the lamp being dispersed broadly by the reflective surface of the lamp.

Ellipsoidal Reflector (ER) Lamps. These lamps cost about the same as R-lamps, but they are longer and have a focal point in front of the lamp. This location of the focal point results in the light being more concentrated as it leaves the lamp, and thus the beam is narrower than from an R lamp.

Quartz-Halogen Lamps. These lamps have a short life and low efficacy. They can be a good choice for areas which need lighting on an irregular basis. These lamps should not be cleaned.

Halogen Lamps. These lamps have a higher efficacy and cost than the lamps listed above and are available in many of the same lamp configurations.

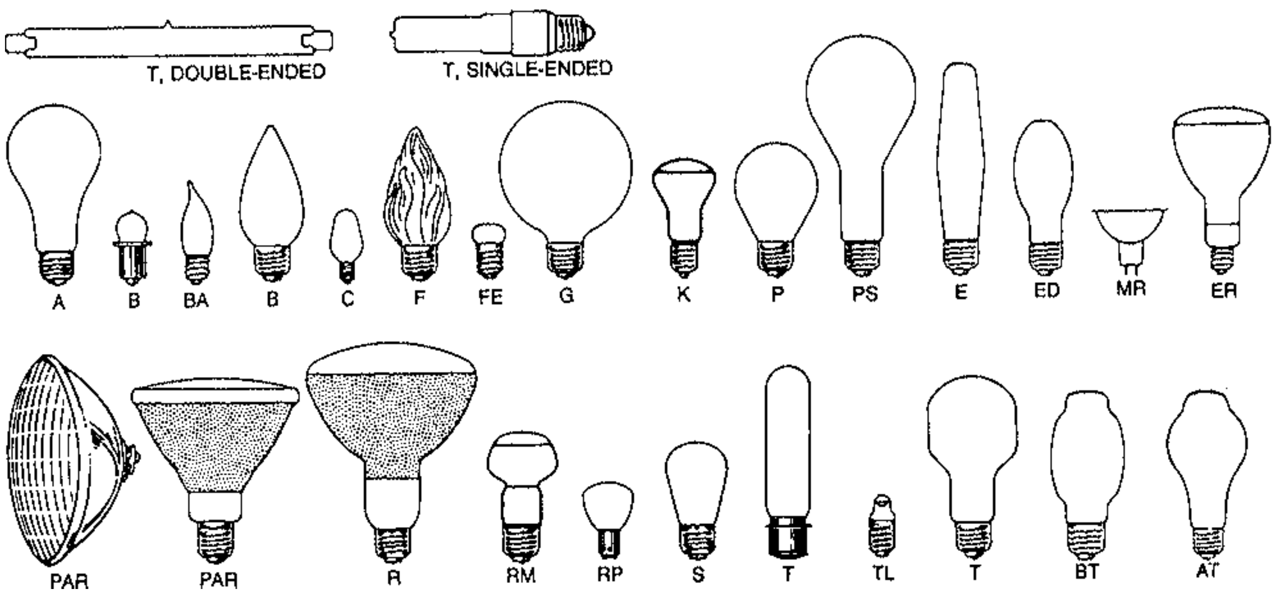


Figure 5-2. Incandescent Bulb Shapes and Designations [ref 1, p. 8-5]

5.1.2.2 Fluorescent Lamps

Fluorescent lamps have high efficacy, long life, and low surface luminance; they are cool and are available in a variety of colors. Figure 5-3 shows many of the commonly used fluorescent lamps.

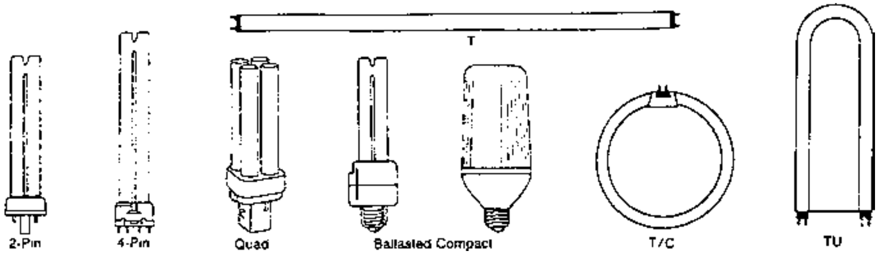


Figure 5-3. Fluorescent Lamp Shapes and Designations [ref 8, Figure 2-14]

Typical Fluorescent Lamps. Fluorescent lamps are available in standard, high output (HO), and very high output (VHO) configurations. The HO and VHO lamps are useful for low-temperature environments and areas where a lot of light is needed with minimal lamp space.

Energy-Saving Lamps. Energy-saving fluorescent lamps which can replace the standard lamps can reduce power demand and energy use by about 15%. They will also decrease light levels about 3-10%. These lamps can only be used with ballasts designed and rated for energy-saving lamps and should not be used in areas in which the temperature falls below 60°F. Fixtures subject to direct discharge from air-conditioning vents are not good candidates for energy-saving fluorescent lamps. Figure 5-4 lists many of the energy-saving lamps available.

T-Measures for Lamps. The T-measure for a fluorescent lamp is the measure of the diameter of the lamp in eighths of an inch. Thus, a T12 lamp is twelve-eighths of an inch (or 1 1/2 inches) in diameter, while a T10 lamp is 1 1/4 inches in diameter.

T10 Lamps. T10 lamps typically contain phosphors which produce high efficacy and color rendition. They will operate on most ballasts designed for T12 lamps.

T8 Lamps with Electronic Ballasts. T8 lamps produce an efficacy of up to 100 lumens/Watt, the highest efficacy of any fluorescent lamp. They will

Figure 5-4. Energy Saving Fluorescent Lamps [ref 1, Figure 8-115]

Lamp description	Lamp watts	Lamp watts replaced	Lamp current (A)	Lamp volts (V)	Lamp life[†] (h)	Nominal length		Base (end caps)	Nominal lumens[‡§]						
						(mm)	(in.)		3000K RE70	3500K RE70	4100K RE70	3000K RE80	3500K RE80	4100K RE80	5000K RE80
Rapid start															
F17T8	17	—	0.265	70	20,000	610	24	Med. Bipin	1325	1325	1325	1375	1375	1375	—
F25T8	25	—	0.265	100	20,000	914	36	Med. Bipin	2125	2125	2125	2200	2200	2200	—
F3278	32	—	0.265	137	20,000	1219	48	Med. Bipin	2850	2850	2850	2975	2975	2975	2700[b]
F40T8	40	—	0.265	172	20,000	1524	60	Med. Bipin	3600	3600	3600	3725	3725	3725	—
F40T12/U/3	36	40	—	—	12,000	610	24	Med. Bipin	—	—	—	—	—	—	—
F40T12/U/6	34	40	0.45	84	16,000	610	24	Med. Bipin	2800[b]	2800[b]	2800[b]	—	—	—	—
F30T12	25	30	0.453	64	18,000	914	36	Med. Bipin	2090	2090	2090[a]	—	—	—	—
F40TI2	34-36[‖]	40	0.46	73	20,000	1219	48	Med. Bipin	2800	2800	2880	2800	2800	2800	—
F48T12/HO	55	60	—	—	12,000	1219	48	Reces. DC	3850[a]	4075	3850[a]	4400[b]			—
F96T12/1500	95	110	0.83	126	12,000	2438	96	Reces. DC	8430	8430	8430	8620	8500[a]	8600[c]	—
F96T12/1500	195	215	1.58	137	12,000	2438	96	Reces. DC	—	—	—	—	—	—	—
F48PG17	95	110	1.53	64	12,000	1,219	48	Reces. DC	—	—	—	—	—	—	—
F96PG17	185	215	1.57	144	12,000	2438	96	Reces. DC	—	—	—	—	—	—	—
Preheat start															
F40T12	34	40	0.45	84	15,0000	1219	48	Med. Bipin	—	—	—	—	—	—	—
F90T17	86	90	—	—	9000	1524	60	Mog. Bipin	—	—	—	—	—	—	—
Instant start (Slimline)															
F48T12	30-32	38-40	—	—	9000	1219	48	Single pin	2610	2610	2610	2700[b]	—	—	—
F96T8	40-41	50-51	—	—	7500	2438	96	Single pin	—	—	—	—	—	—	—
F96T8[b]	56	—	0.26	267	15,000	2438	96	Single pin	—	—	—	5800	5800	5800	—
F96TI2	60	75	044	153	12,000	2438	96	Single pin	5675	5675	5675	5850	5850	5850	—

			Nominal Lumens‡§												
Lamp description	Lamp watts‡	Lamp watts replaced	4150K CRI 60+ Cool white	3000K CRI 50+ Warm white	3470K CRI 60+ white	6380K CRI 70+ daylight	5000K CRI 90+ C50	4180K CRI 80+ Deluxe cool white	2990K CRI 70+ Deluxe warm white (soft white)	4200K CRI 40+ Lite-white	3200K CRI 80+ Optima 32™[d] Natural	3570K CRI 80+ C75	7500K CRI 90+ Vita-lite[d]	5500K CRI 90+	
Rapid start															
F17T8	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F25T8	25	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F32T8	32	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F40T8	40	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F40T12/U/3	36	40	2350[a]	2425[a]	—	—	—	—	—	2500[a]	—	—	—	—	—
F40T12/U/6	34	40	2480	2530	2550	—	—	—	—	2620	—	—	—	—	—
F30T12	25	30	1975	2025	—	—	—	—	—	—	—	—	—	—	—
F40T12	34-36[b]	40	2670	2730	2700	2310	2010	1930	1925	2800	2010	—	—	—	—
F48T12HO	55	60	—	—	—	—	—	—		3900[a]	—				
F96T12HO	95	110	8020	8130	8000	6750[c]	—	5750	—	8400	—	—	—	6000[D]	—
F96T12/1500	188	215	13430	—	—	—	—	—	—	13,880	—	—	—	—	—
F48PG17	95	110	5700[A]	—	—	—	—	—	—	—	—	—	—	—	—
F96PG17	185	215	13,500[A]	—	—	—	—	—		14,100'	—	—	—	—	—
Preheat start															
F40T12	34	40	2700	—	—	—	—	—	—	—	—	—	—	—	—
F90T17	86	90	5765	—	—	—	—	—	—	—	—	—	—	—	—
Instant start (Slimline)															
F40T12	30.7	40	2475	—	—	—	—	—	2525	—	—	—	—	—	—
F96T8	40	50	3450[a]	—	—	—	—	—	—	—	—	—	—	—	—
F96T12	60	75	5430	5570	5370	4730	4050	3950	3900	5670	4200	—	—	4015	—

*The life and light output ratings of fluorescent lamps are based on their use with ballasts that provide operating characteristics. Ballasts that do not provide proper electrical values may substantially reduce lamp life, light output or both.

†Rated life under specified test conditions at 3 hours per start. At longer burning intervals per start, longer life can be expected.

‡"RE" indicates "RARE EARTH" type phosphors. This nomenclature has been developed by NEMA to define a system of color rendering information. RE 70 designates a CRI range of 70-79, RE 80 a range of 80-89, and RE 90 ≥ 90.

ßAt 100 hours. When lamp is made by more than one manufacturer, light output is the average of all manufacturers submitting data.

‖Also in 32 watt cathode cutout but with reduced life.

[a]General Electric,

[b]Sylvania.

[c]"Phillip.

[d]Duro-Test.

not generally operate on standard ballasts rated for T12 lamps. Because they are smaller than the T12 lamps, it is more difficult to replace them with the wrong lamps when they fail. They also use less of the toxic materials found in larger fluorescent lamps. T12 fixtures can be retrofitted with T8 lamps by using socket adapters and replacing the old ballasts with the T8 compatible ballasts.

Compact Fluorescent Lamps (CFLs). These twin-tube (TT) and double twin-tube (DTT) lamps are designed to replace many frequently used incandescent bulbs. These lamps can be used to reduce energy use and power demand by over 70%. For example, a 13-Watt fluorescent TT lamp can be used to replace a 60-Watt incandescent lamp. The light produced is similar in appearance to that of an incandescent lamp (i.e., color temperature of 2700 Kelvins for both). Since these lamps produce less heat, space cooling costs are also reduced. Many TT lamps/ballasts have a low power factor of about 0.5-0.6. A high power factor ballast with low harmonic distortion should be specified if a large number of these lamps is used.

Compact fluorescent lamps can be installed as a screw-in or hard-wired conversion kit and have a lifetime of at least 10,000 hours. Frequent cycles of short operation hours will significantly reduce lamp life. One-piece screw-in compact fluorescent lamps have higher life-cycle costs than two-piece screw-in models or the hard-wire models because the useful ballast life ends when the lamp burns out. Using the hard-wire kits will eliminate the possibility of an uninformed maintenance worker throwing away a two-piece screw-in conversion kit when the lamp fails. A number of facilities such as apartment buildings and motels find that screw-in compact fluorescent lamps are often stolen because they are easy to remove and are fairly expensive. Figure 5-5 lists the characteristics of some of the compact fluorescent lamps available.

5.1.2.3 High Intensity Discharge (HID) Lamps

These lamps are relatively expensive initially but offer low life-cycle costs due to long life and high efficacy. In general, the larger the HID lamp the higher the efficacy. The HID lamp efficacy can be affected by the lamp position, and some of these lamps have a significant color shift and loss of efficacy near the end of their rated life. Figure 5-6 shows some of the commonly used HID lamps.

