PART I

THE SAVINGS POTENTIAL IN COMMON LIGHTING SYSTEMS

PART I addresses common retrofit and relighting opportunities for general lighting system types. Lighting System Retrofit Potential is organized into chapters first by technology, and then by special applications. Technology chapters include:

Linear Fluorescent Systems

Incandescent and Compact Fluorescent Systems

High Intensity Discharge Systems

Special Applications Lighting including:

Industrial Lighting

Outdoor Lighting

Special Commercial Applications

While categorizing by technology avoids repeated discussion of typical lamp- and ballast-based retrofit solutions, the special applications categories are useful in discussing unusual environments and control options. Included for each of these categories is:

1. General discussion of retrofit in the category
2. Brief descriptions of typical existing conditions
3. A discussion of specific retrofit options with guidelines for assessing those options. Tables are provided to quantify specific retrofit savings opportunities by lamp/ballast and luminaire type.

Guidelines for use of lighting controls are discussed in brief in each chapter, as their use may differ from one application and lamp source to another (see following table).

Case studies are offered to relate real-world conditions, where nothing goes exactly as planned. Retrofit often requires a flexible approach to specifying and installing components and lighting controls. The "if this, then that" scenario of specification often seems to work the best, as no matter how carefully you evaluate a facility, there will usually be surprises upon installation.

COMMERCIAL LIGHTING SYSTEMS

Commercial lighting includes the lighting systems used in office buildings, institutions, stores, schools, and all other nonindustrial buildings. Each of the three major lighting systems has broad application in commercial buildings. Industrial lighting systems are often found in environmentally severe conditions. Hospitality, including hotels, restaurants, and spas, is similar to residential lighting in aesthetic demands, but often uses commercial lighting technologies. The need to control these systems by dimming places greater demands for lighting technology improvements in the hospitality sector.

Outdoor lighting systems are unique applications, operating in a broad range of temperatures and climate conditions. Recent technological developments bring new options to the table for this large sector of the lighting market.

Commercial lighting constitutes about 40 percent of the electric lighting load in the United States. Most commercial lighting systems, other than hospitality and retail display lighting, are based on fluorescent and HID lamps. While the design of fluorescent lamps and ballasts has evolved considerably over the last 40 years, much of the older fluorescent technology is still in place, and until recent changes in federal legislation[1] has been commonly sold in the United States. Even the newest products bear strong physical resemblance to the oldest fluorescent products. The

[1] Energy Policy Act of 2005 EPAct, among other measures set minimum ballast efficacy standards and created deadlines to cease production of inefficient ballasts.

LIGHTING SYSTEM RETROFIT APPLICATIONS

Category	Lighting System Type	Notes
General Commercial	Fluorescent Troffers	Most common, and most easily retrofit with new lamp/ballast or fixture replacement
	Fluorescent Nontroffers	Strips, wraparounds, direct/indirect, pendant-mounted, cove lights, undershelf, medical; many retrofit opportunities in older systems
	Downlights	Very common, including wallwashers, accent lights; depending on existing technology includes best retrofit savings potential
	Decorative Luminaires	Chandeliers, pendants, sconces, table and floor lamps, etc., lamp and fixture replacement options; dependent on new lamp technology and how well they match incandescent lamps in appearance and function
	Utility Lighting Exit Signs	Sometimes overlooked, easily retrofitted, Inexpensive to replace although hours of use may limit retrofit economic benefits
	Track Lighting	Commercial retrofit options available for significant energy savings, improved halogen lamp technology for more limited savings but broader application
Hospitality and Residential	Most systems above	Special design and dimming control considerations
Industrial	Fluorescent	Common and easily accomplished with special consideration of broader temperature and exposure conditions
	High Bay	New system replacement options provide excellent savings opportunities, with special temperature and controls considerations
	Low Bay	Retrofit and system replacement options, depending on existing technology and controls
	Damp Location (Vaportight)	Systems deteriorate rapidly, replace rather than retrofit
	Wet Location (Watertight)	Generally requires fixture replacement
	Special Purposes/Environments	Cold and hot temperature, caustic, explosive, etc., special systems not easily retrofit
Outdoor	Roadway and Parking Lots	New technology options, significant maintenance as well as energy savings
	Floodlights	New technology options, maintenance and energy savings
	Security	Replacement and redesign for energy efficiency and improved visibility
	Decorative	New retrofit alternatives to incandescent and mercury vapor, solid state option potential
	Landscaping	Fixture replacement options with new technology

general public, therefore, does not always understand the difference between the poor color quality, noisy, magnetically ballasted T-12 technology of the past, and significantly improved properties of the more advanced, high-efficiency T-8 and T-5 fluorescent systems. Many engineers and local lighting distributors are also not aware of recent advances in high performance lamp and ballast technology, and may not be making optimal selections for efficiency. Rather, sales are often based on what is commonly available.

Lacking assistance and/or intervention by federal and state energy efficiency mandates and programs, obtaining high performance options may involve more hassle and cost than should be the case. However, federal laws prohibit the sale of outdated and inefficient light sources, and higher electricity costs will inevitably bring higher efficiency fluorescent lamp and ballast technology into greater use.

Commercial application of hardwired compact fluorescent (CF) luminaires (as opposed to screw-based compact fluorescent lamps), especially in recessed can lighting, started in the 1980s. The significant energy benefits of hardwired compact fluorescent luminaires, using "permanent" ballast and pin-based compact fluorescent lamps, brought early adoption in many engineered buildings. Compact fluorescent fixtures installed before 2000, and many lower wattage CF fixtures even today, use magnetic ballasts. With the Department of Energy's "Energy Star" rating of electronically ballasted hardwired luminaires, we are now seeing considerable improvement in energy and starting performance for residential luminaires. Commercial luminaires typically have not been evaluated, but often use ballasts that meet or exceed the Energy Star specifications.

Compact fluorescent screw-based lamps (CFL) have become ubiquitous as a retrofit application in all types of buildings where the simplicity of this retrofit has helped overcome initial, as well as continuing, resistance to a full changeover from incandescent sources. More discussion of this category of retrofit option is included in Chapter 2.

High Intensity Discharge (HID) systems have undergone significant improvements as well. The advent of electronic ballasts for metal halide lamps, and the improved color, wattage options, and efficiency of lamps that use them, is creating energy efficient options for commercial, and especially retail, industries heavily dependent on HID pendants and track lighting. Metal halide PAR lamps, relatively indistinguishable from incandescent to the layperson, are a significant efficiency improvement over halogen PAR lamps for the retail industry. Energy efficient pulse-start technology is rapidly replacing older forms of magnetic ballast technologies in other forms of metal halide lighting. See Chapter 3 for more information on this topic.

The remainder of commercial lighting systems include incandescent lighting in common luminaire types such as can downlights and surface-mounted or pendant decorative fixtures. While many manufacturers now offer hardwired compact fluorescent, HID, and solid state lighting options for new construction and relighting applications, new lamp technologies continue to offer good retrofit opportunities in certain types of decorative luminaires.

EMERGING LIGHTING TECHNOLOGY

With the advent of solid state lighting development, there is now an explosion in the number of lamps and luminaires offered with this technology. At the time of this writing, a number of innovative products have been introduced for use in existing luminaires. Many of these will gain better acceptance as the following concerns are addressed:

- Light output and requirements for heat dissipation are related concerns in solid state technology. LEDs can function in many applications, but their output may not be equivalent to incandescent or halogen counterparts. Higher output LEDs need effective methods of removing heat from the small light source, presenting more than a small technical challenge in a luminaire not designed to do this.
- LEDs are excellent at producing directional light. This makes recessed and directional lighting ideal applications, while replacing the standard incandescent "A" type lamp is a greater technical challenge. With the incentive of a $10 million reward for developing the ideal A-lamp replacement, the world's manufacturers are already producing some intriguing options.

Solid state, as LED systems, will be discussed throughout this book. As a retrofit technology, they are included for consideration as an alternative to an existing lighting technology. As such, there is no separate chapter dedicated to solid state lighting.

CHAPTER 1

Linear Fluorescent Systems

THE MOST COMMON COMMERCIAL LIGHTING SYSTEMS are based on the 4′ or 8′ fluorescent lamp. The older "T-12" technology is now obsolete, and a high percentage of the T-12 lighting systems have been retrofit with newer "T-8" lamps since the early 1990s, when electric utilities in some parts of the United States created retrofit incentive programs for its customers. However, despite partial bans on the technology, magnetic ballasts and T-12 lamps have remained available in the marketplace, even though T-8 lamps and ballasts are more economical and energy efficient.

This has changed as of October 2009 when most magnetic T-12 ballasts are no longer sold for replacement through electrical distribution.[1] An opportunity exists to replace—and properly dispose of—the quantities of magnetic ballasts that remain in many commercial facilities. Fortunately, replacement of these systems with the newest high performance T-8 systems makes simple lamp and ballast retrofits more cost effective than ever.

The more common the retrofit of specific lighting systems has become, the better the assurance of successful results. Not only do the products and their quality improve, but installers become accustomed to installing them using cost-effective methods. However, products that made sense five years ago may not be the only choice today.

For this reason, this book includes a number of promising new options as well as tried and true products and techniques in the following chapters. Through an increasing array of retrofit options, costs and affordability will improve for even the smaller lighting retrofit projects—those often left after the first waves of retrofit frenzy have passed.

[1] U.S. Department of Energy Ballast Ruling, related to EPAct 2005.

The ability to reduce energy through linear fluorescent retrofits is a function of several options. Consider all of the following (discussed in more detail in Part II on the retrofit process) in selecting retrofit options.

- *Efficiency of the lamp/ballast and luminaire.* This is often the sole focus of fluorescent lighting retrofits, but it is only part of the equation.
- *General layout (square feet per fixture).* The coverage area per luminaire is critical in determining design lighting level, new lighting level, and any opportunities for intentional lighting level reduction. This is an important element in a luminaire replacement programs where the light distribution patterns from old to new luminaire may be very different.
- *Room surface finishes.* Illuminance requirements are reduced when rooms with dark surfaces are repainted to lighter colors or ceiling tiles replaced when existing tiles are soiled or not white. Improving light levels by increasing room surface reflectance allows as much as 25 percent reduced lighting power with no perceived change in room brightness.
- *Illuminance level.* Reduce lighting levels as appropriate if the space is overlighted.

Additional information on these topics is available in Chapter 7, Lighting Engineering and Evaluation.

HIGH EFFICIENCY FLUORESCENT LAMPS AND HIGH PERFORMANCE BALLASTS

T-8 lamps and electronic ballasts have been used for the last 20 years to improve energy performance in linear fluorescent lighting systems. Since the early 1990s, a series of further advances in fluorescent lamp and ballast technology allow significant additional savings. "High performance" or "super" T-8 systems currently allow for sufficient savings to consider upgrading from earlier T-8 systems. In lamps, more efficient phosphors, barrier coatings, and better cathodes combine to improve lamp efficacy by about 10 percent as well as extending lamp life. Ballast efficiency improvements allow these lamps to be operated at 20-25percent fewer watts to produce the equivalent maintained lumens.

The T-5 lamp and ballast, which had been introduced in Europe several years prior to its introduction in the United States, has now become common throughout the world. In North America, the T-5 technology is commonly used in high bay applications and in smaller linear luminaires with improved optical performance. Their application is limited to luminaire replacement; for relighting projects, the T-5 lamp length differs from T-12 and T-8 fluorescent systems and uses a different socket.

Linear Fluorescent Lamps

Four-foot T-8 lamps are now available in 25, 28, 30, and 32 watts, with many variations in energy performance, lamp longevity, and lamp color properties. Eight-foot T-8 lamps are also available in 50, 54, 57 and 59 watt versions, all fitting the same sockets and luminaires as earlier 8′ T-12 fluorescents. Lamps designed specifically for energy savings, when coupled with appropriate high efficiency ballasts, can provide up to 25 percent energy savings when compared to standard T-8 systems with normal output, standard efficiency ballasts.

More recently introduced in the United States, T-5 lamps are based on metric sizes, so that a 4′ T-5, or T5HO, lamp is slightly shorter than a T-8. T-5 lamps also use a smaller socket than the T-8 and T-12. Therefore, they are not directly retrofittable into T-8 luminaires. The smaller diameter lamp performs well in directional luminaires using well-designed reflectors to throw light farther and more accurately. They can also help reduce luminaire size in indirect, cove, and task applications. While not necessarily more energy efficient than T-8 lamps in normal ceiling height applications, all T-5 ballasts are programmed start, which is best for use with occupancy sensors.

Retrofit applications of high output T-5 luminaires are common in replacement of metal halide high bay luminaires due to their ability to perform well at high mounting heights. Compared with 400 watt metal halide luminaire, a 4-lamp T5HO luminaire can achieve an overall reduction in energy use as well as offering instant starting, step dimming by ballast switching, or full range dimming with electronic dimming ballasts.

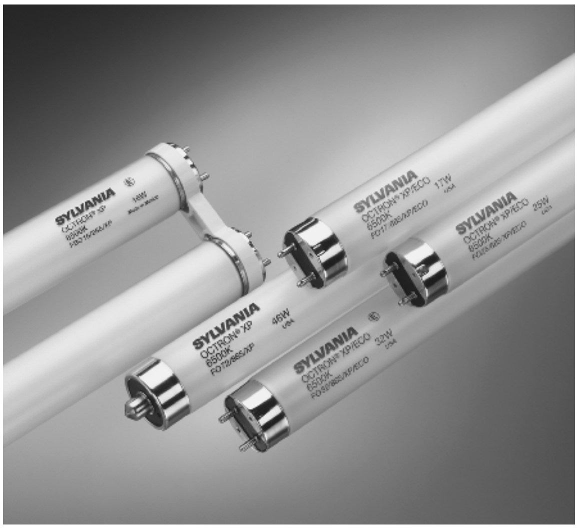


Figure 1-1a T-8 lamps are 1″ in diameter and are available in a wide range of lumen output, lamp life, and efficiency options. *(Photo courtesy of OSRAM SYLVANIA Inc., and Paul Kevin Picone/PIC Corp.)*

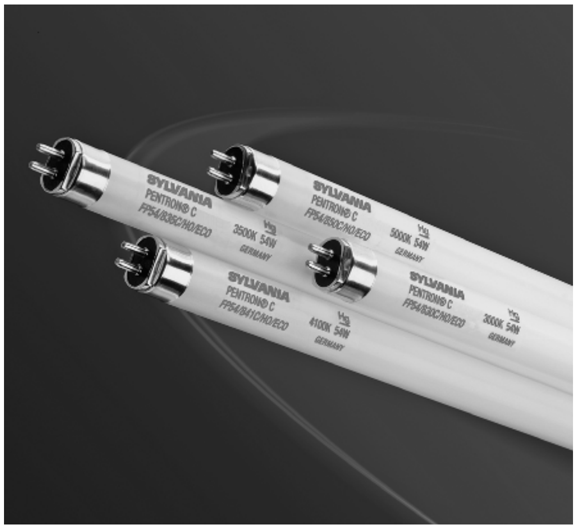


Figure 1-1b T-5 lamps are 5/8″ in diameter and are available in normal and high lumen output. *(Photo courtesy of OSRAM SYLVANIA Inc., and Paul Kevin Picone/PIC Corp.)*

Medium bipin standard T-12 lamps are still available in the marketplace. When operated on an electronic ballast, a high color rendering T-12 lamp can achieve a respectable 75-80 lumens per watt. High output and very high output T-12 lamps also have remained available for special and low temperature applications.

But for many reasons, the T-12 lamp is virtually obsolete. The larger 1 ½″ diameter T-12 lamps use more material to produce, including the more costly phosphors used in higher performance lamps, and are therefore more costly than T-8 lamps.

Recent improvements in fluorescent lamp technology that primarily benefit the T-5 and T-8 lamps include:

- Reduced Energy Use

  Reducing electrical usage has been a driver in the fluorescent lamp industry, pushed along by increases in energy costs, state- and utility-based demand-side-management "efficiency" programs, and federal legislation. Efficiency improvements have recently extended to special bent-tube or "U" tube fluorescent lamps, long compact fluorescent or biax lamps, as well as standard 4′ and 8′ lamps.

  While newer lamp options offer the same or better performance than older systems, the top performance requires efficient ballasts and specific combinations of lamps and ballasts. A series of tables are presented starting with Table 1-1 to help make sense of a complex array of lamp and ballast options based on retrofit priorities.

- Greater Light Output

  Not all 4′ T-8 lamps have the same initial lumen output, and this variable is not always directly proportional to the energy used due to differences in lamp efficacy. The range for a single T-8 lamp is from 2,425 lumens for a 25-watt energy saving lamp to 2,850 lumens for a common 32-watt lamp to 3,100 lumens for high efficiency "super" 32-watt lamps. Moreover, the T-5 and T-8 lamps have far better lumen maintenance than older T-8 lamps and most T-12 lamps

- Longer Lamp Life

  Extended life fluorescent lamps improve the already long life of the standard commercial fluorescent tube. All fluorescent lamps are rated according to their average life, meaning that 50 percent of the lamps will last longer and 50 percent will not last as long as the manufacturer's rating. Based on a three-hour run time per start, the rated life averages from 20,000 to 36,000 hours, and up to 42,000 hours for 12-hours run time per start.

  T-8 lamps typically last longer than T-12 lamps, which have an average rated life of between 9,000 to 20,000 hours, another reason to consider converting to T-8 systems.

Table 1-1 compares various linear fluorescent sources to other sources.

