



APPLICATION NOTE

An In-Depth Examination of an Energy Efficiency Technology

Efficient Lighting Using Compact Fluorescent Lamps and Fixtures

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Summary

Compact fluorescent lamps (CFLs) can provide energy savings of up to 75 percent and slash maintenance costs in many common applications formerly dominated by incandescents. The challenge is to obtain excellent visual quality with these compact sources, as they are often misapplied. This application note draws on the experience of lighting designers, manufacturers, and product users to provide guidance in how—and how not—to apply compact fluorescents.

CFLs come in several sizes and configurations, and can be applied nearly anywhere that incandescent sources are used for general area lighting. Applications include ceiling downlights, task lights, wall sconces, and pendant and decorative fixtures. But even these versatile light sources cannot be used everywhere, and they must be applied carefully to get satisfactory results. Limitations include difficulty in dimming, the availability of lamps in sizes that fit existing fixtures, sensitivity to frequent on-off cycling, and low beam power because of the diffuse linear light source. In addition, lamp orientation and temperature need to be considered, since they can affect light output.

How This Technology Saves Energy

Compact fluorescent lamps are simply miniature versions of full-sized fluorescents, with a few key differences. They are narrower; most CFLs of 13 watts

and less are T4s (four-eighths of an inch in diameter) and most over 13 watts are T5s (five-eighths of an inch). Most are short (six inches or less) and connect to their power supply through a base or socket at one end, as opposed to both ends for full-size fluorescents.

CFLs typically replace lower-efficiency incandescent lamps. Incandescent efficiency ranges from about 5 to 15 **lumens per watt**,¹ while CFLs range from 25 to 75 lumens per watt. They achieve this advantage by using an arc discharge through a phosphor-lined tube, rather than heating a resistance-filament.

CFLs consist of a lamp, a lamp holder, and a **ballast**. As in full-sized systems, the ballast provides the electrical control to strike and maintain an arc. There are three types of CFL lamp-ballast systems: integral, modular, and dedicated. (See Figure 1.)

- **Integral units** combine a lamp, ballast, and a standard Edison screw base in a single sealed assembly, which must

be discarded when the lamp burns out.

- **Modular units** plug a separate lamp into an Edison or other style of adapter/ballast. When the lamp burns out a relatively low-cost (compared to an integral CFL) replacement lamp can be installed in the same ballast base, which typically lasts 40,000 to 60,000 hours. Lamps for these units have either two- or four-pin bases. All those of 9 watts or less use the same ballast and pin configuration; those above 9 watts generally use different bases and ballasts for each wattage, so they can't be interchanged—and users and specifiers must pay careful attention to base configurations.

- **Hardwired systems**—also called dedicated systems—consist of a ballast and fluorescent lamp socket permanently wired into a fixture by the manufacturer or as part of a retrofit kit. As in modular systems, the lamp can be replaced with another pin-based compact fluorescent when it burns out.

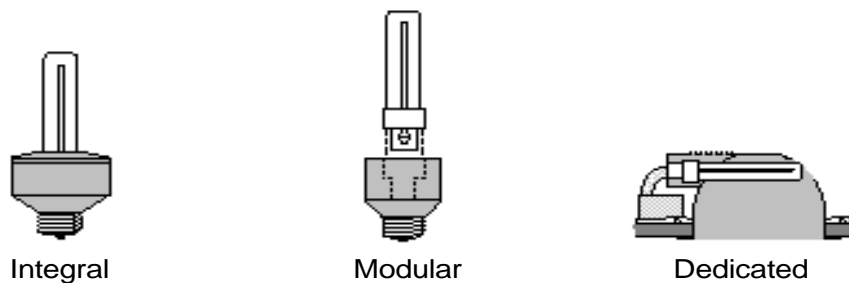


Figure 1: Types of CFL Lamp-Ballast Systems (Source: E Source)

¹ Bold-Italic words are defined in the section titled Definition of Key Terms.

Types of Compact Fluorescents

Compact fluorescent lamps come in a wide array of shapes and sizes. Here are the key shapes and variations:

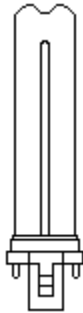


Figure 2: Twin-Tube Compact Fluorescent Lamp (Source: GE Lighting)^a

Twin lamps (Figure 2) consist of two straight, parallel, miniature fluorescent tubes (or one U-shaped tube with parallel legs) ending side-by-side in a plug-in base that contains an integral starter. General Electric calls its family of such lamps Biax (short for “biaxial”) and many people use this term generically. Osram Sylvania uses the original Osram trade name “Dulux.” All these terms describe the same two-legged style of lamp.