Mercury Vapor Lamps. Mercury vapor lamps were the first HID lamps. They can offer good color rendering and low-to-moderate efficacy. Self-ballasted mercury vapor lamps are a direct replacement for large incan-

Figure 5-5. Compact Fluorescent Lamps [ref 1, Figure 8-1171

Generic designation NEMA	Lamp watts	Bulb type	Base	Rated life† (h)	Maximum overall length (mm)	(in.)	Lamp current (A)	Lamp voltage (V)	Approx. initial lumens‡	Lumens per watt	Color§ temperature and/or CRI
Twin tube 2700K, 3500K, 4100K, 5000Kß CRI 80 +											
CFT5W/G23	5	T-4	G23	7500	105	4-1/4	0.180	38	250	50	82
CFT7W/G23	7	T-4	G23	10,000	135	5-7/16	0.180	45	400	51	82
CFT9W/G23	9	T-4	G23	10,000	167	6-9/16	0.180	59	600	67	82
CFT13W/GX23	13	T-4	GX23	10,000	191	7-1/2	0.285	60	888	68	82
CFT5W/2G7	5	T-4	2G7	10,000	85	3-11/32	0.180	35	250	50	82
CFT7W/2G7	7	T-4	2G7	10,000	115	4-17/32	0.180	45	400	57	82
CFT7W/2G7[1, ‖]	9	T-4	2G7	10,000	145	5-22/32	0.180	59	600	67	82
CFT13W/2GX7	13	T-4	2GX7	10,000	175	6-29/32	0.285	59	900	69	82
FT18W/2G11[2]	18	T-5	2G11	12,000	229	9	0.375	60	1250	69	82
FT18W/2G11RS	18	T-5	2G11	20,000	267	10-1/2	0.250	76	1250	69	82
FT24W/2G11	24-27	T-5	2G11	12,000	328	12-29/32	0.340	91	1800	69	82
FT36W/2G11	36-39	T-5	2G11	12,000	422	10-5/8	0.430	111	2900	76	82
FT40W/2G11	40	T-5	2G11	20,000	574	22-19/32	0.270	169	1350	79	82
FT50W/2G11	50	T-5	2G11	14,000	574	22-19/32	0.43	147	4000	80	—
Quad 2700K, 3500K, 4100K, 5000K; CRI 80 +											
CFQ9W/G23	9	T-4	G23-2	10,000	111	4-3/8	0.180	15	575	21	82
CFQ13W/GX23	13	T-4	GX23-2	10,000	125	4-29/32	0.285	15	860	59	82
CFQ10W/G24d	10	T-4	G24d-1	10,000	118	45	0.140	64	600	60	82
CFQ13W/G24d	13	T-4	G24d-1	10,000	152	6	0.170	91	900	69	82
CFQ18W/G24d	18	T-4	G24d-2	10,000	175	6-29/32	0.220	100	1250	69	82
CFQ28W/G24d	26	T-4	G24d-3	10,000	196	7-23/32	0.315	105	1800	69	82
CFQ15W/GX32d	15	T-5	GX32d-1	10,000	140	5-1/2	—	60	900	60	—
CFQ22W/GX32d	20	T-5	GX32d-2	10,000	151	5-15/16	—	53	1200	60	—
CFQ26W/GX32d	27	T-5	GX32d-3	10,000	173	6-13/16	—	54	1600	59	—
CFQ10W/G24q	10	T-4	G24q-1	10,000	117	4-5/8	0.190	64	600	60	82
CFQ13W/G24q	13	T-4	G24q-1	10,000	152	6	0.170	77	900	69	82
CFQ18W/G24q	18	T-4	G24q-2	10,000	173	6-13/16	0.110	80	1250	69	82
CFQ26W/G24q	26	T-4	G24q-3	10,000	194	7-5/8	0.158	80	1800	69	82

(Continued)

Figure 5-5. Compact Fluorescent Lamps [ref 1, Figure 8-1171 *(Continued)*

Typical incandescent lamp substitutes (compact fluorescent lamps, internal ballast)[#]

Generic designation	Ballast type	Incandescent equivalent (W)	Lamp watts	Bulb type	Base	Related life[†] (h)	Maximum overall length** (mm)	(in.)	Lamp current (A)	Lamp voltage (V)	Approx. initial lumens[‡] (Candle-power)	lumens per watt	Color* temperature and/or CRI
7 W[3]	Electronic	25	7	T-4	Med. Screw	10,000	140	5-1/2	0.140	120	400	57	—
11 W[3]	Electronic	40	11	T-4	Mod. Screw	10,000	140	5-1/2	0.170	120	600	55	—
11 W reflector[3]	Electronic	50W .R30	11	P-35	Med. Screw	10,000	148	5-13/16	0.170	120	(315)	—	
11 W globe[3]	Electronic	30	11	G-32	Med. Screw	10,000	168	6-9/16	0,170	120	450	41	—
15 W[1,2,3]	Electronic	60	15	T-4	Mod. Screw	10,000	172	6-25/32	0.240	120	900	60	81
15 W reflector[3]	Electronic	75W.R40	15	RSB	Med. Screw	10,000	183	7-7/32	0.240	120	(1335)	—	—
15 W globe[3]	Electronic	50	15	G-38	Med. Screw	10,000	188	7-13/32	0.240	120	700	47	—
15 W globe[2]	Magnetic	40-60	18	G-30	Med. Screw	9,000	160	6-5/16	—	120	700	47	82
17 W decorative diffuser[1]	Electronic	60	17	T-24	Med. Screw	10,000	149	5-7/8	0.265	120	950	57	—
18 W decorative diffuser[2]	Electronic	75	18	T-24	Med. Screw	10,000	183	7-7/32	0.240	120	1100	61	—
18 W reflector	Electronic	75W.R40	18	R-40	Mod. Screw	10,000	142	5-19/32	0.240	120	800	44	—
18 W4	Electronic	75	18	T-4	Med. Screw	10,000	175	6-7/8	—	120	1100	61	—
20 W[1,2,3]	Electronic	75	20	T-4	Med. Screw	10,000	203	8	0.265[‡‡]	120	1200	60	—
22 W circular lamp[2]	Magnetic	75	22	T-9	Med. Screw	10,000	130	5-1/8	—	120	1200	54	52
23 W[1,3]	Electronic	90	23	T-4	Med. Screw	10,000	176	6-5/16	0.325	120	1550	67	—
26 W[2]	Electronic	90	26	Y-5	Med. Screw	10,000	203	8	0.430	120	1500	58	—

(Continued)

Figure 5-5. Compact Fluorescent Lamps [ref 1, Figure 8-1171 (Continued)

Square 2700 K and 3500 K[2]

Generic designation	Ballast type	Incandescent equivalent (W)	Lamp watts	Bulb type	Base	Related life† (h)	Maximum overall length** (mm)	Maximum overall length** (in.)	Lamp current (A)	Lamp voltage (V)	Approx. initial lumens‡ (Candle-power)	lumens per watt	Color* temperature and/or CRI
F102D/827/4P		10		2D	GR10Q 4PI	8000	94	3-23/32	0.18	72	650	65	82
F162D/827/4P		16		2D	GR10Q 4PI	8000	140	5-1/2	0.195	103	1050	66	82
F212D/827/4P		21		2D	GR10Q 4PI	8000	140	5-1/2	0.26	101	1350	64	82
F282D/827/4P		28		2D	GR10Q 4PI	10,000	203	8	0.32	107	2050	73	82
F382D/827/4P[ßß,||||]		38		2D	GR10Q 4PI	10,000	203	8	0.43	110	2850	79	82

Note: Many compact fluorescent lamps come equipped with normal (formerly called low) power-factor ballasts, either integral or as auxiliaries To minimize line losses and to maximize energy savings and lamp efficiency specifiers should require power-factor ballasts and should insist that luminaires, utilizing these lamps, be so equipped.

*These values are the averages of several manufacturers' data.

†At 3 hours per start.

‡Values for reflector lamps are in beam candlepower.

ßNot all color temperatures available from each manufacturer.

||Also available in red, blue, green.

#Screw base adapters with integral ballasts are available for retrofitting twin and quad tube lamps into incandescent fixtures.

**Some lamps are available in shorter MOLs.

††LLDs not yet available for these lamps.

‡‡Lamps are available with higher power factors and lower line currents.

ßßAdd 2 watts for cathodes when operating on rapid-start circuits.

||Rapid start life is estimated as 12000 hours @ 3 or more hours per start.

1Philips

2General Electric

3Osram

4Sylvania

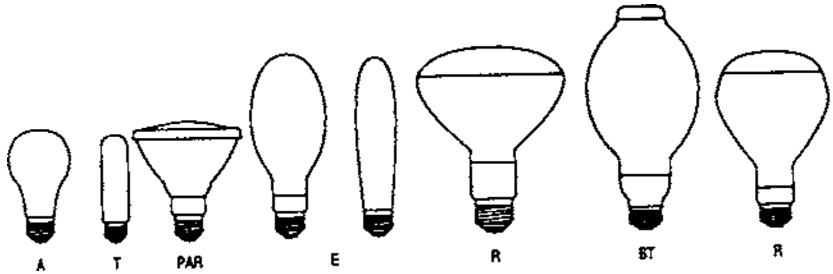


Figure 5-6. HID Lamp Shapes and Designations [ref 8, Figure 2-16]

descent lamps but have only 30-50% of the efficacy of typical mercury vapor lamps. Mercury vapor lamps are good candidates for replacement with more efficient light sources such as metal halide, high-pressure sodium, and low-pressure sodium.

Metal Halide lamps. Many of these lamps produce bright white light. They are used in applications which require good color rendering and high lighting levels such as sports facilities. They do not have as long a life as most other HID lamps. Some metal halide lamps can be installed in fixtures designed to operate mercury vapor lamps.

High Pressure Sodium (HPS) Lamps. HPS lamps offer high efficacy, long life, and a relatively small light source which is easily controlled. The light produced does not render colors well but is useful for tasks in which color rendering is not critical. These lamps are usually the best choice for warehouses, factories, exterior floodlighting, and streetlighting.

5.1.2.4 Low-Pressure Sodium (LPS) Lamps

LPS lamps offer the highest efficacy of any light source (i.e., up to 180 lumens/Watt). They have a long life but are fairly large compared to HID lamps. Their size requires a larger, more complex reflector design to efficiently utilize the light produced. The color of the light is nearly a monochromatic yellow under which very little color discrimination is possible. LPS lamps are common in European street lighting systems.

LPS is useful for interior security lighting. The distinctive yellow light tells law enforcement personnel that the premises should be unoccupied. Thieves and vandals can be mistaken for employees working late when better color-rendering light sources such as fluorescent lamps are used for night-time security.

5.1.3 Ballasts

Light from discharge-type lamps (e.g., fluorescent, mercury vapor, metal halide, high-pressure sodium, and low-pressure sodium) is produced indirectly by a cathode exciting a gas in which an electrical arc forms which then emits light. In a fluorescent lamp, mercury vapor emits ultra-violet radiation which strikes the sides of the lamp wall where phosphors convert it to visible light. A ballast is required to start and operate all discharge lamps.

Each lamp/ballast combination should have test results which state the ballast factor (BF). The lumen rating for a lamp is based on a particular lamp/ballast combination with a ballast factor of 1.0. The ballast factor indicates the light output of a particular system relative to a standard test ballast on which the lamp lumen ratings are based. For example, if a four-foot F32T8 has a rated lamp light output of 3000 lumens, and it is used with a ballast which has a ballast factor of 1.1 for the lamp/ballast combination, the system produces about 3300 lumens.

The ballast label usually gives the electric current drawn for particular lamp types, states whether the ballast does not contain polychlorinated biphenyls (PCB), and shows a wiring diagram. Many older ballasts, especially those manufactured before 1975, utilize PCB oil which contains some of the most toxic chemicals known. Leaking PCB-laden ballasts should be handled as a hazardous waste material during disposal. Ballasts which do not contain PCB can currently be landfilled in most states.

National standards require that all new ballasts have a minimum efficiency and contain no PCBs. Ballasts are usually labeled low-heat (LH), very-low heat (VLH), super-low heat (SLH), energy-saving, or electronic. Not all electronic ballasts on the market will operate at higher efficiency than magnetic ballasts. Claims of "full light output" can be distracting. Use the ballast factor to determine the actual efficiency of the ballast. Many of these new ballasts have much longer operating lives than the ballasts they replace. Some low-efficiency replacement ballasts are still available but should not be used.

Unlike magnetic core-and-coil ballasts, some electronic ballasts can be dimmed, but they also can produce significant levels of harmonic distortion. When recommending electronic ballasts, specify ballasts with a total harmonic distortion (THD) less than 20%.

Strobing and flickering lamps strain the ballast. Strobing occurs as the ballast attempts to restart and operate the lamp(s). The problem is sometimes due to a loose or corroded connection, but most often the lamp has come to the end of its useful life. As lamps age, their light output decreases and they become more difficult to start and operate. If checking the connections and lamps does not reveal the cause of the flickering, then ballast replacement may be necessary.

5.1.4 Luminaires (Fixtures): Lenses, Diffusers, and Reflectors

The luminaire is the complete lighting fixture. It consists of a housing socket, the light source (lamps) and the components which distribute the light such as the lens, the diffuser and the reflector.

The coefficient of utilization (CU) of a lighting fixture is the ratio of the light leaving the fixture to the light produced by the lamps. Light is absorbed and converted to heat by surfaces, by lamp-to-lamp interactions, and by the lenses. Tables of common CU values can be found in the IES Lighting Handbook [1].

5.1.4.1 Types of Fixtures

Some common types of lighting fixtures are listed below. Retrofit options are noted where appropriate.

Jars and Globes: These fixtures typically have low CU values. Although they generally use incandescent lamps, compact fluorescent lamps can also be used in jar and globe fixtures.

Wall Surface-Mounted: These fixtures have moderate CU values.

Pendant: These fixtures utilize a variety of lamp types. They often use bare lamps, but are sometimes fitted with globes, lenses, or diffusers. Large incandescent lamps (e.g., 500-1500 Watt) are frequently used, but more efficient sources are available. These fixtures often hang from the ceilings of production and warehouse areas. They can sometimes be lowered to increase the light levels at the work surfaces if the resulting light distribution is acceptable.

Track and Recessed: These fixtures (sometimes referred to as downlights) baffle some light when A-lamps or deeply-recessed R-lamps are used. Most of the baffled light is converted to heat. Ellipsoidal reflector lamps (ER) are designed to cast more light out of recessed fixtures. If an adjustable-depth can-type fixture without a specular reflector looks bright inside, there is potential for using an ER lamp. However, a protruding ER lamp is not a good application.