TABLE 1-1 PERFORMANCE CHARACTERISTICS OF VARIOUS LIGHT SOURCES

	Lamp Type	Efficacy[1] (Mean Lumens/ Watt) *M=magnetic E=electronic*	Average Life (Hours)	Lamp Lumen Maintenance	Correlated Color Temperature (CCT) (°K)	Color Rendering Index (CRI)
Tungsten	Standard Incandescent	5–20	750–3,000	Poor	2,800	100
	Tungsten Halogen	15–30	2,000–4,000	Very Good	3,000	100
	Halogen Infrared Reflecting	20–30	2,000–3,000	Very Good	3,000	100
Fluorescent	Compact Fluorescent (5–26 Watts)	20–40 M 30–60 E	9,000–12,000	Good	2,700–5,000	80–85
	Compact Fluorescent (27–40 Watts)	50–80 E	10,000–20,000[2]	Very Good	2,700–5,000	80–85
	*Full Size Fluorescent T-12**	50–58 M 70–80 E	20,000[2]	Good	2,700–7,500	50–90
	Full–Size Fluorescent T-8	60–105E	20,000–42,000[2]	Excellent	2,700–17,000[4]	75–90
	Full-size Fluorescent T-5	(T5) 80–105E (T5HO) 75–90E	20,000[2]	Excellent	3,000–17,000[4]	80–90
High Intensity Discharge	*Mercury Vapor**	30–50 M	12,000–24,000	Poor	3,300–5,700	15–50
	Pulse start metal halide (175–1,500 Watts)	35–100M[3]	3,000–20,000	Fair	3,000–6,500	65–85
	Ceramic Metal Halide (20–150 Watts), electronic ballast	45–80[3]E	2,000–20,000	Good	3,200–6,500	60–90
	Ceramic Metal Halide 200–400 watts) electronic ballast	50–85[3] E	10,000–30,000	Good	2,800–4,000	75–92
	High Pressure Sodium	45–130[3] M	16,000–24,000	Excellent	2,100–2,200	22
	Low Pressure Sodium	50–120[3] M	50,000–100,000	Low	Colorless	0
Other	Neon (12mm, 30mA 3000K, 80CRI))	30–35 M	20,000+	Good	Any white or color	Varies
	Cold Cathode (25mm, 60mA, 3000K, 80 CRI)	60–65 M	20,000+	Good	Any white or color	Varies
	Induction (self ballasted, 20–30w)	40–60 E	10,000–20,000	Good	2,700–3,000	80–85
	Induction 50–250w	50–80 E	50,000–100,000	Good	3,000–5,000	80–85
	White LED	15–90 E	20,000–50,000	Good	2,800–7,500 or several colors	70–90

Note

1 Approximate range of values using technology available in 2010.
2 Life affected by starting method and hours of operation. See discussion in the text about ballast selection.
3 Efficacy increases with watts and depends on specific lamp, ballast, operating position and other factors.
4 Common color temperatures of 3000, 3500 and 4100K dominate; color temperatures above 5000 are typically used for specialty applications.

** Obsolete technologies for comparison use only*

- Lamps Designed to Start at Lower Ambient Temperatures

Starting temperature is a factor when considering a low-energy high efficiency lamp. Lower room temperatures may affect the ability of these lamps to start and operate properly, especially the lowest wattage versions such as 25 watt 4′ T-8 lamps. All lamps have a specific temperature above which they are designed to start, and a higher temperature at which they operate optimally. For instance, standard T-8 lamps operate best above 60°F, and most will start at 0°F. Some special T-8 lamps are rated to start at even lower temperatures.

T-5 lamps have a higher ideal operating temperature than T-8 lamps. The manufacturer's ratings for initial and mean lumens are given as 95°F (35°C). This is not an unusual operating temperature for a lamp in a typical 70°F heated space, given the proximity of the ballast and thermal stratification in high ceiling spaces. The higher operating temperature can lead to lower than projected illuminance in an unheated warehouse, ice hockey rink, or other cold locations.

Historically, high output T-12 lamps are often used in cold temperature applications such as outdoor signs, cold storage, and unheated warehouses as they are rated to start as low as –20°F. There is a legitimate concern that T-8 lamps would not operate in these environments, as standard T-8 lamps are, at best, rated to start at 0°F. However, low temperature T-8 performance can be achieved with special low start temperature ballasts.

- Lower Mercury Content

Fluorescent lamp manufacturers have reduced the amount of mercury in fluorescent lamps by nearly 70 percent per lamp since 1990. The U.S. Environmental Protection Agency (EPA) has a test procedure for determining when fluorescent lamps are characterized as hazardous waste called the Toxicity Characteristic Leaching Procedure (TCLP). Today, manufacturers specially label lamps passing this test, usually with a green color band and/or with a catalog number including the letters ECO. However, all fluorescent lamps contain a small amount of mercury, so regardless of labeling, all spent lamps should be recycled to ensure that all of the materials are reused rather than becoming hazardous waste.

Prior to 1996, 4′ fluorescent lamps from major manufacturers contained between 16 to 22 mg of Hg (mercury) per lamp. Currently, some lamps contain as little as 3 mg of Hg per tube, but many still have as much as 10 mg.[2] The most significant hazard for contamination is if new lamps are broken. Proper methods of cleanup are recommended in the U.S. EPA at www.epa.gov/hg/spills/.

Fluorescent Ballasts (Nondimming)

There have been a number of significant improvements in linear fluorescent ballasts, again starting with improvements in energy efficiency.

- Major ballast manufacturers now offer high performance T-8 ballasts that increase overall system efficacy to over 90 mean lumens per watt. Low ballast factor (BF) ballasts combine with high performance lamps to produce the same lamp lumen output as conventional T-8 systems using 20 percent fewer watts. Low, normal and high ballast factor ballasts can be effectively used to "tune" a fluorescent lighting system. A low BF ballast will lower both light output and energy use.
- Many fluorescent ballasts now are "universal" and operate on any voltage from 120 to 277 volts, with some Canadian market versions to 347 volts. This allows one ballast to be used regardless of circuit voltage, in turn allowing for lower manufacturing and inventory costs.
- Ballasts are available in instant start (IS), programmed start (PS) and rapid start (RS) types. IS ballasts are the most efficient, but instant starting reduces lamp life when lamps are frequently switched. PS ballasts effectively soft-start the lamp and preserve lamp life, but are a bit less efficient. RS ballasts are typically used for special dimming ballasts.
- Many ballasts now provide end-of-lamp life protection to lamps, avoiding lamp popping and breakage when they do fail.

Naturally, ballasts with new features cost slightly more than the standard unimproved versions, but the extra cost is often justified as a good lifecycle cost investment.

LINEAR FLUORESCENT LAMP/BALLAST RETROFIT OPTIONS TABLES

The following tables (see Tables 1-2 though 1-7) provide a range of available fluorescent lamp/ballast retrofit options. To use the tables:

1. First, identify the current T-12 or T-8 lighting system from the appropriate table.
2. Then, determine if a reduction in light level is desired, compared with the existing illuminance. The tables examine both maintaining existing illuminance as well as reducing light levels to maximize energy savings. Since many facilities are overlighted based on current lighting standards, see Chapter 7- Lighting Engineering and Evaluation discussion of determining appropriate illuminance for tasks expected to be performed in the space.

TABLE 1-2 CONVERTING FROM AN EXISTING T-12 FOUR-LAMP SYSTEM

Retrofit for T-12 Four-Lamp Existing Lighting System Matching or Within 10 Percent of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	Standard F34T12CW	4	Standard Magnetic BF=0.87	160	7,934	50	20,000	$-		$57.60
			Energy Saving Magnetic BF=0.87	144	7,934	55	20,000	$5.76	10%	$51.84
	Standard F40T12CW		Standard Magnetic BF=0.87	184	10,525	57	20,000	$(8.64)	–15%	$66.24
			Energy Saving Magnetic BF=0.87	172	10,525	61	20,000	$(4.32)	–8%	$61.92
Longest Lamp Life Option	Extra Long Life T-8		T-8 Programmed Start, BF 0.71	88	7,597	86	46,000	$25.92	45%	$31.68
Most Energy Savings Option	Low Energy Use T-8 (28w)		High Efficiency T-8 Instant Start, BF 0.77	84	7,891	94	30,000	$27.36	48%	$30.24
Least Lamps Required Option	High Lumen Output T-8	3	High Efficiency T-8 Instant Start BF 0.87	80	7,608	95	36,000	$28.80	50%	$28.80
Retrofit for T-12 Four-Lamp Existing Lighting System Reduction of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	Standard F34T12CW	4	Standard Magnetic BF=0.87	160	7,934	50	20,000	$-		$57.60
			Energy Saving Magnetic BF=0.87	144	7,934	55	20,000	$5.76	10%	$51.84
	Standard F40T12CW		Standard Magnetic BF=0.87	184	10,525	57	20,000	$(8.64)	–15%	$66.24
			Energy Saving Magnetic BF=0.87	172	10,525	61	20,000	$(4.32)	–8%	$61.92
Longest Lamp Life Option	Extra Long Life T-8	3	T8 Programmed Start, BF=0.60	66	4,815	73	46,000	$33.84	59%	$23.76
Most Energy Savings Option	Very Low Energy Use T-8 (25w)	3	T8 Programmed Start, BF=0.77	58	5,082	88	40,000	$36.72	64%	$20.88
Least Lamps Required Option	High Lumen Output T-8	2	High Efficiency T8 Instant Start BF=0.87	53	5,072	96	36,000	$38.52	67%	$19.08

Notes: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use Instant Start Ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low energy use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F. Use cold temperature or all temperature lamps.

TABLE 1-3 CONVERTING FROM AN EXISTING T-12 THREE-LAMP SYSTEM

Retrofit for T-12 Three-Lamp Existing Lighting System Matching or Within 10 Percent of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	Standard F34T12CW	3	Standard Magnetic*	120	5,951	50	20,000	$-		$43.20
			Energy Saving Magnetic*	108	5,951	55	20,000	$4.32	10%	$38.88
	Standard F40T12CW		Standard Magnetic*	138	7,894	57	20,000	$(6.48)	–15%	$49.68
			Energy Saving Magnetic*	129	7,894	61	20,000	$(3.24)	–8%	$46.44
Longest Lamp Life Option	Extra Long Life T-8	3	T-8 Programmed Start, BF 0.71	68	5,698	84	46,000	$18.72	43%	$24.48
Most Energy Savings Option	Low Energy Use T-8 (28w)	3	High Efficiency T-8 Instant Start, BF 0.77	64	5,918	92	30,000	$20.16	47%	$23.04
Least Lamps Required Option	High Lumen Output T-8	2	High Efficiency T-8 Instant Start BF 1.0	62	5,830	94	36,000	$20.88	48%	$22.32
Retrofit for T-12 Three-Lamp Existing Lighting System Reduction of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	Standard F34T12CW	3	Standard Magnetic*	120	5,951	50	20,000	$-		$43.20
			Energy Saving Magnetic*	108	5,951	55	20,000	$4.32	10%	$38.88
	Standard F40T12CW		Standard Magnetic*	138	7,894	57	20,000	$(6.48)	–15%	$49.68
			Energy Saving Magnetic*	129	7,894	61	20,000	$(3.24)	–8%	$46.44
Longest Lamp Life Option	Extra Long Life T-8	3	T-8 Programmed Start, BF 0.60	66	4,815	73	46,000	$19.44	45%	$23.76
Most Energy Savings Option	Very Low Energy Use T-8 (25w)	3	High Efficiency T-8 Instant Start, BF 0.77	58	5,082	88	40,000	$22.32	52%	$20.88
Least Lamps Required Option	High Lumen Output T-8	2	High Efficiency T-8 Instant Start BF 0.87	53	5,072	96	36,000	$24.12	56%	$19.08

Notes: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use Instant Start Ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low energy use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F. Use cold temperature or all temperature lamps.

*Assumes tandem ballasting (all two-lamp ballasts)

TABLE 1-4 CONVERTING FROM AN EXISTING T-12 TWO-LAMP SYSTEM

Retrofit for T-12 Two-Lamp Existing Lighting System Matching or Within 10 Percent of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	Standard F34T12CW	2	Standard Magnetic* BF=0.87	80	3,967	50	20,000	$-		$28.80
			Energy Saving Magnetic* BF=0.87	72	3,967	55	20,000	$2.88	10%	$25.92
	Standard F40T12CW		Standard Magnetic* BF=0.92	92	5,262	57	20,000	$(4.32)	–15%	$33.12
			Energy Saving Magnetic* BF=0.92	86	5,262	61	20,000	$(2.16)	–8%	$30.96
Longest Lamp Life Option	Extra Long Life T-8	2	T-8 Programmed Start, BF 0.71	47	3,799	81	46,000	$11.88	41%	$16.92
Most Energy Savings Option	Low Energy Use T-8 (28w)	2	High Efficiency T-8 Instant Start, BF 0.77	43	3,945	92	30,000	$13.32	46%	$15.48
Retrofit for T-12 Two-Lamp Existing Lighting System Reduction of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	Standard F34T12CW	2	Standard Magnetic* BF=0.87	80	3,967	50	20,000	$-		$28.80
			Energy Saving Magnetic* BF=0.87	72	3,967	55	20,000	$2.88	10%	$25.92
	Standard F40T12CW		Standard Magnetic* BF=0.92	92	5,262	57	20,000	$(4.32)	–15%	$33.12
			Energy Saving Magnetic* BF=0.92	86	5,262	61	20,000	$(2.16)	–8%	$30.96
Longest Lamp Life Option	Extra Long Life T-8	2	T-8 Programmed Start, BF 0.60	44	3,210	73	46,000	$12.96	45%	$15.84
Most Energy Savings Option	Very Low Energy Use T-8 (25w)	2	High Efficiency T-8 Instant Start, BF 0.77	39	3,388	87	40,000	$14.76	51%	$14.04
Least Lamps Required Option	High Lumen Output T-8	1	High Efficiency T-8 Instant Start BF 0.87	37	3,061	83	42,000	$15.48	54%	$13.32

Notes: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use Instant Start Ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low energy use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F. Use cold temperature or all temperature lamps.

*Assumes tandem ballasting (all two-lamp ballasts)

TABLE 1-5 CONVERTING FROM AN EXISTING T-8 FOUR-LAMP SYSTEM

Retrofit for T-8 Four-Lamp Existing Lighting System Matching or Similar to Current Light Levels

	Lamp Type	# of Lamps	Ballast Type	System Watts	Mean System Lumens	Efficiency (L/W)	Lamp Life	Annual Energy Savings	Percent Savings	Annual Energy Cost
Current Lighting System	First Generation F32T8	4	Standard Instant Start, BF=0.87	111	8,787	79	24,000	$-		$39.96
Lamp Life Option, only lamp replaced	Extra Long Life T-8	4	Standard Instant Start, BF=0.87	110	9,309	85	40,000	$0.36	1%	$39.60
Energy Savings Option, only lamp replaced	Low Energy Use (30 w) T-8 long life	4	Standard Instant Start, BF=0.87	105	8,715	83	36,000	$2.16	5%	$37.80
Most Energy Savings Option, lamp and ballast replaced	Low Energy Use T-8 (28 w)	4	High Efficiency T-8 Programmed Start, BF=0.68	76	6,969	97	30,000	$12.60	32%	$27.36
Least Lamps Required Option, lamp and ballast replaced	High Lumen Output T-8	3	High Efficiency T-8 Instant Start BF 1.0	90	8,745	97	36,000	$7.56	19%	$32.40

Retrofit for T-8 Four-Lamp Existing Lighting System Reduction of Current Light Levels

	Lamp Type	# of Lamps	Ballast Type	System Watts	Mean System Lumens	Efficiency (L/W)	Lamp Life	Annual Energy Savings	Percent Savings	Annual Energy Cost
Current Lighting System	First Generation F32T8	4	Standard Instant Start, BF=0.87	111	8,787	79	24,000	$-		$39.96
Energy Savings Option, only lamp replaced	Very Low Energy Use T-8 (25 w)	4	Standard Instant Start, BF 0.87	88	7,040	80	40,000	$8.28	21%	$31.68
Lamp Life Option, lamp and ballast replaced	Extra Long Life T-8	3	T-8 Programmed Start, BF=0.88	84	7,142	86	46,000	$9.72	24%	$30.24
Most Energy Savings Option, lamp and ballast replaced	Low Energy Use T-8 (28 w)	3	High Efficiency T-8 Instant Start, BF=0.77	64	5,918	92	30,000	$16.92	42%	$23.04
Least Lamps Required Option, lamp and ballast replaced	High Lumen Output T-8	2	High Efficiency T-8 Instant Start BF=1.0	62	5,830	95	36,000	$17.64	44%	$22.32

Notes: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use instant-start ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low energy use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F. Use cold temperature or all temperature lamps.

TABLE 1-6 CONVERTING FROM AN EXISTING T-8 THREE-LAMP SYSTEM

Retrofit for T-8 Three-Lamp Existing Lighting System Matching or Similar Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	First Generation F32T8	3	Standard Instant Start BF=0.87	86	6,917	80	24,000	$-		$30.96
Lamp Life Option, only lamp replaced	Extra Long Life T-8	3	Standard Instant Start, BF 0.87	86	6,982	81	40,000	$-	0%	$30.96
Energy Savings Option, only lamp replaced	Low Energy Use (30 w) T-8 long life	3	Standard Instant Start, BF 0.87	79	6,536	83	36,000	$2.52	8%	$28.44
Most Energy Savings Option, lamp and ballast replaced	Low Energy Use T-8 (28 w)	3	High Efficiency T-8 Programmed Start, BF=0.77	64	5,918	96	30,000	$7.92	26%	$23.04
Least Lamps Required Option, lamp and ballast replaced	High Lumen Output T-8	2	High Efficiency T-8 Instant Start BF 1.18	73	6,705	92	36,000	$4.68	15%	$26.28
Least Lamps Required Option, lamp and ballast replaced	Low Energy Use F28T5 (for comparison)	2	High Efficiency T-5 Programmed Start	67	6,337	95	30,000	$6.84	22%	$24.12
Retrofit for T-8 Three-Lamp Existing Lighting System Reduction of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	First Generation F32T8	3	Standard Instant Start BF=0.87	86	6,917	80	24,000	$-		$30.96
Energy Savings Option, only lamp replaced	Very Low Energy Use T-8 (25 w)	3	Standard Instant Start BF=0.87	67	5,280	79	40,000	$6.84	22%	$24.12
Lamp Life Option, lamp and ballast replaced	Extra Long Life T-8	3	High Efficiency T-8 Programmed Start, BF=0.71	68	5,698	84	46,000	$6.48	21%	$24.48
Most Energy Savings Option, lamp and bal-last replaced	Low Energy Use T-8 (28 w)	3	High Efficiency T-8 Instant Start, BF=0.77	64	5,918	92	30,000	$7.92	26%	$23.04
Least Lamps Required Option, lamp and ballast replaced	High Lumen Output T-8	2	High Efficiency T-8 Instant Start BF=1.0	62	5,830	94	36,000	$8.64	28%	$22.32
Least Lamps Required Option, lamp and bal-last replaced	High Efficiency T-8 (32 w)	2	High Efficiency T-8 Instant Start BF=0.77	48	4,489	97	30,000	$13.68	44%	$17.28

Notes: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use instant-start ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low energy use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F. Use cold temperature or all temperature lamps.