Twin lamps are very versatile for applications that do not need high light output. Their slender shape fits well in task lights, sconces, and ceiling downlight cans. There is little internal shading and fixtures can be designed to distribute their light very efficiently. Most fixtures are of the modular screw-in or hard-wired variety. The lamps are now widely stocked.

High-output twin lamps (Figure 3) ap-



Figure 4: High-Output Twin-Tube Compact Fluorescent Lamp (Source: GE Lighting)^a

proach the output of full-sized fluorescents. They have bases with four pins in a row and are available in power ranges of 18 to 40 watts. The largest put out nearly as much light as a 4-foot T8 fluorescent. They are being designed into many fixture types that formerly used full-sized fluorescents, such as cove lights, pendants, and 2' x 2' parabolic-reflector downlights.

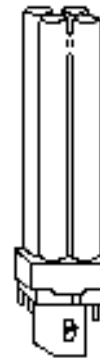


Figure 3: Quad-Tube Compact Fluorescent Lamp (Source: Philips Lighting Company)^b

Quad-tube (Figure 4), double-twin, double biax—or in Philips Lighting’s parlance, PL “clusters” or “PLC” lamps—place four parallel tubes (or two U-shaped tubes with parallel legs) on the same base as twin tubes. They thus provide nearly the same light output as twin tubes of equivalent wattage in only half the length, though internal shading reduces total light output somewhat.

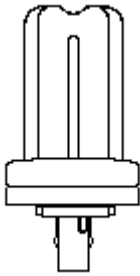


Figure 5: Triple-Twin Tube Compact Fluorescent Lamp (Source: GE Lighting)²

To generate even more light from a shorter lamp, various manufacturers offer CFLs with three twin tubes (Figure 5). GE and Osram Sylvania cluster their triple-tube lamps in a triangular or “delta” configuration. Other manufacturers, including Philips, offer lamps with three parallel arch-shaped curved tubes. These products are often called “triple biax” lamps.

Triple-tube lamps pack very high light output into a small space and can be used in fixtures designed for incandescents, such as table lamps. They are available in integral and modular screw-in designs.

The so called “F-Lamp” (Figure 6) has two twin tubes aligned in a single plane, shoulder to shoulder. It is well suited to task lights and low-profile surface and

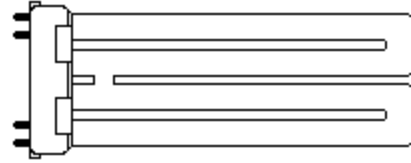


Figure 6: F-Series Compact Fluorescent Lamp (Source: Osram Sylvania)⁶

recessed fixtures, and is currently manufactured by Panasonic and Osram Sylvania.

A newcomer in North America is the “2-D” or “double-D” lamp (Figure 7), originally available only as an import. GE is now the sole U.S. manufacturer of this flat 4-pin configuration, which comes in five models between 10 and 38 watts. This configuration is ideal for low-profile surface and recessed fixtures.

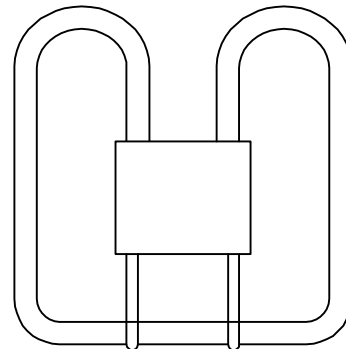


Figure 7: 2D Compact Fluorescent Lamp (Source: GE Lighting)⁹

Circular or “Circline” fluorescent lamps (Figure 8) are not always considered members of the CFL family. They date from the 1940s and many use the same cool white phosphors as standard T12 lamps. However, at least one manufacturer—Lights of America—produces circular fluorescents in warm and cool color temperatures with **rare earth phosphors** and instant-on electronic

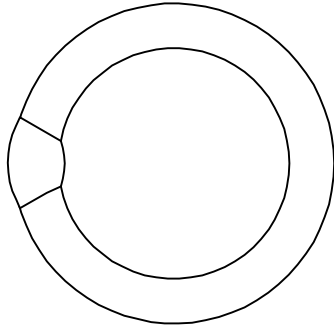


Figure 8: Circline Compact
Fluorescent Lamp
(Source: GE Lighting)^a

ballasts; the 20-, 22-, and 30-watt versions are among the few compact fluorescents that can replace 100- to 150-watt incandescents with comparable light output and still fit in residential reading lamps. Philips offers Circlines with rare earth phosphors but does not sell them with ballasts.