Although there are some excellent downlights available which have been designed for CFLs, in general a compact fluorescent screw-in lamp should not be used in a track or recessed fixture unless lighting levels can be reduced. A CFL casts nearly all of its light out to the sides instead of downward where it is needed in a downlight.

Area Lights: These fixtures are commonly known as barn lights. They cast light in nearly all directions. Much of the light is lost to the sky and overhead trees, or it trespasses off the property. Cutoff luminaires which use reflectors to direct the light where it is needed can produce the same light levels for the area of interest with about a third of the power.

Streetlights: Some types such as barnlights and cobraheads cast light upward and away from the area of interest. Cutoff luminaires offer a good alternative here too.

Figure 5-7 demonstrates the application of well-controlled lighting fixtures to reduce outdoor lighting costs an poorly applied fixtures.

Exit Signs: These signs typically use two 20-Watt or two 25-Watt incandescent lamps which can be replaced by a 7-Watt compact fluorescent TT lamp. This will reduce operating costs by more than 75%. These TT lamps can last up to 20,000 hours when run continuously.

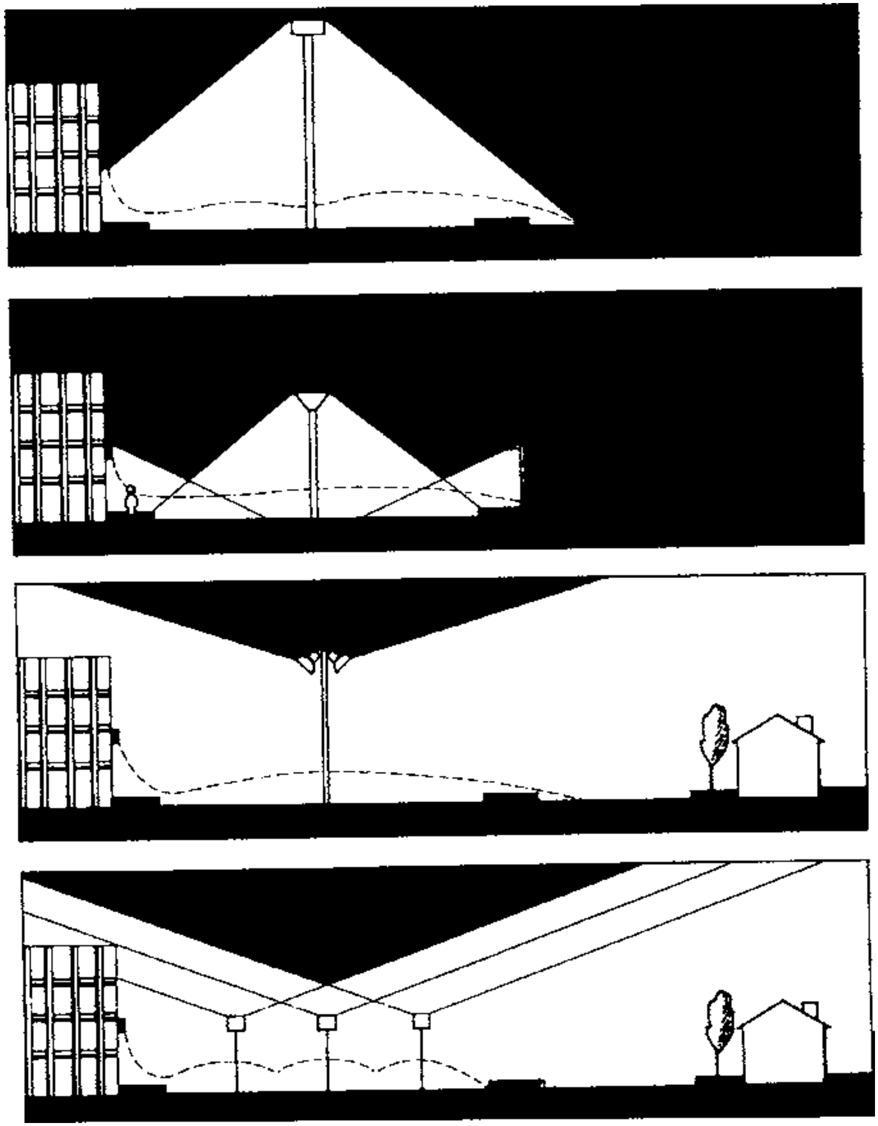
Floodlights: Look for low-efficacy sources such as mercury vapor lamps. High pressure sodium floodlights offer excellent savings.

5.1.4.2 Lenses, Diffusers and Reflectors

Adding lenses or reflectors to a lighting fixture changes the light distribution pattern (i.e., photometrics). Replacing the lens or diffuser can be helpful in situations where the system was poorly designed or the use of the space has changed. For example, many office areas which were lighted appropriately for traditional paperwork now have glare on video terminals because people are using computers instead of typewriters or pens. Polarized lenses can reduce the glare but they also reduce the amount of light leaving the fixture. Figure 5-8 shows how relationships can change when the workstation is altered.

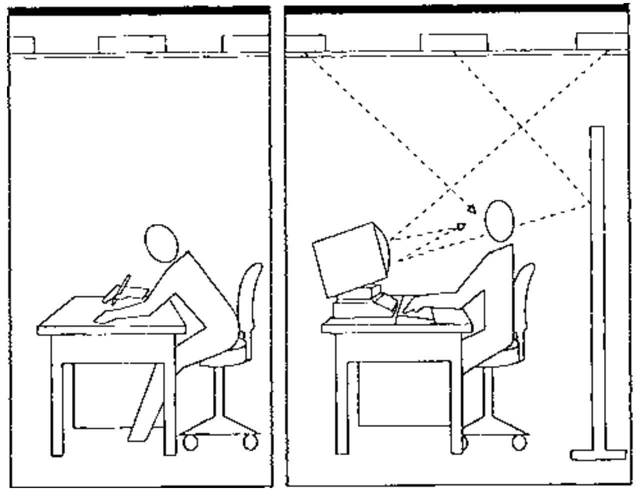
Glare from the specular surfaces reduces visibility. This veiling glare can be reduced with careful fixture positioning and proper selection of diffusers. Glare on video display terminals can often be alleviated by tipping the monitor down or putting a wedge under the back. Figure 5-9 shows how glare can reach the eyes of a worker.

Most fixtures have built-in reflectors. A fixture with a baked white enamel finish has a reflectivity of about 0.88. The practice of removing half the lamps and adding a reflector to a fixture will reduce the amount of



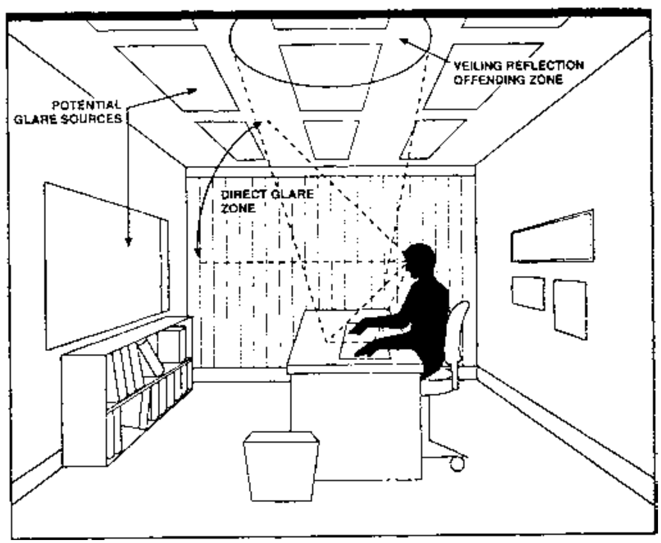
The top two illustrations indicate effective ways of achieving desired lighting for the area involved (indicated by the dotted line). The bottom two approaches waste energy and the "light trespass" effect of the "spill light" can irritate neighbors.

Figure 5-7. Effective Outdoor Lighting [ref 7, Figure 11]



Prevailing relationships between workers, their tasks, and their environments are altered significantly when traditional "white paper tasks" (on left) are changed to VDT-based tasks (on right).

Figure 5-8. Prevailing Lighting Relationships [ref 7, Figure 7]



Veiling reflections commonly occur when the light source is directly above and in front of the viewer, in the "offending zone."

Figure 5-9. Veiling Reflections [ref 7, Figure 3]

light leaving a fixture. Therefore, this is only practical when the area is over-lighted.

The performance of lenses, diffusers, and reflectors depends on environmental factors such as dirt accumulation, oxidation, glare, discoloration due to UV light exposure, and vandalism. Surface finishes react with airborne chemicals and lose some light transmission capability as they age. Choosing materials appropriate for the work environment and cleaning the fixtures regularly will prolong their useful lives. Outdoor lighting presents some special problems. Vandals often delight in shooting at exterior lighting fixtures. Polycarbonate lenses resist damage due to firearms and other projectiles. However, they also discolor from prolonged exposure to UV light produced by the lamp or the sun. Acrylic lenses typically last longer than even UV-inhibited polycarbonate lenses. Table 5-3 gives a comparison of the performance of acrylic and polycarbonate lenses over time.

5.2 DETERMINING LIGHTING NEEDS

A variety of techniques are available for estimating the lighting levels in a given space. The average illuminance method described in the Illuminating Engineering Society IES Lighting Handbook [1] incorporates the major variables affecting light utilization: amount of light produced by lamps, amount of light exiting the fixture, mounting height and spacing of fixture, fixture photometrics, lumen dirt depreciation, lamp lumen depreciation, ballast factor, and room surface finish characteristics. A worksheet to calculate lighting levels is also found in the IES Lighting Handbook.[1]

The IES has developed standards for appropriate lighting levels for typical applications. Lighting levels are generally expressed in terms of illuminance, which is measured in footcandles. Table 5.4 shows the illuminance category for a number of commercial and industrial applications.

Once the appropriate illuminance category has been identified, Table 5.5 can be used to determine the range of illuminance values needed to achieve desirable lighting levels. In using these tables, the IES recommends that the lower values be used for occupants whose age is under 40 and/or where the room reflectance is greater than 70% and that the higher values be used for occupants more than 55 years old and/or where the room reflectance is less than 30%. For occupants between 40 and 55 years of age and where the reflectance is 30-70% or where a young occupant is combined with low reflectance or an older person is in a high-reflectance environment, the intermediate values should be used. In addition, the

Table 5-3. Comparison of Acrylic and Polycarbonate Lenses [ref 7, Table 4]

	Acrylic	High-Impact Acrylic	Polycarbonate
Light Transmission	92%	90%	88%
Aging-Light Stability	10-15 yrs	10-15 yrs	3-4 yrs
Impact Strength	1	10X	30X but degrades rapidly
Haze	Under 3%	Under 3%	Under 3% but degrades
Scratch Resistance	Very Good	Good	Good
Burning Character (U.L. Class)	Slow	Slow	Self-Ext.
Smoke Generation	Slight	Slight	High
Resistance to Heat	200°F	180°F	250°F
Type Smoke	Nontoxic	Nontoxic	Toxic
Relative Cost	1X	2X	4X

Table 5.4. Lighting Recommendations For Specific Tasks

Area-activity	**Illuminance category**
Bakeries	D
Classrooms	D to E
Conference rooms	D
Drafting rooms	E to F
Hotel lobbies	C to D
Home kitchens	D to E
Inspection, simple	D
Inspection, difficult	F
Inspection, exacting	H
Machine shops	D to H
Material handling	C to D
Storage, inactive	B
Storage, rough, bulky items	C
Storage, small items	D
	Footcandles
Building entrances	1-5
Bulletin boards, bright surroundings, dark surfaces	100
Bulletin boards, dark surroundings, bright surfaces	20
Boiler areas	2-5
Parking areas	1-2

Table 5.5. Illuminance Categories and Illuminance Values

Type of activity	Illuminance category	Ranges of illuminances: Lux	Ranges of illuminances: Footcandles	Reference work plane
Public spaces with dark surroundings	A	20-30-50	2-3-5	General lighting throughout spaces
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10	
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20	
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50	Illuminance on task
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100	
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200	
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000	200-300-500	Illuminance on task, obtained by a combination of general and local (supplementary lighting)
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000	
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000	1000-1500-2000	

need for speed and accuracy influences the amount of light needed, with higher speed and accuracy demanding more light.

Lighting levels can sometimes be reduced if there is sufficient contrast between the work and its surroundings. However, too much contrast between the work and the ambient environment will fatigue the eyes. For example, occupants of dark paneled offices who work with pencil on brightly-illuminated white paper will often experience eye fatigue.

The illuminance values considered acceptable have changed through the years in response to emerging technology. Recommended light levels were relatively low in the incandescent lamp era due to restrictions resulting from heat production. From 1945-1960 more efficient light sources were developed and energy costs plummeted, leading to a tripling of the recommended values [3]. Rising energy and power demand costs in the 1970's spurred the industry to reduce the recommended lighting levels to the minimum necessary to provide adequate illumination.

5.3 MAINTAINING THE LIGHTING SYSTEM

In addition to a proper choice of light sources, ballasts, and luminaires, the efficiency of a lighting system depends on maintenance policies. Maintenance includes both cleaning and relamping.

5.3.1 Luminaire Maintenance

The performance of lenses, diffusers, and reflectors depends on environmental factors such as dirt accumulation, oxidation, vandalism, and degradation due to ultra-violet (UV) light exposure. Typical fluorescent lamp performance under various temperature conditions is shown in Figure 5-10.

Lamps, fixtures, reflectors, lenses, and diffusers collect dust and insects. Dust accumulation on lighting fixtures and on surfaces adjacent to lighting fixtures reduces light utilization by up to 40 percent and increases heat production. Periodic cleaning of the fixtures will maintain higher and more uniform light levels. All lamps should be cool before cleaning. Gloves should be worn when cleaning any mirror-like reflective part of a luminaire. Quartz lamps should not be cleaned.