TABLE 1-7 CONVERTING FROM AN EXISTING T-8 TWO-LAMP SYSTEM

Retrofit for T-8 Two-Lamp Existing Lighting System Matching or Similar to Current Light Levels										
	Lamp Type	# of Lamps	Ballast Type	System Watts	Mean System Lumens	Efficiency (L/W)	Lamp Life	Annual Energy Savings	Percent Savings	Annual Energy Cost
Current Lighting System	First Generation T-8	2	Standard Instant Start BF=0.87	59	4,611	78	24,000	$-		$21.24
Lamp Life Option, only lamp replaced	Extra Long Life T-8	2	Standard Instant Start, BF 0.87	59	4,708	80	40,000	$-	0%	$21.24
Energy Savings Option, only lamp replaced	Low Energy Use (28 w) T-8	2	Standard Instant Start, BF 0.87	53	4,253	80	30,000	$2.16	10%	$19.08
Most Energy Savings Option, lamp and ballast replaced	Low Energy Use T-8 (28 w)	2	High Efficiency T-8 Instant Start, BF 0.87	48	4,458	93	30,000	$3.96	19%	$17.28
Retrofit for T-8 Two-Lamp Existing Lighting System Reduction of Current Light Levels										
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Mean System Lumens**	**Efficiency (L/W)**	**Lamp Life**	**Annual Energy Savings**	**Percent Savings**	**Annual Energy Cost**
Current Lighting System	First Generation T-8	2	Standard Instant Start BF=0.87	59	4,611	78	24,000	$-		$21.24
Energy Savings Option, only lamp replaced	Very Low Energy Use T-8 (25 w)	2	Standard Instant Start BF 0.87	43	3,520	82	40,000	$5.76	27%	$15.48
Most Energy Savings Option, lamp and ballast replaced	Low Energy Use T-8 (28 w)	2	High Efficiency T-8 Programmed Start, Very Low BF 0.59	39	3,023	78	30,000	$7.20	34%	$14.04
Least Lamps Required Option, lamp and ballast replaced	High Lumen Output T-8	1	High Efficiency T-8 Instant Start BF 1.15	41	3,352	82	36,000	$6.48	31%	$14.76

Notes: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use instant-start ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low energy use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F. Use cold temperature or all temperature lamps.

The use of data and this format are courtesy of GE Consumer and Industrial Lighting.

3. Prioritize the goals of the retrofit. These include:
   a. Extending the lamp life by selecting a combination of programmed rapid start ballasts with extended life fluorescent lamps.
   b. Obtaining the greatest energy savings, again by selecting a combination of high performance lamps with high efficiency, lower BF ballasts.
   c. Using fewer lamps per fixture, thus saving on lamp purchase, relamping, and disposal costs.

LIGHTING CONTROLS FOR LINEAR FLUORESCENT SYSTEMS

All fluorescent fixtures can be controlled by a range of automatic on/off control devices outlined in Table 1-8.

Occupancy sensors and timer devices have been used for many years, often with great success. As much as 50 percent of lighting energy savings can be achieved with lighting controls, so it is important to develop a good understanding of all the types and their proper use.

Occupancy sensors have become smarter with the incorporation of technology that "learns" and adapts to patterns of use in a room. This helps alleviate false triggering and unintended switch-offs when the room is occupied, but also requires resetting of controls after installation and before normal occupancy. While infrared wall switch sensors make up much of the market for occupancy sensors, understanding the need for dual technology sensors for greater sensitivity to movement can be critical to proper operation in some applications.

Correct placement of occupancy sensors can also make or break an installation. Although ceiling-mounted sensors require additional wiring and a power pack to operate, many larger or irregular shape rooms require them. Rooms beyond the range of a single ceiling sensor will require more than one, wired to control either the entire room or a specific segment of a room, depending on the room use.

A new development of great interest to the retrofit market is the wireless occupancy sensor, which includes a remote ceiling-mounted sensor which communicates with a special wall switch. This solves a common retrofit problem where the cost of running a wire between the wall switch and the sensor is prohibitive, but a ceiling sensor is needed for proper operation.

A whole chapter could be devoted to lighting control systems, and perhaps a future edition of this book will do so. For now, however, a good source of detailed information and education on all types of lighting control systems can be found through the Lighting Controls Association, a trade group which promotes proper use of lighting controls. See www.aboutlightingcontrols.org for more information. Likewise, the Lighting Controls section of the Advanced Lighting Guidelines

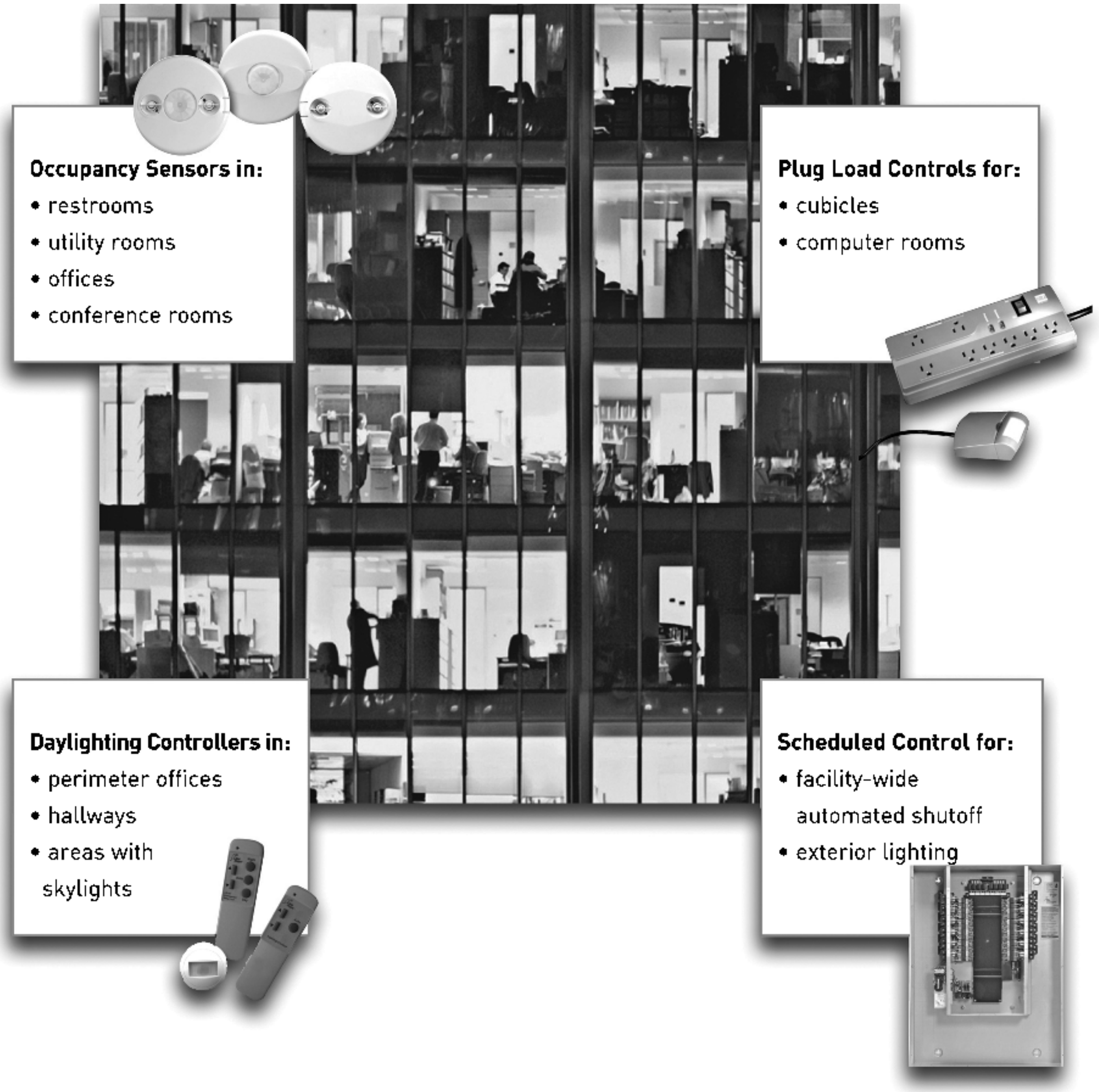


Figure 1-2 A wide variety of lighting controls are available for a range of commercial applications. *(Image courtesy of Watt Stopper®.)*

(www.newbuildings.org) is a farily complete source of information, with a new Controls section scheduled for release in 2010.

The following is an important case study that demonstrates major energy savings for bi-level occupancy sensors, written by Craig DiLouie for the Lighting Controls Association—April 2009, and included with the permission of the author and of the Lighting Controls Association.

TABLE 1-8 OCCUPANCY SENSORS AND APPLICATIONS

Wall Switch Occupancy Sensors			
Type	**Description**	**Typical Applications**	**Features to Look for**
PIR (Passive Infrared) Wall Switch Sensor	Replaces existing wall switches, turns lights on and off by sensing the difference in infrared (heat) energy between warm bodies in motion and the surrounding space	Small offices, small conference rooms, individual restrooms, break rooms, small storage rooms. For all sensor types, use single sensors in spaces no larger than recommended by sensor manufacturer.	Time delay adjustment, sensitivity adjustment, daylight sensing, manual-on option, walk-through mode option (shorter delay), detection processing to help eliminate false triggers, LED indicator that unit is functioning, vandal-resistant lens, optional on override by maintenance personnel
PIR Low Voltage Wall Switch Sensor	In addition to PIR sensor features, can be used to integrate HVAC control features to occupancy	Same as above, with VAV or occupancy control loads other than lighting	
PIR Dual Relay Wall Switch Sensor	Provides ability to control two lighting loads with one sensor, excellent for bi-level lighting systems	Small offices, small conference rooms, individual restrooms, break rooms, small storage rooms	Same as PIR single sensor, should have ability to set one load for auto-on, with the other remaining manual on
Motion Sensor Nightlight Switch	PIR sensor with nightlight	Hotel, hospital, and assisted living bathrooms, or other spaces with a need for a nightlight	Same as PIR single sensor, low brightness energy efficient light source, usually LED
Dimmable Motion Sensor Wall Switch	PIR sensor with slide dimmer, 10% dimming typical, media rooms often require 5% dimming or less.	Small conference rooms, small offices with dimmable lighting, restaurant private dining rooms	Line voltage phase control input for 2-wire fluorescent dimming as well as incandescent, zero voltage turn on/off for sensor and lamp life
Ultrasonic Wall Switch Sensor	Replaces existing wall switches, turns lights on and off using the Doppler Principle and high frequency ultrasound to detect occupancy and turn lighting on. After time delay, lights are automatically turned off.	Individual restrooms, small (two-stall) restrooms, utility and storage rooms	Same as PIR sensors
Ultrasonic Low Voltage Wall Switch Sensor	In addition to Ultrasonic sensor features, can be used to integrate HVAC control features to occupancy	Same as above, with VAV or occupancy control loads other than lighting	
Ultrasonic Dual Relay Wall Switch Sensor	Same as Ultrasonic sensor, for control of 2 lighting loads	Individual restrooms, small (2-stall) restrooms, utility and storage rooms	Same as PIR dual relay wall switch sensors
Dual Technology Wall Switch Sensor	Combines the benefits of PIR and ultrasonic, lights turn on only when both detect presence, eliminating false ons; detection by either keeps lights on until neither senses occupancy	Smaller rooms, offices, and meeting rooms with smaller movement that is not as easily detected by PIR or ultrasonic sensors alone	Same as PIR, plus occupancy logic options to customize control for specific needs
Dual Technology Low Voltage Wall Switch Sensor	In addition to dual technology sensor features, can be used to integrate HVAC control features to occupancy	Same as above, with VAV or occupancy control loads other than lighting	

Type	Description	Typical Applications	Features to Look for
Dual Technology Dual Relay Wall Switch Sensor	Same as dual technology sensor, for control of two lighting loads	Smaller rooms, offices, and meeting rooms with smaller movement that is not as easily detected by PIR or ultrasonic sensors alone	Same as single relay dual technology sensor
Digital Time Switch	Digital timer turns lights off after preset time. Time delay can be reset by user.	Utility and storage rooms	Flash/beep warnings to allow time to reset if someone is present, temporary override and easy reset to original setting
Mechanical Twist-Type Time Switch	Mechanical timer turns lights off after user-defined delay	Utility and storage rooms	
Ceiling-Located Occupancy Sensors			
Ceiling-Mounted PIR Sensor	Low voltage sensor provides better coverage from the ceiling, requires separate power pack to operate	Small to medium sized offices, break rooms, book stacks. Locate sensor for best pattern coverage according to manufacturer's instructions	Same as wallbox PIR sensors, plus lenses that allow for effective detection of infrared energy and better field of view, daylight filters so that the heat from sunlight does not affect performance, work with low voltage manual control switches
Ceiling/Wall-mounted PIR Sensor	Low voltage sensor often provides better control from corner ceiling or wall location, requires separate power pack to operate	Larger offices, warehouses, open offices, classrooms, circulation aisles	Same as ceiling-mounted PIR, as well as coverage patterns that best meet size of room
Line Voltage PIR Ceiling Sensor	Line voltage wiring can be used with these ceiling sensors, which operate at a range of standard VAC power	Open office spaces, conference rooms, computer rooms, classrooms, high ceiling storage and distribution centers	Simple setup sensor adjustments, once installed access may be difficult in high ceiling locations
Wireless Ceiling-Mounted PIR Sensor	A two-part sensor in which a special wall box switch unit communicates by special frequency with the ceiling-mounted sensor, which may or may not be directly wired to electrical circuit	In retrofit locations where a ceiling-mounted sensor is needed, but wiring installation is difficult or expensive	If ceiling sensor uses batteries, warranty on long battery life, testing features
Low Temperature PIR Occupancy Sensor	Gasketed watertight enclosure for outdoor and low temperature applications down to -40°F	Cold storage rooms, freezers, unconditioned spaces in cold climates	Isolated relay contact for interface with HVAC, EMS, or other control systems
Ultrasonic Ceiling Sensor	Low voltage sensor uses broad coverage Doppler technology to sense movement and turn lights on; requires separate power pack to operate	Larger restrooms, conference rooms, and offices with partitions with zone placement	Same as wall ultrasonic, plus 360-degree coverage, easy time delay adjustment, special devices for aisle, hallways, and high ceiling applications, improved signal processing to filter out moving air noise
Ultrasonic Ceiling Sensor for Integration with Lighting Control Panels	Same as ultrasonic ceiling sensor, used with lighting control panel to control multiple zones of lighting	Open offices, large conference facilities	Used with dedicated lighting panels to control large rooms or multiple rooms with the same occupancy patterns

(*continued*)

TABLE 1-8 (*Continued*)

Ceiling-Located Occupancy Sensors			
Type	**Description**	**Typical Applications**	**Features to Look for**
Dual Technology Ceiling/ Wall Sensor	Combines PIR and ultrasonic technology for best, most reliable coverage, requires separate power pack to operate	Large spaces such as classrooms, conference and training rooms with potentially little motion	Same as ceiling/wall PIR sensor, work with low voltage manual control switches
Dual Technology Ceiling Sensor	Same as dual technology ceiling/wall sensor, but for more central ceiling-mount location	Classrooms, open office space with partitions, large offices and computer rooms	Easy mounting systems for ceiling tiles or junction boxes, isolated relay for HVAC integration

While the basic on/off switch is not considered an energy-savings lighting control, it can be if at least two switches are used to control lighting in a space that is configured on two lighting circuits, giving the user a choice of two levels of light output.

Alternate rows, fixtures, or lamps can be switched, offering a choice of 50 and 100 percent light output. Or the center lamps can be switched separately from the outer lamps in three-lamp fixtures, offering a choice of 33, 66, and 100 percent light output. In one study by ADM Associates, the latter option was demonstrated to produce 22 percent energy savings in private offices.

At least one-half of the energy codes in the United States are based on the International Energy Conservations Code (IECC), which requires light level reduction controls such as multilevel switching or dimming in enclosed spaces such as private offices.

Occupancy sensors are just as simple—a switch married with a sensor to enable automatic switching based on whether the sensor detects the presence or absence of people. Occupancy sensing is a reliable method for generating energy savings—according to the Advanced Lighting Guidelines, occupancy sensors in private offices can produce up to 45 percent energy savings.

All energy codes require that general lighting be automatically turned OFF when it's not used. Further, IECC says that if an occupancy sensor is used in an enclosed space such as a private office, light level reduction controls are not needed, suggesting an either/or choice.

What if bi-level switching was combined with occupancy sensor functionality? Would this produce higher energy savings in a private office than bi-level switching or occupancy sensing alone? And, what combination of manual initiative and automation would produce the highest energy savings while also satisfying workers?

The California Lighting Technology Center (CLTC) organized a study in eight private offices at the University of California–Davis in 2008 to attempt to generate useful data related to these questions. Each office, between 90 and 140 square feet with a ceiling height of 9 feet, is lighted by a combination of indirect/direct pendant fixtures and daylight entering through a window with manually adjustable vertical blinds. The study was sponsored by Watt Stopper/Legrand.

The baseline comparison, researchers Theresa Pistochini, Judy Xu, and Rahul Shira wrote in a report on the study, is made to a theoretical case where the occupant has no control over their lighting which is switched ON and OFF by an occupancy sensor.

In the test offices, the pendants are configured with dual circuiting, with ballast driving two lamps (48 watts) placed on each circuit. This enabled the researchers to set up three test conditions and record data on occupancy.

1. Auto-ON to 100 percent: When the office became occupied, an occupancy sensor signaled both relays to automatically turn the lights ON to 100 percent light level. If the occupant wanted a lower light level, they could flick a switch to 50 percent or manual-OFF. When the occupant left the office, the sensor then automatically swept the lights OFF.
2. Auto-ON to 50 percent: When the office became occupied, an occupancy sensor signaled one relay to automatically turn one-half of the lamps ON to achieve 50 percent light level. The user could flick a switch to increase light level to 100 percent or turn the lights OFF. When the occupant left the office, the sensor then automatically swept the lights OFF.

Using a bi-level occupancy sensor

3. Manually ON to 50 or 100 percent: When the office became occupied, the sensor did not turn the lights ON. Instead, the user could turn the lights ON to 50 or 100 percent light level, or leave them OFF. When the occupant left the office, the sensor then automatically swept the lights OFF.

Occupants were informed about the manner in which the electric lights would behave and also that they were participating in a lighting controls study. However, the occupants were specifically not told that the purpose of the study was to measure the impact of their behavior on energy consumption.

ENERGY SAVINGS ACHIEVED

All three scenarios saved energy compared to the baseline scenario, suggesting that combining bi-level switching and occupancy sensing saves more energy than using an occupancy sensor alone. Specifically:

- The auto-ON to 100 percent bi-level occupancy sensor saved 34 percent compared to the baseline.
- The auto-ON to 50 percent bi-level occupancy sensor saved 52 percent compared to the baseline.
- The manual-ON bi-level occupancy sensor saved 46 percent compared to the baseline.