Outdoor lighting has some special maintenance problems. Poorly-sealed gaskets allow insects to clog the lenses of outdoor lighting fixtures. Dead insects can completely block out light. Overgrown vegetation can also reduce lighting levels from outside fixtures. Regular trimming of

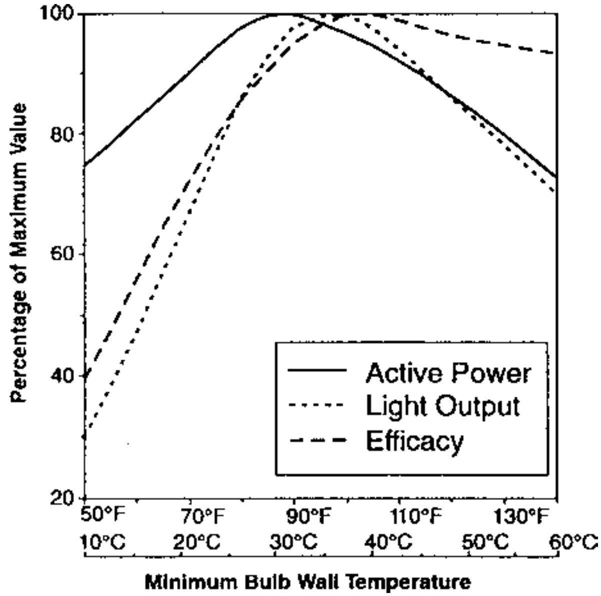


Figure 5-10. Lamp Performance vs. Temperature

shrubs and trees will help to fully utilize these light sources. Small trees planted under or near lighting fixtures can quickly grow to block the light source.

5.3.2 Establishing the Lighting System Maintenance Schedule

Establishing a good maintenance schedule for a lighting system takes three steps. First, you must determine the maintenance characteristics of the luminaires in your facility. Table 5-6 lists the maintenance categories for a variety of luminaires.

The next step is to determine what dirt conditions the luminaires are likely to experience. Table 5-7 shows dirt conditions for representative areas. Once you know both the maintenance category from Table 5-5 and the appropriate dirt conditions for the facility from Table 5-7, then use the graphs in Figure 5-11 to set the luminaire maintenance schedule. These graphs show the effect that dirt accumulation has upon lighting levels over a period of months.

These graphs are for average conditions. Actual conditions may warrant a more frequent cleaning schedule than the graphs indicate. Using open fixtures and diffusers often reduces the potential for light loss since there are fewer surfaces for settling, and particles and dust can be

Table 5.6. Maintenance Categories for Luminaire Types

Maintenance category	Top enclosure	Bottom enclosure
I	1. None	1. None
II	1. None	1. None
	2. Transparent with 15% or more uplight through apertures	2. Louvers or baffles
	3. Translucent with 15% or more uplight through apertures	
	4. Opaque with 15% or more uplight through apertures	
III	1. Transparent with less than 15% uplight through apertures	1. None
	2. Translucent with less than 15% uplight through apertures	
	3. Opaque with less than 15% uplight through apertures	
IV	1. Transparent unapertured	1. None
	2. Translucent unapertured	2. Louvers
	3. Opaque unapertured	
V	1. Transparent unapertured	1. Transparent unapertured
	2. Translucent unapertured	2. Translucent unapertured
	3. Opaque unapertured	
VI	1. None	1. Transparent unapertured
	2. Transparent unapertured	2. Translucent unapertured
	3. Translucent unapertured	3. Opaque unapertured
	4. Opaque unapertured	

Table 5-7. Degrees of Dirt Conditions

	Very clean	Clean	Medium	Dirty	Very dirty
Generated dirt	None	Very little	Noticeable but not heavy	Accumulates rapidly	Constant accumulation
Ambient dirt	None (or none enters area)	Some (almost none enters)	Some enters area	Large amount enters area	Almost none excluded
Removal or filtration	Excellent	Better than average	Poorer than average	Only fans or blowers if any	None
Adhesion	None	Slight	Enough to be visible after some months	High—probably due to oil, humidity, or static	High
Examples	High-grade offices, not near production; laboratories; clean rooms	Offices in older buildings or near production; light assembly; inspection	Mill offices; paper processing; light machining	Heat treating; high-speed printing; rubber processing	Similar to "Dirty" but luminaires within immediate area of contamination

Source: Courtesy of the Illuminating Engineering Society of North America.

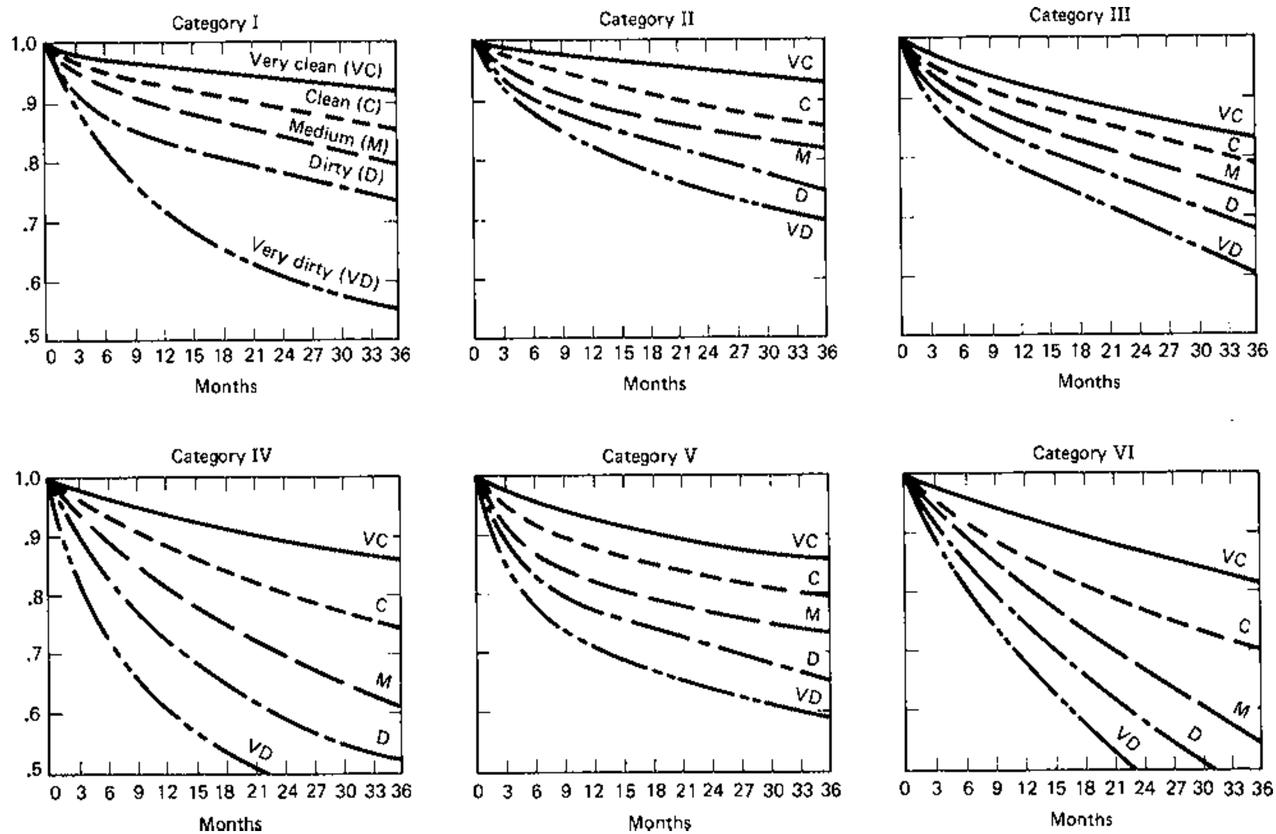


Figure 5-11. Luminaire Dirt Depreciation Factors

[Fraction of full light output is the scale on the y-axis.] (Courtesy of the Illuminating Engineering Society [1]) more easily removed from these fixtures. However, an environment with potentially explosive dust; such as flour, corn, coal, etc., has to have sealed explosion-proof fixtures. Typical lamp lumen depreciation, luminaire dirt depreciation, and room surface dirt depreciation curves for fluorescent lamps are shown in Figure 5-12.

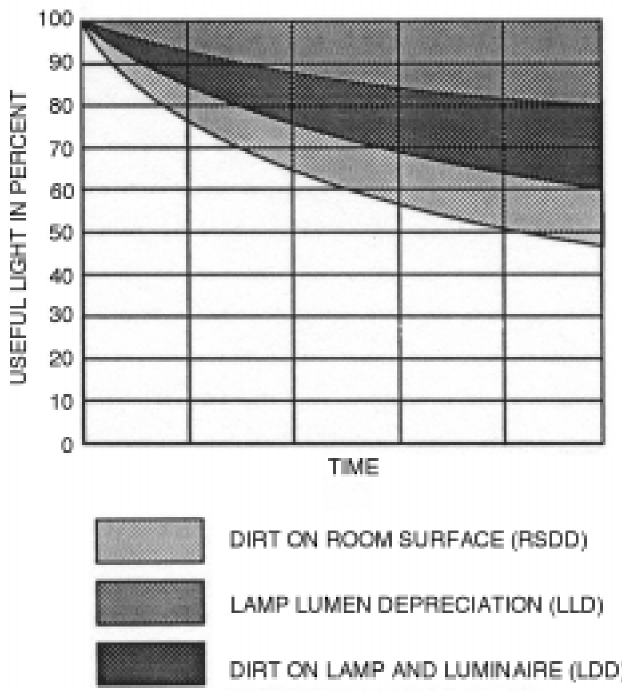


Figure 5-12. Lumen Maintenance Curve For Fluorescent Lighting Systems [ref 8, Figure 2-20]

5.3.3 Relamping strategies.

The usual strategy for replacing lamps in many facilities is to wait until a lamp burns out and then replace it (called spot relamping). This relamping strategy is not necessarily the best one for a facility to follow because it does not consider such factors as labor costs or lumen depreciation. It is often more economical to replace all of the fluorescent and HID lamps in a facility at one time (called group relamping). Spot relamping is more labor intensive and results in less efficient lighting than group relamping. However, spot relamping can be more practical for lamps with a short life such as incandescent lamps.

The reason that spot relamping results in a loss of lighting efficiency is that the amount of light that comes from a lamp declines with the age of the lamp. Performance curves, such as those in Figures 5-13, 5-14, and 5-15 show how the light output is reduced as a function of ordinary usage. Note that the life of a lamp is measured in hours of use rather than installed hours. In addition to degraded performance of individual lights, the total lighting system performance is decreased as individual lamps burn out. Typical mortality curves, showing the percent of lamps in service as a function of time, are given in Figures 5-16, 5-17, and 5-18.

As these figures show, lamp mortality at 85-100% of rated life is about twenty-five times that of lamps aged 0-70% of rated life. Therefore, fixtures should be group relamped when lamps are between 70-80% of the rated lamp life.

The average useful lamp life is shown in Figure 5-19.

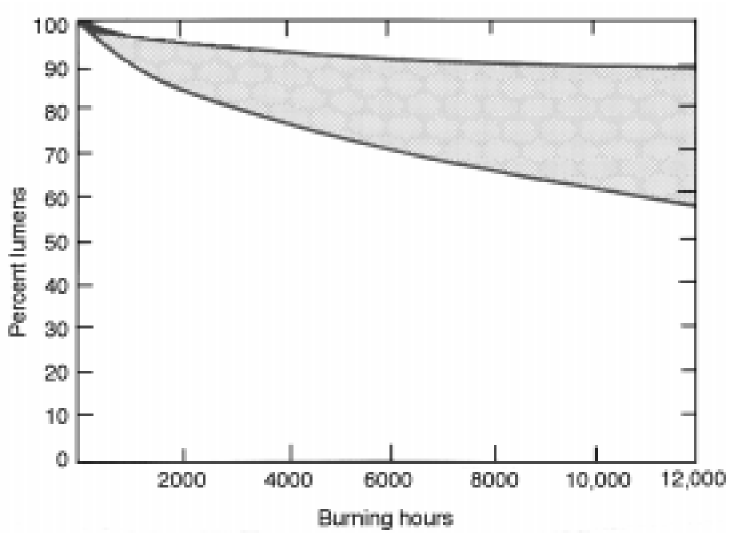


Figure 5-13. Typical lumen maintenance curve for fluorescent lamps. (From General Electric Technical Pamphlet TP-105. Courtesy of General Electric Co.)

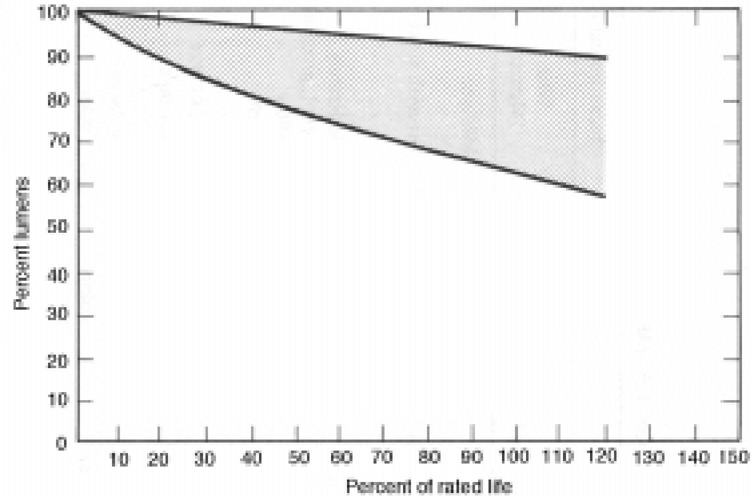


Figure 5-14. Typical lumen maintenance curve for filament lamps. (From General Electric Technical Pamphlet TP-105. Courtesy of General Electric Co.)

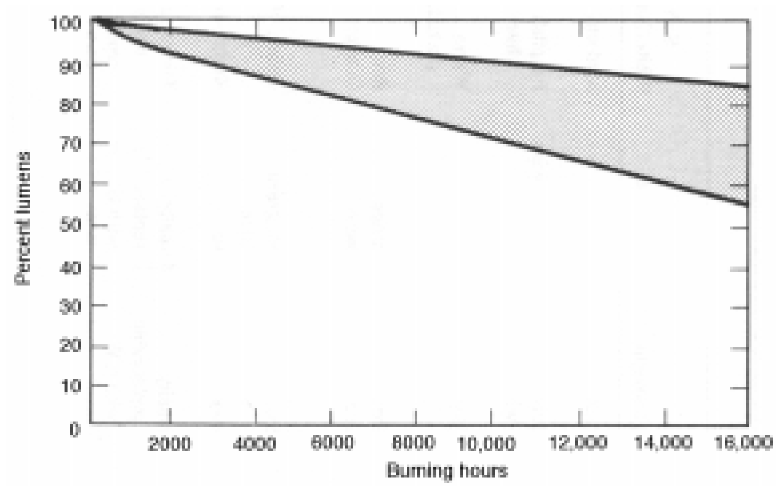


Figure 5-15. Lumen Maintenance Curve for HID Lamps (From General Electric Technical Pamphlet TP-105. Courtesy of General Electric Co.)

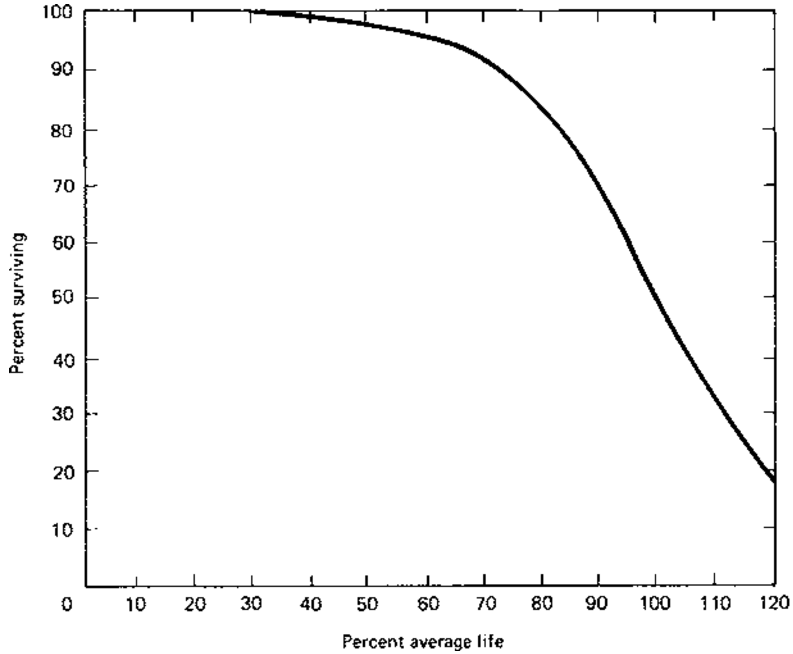


Figure 5-16. Typical mortality curve for fluorescent lamps. (From General Electric Technical Pamphlet TP-105. Courtesy of General Electric Co.)

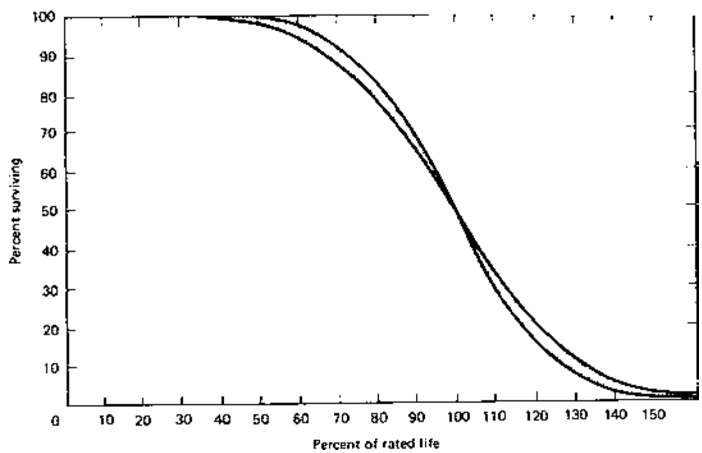


Figure 5-17. Typical mortality curve for filament lamps. (From General Electric Technical Pamphlet TP-105. Courtesy of General Electric Co.)

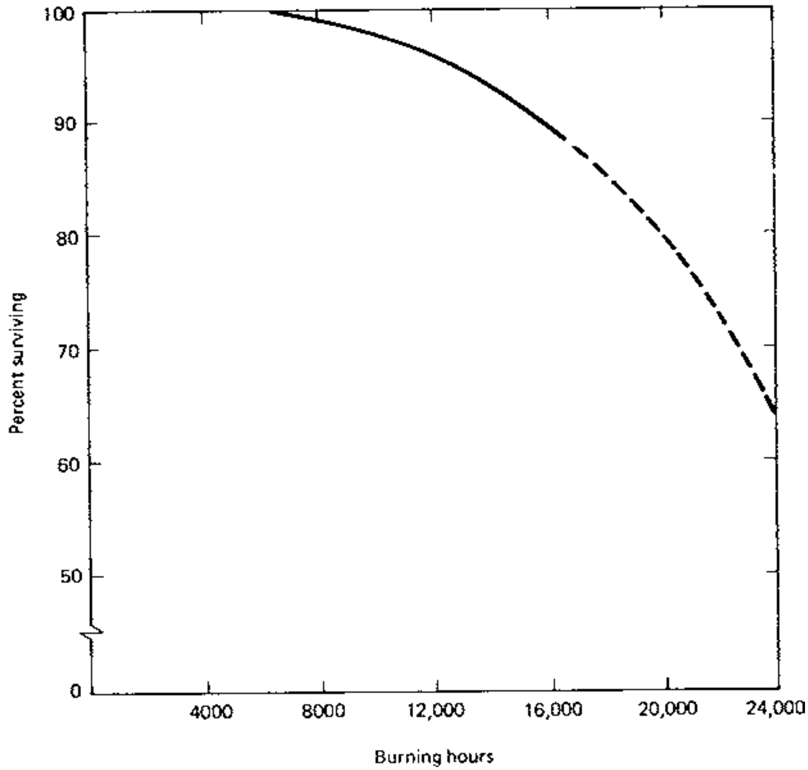


Figure 5-18. Typical mortality curve for HID (mercury vapor) lamps. (From General Electric Technical Pamphlet TP-105. Courtesy of General Electric Co.)

Since most F40T12 four-foot fluorescent lamps are rated for 20,000 hours, they should be replaced after 16,000 hours of operation. Lamp life ratings indicate the point at which half of the lamps are likely to have failed. Fluorescent lamp lifetimes are rated at three hours per start, HID lamps are rated at five hours per start. Operating the lamps for shorter periods will reduce lamp life.

Group relamping can:

1. **Reduce Labor Costs:** Spot relamping can require up to 30 minutes to move furnishings or equipment, set up, replace the lamp, and put equipment away (e.g., ladder, lamps, tools). In group relamping, a fixture can usually be relamped and cleaned in 5 minutes. The loss-of-use cost of replacing a few lamps before they have burned out is

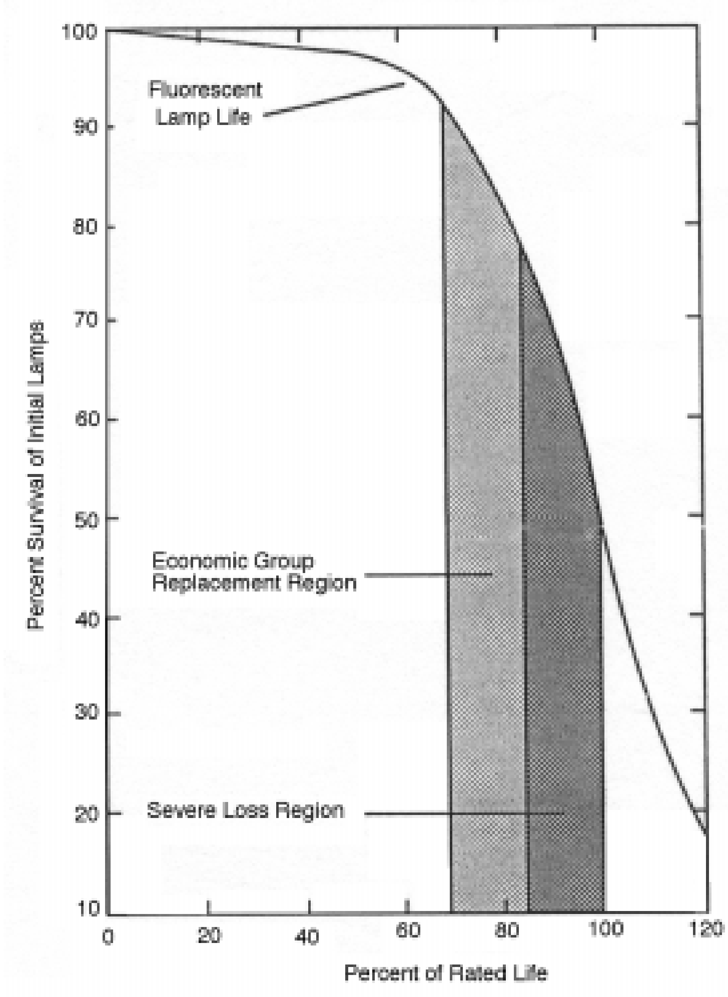


Figure 5-19. Lumen Maintenance Curve For Fluorescent Lighting Systems [ref 8, Figure 2-20]

generally less than the increased cost of the labor to individually replace burned out lamps.

2. **Reduce Lamp Costs:** Purchasing a large number of lamps at one time allows for high volume discounts. Fewer purchases result in less time spent ordering, receiving, and stocking lamps.

3. **Allow Lamp Maintenance to be Scheduled:** Relamping can be scheduled for slow periods for the maintenance staff. Scheduled relamping

also allows a regular schedule to be set for regular inspection and cleaning of lamps and fixtures.

4. **Maintain Higher and More Uniform Lighting Levels:** The light output of a lamp decreases with age. Group relamping insures that all lamps have a high light output. Fewer lamp failures, less flickering, and reduced swirling and color shift produce a safer, more comfortable work environment. If the lighting system was over-designed to allow for loss of light levels, group relamping may allow for some delamping.

5. **Reduce Inventory Needs:** Fewer lamps must be stored in inventory since fewer spot failures occur in group relamped fixtures when the relamping interval is set correctly.

6. **Insure the Correct Lamp Use:** Spot relamping often results in the installation of a variety of lamp types with inconsistent light output levels, lifespans, and colors. This can occur when the inventory of spare lamps runs out and the person who purchases a quick replacement either does not know the correct lamp type, cannot locate the correct type, or does not realize that the cheapest lamp may not be the best value. Group relamping provides an opportunity to install the newest energy-efficient lamps.

7. **Extend Ballast Life:** Ballasts have to work harder to start and operate strobing lamps which are near the end of their life.

8. **Reduce Interruptions in Work Area:** Group relamping prevents most of the unplanned lamp replacements.

General Electric [4] has provided the following cost formulas for determining relamping costs:

Spot Replacement Costs

$$C = L + S \tag{5-1}$$

Group Relamping Costs

$$C = \frac{L + G}{I} \tag{5-2}$$

where: C = total replacement cost per lamp
L = net price per lamp
S = spot replacement labor cost per lamp
G = group replacement labor cost per lamp
I = group relamping interval (% of rated lamp life)

Example 5-1: An office building contains a number of small (400 ft^2) rooms, each of which has four two-lamp fluorescent fixtures. Every time a maintenance person changes lamps, they must bring a ladder into the room and clear away furniture. It takes the person 15 minutes to replace one lamp. It takes 25 minutes to replace all the lamps in a room and clean the luminaires if all the work is done at one time. The lamps cost $0.85 each, and labor costs are $10/hour. The lamps are used about 2000 hours/year. The average lamp life is 20,000 hours. Determine whether group relamping with I = 0.8 is preferable to spot relamping for this building.

Solution: Find the cost for spot relamping and group relamping using equations 5-1 and 5-2, and select the method with lowest cost.

$$
\begin{aligned}
L &= \$0.85 \text{ per lamp} \\
S &= (\text{time to replace lamp in hours}) \times (\text{cost of labor per hour}) \\
&= 15/60 \times \$10 = \$2.50 \\
G &= (\text{time to replace lamp in hours}) \times (\text{cost of labor per hour}) \\
&= 3/60 \times \$10 = \$0.50. \\
I &= 0.8
\end{aligned}
$$

and thus

$$
\begin{aligned}
C_{spot} &= 0.85 + 2.50 \\
&= \underline{\$3.35/\text{lamp}} \\
C_{group} &= (0.85 + 0.50)/0.80 \\
&= \underline{\$1.69/\text{lamp}}
\end{aligned}
$$

Therefore, the decision should be made to use group relamping. The reduced labor cost more than offsets the cost of the lost lamp life; in fact, the savings from group relamping is almost twice the full cost of each lamp.

5.4 THE LIGHTING SURVEY

To perform an objective evaluation of the lighting system, the energy auditor must gather the following data: lighting needs/objectives, hours/days that lighting is required, lighting levels, type of lamps, age of lamps, age of the lighting installation, ambient environment of lighting fixtures (e.g., dust exposure, air temperature, etc.), room surface characteristics, type of ballasts, condition of fixtures, and relamping practices. Building plans are not useful unless the facility was built as planned and few modifications have been made.

Forms are useful for recording the specific lighting data needed. Chapter Two, Figure 2-5 provided a sample lighting data collection form. Figure 5-20 shows a sample data collection form for recording the lighting system condition, while Figure 5-21 illustrates a sample form for recording lighting needs.

Two basic surveys should be conducted to look for savings opportunities: one to see how the facility operates while in production and another to determine the lighting practices when the facility is dormant or shut down for the night.

5.4.1 Interviews with employees

Interviews with the managers and workers help the energy auditor to evaluate the relamping and maintenance practices, determine problems with the lighting system, ascertain the employees' satisfaction level, find out when light is needed, and uncover the potential for cost savings. The first question should be—Are you happy with your lighting? Major retrofits such as fixture replacement and color changes affect everyone in the work environment, so the opinions of all participants should be considered.