"This is quite impressive given that the designed lighting power density in the offices was already quite low at 0.7 to 0.9 watts per square foot," says Pistochini, development engineer for CLTC. "Giving individuals control of their lighting is important for achieving both user satisfaction and efficient use of energy."

(*continued*)

An advantage of bi-level switching is that users have a choice of light levels, enabling them to adjust light levels based on preference for different tasks or lighting conditions, such as the variable availability of daylight.

Pistochini says about half the study participants preferred the auto-ON to 50 percent scenario, while the other half preferred complete control and therefore preferred the manual-ON scenario. "The hypothesis with automatic-ON to 50 percent is that the occupant, when presented with manual-ON switches, will not give much thought to the amount of light needed and turn ON both of them. With the automatic-ON to 50 percent, the occupant often enters the office, finds the light level acceptable, and continues working. Occasionally, they desire more light and turn ON the other switch."

Whenever possible, use common-sense approaches to installing occupancy sensors in existing buildings. Too often, using an inexpensive sensor may cause more energy to be used than with a simple ON/OFF switch. When installing occupancy sensors without bi-level switching in rooms with windows, only use quality devices that allow you to select a manual-ON mode (also known as a vacancy mode). Not doing so will cause lights to go on when there is adequate light in the room and the user may not want them.

THE IMPACT OF OCCUPANCY SENSORS ON FLUORESCENT LAMP PERFORMANCE

The use of occupancy sensors with fluorescent lamps continues to grow and shows good opportunity for the end user to save energy in areas of a facility that have limited traffic. With this being said, there are certain operating parameters that should be considered when using these devices to ensure that rated lamp performance and life requirements are met.

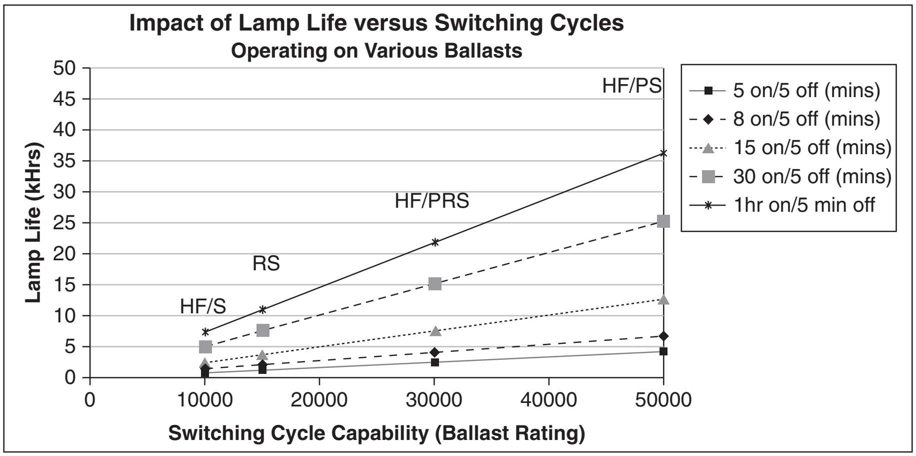
Fluorescent lamp life is dependent on the lamp electrode emitter loss, which occurs during each start and during steady state operation. The effect of starting on lamp life is the main concern when using occupancy sensors. With respect to starting, there are two main concerns: how the lamp is started, for instance, what type of ballast—instant start, rapid start, programmed rapid start, and programmed start, and the cycle or time setting that is used in switching the lamps on and off.

Although ballast design and starting scenario has a major impact on performance with occupancy sensors, the item that has the biggest impact on performance that can be controlled by the end user is the amount of on-time after the occupancy sensor has been activated. The greatest energy can be saved by setting the on-time to the minimum level available on the occupancy sensor, the energy savings are offset by the expense of replacing lamps that have failed prematurely due to the short cycling.

Because of the physics of the lamps and the characteristics of the lamp electrode system, fluorescent lamps perform best when switching is kept to a minimum. The longer the lamps are allowed to operate, the better the life will be. This can be seen in many of the new fluorescent lamp ratings that indicate that lamp life can be increased as much as 25 percent by operating the lamps for a minimum of 12 hours and 50 percent when the lamps are operated continuously, as compared to the standard 3-hour cycle used for identifying median lamp life. The opposite occurs when going to more rapid switching cycles and the negative results are even more exaggerated as the switching cycle is reduced.

As previously mentioned, fluorescent lamp cathode is depleted to some degree every time the lamp is ignited. This degradation is far less with programmed start ballasts than with instant start or rapid start systems because the coils are always hot and on emission prior to starting. Due to this "soft start," switching cycles equal to and even in excess of 50K are common with programmed start ballasts. Instant start and rapid start ballasts offer far less starts and typically provide for only 10K and 15K switches, respectively. All ballast manufacturers should have information on the number of switching cycles available with their ballast design. Based on the number of switches expected and the switching cycle set with the occupancy sensor, a simple calculation can be made to predict the expected lamp life when used on different ballasts. Based on this calculation, the following curve has been identified to show the impact on lamp life based on the expected switching cycles available from the ballast.

There may be other extenuating circumstances that affect lamp performance and life in occupancy sensor applications, but these must be addressed on a case by case basis.



Ballast Types: HF/IS = High Frequency Instant Start; RS = Rapid Start; HF/PRS = High Frequency Programmed Rapid Start
HF/PS = High Frequency Programmed Start

Figure 1-3 Impact of occupancy sensors on fluorescent lamp life. *(Courtesy Craig DiLouie and the Lighting Controls Association. Source: Philips Lighting, Fluorescent Dept whitepaper, www.lighting.philips.com.)*

Based on the curves provided, it is clear that instant start operation will always result in shortened lamp life when reduced on-time switching cycles are used. This is why at least one major lamp manufacturer does not recommend the use of occupancy sensors in combination with instant start systems.[2]

The provided curves hold true for the whole of T-8 rapid start family of lamps included the F17T8 (2′), F25T8 (3′), F32T8, and the 4′ F32T8 Energy Saver lamps. Based on the curve, standard lamp warranties should only be offered on lamps that are operated with occupancy sensors that allow the lamps to operate for at least 20 minutes prior to shutting off Programmed Rapid Start and Programmed Start ballasts. Based on the impact of starting with IS ballasts, these systems will most likely never achieve rated life if occupancy sensors are used that operate the lamps much less than the 3 hours on /20 minutes off cycles used in the normal life ratings. It should be stated for reference that the number of switches cycles experienced with the standard cycle median life requirement is 6,006 cycles for a 20-kHr rated life lamp and 7,207 cycles for a 24-kHr rated life lamp.[3]

Low energy type lamps, such as the 25- and 28-watt 4′ lamps, may not start or operate properly when used with occupancy sensors and may not be recommended by specific manufacturers for use with low energy ballasts. This is particularly true when starting temperatures are below 60°F, which is quite common where HVAC night setbacks keep temperatures low outside normal working hours.

On/Off Fluorescent Lighting Controls for Daylighting

On/off daylight controls may be successfully applied to fluorescent lighting systems in retrofit applications.

Photosensing devices are most cost-effective in controlling a single switched zone, not an individual fluorescent fixture. If a facility has a single switched zone that includes a number of fixtures that could reasonably be shut off when adequate daylight exists, it makes sense to control all of them with a single photoswitch.

When the switched zone contains fixtures in both daylit areas and some that are not well daylit, as is often the case, a different solution is required. One option is to rewire the daylit zone to operate independently of the remainder of the zone through a photoswitch and separate switch.

Another approach is to control up to two fixtures with one dedicated ballast controlled by a locally mounted photoswitch. Some manufacturers integrate an occupancy control and photoswitch into the luminaire, which reduces total installation costs and should eliminate calibration requirements. Additional care in locating, adjusting, and calibrating the photoswitch is required when the photoswitch is not integrated.

However, photoswitches are notoriously hard to manage and often have a short lifespan (<10 years). Therefore, a third option is to switch lights using a programmable

[2] Philips Lighting website, www.lighting.philips.com.

[3] From Philips Lighting website, whitepaper: "The Impact of Occupancy Sensors on Fluorescent Lamp Performance," www.lighting.philips.com/us.

astronomic switch. Many interior spaces have excessive daylight and as a result, even cloudy and stormy days produce enough daylight. A programmable switch can turn lights on a fixed period before sunset and off a fixed period at or after sunrise, and offers manual override (if accessible). Most of these devices offer the option of turning off lights by clock, such that lighting is operated between sunset and fixed time of business closure, such as 10PM or midnight.

Dimming Fluorescent Ballasts

Dimming ballasts represent a range of new opportunities in fluorescent lighting retrofit, limited by the cost of the ballasts and more complex control installation. While step dimming can be accomplished with nondimming ballasts and bi-level wiring, any type of dimming control can have a positive psychological effect. One Canadian study showed a greater sense of empowerment by workers who were able to control their own light levels.[4]

In another laboratory study, other positive results were noted. Subjects with dimmable lighting were more satisfied with the lighting, felt more comfortable in the room, rated the tasks less difficult, and rated the lighting quality as higher than subjects who did not have control. Using the lighting control system also produced a 42 to 45 percent decrease in electrical consumption.[5]

As a general rule, applications are divided between "architectural" dimming, where the emphasis is placed on convenience, quality and utility, and "energy management" in which the emphasis is placed on dimming for daylighting and other energy saving uses. Most energy management applications are intended such that the space occupants are largely unaware of dimming.

Fluorescent dimming ballasts can be divided into several groups, as follows:

Circuit and Control Type

- Two-wire dimming ballasts (dimmed hot and neutral)
- Three-wire dimming ballasts (hot—dimmed hot—neutral)
- Four-wire dimming ballasts, also known as 0-10 volt (hot—neutral—plus 10 volts—minus 10 volts)
- DALI ballasts and DALI-like proprietary ballasts (digital control)
- Power line carrier ballasts (control signal carried on hot and neutral wires)

While most ballasts only operate on one of these circuit types, there are a few special ballasts that can operate on two or more. Current examples include those that

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[4] Veitch, J., and G. Newsham. Consequences of the perception and exercise of control over lighting. 106th Annual Convention of the American Psychological Association, August 1998. San Francisco, CA.

[5] Boyce, P.R., N.H. Eklund, and S.N. Simpson. 2000. Individual lighting control: task performance, mood and illuminance. *Journal of the Illuminating Engineering Society*. Winter: 131–142.

can be either two-wire or four-wire circuits, and those that can operate on DALI-like or three-wire circuits.

Dimming Range

- Full range, capable of operating the lamp from 100 percent light level to about 1 percent (100:1 dimming ratio). These are typically used for demanding architectural applications.
- Wide range, capable of 100 percent to 5 percent light level (20:1 dimming ratio). These are typically used for architectural applications.
- Standard energy management range, capable of 100 percent to 10 percent light level (10:1 dimming ratio). These are used for architectural and energy management applications.
- Limited energy management range, capable of 100 percent to 25 percent light level (4:1 dimming ratio). These are used primarily for energy management applications.

Efficiency

- High efficiency, with full light output power approximately the same as a high efficiency programmed start non-dimming ballast
- Normal efficiency, with full light output power approximately the same as a standard programmed start non dimming ballast.
- Low efficiency, with full light output power approximately 10 percent more than a standard programmed start non dimming ballast.

FLUORESCENT BALLASTS WITH MANUAL DIMMING CONTROLS

Manual dimming controls for fluorescent ballasts are the most straightforward as they do not require wiring and commissioning of additional controllers and/or sensors. For retrofit purposes, two-wire dimming ballasts are most often used. They operate using the same wiring as an undimmed luminaire. A compatible fluorescent dimmer is recommended. With the recent advent of wireless controls, it may be possible to retrofit another ballast type, such as 0-10 volt ballasts, with a compatible wireless controller.

Common applications of manual fluorescent dimming are “architectural” and generally are provided for convenience and utility. Typical applications include:

Atriums

Auditoriums

Ballrooms (cove lighting)

Classrooms, particularly with AV systems

Conference rooms

Dining areas (cove lighting)

Food preparation areas, especially when viewable from public dining

Lobbies

Executive offices

Patient rooms

Spas and beauty salons

While the use of architectural dimming is usually not counted as an energy savings measure, savings are often realized as people will often choose to dim lights at least a little. Estimating the energy savings from a manual dimming system is tricky, as it is based on assumptions of use. A multiplier can be used to reduce the annual energy consumption by the percentage of the total, but only if one can justify the reduction in usage on a room by room basis. The savings from a manual dimming system should not be assumed to be greater than 30 percent.

Architectural scene dimming systems are now designed to incorporate fluorescent dimming ballasts. Many can drive any of the various ballast wiring types, including DALI ballasts and DALI-like proprietary ballasts.

Table 1-9 allows the energy manager to quickly estimate energy reduction potential and savings through the use of fluorescent dimming. As with previous tables, choose the table corresponding to the existing lamp quantity. Dimming options are listed by lamp and ballast type. The percentage of dimming is set at twenty-five and fifty percent for simplicity, and to offer the potential range of savings. Actual savings will vary.

Figure 1-4 Manual dimming of fluorescent lighting is essential for spas and many other uses where sustainability is a factor.

TABLE 1-9 COMPARING ENERGY USE WITH FLUORESCENT DIMMING BALLASTS

Retrofit for Dimmable T-8 Four-Lamp Existing Luminaire

	Lamp Type	# of Lamps	Ballast Type	Maximum System Watts	Minimum System Watts	Percent Energy Reduction	Annual Energy Savings	Percent Savings	Annual Energy Use
Current Lighting System	Standard F32T8	4	Standard Instant Start BF 0.87	112	112	–	$-		$40.32
Dimming Energy Savings Option, ballast only replaced	F32T8	4	(2) Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	136	30	25	$3.60	9%	$36.72
Dimming Energy Savings Option, ballast and lamp replaced	F28T8	4	(2) Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	132	29	25	$4.68	12%	$35.64
Dimming Energy Savings Option, ballast only replaced	F32T8	4	(2) Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	136	30	50	$15.84	39%	$24.48
Dimming Energy Savings Option, ballast and lamp replaced	F28T8	4	(2) Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	132	29	50	$16.56	41%	$23.76
Dimming Energy Savings Option, T-5 ballast and lamp for comparison	F54T5/HO Energy Saver Lamp	2	Two-lamp, two-wire T-5 dimming ballast BF 1.0/0.03	117	24	25	$8.73	22%	$31.59
Dimming Energy Savings Option, T-5 ballast and lamp for comparison	F54T5/HO	2	Two-lamp, two-wire T-5 dimming ballast BF 1.0/0.03	117	24	50	$19.26	48%	$21.06

* Light level reduction is greater than energy reduction. A 25 percent energy reduction will bring light levels down around 30 percent. Consult specific ballast manufacturer for data.

Dimming savings are higher when used with higher lumen output lighting systems if users feel current light levels are excessive.

System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Very low energy use lamps using 25 or 28 watts should not be used with dimming ballasts unless specifically recommended by both the lamp and ballast manufacturer

T5HO dimming options shown for fixture replacement only. T-5 lamps are not retrofittable into T-8 or T-12 luminaires.

For additional energy savings, look for new, high performance dimming ballasts.

Retrofit for Dimmable T-8 Three-Lamp Existing Luminaire

	Lamp Type	# of Lamps	Ballast Type	Maximum System Watts	Minimum System Watts	Percent Annual Energy Reduction	Annual Energy Savings	Percent Savings	Annual Energy Use
Current Lighting System	Standard F32T8	3	Standard Instant Start BF 0.87	86	86	–	$-	–	$30.96
Dimming Energy Savings Option, ballast only replaced	F32T8	3	Three-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	100	20	25	$3.96	13%	$27.00

	Lamp Type	# of Lamps	Ballast Type	Maximum System Watts	Minimum System Watts	Percent Annual Energy Reduction	Annual Energy Savings	Percent Savings	Annual Energy Use
Dimming Energy Savings Option, ballast and lamp replaced	F28T8	3	Three-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	96	19	25	$5.04	16%	$25.92
Dimming Energy Savings Option, ballast only replaced	F32T8	3	Three-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	100	20	50	$12.96	42%	$18.00
Dimming Energy Savings Option, ballast and lamp replaced	F28T8	3	Three-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	96	19	50	$13.68	44%	$17.28

Retrofit for Dimmable T-8 Two-Lamp Existing Luminaire

	Lamp Type	# of Lamps	Ballast Type	Maximum System Watts	Minimum System Watts	Percent Annual Energy Reduction	Annual Energy Savings	Percent Savings	Annual Energy Use
Current Lighting System	Standard F32T8	2	Standard Instant Start BF 0.87	59	59	–	$-		$21.24
Dimming Energy Savings Option, ballast only replaced	F32T8	2	Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	68	15	25	$2.88	14%	$18.36
Dimming Energy Savings Option, ballast and lamp replaced	F28T8	2	Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	64	14	25	$3.96	19%	$17.28
Dimming Energy Savings Option, ballast only replaced	F32T8	2	Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	68	15	50	$9.00	42%	$12.24
Dimming Energy Savings Option, ballast and lamp replaced	F28T8	2	Two-lamp, two-wire T-8 dimming ballast BF 1.0/0.05	64	14	50	$9.72	46%	$11.52
Dimming Energy Savings Option, T-5 ballast and lamp for comparison	F54T5/HO Energy Saver Lamp	1	One-lamp, two-wire T-5 dimming ballast BF 1.0/0.03	59	13	25	$5.31	25%	$15.93
Dimming Energy Savings Option, T-5 ballast and lamp for comparison	F54T5/HO Energy Saver Lamp	1	One-lamp, two-wire T-5 dimming ballast BF 1.0/0.03	59	13	50	$10.62	50%	$10.62

DIMMING FLUORESCENT BALLASTS WITH AUTOMATIC CONTROL DEVICES

Energy-management lighting control systems are best applied using dimming ballasts. There are two primary ways to apply dimming ballasts connected to sensors, to manage energy. The easiest application is where a unit photosensor can directly drive several compatible ballasts. With simple low voltage wiring between sensor and luminaires, conventional line voltage switches control on/off operation and a cost-effective small system is created.

However, some facilities connect lighting control systems to a Building Automation System (BAS) so that managers can review and manage energy use. Until recently, systems using low voltage or digital photosensor controls driving compatible ballasts have been difficult to retrofit into an existing facility. Swapping ballasts and running low voltage control wire from each ballast to the controllers is expensive and usually only feasible in an easily accessible or open ceiling condition. However, new technology using wireless or power line carrier methods makes retrofitting control systems cost effective in many situations.