5.4.2 Measuring Light Levels

A light meter is needed to measure illuminance levels. An inexpensive analog light meter is practical and rugged for screening lighting levels and determining relative values. A self-calibrating digital light meter (photometer) is very useful to get fast, accurate, and repeatable measurements. Using a lightmeter, the auditor should record light intensity readings for each area and task of the facility.

Taking notes on the types of tasks performed in each area will help the auditor select alternative lighting technologies that might be more energy efficient. Other items to note are the areas that may be infrequently used and are potential candidates for controlling the lighting with occupancy sensors, or the areas where daylighting may be feasible.

Location ____________________________ Light type (HPS, FL, etc.)____________________

Lamps _____________

		Watts			Condition of system*	
Lighting level (fc)	No.	Each	Total	% burning	Luminaires	Reflective surfaces
______________	___	____	____	_______	________	______________
______________	___	____	____	_______	________	______________
______________	___	____	____	_______	________	______________
______________	___	____	____	_______	________	______________
______________	___	____	____	_______	________	______________

*From Table 5-7

Figure 5-20. Lighting System Condition Form

Location	Hours when light is needed	Importance of color rendition	Task lighting possible?	Light levels required (fc)
______	________	________	______	_______
______	________	________	______	_______
______	________	________	______	_______
______	________	________	______	_______
______	________	________	______	_______

Figure 5-21. Lighting needs form.

5.5 REGULATORY/SAFETY ISSUES

The lighting industry is encountering increasing safety and environmental concerns. Some of the materials used in lighting fixtures are, or will soon be, labeled hazardous for disposal.

For example, older ballasts and capacitors may contain polychlorinated biphenyl (PCB) oil which should be sent to a facility certified for handling hazardous wastes. Federal law 40CFR Part 761 requires proper disposal of leaking ballasts containing PCB oil. Fluorescent lamps contain mercury vapor (Hg), antimony (Sb), cadmium (Cd) and other toxic chemicals. The new T8 lamps (e.g., 1" diameter) use less phosphor material and mercury gas than the conventional T12 lamps (e.g., 1-1/2" diameter). Using T8 lamps should reduce disposal costs and environmental impacts.

5.5.1 Safety Issues

Lamps are fragile and break easily. Broken fluorescent lamps are difficult to transport and recycle. Areas subject to vibration or other mechanical stress should be illuminated with durable lamps or with fixtures which have adequate containment for broken lamps within the fixture housing. Delamping inexpensive fluorescent lighting fixtures can also be hazardous if the lamp pins come in contact with the fixture housing.

Insulation placed on top of lighting fixtures recessed in the ceiling may pose a fire hazard unless the fixture is rated for insulation contact. The insulation can increase the operating temperature of the lamps and ballasts of fluorescent or high intensity discharge (HID) fixtures, which will reduce the lifespan of all the system components.

High intensity discharge lamps have arc tubes which operate at high temperatures. Pieces of hot arc tube can fall from the fixture if the lamp wall is fractured. Some manufacturers recommend using lenses or fixture housings capable of containing incendiary materials.

5.5.2 Energy Policy Act of 1992

As part of the Federal Energy Policy Act of 1992, Congress placed restrictions on the production and sale of inefficient fluorescent and incandescent lamps [10]. These restrictions will require facility managers to take a hard look at the emerging high-efficiency lighting technologies when many of the lamps currently in use become difficult or impossible to find.

Standard cool-white and warm-white F40T12 lamps, the fluorescent lamps most often seen in commercial lighting fixtures, are specifically targeted by the Act. The manufacture and sale of low-efficacy F96T12 lamps and many reflector-type and PAR-type incandescent lamps are also restricted.

Table 5-8 from the Energy Policy Act of 1992 lists the minimum lamp efficacy and color rendering index requirements for fluorescent and incandescent lamps. Manufacturers must comply with these restrictions between 18 and 36 months after the date of the Act—which was October 24, 1992.

While lamps can be exempted from these restrictions for specialty applications, this law means that facility managers will be able to reduce life-cycle operation costs for lighting more easily. Since there are some gaps in suitable lamp replacements, particularly for incandescent downlights, the law will also spur research and development of new lighting technology. The Act will be evaluated and amended, if necessary, around the year 2000.

5.6 IDENTIFYING POTENTIAL EMOS

Lighting is used primarily for workplace illumination, for safety, and for decoration. In each of these uses, the same three questions can be asked: (1) How much light is needed? (2) How must the light be controlled? (3) How can lighting be provided most efficiently? When examining an existing system of lighting, the answers to these questions can be used to decrease lighting cost and improve lighting efficiency.

Lighting improvements provide cost savings in a number of ways:

Table 5-8. Criteria for Manufacturing Lamps

Fluorescent Lamps

Lamp Type	Nominal Lamp Wattage	Minimum CRI	Minimum Average Lamp Efficacy (LPW)	Effective Date (Months)
4-foot medium bi-pin	>35W	69	75.0	36
	<35W	45	75.0	36
2-foot U-shaped	>35W	69	68.0	36
	<35W	45	64.0	36
8-foot slimline	>65W	69	80.0	18
	<65W	45	80.0	18
8-foot high output	>100W	69	80.0	18
	<100W	45	80.0	18

Incandescent Reflector Lamps

Nominal Lamp Wattage	Minimum Average Lamp Efficacy (LPW)	Effective Date (Months)
40-50	10.5	36
51-66	11.0	36
67-85	12.5	36
86-115	14.0	36
116-155	14.5	36
156-205	15.0	36

reduced energy use and power demand; reduced heat production; lower life-cycle lamp costs; reduced need for maintenance; and increases in safety and productivity. In some instances, improving lighting quality increases worker productivity, and can result in greater profitability for a facility since the benefits of even a small change in worker productivity can vastly outweigh the relamping and maintenance costs. Figure 5-22 presents the results of a study of productivity in an office building when the lighting levels were first cut in half, then restored.

In examining the lighting system, the energy auditor should ask three questions: first, whether the light is needed; second, whether the correct amount of light is being used; and third, what is the most cost-effective lighting technology to use to supply the correct amount and quality of light. To locate the energy management opportunities, the auditor should specifically:

- Identify and characterize the visual tasks, and determine the contrast of the work to the surrounding surfaces.

- Look for the potential to use daylighting and task-specific lighting to displace high ambient, artificial lighting levels.

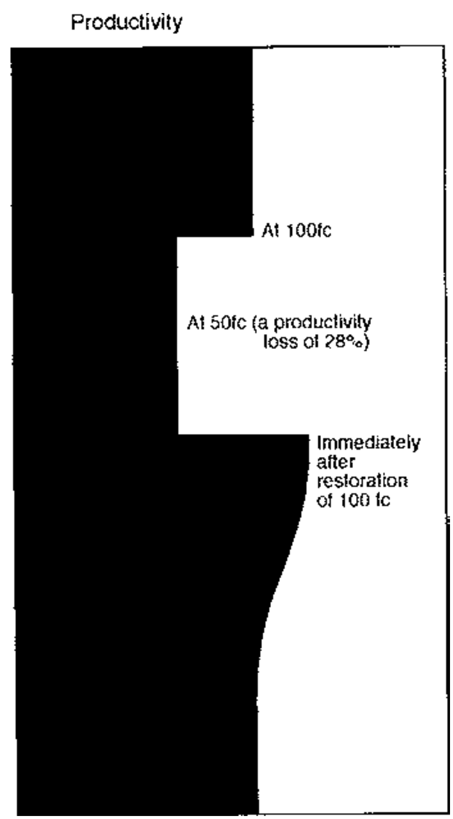


Figure 5-22. Productivity Loss from Light Reduction [ref 6, Figure 2]

- Determine the appropriate lighting levels and the quality of light needed.

- Select alternative lighting systems to meet the needs, and analyze the cost-effectiveness of each alternative.

- Select the best alternative to implement.

The remainder of this section provides some specific recommendations for areas that can result in cost-effective improvements in lighting systems. The advice of a qualified lighting consultant should be solicited before undertaking any major lighting retrofit to ensure the task is completed with the best available technology and the lowest life-cycle costs.

5.6.1 Delamping

Major savings can be obtained by removing some of the lamps that are producing excessive levels of illumination. The lighting levels in many facilities have been over-designed to allow for poor maintenance and relamping practices. The first place to check for excessive light levels is in corridors and at work stations. The range of footcandles for each task was given in Table 5-1. Other places where lighting should be examined carefully include warehouses and storage areas.

There is often a good potential for delamping fixtures when planned group relamping is practiced. For example, a fluorescent light fixture with four new F40T12 40-watt lamps may provide over twice the actual illumination specified by IES standards for a particular task. In such a case, half of the lamps can often be removed while still providing the area with sufficient light levels and light distribution patterns. Hallways with 4-lamp fixtures frequently offer a good opportunity for removing half the lamps while maintaining adequate light levels.

If two lamps are removed from a four-lamp fixture, it is usually better to remove either the inboard or outboard set. Which set depends on the fixture design. Measuring the light levels after removing each set of lamps in turn will reveal which set should be removed. The best light distribution is typically achieved when the lamps are centered in the fixture. There are low-cost kits available for repositioning lamps. Although some reflector sales people advertise their product as capable of maintaining the same fixture light output with half the lamps, much of the increase in light levels is due to centering the lamps in the fixture.

There is usually one ballast for each two fluorescent lamps. The ballast for rapid-start lamps will continue to consume some power even when the lamps are removed. Disconnecting the ballast and capping the power leads will eliminate this power draw and provide a readily accessible replacement ballast already mounted in the fixture. The ballasts in instant-start (IS) fixtures automatically disconnect when the lamps are removed. Leaving burned-out lamps in IS fixtures reduces ballast life.

Example 5-2: The packing and shipping area in a plastic jar production facility is lighted with 50 fluorescent fixtures that each have four F40T12 40-Watt lamps. It operates two shifts per day for 250 days a year. Light level measurements show that the average illumination level is about 110 footcandles. Is delamping warranted, and if so, how much can be saved if electricity costs 8 cents per kWh?

Solution: The IES illumination level standard (Tables 5-4 and 5-5) for packing and shipping—which are material handling tasks—is 50 footcandles as an upper limit for tasks involving large items. Thus, half of the lamps can be removed if the resulting light distribution pattern is still acceptable. Assume that each light fixture has two ballasts, and that each ballast serves two lamps. The two lamps and ballast removed will save 80 Watts for the two lamps, and an additional 15%—or 12 Watts—for the ballast. The total energy cost savings from this delamping can be calculated as follows:

$$\begin{aligned}\text{Cost savings} &= (92\ \text{Watts/fixture}) \times (50\ \text{fixtures}) \times (16\ \text{hours/day}) \times \\ &\quad (250\ \text{days/year}) \times (1\ \text{kWh}/1000\ \text{Wh}) \times (\$.08/\text{kWh}) \\ &= \underline{\$1472/\text{year}}\end{aligned}$$

5.6.2 Task Lighting

Ambient lighting levels can be reduced when adequate task lighting is supplied for the work. Ambient lighting levels of 25 footcandles or less are frequently sufficient if the individual work areas have sufficient light from task-dedicated lighting fixtures. Figure 5-23 demonstrates the placement of supplementary luminaires.

5.6.3 Relamping

Replacing existing lamps, ballasts and luminaires with newer, more energy-efficient models offers the potential for significant savings on lighting system costs in many facilities. Lamp replacement is often a

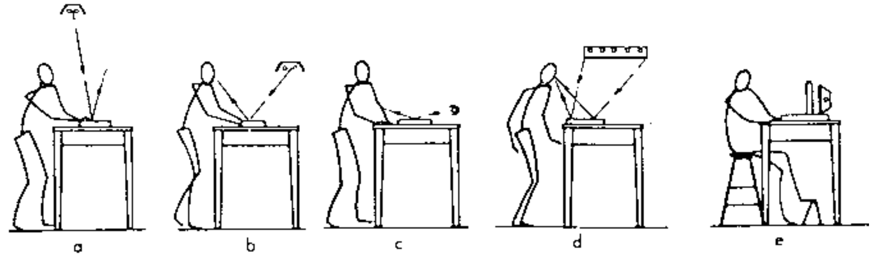


Figure 5-23. Supplementary Luminaires [ref 1, Figure 9-11]. Examples of placement of supplementary luminaires: a. Luminaire located to prevent veiling reflections and reflected glare; reflected light does not coincide with angle of view. b. Reflected light coincides with angle of view. c. Low-angle lighting to emphasize surface irregularities. d. Large-area surface source and pattern are reflected toward the eye. e. Transillumination from diffuse source.

simple procedure if the new lamp works with the existing ballast and fixture. For example, replacing existing F40T12 40-watt lamps with F40T12 34-watt lamps in appropriate areas offers an easy and cost-effective lighting system improvement. Replacing existing F40T12 40-watt lamps with F32T8 32-watt lamps is a little more complicated as it requires a change of ballasts and lamp sockets in addition to the lamp change. This may still be very cost-effective, but it costs more for equipment and labor, and must be analyzed to see if it is truly cost-effective for a particular facility.

As another example, a 2'×4' lighting troffer (fixture) using four F40T12, 34-watt energy-saving lamps can be retrofitted with three F40T10 40-watt high-efficacy lamps or three F32T8 lamps and an electronic ballast. These alternatives will maintain or increase light levels and reduce energy use by about 14% and 35%, respectively.

There are many potential lamp substitutions possible, and it is important to know what kind of substitutions are reasonable. Table 5-9 shows some of the lamp substitutions which can produce lower life-cycle costs. Many other lamps are also suitable for replacing commonly used lamps.

Table 5-10 shows more possible lamp substitutions including some compact fluorescent lamps.