When choosing ballasts for energy management applications, consider the following points:

- DALI, DALI-like and other digital ballasts contain a computer chip, and each ballast has a unique identity. This permits individual control and monitoring through a digital control network.
- Four-wire (0-10 volt) ballasts are not individually addressable or separately controllable. They are controlled in “zones” using hard-wiring that cannot be changed without rewiring.
- Currently, 0-10 volt controls are the most common and generic. Compatible ballasts are made by most ballast companies.
- Digital controls are not as common, and are often sold in proprietary systems which include the ballasts.
- Digital ballasts can provide users with data for individual or groupings of luminaires that can be used to manage lamp maintenance and track energy use.
- Digital ballast systems allow flexible adaptation of lighting control zones to meet changing operational needs through simple reprogramming.
- Initial installation is less complicated for the electrician with a digital system, as controls are not wired to specific luminaires. However, identifying and programming the system involves effort and time after installation.
- Digital ballasts can save on the cost of wiring line voltage devices such as relays, motion sensors, and wall switches.

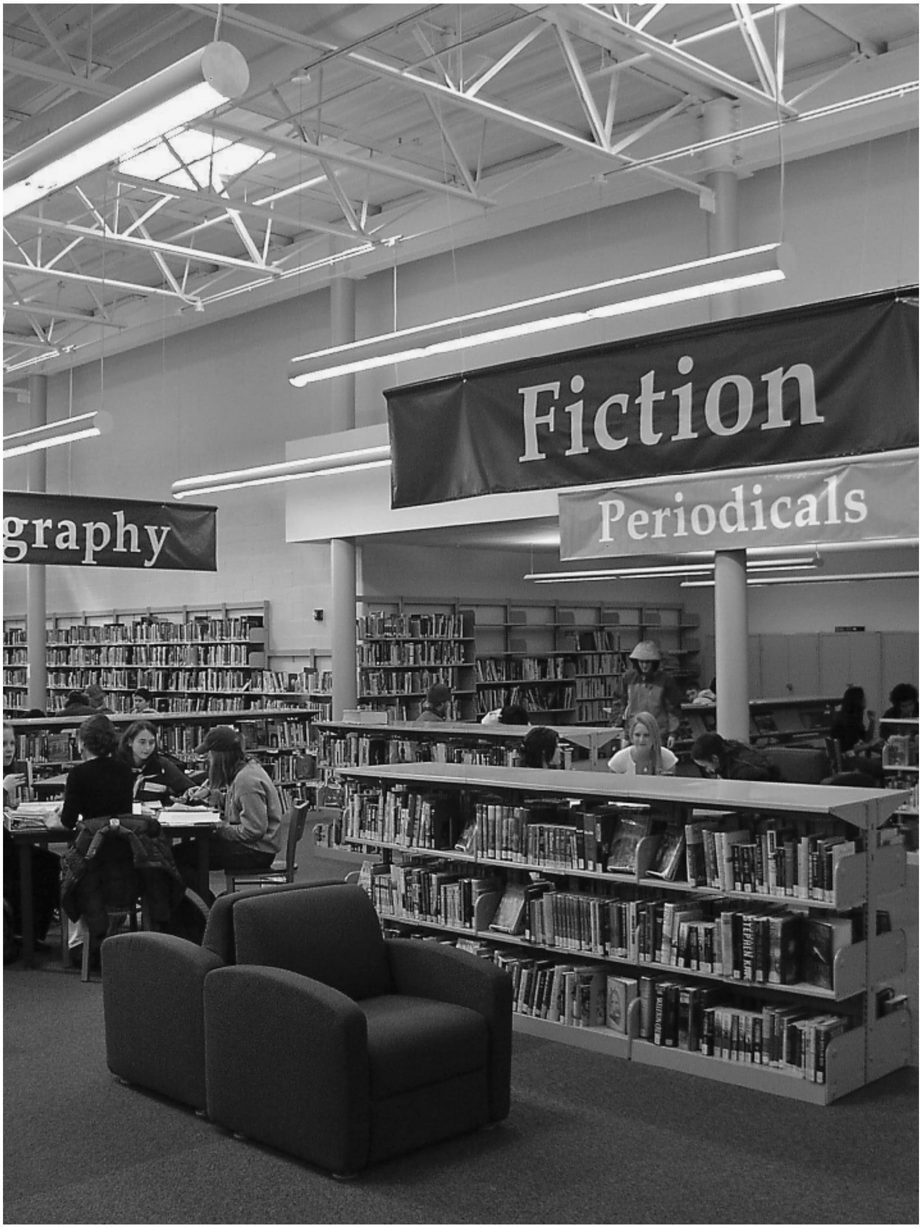

Figure 1-5 Dimming ballasts control lighting imperceptibly in skylit spaces.

- While digital ballasts are not necessarily more expensive, the systems may be more costly due to their proprietary nature. DALI, or Digital Addressable Lighting Interface, is a protocol for digital ballasts which is intended to standardize digital ballast systems. But in practice, systems using DALI concepts but with proprietary improvements offer the best performance.

Lighting control systems with controllable or dimming ballasts offer versatility and can be connected into integrated systems with many types of controllers and functions, including:

- Occupancy sensors
- Daylight harvesting controllers and photosensors
- Building management systems
- Manual dimmers

Building management systems are increasingly being used to communicate with electric utility demand reduction commands to reduce peak demand, a function called "Demand Response" or "DR." As utilities begin to charge electricity rates based on hourly time of day using "smart meters," lighting systems linked to load shedding will become a valuable tool for commercial customers. Reductions of 20 percent or more done at the time when kWh are most expensive will help pay for the higher initial cost of these systems.

Additional energy savings are available by using dimming ballasts for light tuning. Most lighting systems are slighting over-designed by rounding up the number of luminaires or lamps to the next whole number, or in some cases, to a number that results in an attractive layout. Using dimming ballasts, lighting systems can often be dimmed 10–20 percent and still provide the intended light level. These savings are direct and proportionate; 20 percent dimming equals a 20 percent reduction in energy use. Recent studies in California show that at the state's utility rates, tuning alone can justify the added cost of controllable systems and dimmable ballasts.

IMPROVING EXISTING FLUORESCENT LUMINAIRE PERFORMANCE

When an existing luminaire can be made more efficient through minor modifications, and this would involve less cost, time, and materials than replacing it with a new one, a good case can be made for component retrofit. The components that may be replaced to improve efficiency include:

- Older ballasts, sockets, and lamps as discussed in the previous section
- Diffusers which have become yellow or unrestorably dirty over time
- Reflectors that are insufficiently reflective or poorly designed to permit light to efficiently escape the luminaire
- Louvers or grid shields that do not allow light to efficiently pass through to the room

Retrofitting, rather than replacing fluorescent luminaires, has been a major component of energy retrofitting in the past two decades due to the earlier predominance of T-12 lamp and magnetic ballast technology. While replacing lamps and ballasts, it just made sense to replace inefficient diffusers and reflectors. This type of retrofit was also generally less invasive to the operations of a facility.

The availability and cost of replacement parts, as well as labor costs and how well the new parts fit the existing luminaires, are considerations that may tip the scales for or against component replacement. Energy service companies may have better negotiating leverage to purchase components, but often individual replacement parts such as special diffusers for older luminaires may be just as expensive as purchasing more common types of new luminaires. Many large luminaire manufacturers are not set up to sell parts. Specialty companies also produce retrofit components designed to fit in standard fixtures. These may be adequate in some cases, and not in others. The lighting engineer will also require some time to research the availability of parts. All of these costs must be weighed.

Also, many luminaires were designed with inexpensive components, especially fastening devices, which fail over time. Once this happens, it is often not worth trying to repair, as the repair may not add much more life to the luminaire. It is better, and perhaps not significantly more costly, to invest in new luminaires.

Linear Fluorescent Troffer Luminaires

The fluorescent "troffer" has been and continues to be the most common type of commercial lighting system due to their use in utilitarian applications and low budget installations. Troffers using a flat plastic "lens" or diffuser as the shielding and refracting medium were at one time the most common. Along the way, small-cell louver panels, sometimes called "egg-crate" or "paracube" louvers, were installed in place of the lens. While this removed the often objectionable glare that occurs when using prismatic fixtures in an otherwise dark ceiling, these smaller louvers resulted in very low luminaire efficiencies and dark walls. After 1980, larger celled "parabolic" louvered fixtures became increasingly popular. These could be much more efficient in their light output, but still tended to result in rooms with dark walls.

Troffer lighting systems often make excellent lighting retrofit opportunities. Without changing illumination levels, lighting power demand and energy can often be reduced up to 40 percent. With a reduction in light levels to current IESNA standards, power demand and energy savings can be up to 60 percent.

Luminaire efficiency for prismatic troffers varies by the depth of the luminaire box, the effectiveness of the reflector, the acrylic diffuser design, and, of course, the efficacy of the lamp and ballast. All of these factors except the depth reduce in efficiency with age, but can be improved with component replacement.

Improvements in parabolic louver designs allow luminaire efficiencies into the low 80 percent range. Shallower louver depth and wider spacing increases luminaire efficiency, but also increases glare potential. Highly specular parabolic louver finishes improve efficacy, but also increase glare and highlight fingerprints. Softer, more comfortable semi-specular surfaces provide improved comfort with reasonable efficiency. Highly specular troffer liners can provide increased luminaire efficacy with little or no additional glare.

Figure 1-6a Prismatic fluorescent troffer. *(Provided by Philips Lightolier.)*

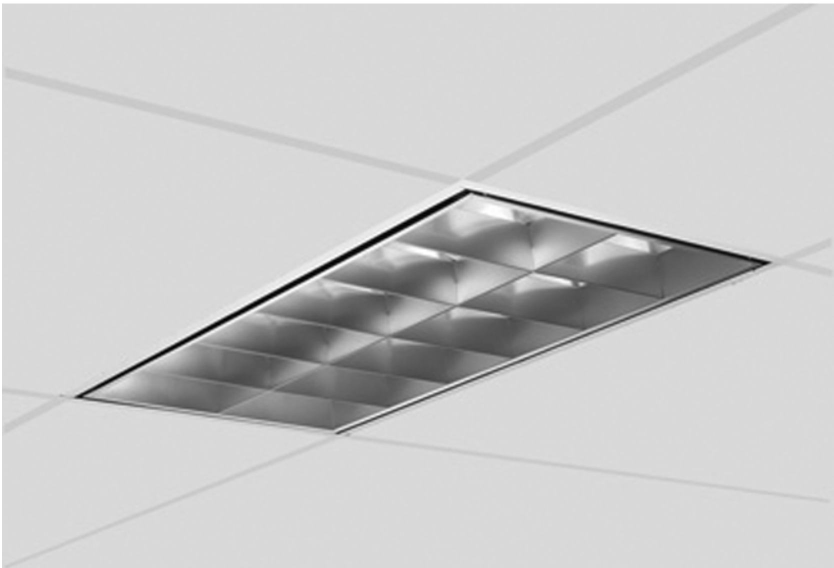

Figure 1-6b Parabolic fluorescent troffers are available with a range of cell configurations offering low angle glare control. *(Provided by Philips Lightolier.)*

It is useful to look at parabolic luminaire test data and photometry to determine the efficiency of parabolic luminaires. This information is provided by fluorescent luminaire manufacturers as part of its specification data.

Luminaire Efficiency: the ratio of lumenous flux (lumens) emitted by a luminaire to that emitted by the lamps used therein.[6] This data should always be provided by an independent testing agency.

LER or Luminaire Efficacy Ratio: the ratio of lumen output to the fixture wattage. This is different than luminaire efficiency, as it factors in energy use.

IW or Input Wattage: the total power requirement of the luminaire using the specified lamp and ballast. This can be changed by using a different lamp and/or ballast.

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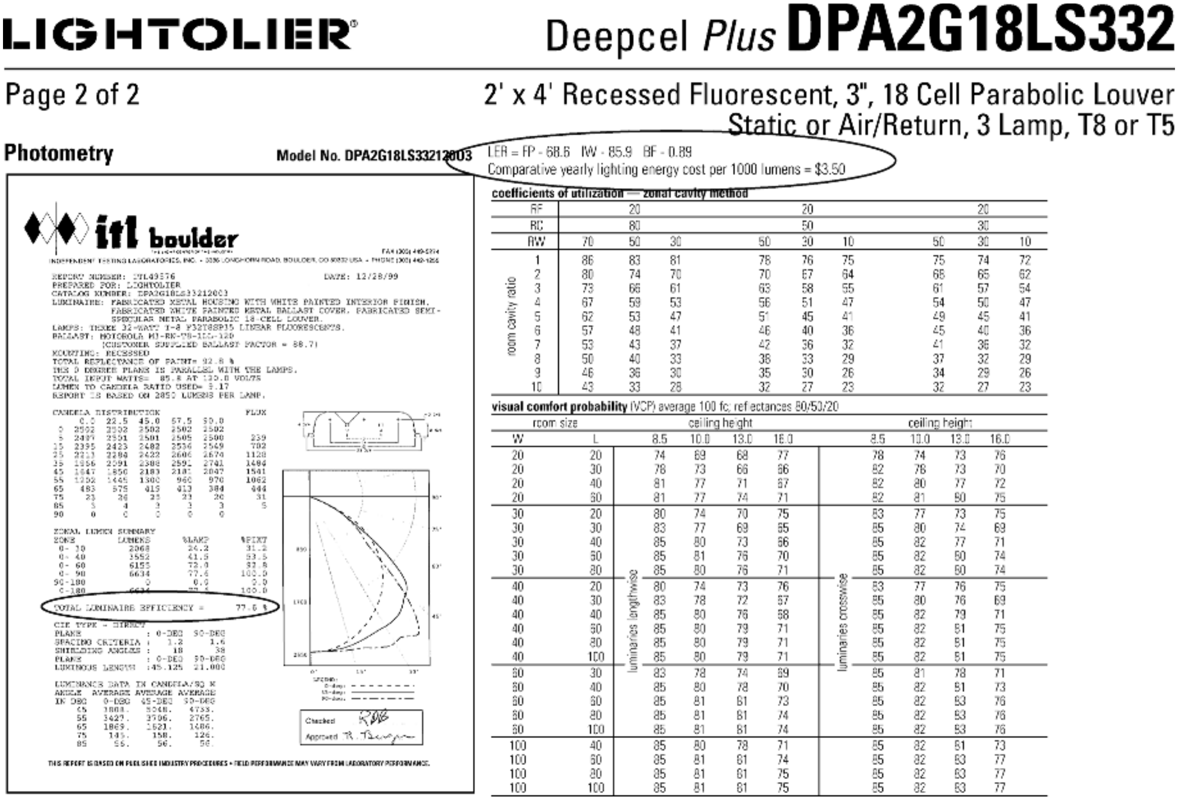
[6] Glossary of lighting terminology, *The IESNA Handbook*, 9th edition, copyright 2000. The Illuminating Engineering Society of North America, New York, NY.



LIGHTOLIER® Deepcel *Plus* **DPA2G18LS332**

Page 2 of 2

2' x 4' Recessed Fluorescent, 3", 18 Cell Parabolic Louver
Static or Air/Return, 3 Lamp, T8 or T5

Photometry

Model No. DPA2G18LS33212003

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REPORT NUMBER: ITL49576 DATE: 12/28/99
PREPARED FOR: LIGHTOLIER
CATALOG NUMBER: DPA2G18LS33212003
LUMINAIRE: FABRICATED METAL HOUSING WITH WHITE PAINTED INTERIOR FINISH. FABRICATED WHITE PAINTED METAL BALLAST COVER. FABRICATED SEMI-SPECULAR METAL PARABOLIC 18-CELL LOUVER.
LAMPS: THREE 32-WATT T-8 F32T8SP35 LINEAR FLUORESCENTS.
BALLAST: MOTOROLA M3-RN-T8-1LL-120
(CUSTOMER SUPPLIED BALLAST FACTOR = 88.7)
MOUNTING: RECESSED
TOTAL REFLECTANCE OF PAINT= 92.8 %
THE 0 DEGREE PLANE IS PARALLEL WITH THE LAMPS.
TOTAL INPUT WATTS= 85.8 AT 120.0 VOLTS
LUMEN TO CANDELA RATIO USED= 3.17
REPORT IS BASED ON 2850 LUMENS PER LAMP.

CANDELA DISTRIBUTION

	0.0	22.5	45.0	67.5	90.0	FLUX
0	2502	2502	2502	2502	2502	
5	2497	2501	2501	2505	2500	239
15	2395	2423	2482	2536	2549	702
25	2213	2284	2422	2606	2674	1128
35	1956	2091	2388	2591	2741	1484
45	1647	1850	2183	2181	2047	1541
55	1202	1445	1300	960	970	1062
65	483	575	415	413	384	444
75	23	26	25	23	20	31
85	5	4	3	3	3	5
90	0	0	0	0	0	

ZONAL LUMEN SUMMARY

ZONE	LUMENS	%LAMP	%FIXT
0- 30	2068	24.2	31.2
0- 40	3552	41.5	53.5
0- 60	6155	72.0	92.8
0- 90	6634	77.6	100.0
90-180	0	0.0	0.0
0-180	6634	77.6	100.0

TOTAL LUMINAIRE EFFICIENCY = 77.6 %

CIE TYPE - DIRECT

PLANE	: 0-DEG	90-DEG
SPACING CRITERIA	: 1.2	1.6
SHIELDING ANGLES	: 18	38
PLANE	: 0-DEG	90-DEG
LUMINOUS LENGTH	:45.125	21.000

LUMINANCE DATA IN CANDELA/SQ M

ANGLE IN DEG	AVERAGE 0-DEG	AVERAGE 45-DEG	AVERAGE 90-DEG
45	3808.	5048.	4733.
55	3427.	3706.	2765.
65	1869.	1621.	1486.
75	145.	158.	126.
85	56.	56.	56.

THIS REPORT IS BASED ON PUBLISHED INDUSTRY PROCEDURES • FIELD PERFORMANCE MAY VARY FROM LABORATORY PERFORMANCE.

LER = FP - 68.6 IW - 85.9 BF - 0.89
Comparative yearly lighting energy cost per 1000 lumens = $3.50

coefficients of utilization — zonal cavity method

RF	20			20			20		
RC	80			50			30		
RW	70	50	30	50	30	10	50	30	10
room cavity ratio 1	86	83	81	78	76	75	75	74	72
2	80	74	70	70	67	64	68	65	62
3	73	66	61	63	58	55	61	57	54
4	67	59	53	56	51	47	54	50	47
5	62	53	47	51	45	41	49	45	41
6	57	48	41	46	40	36	45	40	36
7	53	43	37	42	36	32	41	36	32
8	50	40	33	38	33	29	37	32	29
9	46	36	30	35	30	26	34	29	26
10	43	33	28	32	27	23	32	27	23

visual comfort probability (VCP) average 100 fc; reflectances 80/50/20

room size W	room size L	luminaries lengthwise, ceiling height 8.5	10.0	13.0	16.0	luminaries crosswise, ceiling height 8.5	10.0	13.0	16.0
20	20	74	69	68	77	78	74	73	76
20	30	78	73	66	66	82	78	73	70
20	40	81	77	71	67	82	80	77	72
20	60	81	77	74	71	82	81	80	75
30	20	80	74	70	75	83	77	73	75
30	30	83	77	69	65	85	80	74	69
30	40	85	80	73	66	85	82	77	71
30	60	85	81	76	70	85	82	80	74
30	80	85	80	76	71	85	82	80	74
40	20	80	74	73	76	83	77	76	75
40	30	83	78	72	67	85	80	76	69
40	40	85	80	76	68	85	82	79	71
40	60	85	80	79	71	85	82	81	75
40	80	85	80	79	71	85	82	81	75
40	100	85	80	79	71	85	82	81	75
60	30	83	78	74	69	85	81	78	71
60	40	85	80	78	70	85	82	81	73
60	60	85	81	81	73	85	82	83	76
60	80	85	81	81	74	85	82	83	76
60	100	85	81	81	74	85	82	83	76
100	40	85	80	78	71	85	82	81	73
100	60	85	81	81	74	85	82	83	77
100	80	85	81	81	75	85	82	83	77
100	100	85	81	81	75	85	82	83	77

Figure 1-7 Associated test data and photometry for 18-cell parabolic luminaire. *(Provided by Philips Lightolier.)*

BF or Ballast Factor: the fractional flux (lumen output) of a fluorescent lamp when operated on the specified ballast as compared with a reference ballast. The lower the ballast factor of the ballast, the lower the lumen output.

Comparative yearly lighting energy cost per 1,000 lumens: A common metric used to relate luminaire efficiency to operating cost.

LAMP/BALLAST REPLACEMENT OPTIONS

Lamps and Ballasts. Most currently installed troffers were designed for either F40T12 or F32T8 fluorescent lamps. Standard sizes include 2′ by 4′ and 1′ by 4′, with narrower 4′ long options in 6″ to 20″. Some 5′ long units have been manufactured to utilize less common F60T12 and F40T8 fluorescent lamps.

2′ by 2′ troffers were designed either for FB40T12 or FB32T8 U-lamps or F20T12 or F17T8 24″ nominal length straight lamps. High output T-12 or T-8 lamps are not common in troffers.

Other lamp types that may be encountered in troffers include single-pin slimline lamps in either T-12 or T-8 lamp diameter. Slimline lamps have higher efficacy than standard T-12 lamps, but a shorter lamp life.

Ballasts are located in compartments, generally accessible from the interior of the luminaire by removing the lens or louver and the ballast enclosure. However, some products may have outboard ballast compartments on one side to make for a shallower troffer. Fixtures originally installed prior to the late 1980s (prior to 1982 in California) may be assumed to have inefficient magnetic ballasts installed as original equipment. Some magnetic ballasts have remained on the market in lower-cost troffers sold to the general nonspecification market, and will not be eliminated as replacement products until 2011.

Troffers employing either T-12 or T-8 bi-pin lamps have direct T-8 substitutes that will fit the existing sockets (also called "tombstones"). Sockets should be replaced if they need to be relocated, which occurs when fewer lamps are used, or if they appear cracked or otherwise broken. Also, when the ballast starting method changes, the sockets must be changed as well. Instant start sockets are not the same as similar-appearing rapid start, programmed rapid start, and dimming T-8 ballasts, and replacing the socket protects the ballast and lamp from failures that will occur when lamps, sockets, and ballasts are incorrectly paired.

When converting from T-12 to T-8 lamps, conversion to electronic ballasts is standard procedure. Most fluorescent magnetic ballasts will no longer be available after 2011 as per federal legislation and regulations. See Tables 1-2 through 1-7 for common 4′ lamp conversions and respective energy and cost savings for various high efficiency ballast options. The number of lamps operated per ballast can be maximized to reduce the cost of reballasting. Lighting controls are also a factor in the type, number, and location of replacement ballasts. Control options for linear fluorescent fixtures include:

- Bi-level switching. Using two ballasts per luminaire for bi-level switching allows two or three light level options to meet energy code requirements. With tandem wiring, two ballasts operate at least one lamp in each of two separate fixtures. The cost of labor to accomplish either of these options is a factor in retrofit applications. Inaccessible wiring in ceilings or walls can make this retrofit option impractical.
- Daylight controls. When using switching to accomplish daylight lumen reduction, some people prefer to keep some lamps on. This can be accomplished with a special multi-level ballast and a toggle switch.
- Always consult with the ballast manufacturer for compatible switch requirements, as recommendations differ.
- Occupancy sensors. A minimum level of lighting is required in paths of egress when lights are diminished through occupancy sensors. To keep one lamp turned on in some luminaires, an additional emergency ballast may be included. A less costly installation method is to keep occupancy sensors separate from egress luminaires.

TABLE 1-10 CONVERTING U-BENT LAMP SYSTEMS

Note: Only for converting 6″ leg spacing lamps. Similar results may not be possible with other leg spacing lamps.

Retrofit for U-Bent T-12 Existing Lighting System									
	Lamp Type	**# of Lamps**	**Ballast Type**	**System Watts**	**Lamp Life**	**Mean Lamp Lumens**	**Annual Energy Savings compared to T-12**	**Annual Energy Savings compared to T-8**	**Annual Energy Cost**
Current Lighting System	F34T12/U	2	Standard magnetic	80	18,000	3,654			$28.80
			Energy Saving Magnetic	72	18,000	3,654	$2.88		$25.92
	F32T8/U/7xx	2	First generation electronic	61	15,000	4,054	$6.84		$21.96
Energy Savings Option, lamp and ballast replaced	Standard T-8 U-Bent 6″ (32 w)	2	High efficiency, extra low ballast factor program start, BF 0.60	45	24,000	3,042	$12.60	$9.36	$16.60
Energy Savings Option, lamp and ballast replaced	Energy Saving T-8 U-Bent 6″ (25 w)	2	High Efficiency T-8 Instant Start, BF 0.77	39	18,000	3,728	$14.76	$7.20	$14.04
Energy Savings Option, reconfigure fixture to use (3) 2′ T-8 lamps	Standard 17 w T-8 Lamps	3	Electronic T-8 Programmed Start, BF 0.88	50	24,000	3,654	$10.80	$11.16	$18.00
Energy Savings Option, reconfigure fixture to use (2) 2′ T-8 lamps	Standard 17 wT-8 Lamps	3	Electronic T-8 Programmed Start, BF 1.18	47	24,000	3,612	$11.88	$10.08	$16.92

Mean system lumens is based on mean lamp lumens modified by ballast factor and ballast efficiency. Luminaire test data are required to determine actual lumen output.

System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use instant-start ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

The use of this data and format are courtesy of GE Consumer and Industrial Lighting.

2 by 2 Troffers with U-Bent Lamps

U-bent T-12 lamps are now easily converted to U-bent T-8 lamps, which are available in both 32- and 25-watt high efficiency versions. Often, converting from a U-bent lamp to straight FO17T8 lamps makes sense, as the U-bent lamps are both expensive and take considerable storage room. Kits that include the new sockets, ballast covers, and wireways are available with or without a reflector. Note that it is often cost effective to retrofit T-8 U-bent systems with modern lamps and ballasts.

The table above provides guidelines for options and energy savings for 2 by 2 troffers.

Linear Fluorescent Retrofit to LED

LED lamp retrofits, replacing fluorescent lamps in existing luminaires, are beginning to hit the market. As of this writing, such retrofits are not recommended, as the lumen output of the LED does not usually equal that of fluorescent lamps. This will probably change over time, so awareness of evolving LED technology is strongly recommended.

The following case study by James Brodrick of the U.S. Department of Energy Building Technology Program is very helpful in putting a current perspective on an application of LED as a replacement to linear fluorescent lamps.

CASE STUDY

U.S. DEPARTMENT OF ENERGY BUILDING TECHNOLOGY PROGRAM CASE STUDY

At the headquarters of the U.S. Department of Labor (DOL) in Washington, D.C., many energy saving improvements have already been made to the Energy Star–rated, 2 million-sq-ft facility. In this building, after HVAC, lighting is believed to be one of the few areas still offering energy saving potential, so DOL considered replacing linear fluorescent lamps with LED luminaires. The building's primary luminaire is a recessed 1-ft by 4-ft parabolic louver troffer containing two T-8 fluorescent lamps.

The LED product under consideration was installed in a single DOL conference room. Lighting levels in the room averaged 96 foot-candles on the work plane with a 61 watt, two fluorescent lamp luminaire, and 50 foot-candles with a 40 watt, single fluorescent lamp. By contrast, the room averaged 63 foot-candles at 29 watts with two LED replacement lamps per fixture, and 34 foot-candles at 14 watts with one LED replacement lamp.

Subjective evaluation of the LED lighting was favorable: the color temperature of both the fluorescent and LEDs was the same (4100K); the color rendering of the LED appeared good; and the distribution was the same.

However, the LED lamp could not be used in-line with the existing ballast, which would have to be disconnected, adding labor cost. In addition, the existing workspace was overlighted with two fluorescent lamps—a common condition. Disconnecting the ballast to switch to LED lamps costs roughly the same as replacing the ballast with one designed for a single fluorescent lamp, and would save as much energy.

Conclusion: Switching to LEDs did not make sense at DOL headquarters. LED replacement lamps cost between $40 and $150 each, compared with just $1.50 to $5 for a fluorescent lamp, and with comparable lifetimes (24,000 to 46,000 hours for fluorescent versus a projected 50,000 hours for LED).

The author of this case study, James Brodrick, is the lighting program manager for the U.S. Department of Energy, Building Technologies Program. The Department's national strategy to guide high-efficiency, high performance solid state lighting products from laboratory to market draws on key partnerships with the lighting industry, research community, standards organizations, energy efficiency programs, utilities , and many other voices for efficiency.

Delamping

Many of the most effective retrofit programs involve some form of delamping to reduce energy consumption. This is relevant today as older lighting systems are overdesigned in comparison to modern standards. For example, a popular office lighting layout from the 1980s employed three and four-lamp F34T12 lensed troffers on 8′ by 8′ spacing. Using conventional cool white energy-saving lamps and magnetic energy-saving ballasts, this system produced at least 85 initial foot-candles, average, in the average private office and over 100 initial foot-candles in an open office area at 1.68 to 2.25 watts per square foot. This compares with current lighting technology and design potential for open office areas at less than 50 foot-candles and 0.8 watts per square foot.

A significant part of the opportunity for energy savings includes reducing light levels to current norms by delamping. In today's electronic office, general (ambient) light levels can be dropped to 30 footcandles as long as task lighting is offered to individuals who require additional illuminance. Consider the age of workers when reducing light levels. Many older individuals feel more comfortable in a brighter environment, which is also a function of the reflectivity of floors, walls, ceilings, and furnishings. Reducing the ambient light level to currently accepted standards while using lighter color wall and floor finishes and clearly marked floor level changes will contribute to greater efficiency and may result in improved safety and comfort.

The following table and illustrations offer comparisons for four types of fluorescent office lighting systems for individual offices at both 30 and 50 footcandles. In such spaces with windows, lower illuminance levels are well accepted by most employees, and preferred by many.

High Efficiency Reflectors with Delamping

A widely adopted retrofit product is the high efficiency reflector. The installation provides a new internal reflecting surface for the luminaire. Although some of the advertising for these products may be technically misleading, retrofit reflecting surfaces

All comparisons are based on a 12′ x 14′ x 9.5′H room with 80/50/20 surface reflectance and 0.9 LLF.
LPD results will vary depending on the size of the room and room reflectances.

Fixture Type	Number of Lamps	Total Lamp Lumens per Fixture	Luminaire Wattage (watts)	Luminaire Efficiency (%)	Average Illuminance (fc)	Number of Luminaires	Lighting Power Density (w/sf)	Percentage of Code-Allowed Energy Use (1.1 w/sf)	Annual Energy Cost for Lighting (2500 hrs, $0.10/kwh)
Prismatic 2x4 Troffer (CU = 0.493)	2 T-8	5,600	59	79.4	59	4	1.4	127	$59.00
Prismatic 2x4 Troffer (CU = 0.493)	2 T-8	5,600	59	79.4	30	2	0.7	64	$29.50
18 cell 2x4 Parabolic Troffer (CU = 0.505) (see note)	3 T-8	8,550	96	77.6	46	2	1.14	104	$48.00
12 cell 2x4 Parabolic Troffer (CU = 0.503) (see note)	2 T-8	5,700	62	80.0	31	2	0.73	66	$31.00
High Efficiency 2x4 Direct/Indirect Troffer w/ Prismatic Lens (CU = 0.526)	1 T5HO	4,400	62	87.2	47	4	1.49	135	$62.00
High Efficiency 2x4 Direct/Indirect Troffer w/ Prismatic Lens (CU = 0.526)	1 T5HO	4,400	62	87.2	30	2	0.75	68	$31.00
Direct/Indirect Linear Pendant (CU=0.340) with 90% reflective ceiling	2 T-8	5,800	66	78.6	50	4	1.58	144	$66.00
Direct/Indirect Linear Pendant (CU=0.340) with 90% reflective ceiling	2 T-8	5,800	66	78.6	38	3	1.18	107	$49.50

Note: When reducing fixture quantities to reduce LPD, select luminaire types such as prismatic, direct/indirect, or linear pendants that provide illuminance high on adjacent walls. Locate fixtures so that the highest illuminance is at the task area. Use caution with parabolic fixtures, as placing them more than 3′ from walls can result in a dark and gloomy room appearance.

Figure 1-8a Small office fluorescent lighting alternates comparison.

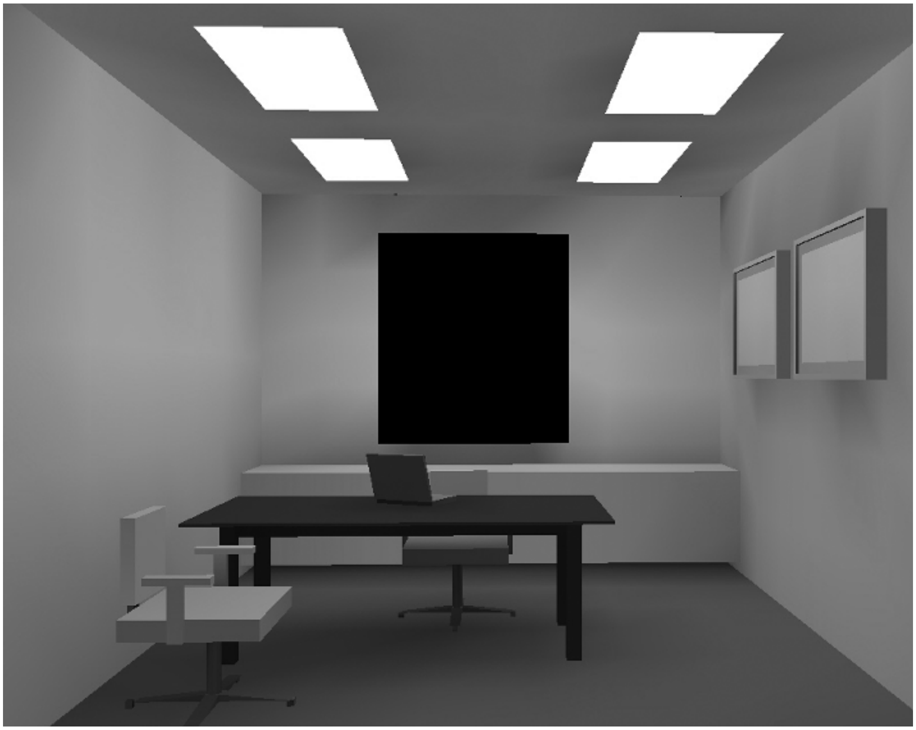

Figure 1-8b Small office 50-foot-candle ambient lighting.

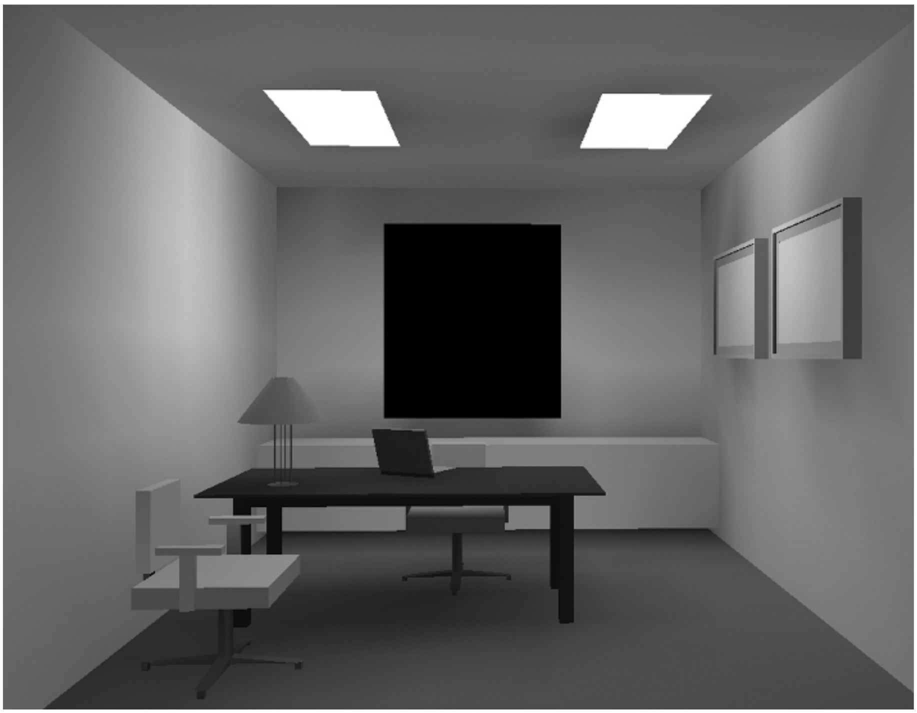

Figure 1-8c Small office 30-foot-candle ambient lighting.

can be effective when combined with a power reduction strategy such as delamping and/or T-8 lamp and high-performance electronic ballast conversion. There are three primary retrofit reflector types:

- Specular (shiny) high-purity aluminum, having a total reflectivity of 84 to 92 percent, and formed into an imaging faceted reflecting surface
- Enhanced specular mirror finish on a substrate, having a total reflectivity of 95 percent, also formed into an imaging faceted reflecting surface
- White polyester powder coat paint on steel or aluminum, having a total reflectivity of about 90 percent, formed into a simple semi-diffuse reflecting surface

Specular imaging reflectors are designed to reflect mirror images of the lamp's sides directly onto the lens, thereby increasing the luminaire efficiency. In deep fixtures (aperture to reflecting surface 4" or greater) significant efficiency benefits are achieved through the use of imaging reflectors regardless of the condition of the original reflecting surface. In shallow fixtures, especially with well-maintained or new white-painted reflecting surfaces, the benefits of imaging are less dramatic.