Table 5-9. Lamp Substitutions [ref 5, Table 5.8]

Present lamp	Substitute	Light level	Energy saved (w/%)
60-W In	30-W RI	100%	30/50
(1000 h)	50-W RI	200%	10/16
60-W In	50-W RI	200 + %	10/16
(2500 h)	55-W PAR/FL	200 + %	5/8
75-W In	55-W PAR/FL	150%	20/27
100-W In	75-W IR	125%	25/25
(750 h)	75-W PAR/FL	200 + %	25/25
	75-W ER	200 + %	25/25
100-W In	75-W PAR/FL	100 + %	25/25
(2500 h)			
150-W PAR/FL	100-W PAR/FL	70%	50/33
150-W R/FL	100-W PAR/FL	150%	50/33
200-W In	150-W PAR/FL	200 + %	50/33
(750 h)	(2000 h)		
30-W F	30-W EEL	87%	5/16
40-W F	40-W EEL	89%	6/15
96-W F	96-W EEL	91%	15/20
96-W F/HO	96-W EEL/HO	91%	15/14
96-W F/SHO	96-W EEL/SHO	90%	30/14
175-W MD	100-W HPS	104%	75/42
400-W MD	200-W HPS	96%	200/50
300-W In	150-W HPS	250%	120/50
750-W In	150-W HPS	104%	570/80
1000-W In	200-W HPS	93%	770/80

[a]Abbreviations:

EEL	energy-efficient fluorescent light (such as Watt-Mizer, Super-Saver, etc.)
ER	elliptical reflector (shape and inside coating of lamp)
F	fluorescent
FL	floodlight
HO	high output: 1000-ma filament
HPS	high-pressure sodium
h	hour (mean life expectancy)
In	incandescent
MD	mercury deluxe: mercury vapor corrected to improve color
PAR	parabolic aluminized reflector (see ER)
RI	reflective coated incandescent
SHO	superhigh output: 1500-ma filament
W	Watt

Table 5-10. Lamp Substitutions (including TT) [ref 7, Table 2]

Standard Lamp	Replacement Lamp	Wattage Savings[2]	Comparative Light Output of Replacement Lamp[3]	Value of Energy Savings over Life of Replacement Lamp at $0.08/kWh	Other Benefits[4]
60W Incandescent	55W Reduced-Wattage Incandescent	5	=	$0.40	
	13W TT Compact Fluorescent with Ballast Adapter	44.5	+	$35.60	x
75W Incandescent	70W Reduced-Wattage Incandescent	5	=	$0.40	
	22W Circline Fluorescent	45	=	$43.20	x
	18W Compact Fluorescent	57	=	$34.20	
100W Incandescent	95W Reduced-Wattage Incandescent	5	=	$0.40	
	44W Circline Fluorescent	56	=	$33.60	x
75W PAR-38 Spot or Flood Incandescent	65W PAR-38 Spot or Flood Incandescent	10	=	$1.60	
	45W Incandescent (Halogen)	30	=	$4.80	
150W R-40 Flood Incandescent[5]	75W ER-30 Incandescent[5]	75	=	$12.00	
	120W ER-40 Incandescent[5]	30	+ +	$4.80	x
150W PAR-38 Spot or Flood Incandescent	90W PAR-38 Spot or Flood Incandescent (Halogen)	60	=	$9.60	
	120W PAR-38 Incandescent	30	=	$4.80	
300W R-40 Flood Incandescent[5]	120W ER-40 Incandescent[5]	180	=	$28.80	

500W Incandescent	450W Self-Ballasted Mercury Vapor[6]	50	•	$64.00	
1,000W Incandescent	750W Self-Ballasted Mercury Vapor[6]	250	–	$320.00	
F-40 Fluorescent	F-40 Reduced-Wattage, High-Efficiency Fluorescent	7	=	$11.20	
	F-40 Reduced-Wattage, High-Efficiency Cathode-Disconnect Fluorescent	9.5	=	$15.20	
	F-40 Reduced-Wattage, High-Efficiency, Color-improved Fluorescent	7	•	$11.20	x
	F-40 Reduced-Wattage, High-Efficiency, Color-improved Cathode-Disconnect Fluorescent	9.5	•	$15.20	x
	F-40 High-Brightness Fluorescent	0	+	$0.00	x
F-40 Fluorescent (U-Shape)	F-40 Reduced-Wattage, High-Efficiency Fluorescent (U-Shape)	7	=	$11.20	
F-96 Fluorescent	F-96 Reduced-Wattage, High-Efficiency Fluorescent	17.5	•	$16.80	
F-96 HO Fluorescent	F-96 HO Reduced-Wattage, High-Efficiency Fluorescent	21	•	$20.20	
F-96 1,500 MA Fluorescent	F-96 1,500 MA Reduced-Wattage, High-Efficiency Fluorescent	25	•	$20.00	
175W Mercury Vapor	150W Retrofit High-Pressure Sodium	40	+ +	$ 38.40	x
250W Mercury Vapor	215W Retrofit High-Pressure Sodium	65	+ +	$62.40	x

(*Continued*)

Table 5-10. Lamp Substitutions (including TT) (*Conclusion*)

Standard Lamp	Replacement Lamp	Wattage Savings[2]	Comparative Light Output of Replacement Lamp[3]	Value of Energy Savings over Life of Replacement Lamp at 0.08/kWh	Other Benefits
400W Mercury Vapor	325 Retrofit Metal Halide	70	+ +	$112.00	x
	400W Retrofit Metal Halide	0	+ +	$ 0.00	x
	360W Retrofit High-Pressure Sodium	60	+ +	$76.80	x
1,000W Mercury Vapor	880W Retrofit High-Pressure Sodium	160	+ +	$204.80	x
	950W Retrofit Metal Halide	50	+ +	$48.00	x

NOTES

1. This table does not indicate all possible lamp replacement options and, in some cases, replacing the ballast and lamp, or relying on a new fixture, ballast and lamp will provide better overall performance and energy management than the replacement shown. All numbers reported in the table are approximations, and in certain cases assumptions are made about the types of fixtures and other conditions involved. Consult manufacturers for accurate data relative to direct replacements possible for a given installation as well as any ballast operating temperature or other restrictions which may apply.
2. Wattage savings include ballast losses, where applicable, assuming use of a standard ballast. Actual ballast losses to be experienced depend on the specific type of ballast involved and operating conditions which affect its performance. In those cases where wattage savings exceed the difference in lamp wattage (if any), operation of the replacement lamp also has the effect of reducing ballast losses.
3. Symbols used indicate the following: + + (substantially more) + (more) = (about the same) • (less) – (substantially less). Consult manufacturers for accurate information relative to conditions unique to the lamps and installations involved.
4. Other benefits typically provided by retrofit lamps include: maintenance costs due to longer lamp life; improved productivity, safety/security, quality control, etc., due to higher light output; ability to reduce the number of lamps installed systemwide due to higher output of retrofit lamps, and improved color rendition.
5. When installed in a stack-baffled downlight.
6. For high voltages only.

Example 5-3: Calculate the annual savings from replacing 40-watt F40T12/Workshop lamps with 34-Watt energy-saving lamps in two hundred (200) 4-lamp fixtures which are operated continuously. Assume the following:

The F40T12/Workshop lamps cost \$1.00 each and last for 12,000 hours. The 34-Watt F40T12 lamps cost \$1.50 each and last for 20,000 hours. Electric energy costs \$0.05 per kWh. The demand charge is \$5.50 per kW. The facility is not air conditioned.

Solution:

Annual Energy Savings (ES):

ES = (# of fixtures) × (# of lamps/fixture) × (wattage of low-efficiency lamps–wattage of high-efficiency lamps) × (annual operating hours)

= (200 fixtures) × (4 lamps/fixture) × (40 - 34) Watts/lamp × (8760 hours/yr)

= 800 lamps × 6 Watts/lamp × 1 kW/1000 Watts × 8760 hr/yr

= 42,048 kWh/yr

Energy Cost Savings (ECS):

ECS = ES × (cost of electricity)

= 42,048 kWh/yr × \$0.05/kWh

= \$2102/yr

Demand Reduction (DR):

DR = (# of lamps) × (wattage reduction)

= (800 lamps) × (6 Watts) × 1 kilowatt/1000 Watts

= 4.8 kW

Annual Demand Cost Savings (ADCS):

ADCS = DR × Demand Charge

= 4.8 kW × \$5.50/kW/month × 12 months/yr

= \$317/yr

Annual Lamp Cost Savings (ALCS):

The Workshop lights only have a lifetime of 12,000 hours, where the replacement lamps have a lifetime of 20,000 hours. Each of these costs must be annualized to determine the actual cost savings. The total number of lamp hours used in one year is found from multiplying the number of lamps times the hours of use in one year.

Total annual use = 800 × 8760 hr = 7,008,000 lamp hours

1. Workshop light cost:

To compute the number of Workshop lights needed for one year, divide the total annual lamp hours needed by the life of one Workshop light.

Number of lights needed = 7,008,000/12,000 = 584 lamps

The annual cost is:

584 lamps/yr × $1.00/lamp = $584

2. 34 Watt light cost:

Number of lights needed = 7,008,000/20,000 = 350 lamps

The annual cost is:

350 lamps/yr × $1.50/lamp = $525

ALCS = $584 - $525 = $59 per year

The total annual savings from this relamping EMO is the sum of all the savings calculated above.

Total annual cost savings = $2102 + $317 + $59 = $2478

Note that for air-conditioned facilities, the operating costs associated with lower wattage or more efficient lamps will be reduced because they produce less heat. Less air conditioning will be needed with this lower amount of heat produced. This will be discussed further in the air conditioning chapter in Section 6.4.1.5.

Lighting options should be compared to the existing system in a recently relamped and cleaned condition. A reasonable estimate of the lighting levels in the relamped system can be made from measuring lighting levels and noting the age/operation hours of the lamps. Some lamp sales representatives demonstrate how their lamp is superior to the lamps in use by relamping a fixture for comparison with adjacent fixtures. The results can be misleading due to light losses caused by lamp lumen depreciation (i.e., old lamps) and lumen dirt depreciation (i.e., the relamped fixture is usually wiped clean during lamp installation). Make sure both fixtures are clean and contain new lamps before comparing lamp alternatives.

5.6.4 Ballasts

Ballasts are an important part of a lighting system, and each ballast uses from five to twenty percent of the power of the lamp it is associated with. Furthermore, the ballast draws some power even if the lamp has been removed. Therefore, when a lamp is removed from a fixture, the ballast should usually be removed too. The ballast can be stored for future use, saving additional replacement costs. Ballasts should also be replaced if they overheat or smoke.

When older coil and core ballasts in a lighting fixture fail, replacement with an electronic ballast should be considered. New, electronic ballasts are much more efficient than the older magnetic ballasts, and offer desirable features such as dimming capabilities. When T8 fluorescent lamps are used, an electronic ballast is usually specified, too.

5.6.5 Control Technologies

Areas which are seldom occupied do not need constant light, yet lights are frequently left on in such places. Lights should not be left on in warehouses and storage areas unless the lights serve some function—illuminating storage areas for assistance in finding a product or reading labels, security, or other identified functions. Occupancy sensors have benefits to offer in these cases.

Fluorescent lamps should be turned off if they will not be used for five minutes or more. HID lamps should be turned off if they will not be used for about thirty minutes and quick restart time is not critical. HID lamps take up to fifteen minutes to regain full light output after restarting.

There are a number of cost-effective control EMOs that can be used to turn off lights that are not needed, or to utilize daylighting to supplement artificial lighting. These control technologies are discussed below, and additional discussion of controls is covered in chapter nine. Example 9-3 illustrates the savings from an application of occupancy sensors.

Switches: Many types of switches are available for controlling lighting. The simplest is the standard wall-mounted snap switch. Switches should be installed in the areas in which the fixtures are controlled. Rewiring to reduce the number of fixtures controlled by a single switch increases the ability of occupants to control the amount of lighting that is used. Installing switches next to one another frequently results in all the available lighting operating at once because people tend to turn on all the switches at once. If switches are installed next to each other, installing the switch upside-down that controls the least-needed lights will reduce the chance of that switch being turned on accidentally.

Other types of switches control lighting fixture operation on the basis of lighting levels, time, motion, or infrared radiation. Exterior lighting should be controlled by a light-sensitive switch. Photocells operate the lighting between dusk and dawn. They are available in various sensitivities. It is best to use photocells which turn the fixture on when they fail; this provides a good signal that replacement is necessary. The fail-off type can remain undetected and leave a facility without security lights.

Photocell input can also be used as a basis for controlling interior lighting. Some energy management control systems (EMCS) can use photocell input data for automatically adjusting indoor lighting levels to maintain a constant value when dimmable ballasts are used.

Timers: Timers can be used to control outdoor lighting but some are subject to inaccuracy due to seasonal changes in day-length, daylight savings time changes, clock slippage, power outages, and manual override. Adjustments should be made to simple timers about four times per year to prevent unnecessary operation of equipment. Timers can be used in conjunction with photosensors to reduce lighting costs if the lighting can be turned off before dawn.

Occupancy Sensors: Occupancy sensors can also be used to reduce unnecessary lighting use. Infrared sensors are directional and useful for active areas; ultrasonic sensors are fairly non-directional. The sensor's coverage of the area must be complete or nuisance cutoffs will occur and the occupants will remove the sensors.

Example 5-4: The prisoner holding cells in a courthouse utilize two fixtures with two F40T12 lamps each to illuminate an 8'×12' area. The cells are usually occupied a maximum of 45 minutes per day but they are illuminated about 12 hours per day. How much can you save by installing occupancy sensors in these cells? Calculate the simple payback period and return on investment if the sensors cost $70 installed and have a ten year life? Electricity costs 8 cents per kWh.