The enhanced specular mirror finish produced and popularized by a single manufacturer has gained the majority of the reflector market with its cost competitiveness, high performance, and excellent warranty.

Specular imaging reflectors are best used to improve light output in deep prismatic troffers, or in conjunction with deep parabolic louvered fixtures that shield the specular lining from view at normal viewing angles. White polyester powder-coat reflectors may be used where a shallow louvered luminaire has an aged or deteriorated reflector surface, and a direct view of the reflector would cause discomfort glare.

The following table provides estimates of luminaire efficiency with reflector upgrades.

TABLE 1-11 REFLECTOR RETROFIT IMPROVEMENTS

Type of Luminaire	Standard Efficiency	Efficiency with Best Reflector Upgrade	CU at RCR 2.5, 50/30/20 Reflectances	CU with Best Efficiency Upgrade
Strip Light	92%	92%	65%	70%
Industrial	90%	92%	68%	74%
Wraparound	68%	74%	48%	54%
Supermarket Trough	88%	91%	68%	72%
Washdown / Watertight	66%	72%	50%	54%
Recessed Troffer	68%	76%	55%	64%

High efficiency reflectors can be purchased as standard items, although a standard reflector may not fit or provide as great an improvement in luminaire output as desired. Luminaires that do not have vertical sides may also be difficult to fit. Specialty manufacturers provide both standard and custom made reflectors at prices under $20 per unit.[7]

UL rated retrofit kits are available including all the components for a troffer retrofit, including new reflector, ballasts and sockets, as well as louvers or lenses. These are designed to simplify the process and make retrofit more attractive to building managers as well as electrical contractors.

In this type of retrofit, the "guts" of the luminaire are entirely replaced. Leaving the original box in place, the lens, door, socket bridges and ballast channel(s) are removed, leaving nothing more than the incoming wiring. Then, the retrofitter installs a kit that contains all the required parts, prewired and fitted to match the existing box. Currently, the most popular kit converts the luminaire to the latest high efficiency "volumetric" style with either T-5 or T-8 lamps.

There are many advantages to this process. The resulting installation is essentially "renewed" in appearance as well as more efficient. Labor is the same or less than a part-by-part replacement, and the new installation has the benefit of new sockets, new wires and a clean, high performance reflector. Hidden benefits include a UL listing and not having to move the existing housing, thus avoiding problems such as existing seismic hangers or asbestos above the ceiling.

Replacement of Shielding Media

Lenses or louvers that appear brown, yellow, or dingy need to be replaced. This discoloration is a sign of UV degradation and/or age, and reveals a surface whose efficiency has fallen by 30 to 60 percent. Any lens over 10 years old should also be replaced if light depreciation is a concern. Although not apparent, the transmitting efficiency may also have degraded by as much as 15 percent. A new pattern 12 acrylic prismatic lenses is generally adequate. Special prismatic lenses can also be used with various results. However, many of the special lenses and louvers were developed during the era of the cathode ray tube (CRT) computer display and don't really have as much of a purpose in the age of the flat screen.

Nonstandard Size Troffers

Retrofit solutions for uncommon size troffers may yield energy savings if common size lamps and ballasts can be used. Less common lamp and ballast sizes are normally not available with high performance options. However, reflector and lens/louver replacements are possible with some customization.

[7] M. Kiley, Kiley and Company, Peacham, VT.

Figure 1-9a

Figure 1-9b

Figure 1-9c

Figure 1-9d

Figure 1-9e

Figure 1-9f

Figure 1-9a–f Retrofit kits are designed to reduce purchase hassles and save installation time. This series shows basic steps in the installation of a two-lamp parabolic kit. *(Provided by Philips Lightolier.)*

Figure 1-10 Use partition-mounted luminaires with white, reflective ceilings to provide soft indirect lighting without high installation costs. *(Copyright the Lighting Quotient)*

As lamp and ballast manufacturers discontinue products, as happens frequently to cut down on stocking costs, a facility owner may need to upgrade the luminaire as well as the ceiling system. In such situations, it is worth considering luminaires which mount to furnishing systems rather than to the ceiling. Although partition-mounted luminaires tend to be expensive, such systems can be very cost effective when changes to the ceiling system are prohibitive.

Luminaire Replacement

One frequently encountered problem with retrofitting older luminaires of all types is that hardware and fasteners wear out and replacing them becomes difficult. Lower quality luminaires most often fail not electrically, but mechanically. When repairs no longer suffice, it frees the owner to consider replacement with new luminaires.

Upgrading to a luminaire with higher luminaire efficiency rather than whatever the supplier has on his shelf often makes good economic sense. The increased incremental cost is minimal when the cost of labor is a wash.

Replacement of standard-size luminaires in standard types of grid ceilings is easy, and labor costs would be less than a new installation if current electrical circuits are reused. Recessed troffers may also be replaced in sheet rock ceilings when the new luminaire fits the existing supporting trim.

A more costly situation is encountered when an existing fixture of an unusual size or shape needs to be replaced, or an inefficient design layout must be reconfigured. Additional costs include:

- Costs for rewiring
- Cost for replacing ceiling tiles
- Patching and repainting an existing sheet rock ceiling

Replacement of existing luminaires, in the majority of cases, is a decision predetermined by the project owner or manager. The decision is often based on a desire to upgrade the facility. Lighting is an obvious aesthetic improvement that also provides a return on investment, a claim that few other improvements can make. The lighting engineer can best assist by helping select replacement luminaires that achieve both aesthetic and efficiency goals, and establish the budget needed to properly complete the project.

CASE STUDY

TOWN HALL CASE STUDY

A typical case-in-point is a town hall, where continuous rows of deep parabolic, 6″ wide recessed single-lamp T-12 luminaires were in need of an upgrade. T-12 lamps could have been easily retrofitted with high performance T-8 lamps and ballasts. However, the hardware, which had been failing when the last lamp replacement was done four years earlier, was supplemented with screws and tape. Rather than invest further in a lamp/ballast retrofit, a decision was made to replace the luminaires.

Replacement with a more efficient recessed luminaire was complicated by the sheet rock ceiling, which was in excellent condition. In a 2 by 2 or 2 by 4 acoustic drop ceiling, such a replacement would be easy and relatively inexpensive. Replacement in a sheet rock ceiling with an updated version of the same luminaire was possible, but illuminance and efficiency improvement was limited.

The electrician suggested using a surface-mounted fixture to keep installation costs down. Knowing that few surface-mounted luminaires would provide the glare control of the current recessed units, the lighting designer specified an attractive, reasonably priced, low-glare surface luminaire. Glare control was especially important with the low 8′ ceiling height. Using two lamp, 4′ long surface luminaires with a 15 percent higher fixture efficiency than the old system, 46 percent fewer fixtures were required. Careful placement of these luminaires over fixed workstations allowed improved task illuminance, and a small increase in overall illuminance. Projected annual energy savings of 3,800 kwh and annual electricity cost savings of $500 were mostly offset by installation of a large, new laser print and copy machine. The office staff, however, continues to enjoy their cheerful, new work environment accomplished with only a lighting upgrade.

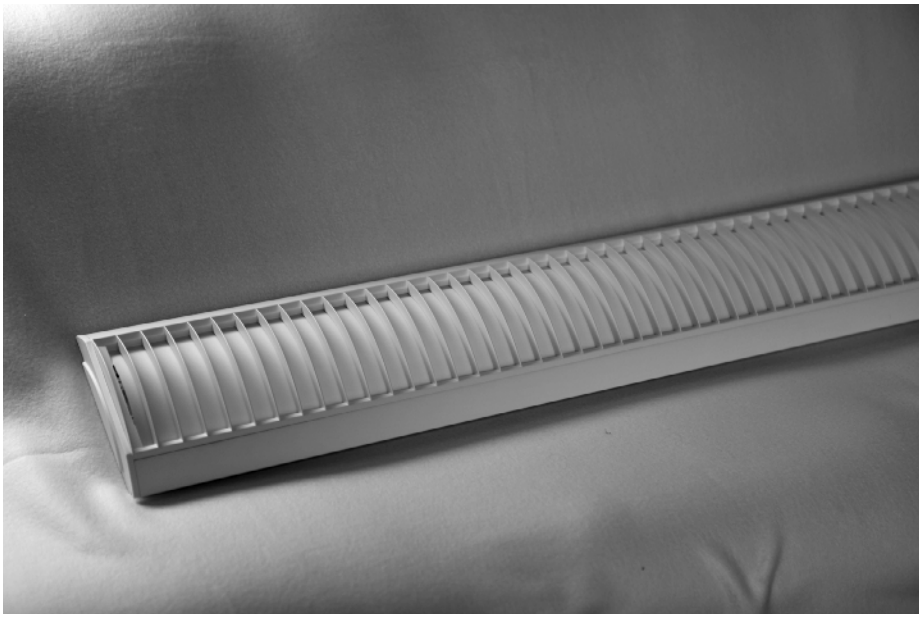

Figure 1-11 Attractive fluorescent surface luminaire with external glare control louvers.

HIGH PERFORMANCE REPLACEMENT LUMINAIRES

An important development in recent years has been the high performance, multilensed recessed luminaire which suggest the aesthetic appeal and wide light distribution of indirect luminaires, with the efficiency of prismatic lensed fixtures. These are sometimes referred to as "volumetric" lighting, or volumetric high performance (VHP) luminaires. The luminaire efficiency of many of these products is over 85 percent, and there are many similarities between products. Provided with T-5 or T5HO lamp and ballast technology, these fixtures have broken through price barriers largely because customers prefer their appearance, their long life, and energy benefits. A few good sales reps heavily promoting the products don't hurt sales either.

Another type of fluorescent luminaire that has gained popularity for high-end offices and anywhere an updated look and softer indirect lighting is desired is the recessed direct/indirect luminaire. While highly desired from an aesthetic viewpoint, these luminaires often lack the high performance energy efficiency of the VHP luminaires previously discussed. Whether higher efficiency or aesthetics rules the decision needs to be decided on a case-by-case basis. This case study presents such a comparison, that was aided by the ability to see samples of each luminaire, onsite and in person.

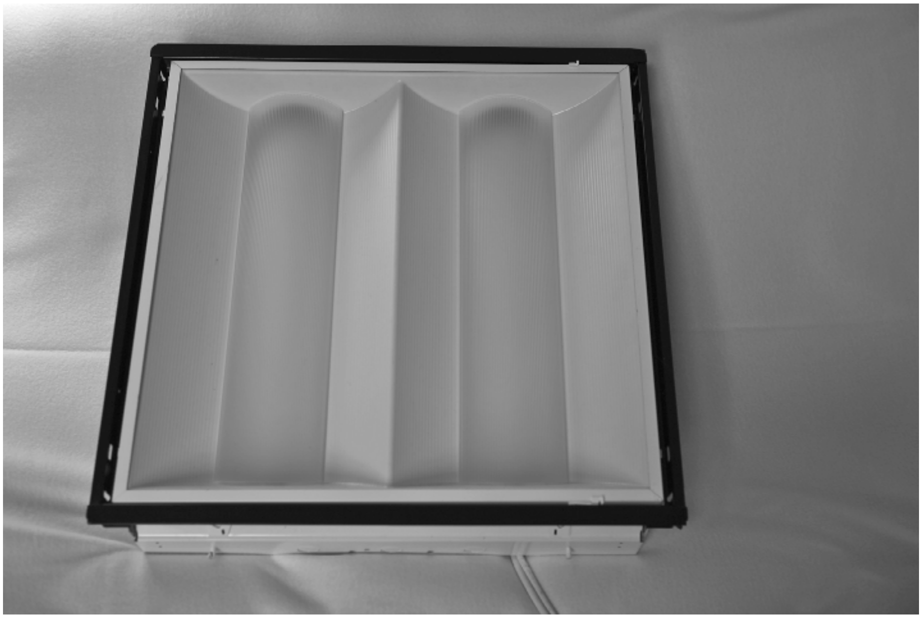

Figure 1-12 High performance volumetric replacement luminaires fit easily into existing recessed applications.

CASE STUDY

CREDIT UNION CASE STUDY

A relatively new three-story building housing a credit union sought to retrofit or replace most of its 2′ by 2′ fluorescent luminaires, each with three 32-watt U-bent 1 5/8″ lamps in a nine-cell parabolic luminaire. Each 10′ by 12′ office included four of these fixtures, yielding a lighting power density of 2.02 watts per square foot and average illuminance levels of 65 to 75 foot-candles. Management and employees agreed that the existing lighting was too "bright" and that energy costs were too high. For minimal disruption of operations, the solution had to either retrofit or replace all four fixtures in each office in their current locations. While retrofitting lamps and ballasts was not ruled out, there was a desire to replace parabolic troffers, which were seen as providing too high a light intensity (even though most areas were bi-level switched), and too much contrast on walls. A side-by-side comparison of four direct/indirect recessed 2 by 2 luminaires with three VHP luminaires, conducted onsite, provided not only a good opportunity to compare energy savings, but a great chance to see which fixtures were preferred from a visual standpoint.

Most of the direct/indirect recessed luminaires resembled small skylights with an acrylic lined metal perforated shielding over the center-mounted lamps. The most efficient of the direct/indirects had over 85 percent luminaire efficiency with only acrylic shielding of the lamps. Those with acrylic and perforated metal shielding had lower luminaire efficiency of around 74 percent.

The volumetric luminaires resembled a more sculptured approach to a prismatic troffer with a nod to aesthetics of the direct/indirect luminaires. A white reflector surrounds each of the curved acrylic diffusers, and each diffuser contains a single T-5 (or T-8 in some cases) lamp. The efficiency of all of these was above 80 percent, with one at 86 percent. The most efficient option was also available as a retrofit insert for existing 2 by 2 housings.

A variation on the VHP type used glass with a holographic laminate rather than acrylic, which expressed much less surface brightness.

Most people clearly preferred the softer look of the recessed direct/indirect or the holographic VHP. It was clear that the brightness of the acrylic diffuser, even though recessed, presented a “busy” appearance, particularly in open office spaces with an irregular luminaire configuration. However, the high performance luminaire was seen as a good choice in smaller private offices, where the luminaire surface brightness was not as objectionable.

Only 2 by 2 luminaires in offices were being replaced in the initial retrofit. Using T-5 lamps in a retrofit would force maintenance to stock new lamp types. This needed to be considered.

Both the T-5 and T-8 considerations offered bi-level ballasts as options. This was important since the offices were already switched for bi-level controls. Other luminaires could be ordered with tandem wiring to achieve the same control if there was an even number of luminaires in the room.

In the end, the lower cost VHP T-8 option with a single bi-level ballast was chosen for the small offices.

Table 1-12 is a schedule of the luminaire options considered. An energy savings comparison to the existing system is shown in Table 1-13. The numbers are based on a one-room comparison.

TABLE 1-12 PROJECT: CREDIT UNION DEMO PROJECT LIGHTING FIXTURE OPTIONS SCHEDULE

Project: Credit Union Demo Project		Lighting Fixture Options Schedule						
Option Type	**Description**	**Lamp**	**# of Lamps**	**Ballast or Transformer**	**Fixture Watts**	**Horizontal Avg fc w/ 4 fixtures**	**LPD w/sf**	**Remarks**
Existing								
EXG	Specular parabolic 2 × 2, (3)T-8 bent tube, w/ (2) ballasts	FB31T8/835 (U-bent 1/5/8” spacing)	3	Dual electronic ballast for bi-level switching BF 0.78	74	82	2.08	Complaints of glare and high energy use, bi-level switching not widely utilized

(*continued*)

TABLE 1-12 (*Continued*)

Project: Credit Union Demo Project		Lighting Fixture Options Schedule						
Option Type	**Description**	**Lamp**	**# of Lamps**	**Ballast or Transformer**	**Fixture Watts**	**Horizontal Avg fc w/ 4 fixtures**	**LPD w/sf**	**Remarks**
Direct/Indirect Distribution Recessed								
A	Mfr A - Direct/ Indirect 2 × 2 with perforated metal shield	F17T8/835	2	Bi-level electronic ballast BF 1.0	33	31	0.94	74.6% fixture efficiency, 5″ fixture depth, T-8 lamp options
B	Mfr D - Deeply recessed direct/ indirect 2 × 2 w/ frosted lamp shield	F17T8/835	2	Tandem wired programmed start for bi-level switching BF 0.88	31	30	0.88	74.6% fixture efficiency, 6″ fixture depth, T-8 and TT5 options
C	Mfr A - Direct/ Indirect 2 × 2 with acrylic shield	F14T5/835	2	Tandem wired programmed start for bi-level switching BF 1.06	35	35	1	85.3% fixture efficiency, 5 1/2″ fixture depth, T-5, T5HO, or TT5 options
Direct Distribution Designed to Simulate Indirect								
D	Mfr B - Recessed direct 2 × 2 w/ holographic film diffuser, looks like direct/indirect	F17T8/835	2	Tandem wired programmed start for bi-level switching BF 0.88	31	32	0.88	79% fixture efficiency, 4 3/8″ fixture depth, T-5, T5HO, or TT5 options
E	Mfr C - Recessed direct prismatic 2 × 2, looks like direct/indirect	F17T8/835	2	Tandem wired programmed start for bi-level switching BF 0.88	31	31	0.88	74% fixture efficiency, 4 1/4″ fixture depth, T-5, T-8, and TT5 options
Direct Distribution VHP								
F	Mfr E - High Efficiency Direct 2 × 2 w/ dual prismatic (volumetric) diffusers	F14T5/835	2	Bi-level electronic ballast BF 1.0	33	35	1	86% fixture efficiency, 3 1/8″ fixture depth, T-5 and T5HO only
Bi-Level Occupancy Control								
Type	Description		Adjustment			Finish		Remarks
OS-1	IR dual-circuit wall box sensor		Auto on one circuit, 2nd circuit manual on, both auto off			White		Ensure clear visual access to all occupied areas of the room

TABLE 1-13 ENERGY SAVINGS COMPARISON FOR CREDIT UNION DEMO OFFICE

Building Lighting Power Density–ASHRAE 90.5-2001 Guideline for enclosed offices 1.3 w/sf (for Federal Tax Credit Calculation)

Rooms	Area	LPD Current	Ambient fc Provided	Current Wattage	Reduced Wattage	kW Saved	LPD Provided	Annual kWh Saved (2,600 hrs/yr)	Annual Cost Savings	Lighting Controls
Replace Office Fixtures with Options C or F	140	2.08	35 fc avg ambient	291	140	0.1512	1.00	393.12	$54.66	Existing manual control
Options C or F with Dual Level OCC Sensor	140	2.08	35/18 fc avg ambient	291	64	0.1512	1.00	550.37	$67.99	Auto on to 50%, manual to 100% providing 40% savings

Estimated annual cost savings calculation for one typical four-fixture room.
All hours of use are on-peak (7 a.m.-7 p.m. M-F)

kW Saved On-Peak	On-Peak Demand Charge	Demand Savings	kWh Saved On-Peak	On-Peak Energy Charge	Peak Energy Cost Savings	Total On-Peak savings
0.151	$11.20	$20.32	393.12	$0.088	$31.77	$52.09
kW Saved Off-Peak	Off-Peak Demand Charge	Demand Savings	kWh Saved Off-Peak	Off-Peak Energy Charge	Energy Savings	Total Off-Peak Savings
0	$2.92	$-	0	$0.0600	$-	$-
Cost Saved/yr	Taxes and Other Charges	Tax and Other Savings				
52.09	4.924%	$2.57				
					Yearly Cost Savings	$54.66

(*continued*)

TABLE 1-13 (*Continued*)

Estimated annual cost savings calculation for one 4-fixture room with dual level occupancy sensor (w/auto-on to 50%)						
kW Saved On-Peak	On-Peak Demand Charge	Demand Savings	kWh Saved On-Peak	On-Peak Energy Charge	Peak Energy Cost Savings	Total On-Peak savings
0.151	$11.20	$20.32	550.37	$0.08	$44.48	$64.80
(15% demand savings)			(40% energy savings)			
kW Saved Off-Peak	Off-Peak Demand Charge	Demand Savings	kWh Saved Off-Peak	Off-Peak Energy Charge	Energy Savings	Total On-Peak Savings
0	$ 2.92	$-	0	$0.06	$-	$-
Cost Saved/yr	Taxes and Other Charges	Tax and Other Savings				
64.80	4.9241%	$ 3.19				
					Total Cost savings	$ 67.99

FLUORESCENT LINEAR SURFACE-MOUNTED AND PENDANT LUMINAIRES

Other than troffers, fluorescent luminaires include a wide variety of other options from strip fluorescent lights to retail luminaires and shop lights. Most surface-mounted luminaires can be installed as pendants, for instance, suspended from the ceiling on cables or pipe, and are included in this group. A more recent category of indirect fluorescent pendants are designed to reflect all or a portion of their light off the ceiling. Indirect linear fixtures are suspended on cable or pipe at least 18″ below the ceiling. Surface- and pendant-mounted fluorescent luminaires offer similar energy-efficient retrofit opportunities to troffers, along with some unique considerations.

Retrofitting Lamps and Ballasts

The primary retrofit for fluorescent luminaires in this category is to replace standard ballasts with high efficiency, low ballast factor electronic ballasts, and where necessary, convert T-12 lamp systems to T-8. Unlike troffer lighting, many commercial strips and troughs are equipped with 8′ lamps and with slimline or high output (HO) T-12 lamps operating with standard magnetic ballasts.

Eight-foot T-12 systems can be favorably retrofitted with electronic ballasts for T-8 lamps. Table 1-14 provides options and consequent changes in energy use and lumen output. For equivalent lighting, either 4′ F32T8 lamps or 8′ F96T8 lamps can be suitable. New lower-energy F96T8 lamps that use only 51watts provide significantly longer lamp life than 8′ T-12 products, but don't produce the same lumen output.

For high output T-12 systems, both 8′ T8HO lamps as well as 4′ T5HO replacement luminaires and lamps are reasonable options, with the T5HO lamps and ballasts offering not only longer life, but programmed start ballasts that can be more effectively used with occupancy sensors. The following table provides several options and decision-making criteria for conversion of high output systems using 8′ lamps.

Retrofit Reflectors and Diffusers Combined with Delamping

Both specular imaging and high reflectivity white reflectors may be used to improve lighting systems' performance, usually with delamping and ballast retrofit with fewer lamp lumens. However, few surface or pendant fluorescent luminaires other than surface troffers can benefit from this option.

TABLE 1-14 CONVERTING FROM 8′ T-12 LIGHTING SYSTEMS

	Lamp Type	# of Lamps	Ballast Type	System Watts	Lamp Design Lumens	Efficacy (L/W)	Lamp Life	Annual Energy Savings	Percent Savings	Annual Energy Use
Current Lighting System	Single-Pin 75 w Slimline F96T12	2	Electromagnetic Instant-Start BF 0.97 (no longer available)	170	6,425	72	12,000	$-		$61.20
Alternate Lighting System	Medium Bi-Pin 60 w Coated F96T12	2	Electromagnetic Instant-Start BF 0.86	158	5,400	57	12,000	$4.32	7%	$56.88
Energy Savings Option, lamp and ballast replaced	Single-Pin 51 w Instant Start Slimline F96T8	2	Electronic Instant-Start, BF 0.87	107	5,300	85	24,000	$22.68	37%	$38.52
Energy Savings Option, replace fixture w/ four-lamp T-8 and HP ballast	Medium Bi-Pin Long Life F32T8	4	Programmed Start, BF 0.87	102	2,950	99	30,000	$24.48	40%	$36.72

Source: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

Do not use instant-start ballasts where frequent on/off cycles are expected and with occupancy sensors. Use programmed start instead.

Very low-energy-use lamps using 25 or 28 watts should not be used where ambient temperatures are below 60°F.

TABLE 1-15 CONVERTING FROM 8′ T-12 HIGH OUTPUT LIGHTING SYSTEMS

	Lamp Type	# of Lamps	Ballast Type	System Watts	Lamp Design Lumens	Min Start Temperature	Efficacy (L/W)	Lamp Life	Annual Energy Savings	Percent Savings	Annual Energy Use
Current Lighting System	High Output F96T12 recessed DC (110 w)	2	Electromagnetic Rapid Start, BF 0.98	245	8,550	–20°F/–29°C	66	12,000	$-		$88.20
Alternate Energy Saver Lamp	High Output F96T12 Energy Saver re-cessed DC (85 w)	2	Electromagnetic Rapid Start, BF 0.79	210	7,750	60°F/16°C	57	12,000	$12.60	14%	$75.60
Energy Savings Option, lamp and ballast replaced	High Output F96T8 recessed DC (86 w)	2	Electronic Programmed Start, BF 0.95	185	7,625	–20°F/–29°C	77	24,000	$21.60	24%	$66.60
Energy Savings Option, replace lamp and ballast	Medium Bi-Pin Very High Output F48T8 VHO (84 w)	2	Programmed Start, BF 1.00	185	7,200	–20°F/–29°C	67	25,000	$21.60	24%	$66.60
Reduced System Output Fixture replace-ment w/ T5HO system	High Output F54T5HO Mini Bi-Pin Lamp	2	Programmed Start, BF 1.00	117	4,750	–20°F/–29°C	80	25,000	$46.08	52%	$42.12

Source: *System watts and mean lumens are based on 277 volts. Results for other voltages will differ slightly.*
Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.
Although HO system may start at –20°F/–29°C, lamp lumens will be significantly reduced when lamps are operated at cold temperatures.

Open fluorescent trough fixtures already offer high efficiency, leaving little opportunity to increase illumination. Gaining a meaningful increase would require specular reflectors that may create objectionable and uncomfortable glare. Wraparound fixtures may suffer undesirable changes in light distribution if reflectors were added.

Strip luminaires can, however, benefit from adding reflectors.

Retrofitting Specific Surface and Pendant Luminaire Types

Strip lights. Strip lights or "channels" are the most basic of fluorescent luminaires. Lacking optical reflectors, these fixtures create general light without directional focus.

Strip lights are often used in special situations, such as inside cabinets or cases, in coves or valances, behind Plexiglas sign panels, or other applications where a line or volume of light is needed. Strip lights often have reflectors added to more effectively direct light to where it is most needed.

- *General strip lighting.* Adding a symmetrical reflector can increase the coefficient of utilization (CU) of strip light systems, especially when the strips are suspended from a ceiling or if the ceiling has low reflectance. The reflector can be white, semi-specular, or for a special appearance, white perforated to allow a little uplight. Maintaining equal task illumination at the work plane can occur with lower system wattage and greater savings.
- *Covelights and valances.* Fluorescent strips are often used for covelighting. Adding an asymmetric reflector to direct light farther into the space can increase application efficiency and make lower wattage lamp use possible. T-5 and T-8 lamps, due to their smaller diameter, perform significantly better with reflectors than T-12 lamps. T-5 lamps, at 46″ in length, cannot be used to replace T-12 systems directly. T-8 lamps and ballasts can serve as direct replacements with socket changeouts.

Commercial wraparounds. Wraparounds are strip fixtures with an added diffuser surrounding the lamp on three sides. Light distribution is similar to the strip, but with a softened appearance. One- and two-lamp "wraps" are used in corridors, stairs, and a wide variety of general lighting and utility applications. Three- and four-lamp wraps have been used in many small office applications, where overhead glare and luminaire brightness can be detrimental. Retrofit options for fluorescent wrap fixtures include:

- Replacement of older lenses that have depreciated. This can significantly raise light levels and is necessary for luminaires older than 15 years.
- Fluorescent wraparounds are often used in lower-cost construction, which also means that light levels may not have been "designed," and could be unnecessarily high. Delamping or removing or relocating some luminaires may be needed to achieve appropriate light levels.
- Spaces with intermittent usage should be evaluated for installation of occupancy sensors.
- Consider replacing wraparound luminaires with better shielded surface luminaires when used in offices, schools, or other work environments inhabited eight or more hours a day, and where discomfort glare is an issue. These inexpensive luminaires are often used in spaces where they may contribute to an uncomfortable environment, especially when used in spaces with dark colored walls and ceilings. However, for many types of workshops and other general commercial applications, they are an acceptable low-cost and energy-efficient solution.

Commercial trough luminaires. Some discount retailers and grocery stores prefer shallow "trough" luminaires. In retail lighting, exposing the fluorescent lamps is accepted both for economy and to convey to the customer that the store is "open." Fluorescent troughs provide energy efficiency by directing light toward the floor and walls as well as flexible layout options. Different reflector designs offer broad or narrow aisle coverage, and are far more efficient than lensed or louvered lighting.

Commercial trough luminaires are good candidates for high efficiency T-8 ballast and lamp retrofits. Significant performance variations exist between different reflector configurations, and lighting analysis using CAD-based software is valuable in helping achieve but not exceed the appropriate light levels. Increasing the reflectivity of wall and particularly large floor surfaces can be used to increase the room CU, and reduce lighting requirements. Some retrofitters add high performance reflectors to commercial trough luminaires to increase efficiency, but this may visually "darken" the look of the luminaires, reduce visual comfort, and may make it look like the store is closed. Retrofitters are encouraged to carefully assess more than energy concerns when considering a reflector treatment.

Shielded or lensed surface luminaires. Many applications require a surface-mounted luminaire with shielding similar to parabolic troffers. Troffers can be surface-installed with enclosure options, while a few manufacturers provide attractive, louvered surface-mounted luminaires as an upgrade to the wraparound. Many inexpensive residential surface-mounted fluorescents are still found with magnetic ballasts and T-12 lamps. These often end up in small municipal and commercial buildings, and make good targets for small-scale ballast and lamp retrofit. The best residential retrofit target market is in hotels and multifamily homes where quantities of the same lamps and ballasts are replaced most cost-effectively.

Refer to the previous section on recessed troffers for retrofit considerations, as they are, by and large, the same.

Additionally, surface-mounted luminaires are frequently installed in "hard" sheet rock ceilings, or ceilings where patching and relocation of wires is needed to relocate luminaires. This can add significantly to the cost of the retrofit, so adding and moving luminaires should generally be avoided. Lamp and ballast changeouts, replacement with luminaires of the same size, and delamping, will typically be more cost effective for surface fixtures attached to hard ceilings.

When replacing wraparound luminaires with shielded luminaires, look for options that direct some light to the side, thus avoiding a dark ceiling effect. Recently, several manufacturers have developed such shielded luminaires that are also shallow enough to work well in low ceiling applications. These can be useful tools for replacing older fluorescent wraps, recessed can lights, as well as older incandescent surface luminaires in insulated ceiling applications (by helping combat thermal bypass). A fixture of this type is shown in the figure on page 51.

Indirect pendant-mounted lighting. Favored for their soft, glare-free appearance, indirect lighting systems started appearing in the 1980s. This type of luminaire

Figure 1-13a Linear indirect fluorescent luminaire with metal perforations softens the silhouette against the ceiling *(Provided by Philips Lightolier.)*

Figure 1-13b Direct/indirect fluorescent luminaire combines the softened effect of indirect lighting with a direct light component. *(Provided by Philips Lightolier.)*

is often installed in continuous rows, which can yield both excessive illuminance and energy use when designed without accurate computer simulation. Systems installed with only general guidelines and not the specific wall and ceiling reflectance may benefit from increasing reflectance values to allow use of fewer lamps or a lower ballast factor.

As the pendant luminaire enclosure became smaller, ballast sizes also became a critical design factor. Therefore, it is unlikely that linear pendant luminaires would have been made with the larger, heavier magnetic ballasts. If there is a desire to retrofit such a system with new ballasts, make sure the replacement ballast will fit the enclosure.

Indirect fluorescent pendant applications, particularly those with continuous three lamp installations, have room for energy improvements through both delamping and ballast/lamp retrofits. Retrofits should be modeled using the actual ceiling and wall reflectance, as it has a greater impact on these fixtures than other types.

An important variable in indirect lighting is mounting height, particularly the distance between the ceiling and the top of the luminaire. Most indirect lighting systems require at least 18″ clear above the luminaire for light to diffuse effectively over the ceiling surface. Lighting efficiency and visual comfort drops when fixtures are mounted too close, or the ceiling has a low reflectance. If lowering the luminaire mounting height is not possible, replacement with a luminaire with at least 50 percent direct (downward) light distribution may also allow for an overall reduction in lumens and energy used.

A number of newer indirect luminaires include special "kick" reflectors to distribute light more effectively from closer to the ceiling. Use of retrofit reflectors to achieve the same effect may be possible.

Figure 1-14a Mounting indirect luminaires close to the ceiling can reduce overall system efficacy.

Figure 1-14b A lower mounting height improves the appearance and efficacy of indirect lighting systems. *(Provided by Pinnacle Lighting.)*

Task lighting. Ranging from bare strips to sophisticated luminaires with special lenses, fluorescent task lights are employed under cabinets in office workstations and over vanity and countertops in labs, kitchens, exam rooms, and many other types of facilities. Use of task lighting at illuminance levels of 60 to 120 foot-candles is an important energy conservation strategy since they allow an overall reduction in ambient light levels.

CASE STUDY

If our experience is at all typical, any office lighting retrofit project will encounter a range of personal, usually incandescent task lights or halogen torchieres in work cubicles and personal offices. Convincing the owners of these lights to give them up often involves a discussion of why they dislike fluorescent lighting. In one library project, an indirect fluorescent recessed luminaire was selected and a warmer 3,500K lamp was used in personal offices as a direct result of such a discussion.

Not all project managers allow special lighting requests, but they can improve acceptance by offering compact fluorescent task lights and/or undercabinet lighting whenever general lighting reductions are undertaken. Task lighting is key to substantial reductions in ambient lighting density for offices, just as accenting product in retail stores with efficient fluorescent and HID sources can reduce ambient light levels.

Many existing fluorescent task lights use magnetic lamp and ballast technology, but may not be cost effective to retrofit. Commodity type undercabinet lights with T-8 or T-5 lamps and electronic ballasts are relatively inexpensive as replacements. Specify units that use 2′ to 4′ T-8 or T-5 lamps. Shorter length T-5 lamps in 8 and 11 watts can be expensive to replace and are not as readily available.

Many fluorescent undercabinet lights produce higher footcandles than is required. If replacing fluorescent undercabinet lights, adequate light can be provided

Figure 1-15 LED undercabinet light offers an efficient alternative to halogen with lower lumen output than fluorescent. *(Courtesy of Philips Color Kinetics.)*

TABLE 1-16 COMPARING LIGHT SOURCES FOR UNDERCABINET LIGHTING

	Lamp Type	# of Lamps	Ballast or Transformer Type	Watts/ ft	Total Initial Lumens/ ft	Efficacy (L/W)	Avg Rated Lamp Life	Annual Energy Savings per Foot	Percent Savings	Annual Energy Use per Foot
Line Voltage Halogen Modular	25 w Bi-Pin Halogen	3 @ 6″ o.c.	None	50	800	25	2,000			$18.00
Low Voltage (12 v) Halogen Standard Length	20 w G4 Bi-Pin SEQ Lamps	4 @ 6″ o.c.	Electronic In-Line or Remote	42	700	17	2,000	$2.88	16%	$15.12
Low Voltage (12 v) Xenon Standard Length	18 w T-3 Wedge Base Xenon Lamp	4 @ 6″ o.c.	Electronic In-Line or Remote	38	500	25	10,000	$4.32	24%	$13.68
Fluorescent T-8 Standard Length	T-8 Medium Bi-Pin 48″ Energy Saver Lamp	(1) 32 w	Electronic Instant Start, BF 0.88	8	700	81	24,000	$15.30	85%	$2.70
Fluorescent T-5 Standard Length	T-5 Miniature Bi-Pin 46″ Lamp	(1) 28 w	Programmed Start, BF 1.00	7	688	91	25,000	$15.66	87%	$2.34
White LED Standard Length 4,000K	Permanent LED	Integral	Integral 12 v Driver	6	185	29	55,000	$15.84	88%	$2.16

Source: *System watts and mean lumens are based on 120 volts.*

Energy savings are based on reductions in energy from the base case, and assuming 3,600 hours of annual use at $0.10 per kWh.

LED performance is directional. Therefore, although efficacy appears lower than some sources, a very high percentage of this light is deliverd to the working task surface.

without continuous end-to-end mounting. Provide wall-switched undercabinet lights with an integral on/off rocker switch, so that sections of workspace not being used are not lighted unnecessarily.

Consider replacing incandescent or fluorescent undercabinet lights with new LED undercabinet lights. These can use as little as 6 watts per foot, compared with low voltage halogen at 35 watts per foot and fluorescent at 14 watts per foot. New LED undercabinet units by different manufacturers are not equally efficient, and there is a degree of variation in available color temperatures. Do review specifications and independent testing using the IES LM-79-08 testing protocol, and review samples before ordering. Table 1-16 is a comparison of light sources using undercabinet lighting.