Solution: Assume that the occupancy sensor has a delay built into its operation, and that the lights will operate 1 hour a day, five days a week, 50 weeks a year. Further assume that each light fixture with its ballast consumes 80 Watts for the two lamps, and an additional 15%—or 12 Watts—for the ballast. Thus, the total savings from the occupancy sensor is found from:

Cost Savings = (2 fixtures/cell) × (92 Watts/fixture) × (1 kW/1000 Wh) × (11 hours/day) × (5 days/week) × (50 weeks/year) × ($.08/kWh)

= $40.48/year per cell

SPP = Installed cost/annual savings

= $70/$40.48/year

= 1.73 years

ROR = Solution to:

= $40.48 – (P/A, i, 10) = $70

= 57.2%

Dimmers: Dimmers are good for areas which require low ambient lighting levels most of the time with an occasional need for bright lighting. Solid-state dimmers operate by reducing the voltage supplied to the lamps. This reduces energy use and extends lamp life. However, fluorescent and HID lamps cannot be dimmed without dimmable ballasts. Rheostat dimmers are not recommended for any application because they produce considerable heat and do not save energy.

5.6.6 Other Lighting EMOs

5.6.6.1 Exterior Lighting

Exterior lighting is another area in which lighting energy is often wasted. In motels, for example, peripheral lighting is often left on both day and night. Such waste can be easily corrected with a timer or with a light switch turned on and off by a photocell. Each of the perimeter and outside lights should be carefully considered to see when it should be on, how much light is needed for the intended function, and whether more efficient lighting sources would work as well as those now being used.

5.6.6.2 Daylighting

Windows and skylights are often used to add light in a given area. One problem is that windows admit radiant heat as well as light, and it may be more expensive to remove the heat than to supply the light. In that case, the windows should be treated with exterior-mounted solar screens, louvers, or a reflective film with a low shading coefficient and a high percentage transmission of visible light. Daylighting is discussed in more detail in Chapter 13.

5.6.6.3 Environmental Factors

An area can appear to be dark if the walls, floors, or ceilings are painted (or otherwise covered) in dark colors or are greasy or dirty. Using light colors for paint and flooring, or cleaning these surfaces more often can make the existing light more effective and thereby save money.

5.6.7 Selecting Lights for a New Facility

Any time a new facility is built, or an existing facility is expanded, there is a significant opportunity to save on energy costs by selecting and installing cost-effective, energy-efficient lighting systems at the time of construction. It is almost always cheaper to install correct equipment the first time than to retrofit existing equipment. Greater first costs may produce significantly lower operating costs, and provide cost-effective savings for the facility. Unfortunately, many design decisions are made on the basis of first cost rather than life-cycle costs which include operation and maintenance costs. Utilizing life-cycle costing can assure the lowest lighting costs throughout the life of the lighting system.

Example 5-5. Gator Plastics Company is experiencing such a growth in demand for their products that they are planning on adding a new production room. Their Industrial Engineer is responsible for selecting the lighting system to be installed. The IE has identified two alternative lighting systems. Alternative One uses 40 fluorescent light fixtures with four 34-Watt lamps in each fixture, together with a four-lamp ballast that consumes a total of 20 watts. This system costs $2000 to purchase and $2000 to install. Alternative Two uses 40 fixtures with three 40-Watt T10 lamps, together with one three-lamp electronic ballast that consumes a total of 15 Watts. This system costs $2400 to purchase and $2000 to install. If each lighting system lasts six years, the lights are used 2000 hours per year, electricity costs $0.08 per kWh, and the company's investment rate is 8%, which alternative should the IE select? Calculate the three standard economic evaluation measures for each alternative—SPP, ROR and B/C ratio.

Solution:

Alternative One: The operating cost is found as follows:

Annual cost = (40 fixtures) × (156 Watts/fixture) × (2000 hours) × (1 kWh/1000 Wh) × ($0.08/kWh)
= $998.40

Alternative Two:

Annual cost = (40 fixtures) × (135 Watts/fixture) × (2000 hours) × (1 kWh/1000 Wh) × ($0.08/kWh)
= $864.00

Economic evaluation: Alternative Two costs $400 more than Alternative One, but it saves ($998.40 - $864.00) = $134.40 per year in operating costs. To determine if this additional cost is a good investment, we need to calculate the three standard economic performance measures.

SPP = Initial cost/Annual cost savings
= $400/$134.40 = <u>3.0 years</u>

The ROR is found by solving:

($134.40 (P/A, i, 6) = $400

ROR = 24.6%

Using the methods from Chapter 4 to find the present worth of the annual savings gives:

B/C = $134.40 × (P/A, 8%, 6)/$400
= $134.40 × 4.623/$400 = <u>1.55</u>

Thus, for many companies the added cost of alternative two would be considered a good investment.

5.7 LIGHTING CHECKLIST

Lighting and maintenance costs can be reduced with a concurrent improvement in worker productivity, safety, and comfort. Figure 5-24 presents a checklist of energy-saving guidelines for lighting developed by the Illuminating Engineering Society.

5.8 EPA GREEN LIGHTS PROGRAM

In 1991, the U.S. Environmental Protection Agency (USEPA) initiated an innovative pollution prevention strategy with its Green Lights Program. Working in partnership with corporations and governmental entities, this program was designed to achieve voluntary reductions in energy use through the adoption of revolutionary lighting technologies.

The EPA has estimated that energy-efficient lighting can reduce lighting electricity demand by over 50 percent which translates into a cut of more than 10 percent in the nation's demand for electricity. This means that the power plants will burn less fuel. For every kilowatt-hour of electricity that is avoided, the EPA estimates that the country avoids the emission of 1.5 pounds of carbon dioxide, 5.8 grams of sulfur dioxide, and 2.5 grams of nitrogen oxides. Other pollution is reduced from mining and transporting power plant fuels and disposing of power plant wastes. As of January 31, 1993, the program had reduced lighting electricity consumption by over 100 million kilowatt-hours per year. By the year 2000, the Green Lights program is expected to save 226.4 billion kWh annually, resulting in total electricity demand savings of 39.8 million kilowatts.

To become a Green Lights Partner, an organization must sign a Memorandum of Understanding (MOU) with the EPA. In the MOU, Green Lights participants agree to survey their facilities and, within 5 years of signing the MOU, to upgrade lighting in 90 percent of their square footage, where it is profitable and where lighting quality is maintained or enhanced. Participants also agree to appoint an implementation manager who oversees participation in the program. As of March 1993, over 800 organizations had joined the Green Lights program.

The EPA provides the Green Lights partners with a number of products, information, and services:

- state-of-the-art computer software package that enables Partners to survey lighting systems in facilities, assess lighting options, and select the best energy-efficient upgrade.

Figure 5-24. Checklist of Energy Saving Guidelines for Lighting Ideas [ref 1, Figure 4-6] [ref 6, figure 2]

Lighting Needs	
• Visual tasks: specification	Identify specific visual tasks and locations to determine recommended illuminances for tasks and for surrounding areas.
• Safety and esthetics	Review lighting requirements for given applications to satisfy safety and esthetic criteria.
• Overlighted application	In existing spaces, identify applications where maintained illumination is greater than recommended. Reduce energy by adjusting illuminance to meet recommended levels.
• Groupings: similar visual tasks	Group visual tasks having the same illuminance requirements, and avoid widely separated workstations.
• Task lighting	Illuminate work surfaces with luminaires properly located in or on furniture; provide lower ambient levels.
• Luminance ratios	Use wall washing and lighting of decorative objects to balance brightnesses.
Space Design and Utilization	
• Space plan	When possible, arrange for occupants working after hours to work in close proximity to one another.
• Room surfaces	Use light colors for walls, floors, ceilings and furniture to increase utilization of light, and reduce connected lighting power to achieve required illuminances. Avoid glossy finishes on room and work surfaces to limit reflected glare.
• Space utilization: branch circuit wiring	Use modular branch circuit wiring to allow for flexibility in moving, relocating or adding luminaires to suit changing space configurations.
• Space utilization: occupancy	Light building for occupied periods only, and when required for security or cleaning purposes (see chapter 31, Lighting Controls).

(*Continued*)

Figure 5-24. Checklist of Energy Saving Lighting Ideas (*Continued*)

Daylighting	
• Daylight compensation	If daylighting can be used to replace some electric lighting near fenestration during substantial periods of the day, lighting in those areas should be circuited so that it may be controlled manually or automatically by switching or dimming.
• Daylight sensing	Daylight sensors and dimming systems can reduce electric lighting energy.
• Daylight control	Maximize the effectiveness of existing fenestration-shading controls (interior and exterior) or replace with proper devices or shielding media.
• Space utilization	Use daylighting in transition zones, in lounge and recreational areas, and for functions where the variation in color, intensity and direction may be desirable. Consider applications where daylight can be utilized as ambient lighting, supplemented by local task lights.
Lighting Sources: Lamps and Ballasts	
• Source efficacy	Install lamps with the highest efficacies to provide the desired light source color and distribution requirements.
• Fluorescent lamps	Use T8 fluorescent and high-wattage compact fluorescent systems for improved source efficacy and color quality.
• Ballasts	Use electronic or energy efficient ballasts with fluorescent lamps.
• HID	Use high-efficacy metal halide and high-pressure sodium light sources for exterior floodlighting.
• Incandescent	Where incandescent sources are necessary, use reflector halogen lamps for increased efficacy.
• Compact fluorescent	Use compact fluorescent lamps, where possible, to replace incandescent sources.
• Lamp wattage reduced-wattage lamps	In existing spaces, use reduced-wattage lamps where illuminance is too high but luminaire locations must be maintained for uniformity. *Caution:* These lamps are not recommended where the ambient space temperature may fall below 16°C (60°F).
• Control compatibility	If a control system is used, check compatibility of lamps and ballasts with the control device.
• System change	Substitute metal halide and high-pressure sodium systems for existing mercury vapor lighting systems.

Luminaires	
• Maintained efficiency	Select luminaires which do not collect dirt rapidly and which can be easily cleaned.
• Improved maintenance	Improved maintenance procedures may enable a lighting system with reduced wattage to provide adequate illumination throughout system or component life.
• Luminaire efficiency: replacement or relocation	Check luminaire effectiveness for task lighting and for overall efficiency; if ineffective or inefficient, consider replacement or relocation.
• Heat removal	When luminaire temperatures exceed optimal system operating temperatures, consider using heat removal luminaires to improve lamp performance and reduce heat gain to the space. The decrease in lamp temperature may, however, actually increase power consumption.
• Maintained efficiency	Select a lamp replacement schedule for all light sources, to more accurately predict light loss factors and possibly decrease the number of luminaires required.
Lighting Controls	
• Switching: local control	Install switches for local and convenient control of lighting by occupants. This should be in combination with a building-wide system to turn lights off when the building is unoccupied.
• Selective switching	Install selective switching of luminaires according to groupings of working tasks and different working hours.
• Low-voltage switching systems	Use low-voltage switching systems to obtain maximum switching capability.
• Master control system	Use a programmable low-voltage master switching system for the entire building to turn lights on and off automatically as needed, with overrides at individual areas.
• Multipurpose spaces	Install multicircuit switching or preset dimming controls to provide flexibility when spaces are used for multiple purposes and require different ranges of illuminance for various activities. Clearly label the control cover plates.
• "Tuning" illuminance	Use switching and dimming systems as a means of adjusting illuminance for variable lighting requirements.
• Scheduling	Operate lighting according to a predetermined schedule.

(*Continued*)

Figure 5-24. Checklist of Energy Saving Lighting Ideas (*Conclusion*)

• Occupant/motion sensors	Use occupant/motion sensors for unpredictable patterns of occupancy.
• Lumen maintenance	Fluorescent dimming systems may be utilized to maintain illuminance throughout lamp life, thereby saving energy by compensating for lamp-lumen depreciation and other light loss factors.
• Ballast switching	Use multilevel ballasts and local inboard-outboard lamp switching where a reduction in illuminances is sometimes desired.
<u>Operation and Maintenance</u>	
• Education	Analyze lighting used during working and building cleaning periods, and institute an education program to have personnel turn off incandescent lamps promptly when the space is not in use, fluorescent lamps if the space will not be used for 5 min or longer, and HID lamps (mercury, metal halide, high-pressure sodium) if the space will not be used for 30 min or longer.
• Parking	Restrict parking after hours to specific lots so lighting can be reduced to minimum security requirements in unused parking areas.
• Custodial service	Schedule routine building cleaning during occupied hours.
• Reduced illuminance	Reduce illuminance during building cleaning periods if building is not otherwise occupied.
• Cleaning schedules	Adjust cleaning schedules to minimize time of operation, by concentrating cleaning activities in fewer spaces at the same time and by turning off lights in unoccupied areas.
• Program evaluation	Evaluate the present lighting maintenance program, and revise it as necessary to provide the most efficient use of the lighting system.
• Cleaning and maintenance	Clean luminaires and replace lamps on a regular maintenance schedule to ensure proper illuminance levels are maintained.
• Regular system checks	Check to see if all components are in good working condition. Transmitting or diffusing media should be examined, and badly discolored or deteriorated media replaced to improve efficiency.
• Renovation of luminaires	Replace outdated or damaged luminaires with modern ones which have good cleaning capabilities and which use lamps with higher efficacy and good lumen maintenance characteristics.
• Area maintenance	Trim trees and bushes that may be obstructing outdoor luminaire distribution and creating unwanted shadows.

- Green Lights bulletin board system which provides participants with software files to download to their own computer systems.
- user-friendly data bases of every third party financing program available.
- an Ally Program which induces lighting manufacturers, lighting management companies, and electric utilities that have agreed to educate customers about energy-efficient lighting.
- technical support including a technical services hotline, workshops, and a comprehensive Lighting Upgrade Manual.
- a National Lighting Product Information program which makes information about lighting available to members. This program has published information of electronic ballasts, reflectors, current limiters, occupancy sensors, compact fluorescent packages, and parking lot luminaires. It also publishes a Guide to Performance Evaluation of Efficient Lighting Products.

5.9 SUMMARY

The lighting system in a facility is an important area to examine and to improve in terms of energy efficiency and quality of light. This chapter has discussed the lighting system, described the components of the system, and provided suggestions for ways to improve the system. Lighting technology is changing at a rapid pace, and new lamps and ballasts are being developed and marketed almost daily. Major energy savings opportunities exist in most older lighting systems, and additional cost-effective savings is often possible in relatively new systems since technology is continually improving in this area.

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