Prices of CFL products vary considerably among regions. Most fall into the following ranges, depending on wattage and quantity purchased:

- **Modular CFL lamp and ballast:** \$5 to \$20
- **Integral CFLs:** \$10 to \$30
- **Retrofit kits:** \$25 to \$50 including reflector
- **New CFL fixtures:** \$30 to \$250

Applicability

CFLs can be used in a great many commercial applications traditionally served by incandescents. They come in a wide variety of fixtures, including re-

cessed downlights, wall washers, desk lights, table lights, wall sconces, pendants, under-cabinet fixtures, landscape lights, and floodlights. Their long life makes them particularly appealing for hard-to-reach places, where the costs and risks of frequent lamp changes are high.

Table 1 shows which types of CFLs are best used for which applications.

Installation Issues and Limitations

While CFLs have many uses, there are some applications where they just do not make sense or where extra care must be taken to achieve satisfactory performance:

- **Most CFLs do not produce enough light for high-ceiling** (above 12 feet) ambient lighting applications, although this can be overcome in some fixtures by using multiple lamps. Other alternatives include high-color-rendering **HID** sources and **halogen infrared** lamps, often more effective in such applications because of their higher light output.
- **Because they are a linear diffuse light source**, CFLs are not appropriate for accent lighting or glittery retail display, where tight beam spread or sparkle is needed. Halogen or compact HID sources are better efficiency choices in such instances.

- **Downlight retrofits** should use kits or lamps with built-in reflectors rather than lamp-only replacements that may not work with existing reflectors.

	Downlights	Surface Lights	Pendant Fixtures	2'x2' Fixtures	Sconces	Exit Signs and Other Signage	Floodlights	Table and Floor Lamps
Twin Tube	1	2	2	3	1	1	1	3
High-Output Twin Tube	3	2	3	1	2	3	2	3
Quad Tube	1	2	2	3	1	2	2	2
Circline	3	1	2	3	2	3	3	1
2D	1	1	2	3	2	2	3	2
Triple-Twin Tube	2	3	2	3	3	3	2	1
F-lamp	3	1	1	2	3	2	2	2

Key: 1 = superior choice, 2 = suitable choice, 3 = poor choice

Table 1: Compact Fluorescent Application Matrix (Source: E Source)

- **The reflectors in many fixtures** designed for incandescents may not provide the desired quantity or distribution of light when retrofitted with a CFL. Many retrofit reflector kits are available to adapt existing fixtures for a CFL source.

- **CFLs are valuable** and may be stolen from public areas; theft-resistant devices are available.

- **Many CFLs are too long** for fixtures designed for incandescents— some models may protrude below the ceiling line when retrofitted into downlights, or stick up above a table lamp shade, causing unacceptable glare. Such problems are avoidable by selecting a shorter lamp (such as the triple-tube lamps) or by using the various products available for adapting the fixture.

- **The screw-in adapter/ballast**

bases of some CFLs are too wide to fit in some luminaires. This problem can be avoided by selecting a different model of CFL, by using fixture adapters, or by using a luminaire designed for CFLs.

- **CFL light output and lifetime are reduced** by ambient temperatures that are too hot or too cold. Care is thus required outdoors where temperatures drop below freezing and in unvented indoor fixtures where heat may build up.

- **Some magnetically ballasted CFLs flicker** for a few seconds when starting and produce an audible hum, which may make them unacceptable in quiet settings such as homes and libraries. Some such CFLs are also fairly bulky and heavy and may tip over small table lamps. All these problems can be avoided by using lighter, silent, and in-

stant-starting **electronically ballasted** units.

- **CFLs cannot be installed on existing dimming circuits.** Only 4-pin CFLs with dimming electronic ballasts can be dimmed, and complete packages are expensive (about double the cost of non-dimming equipment), although prices are expected to fall with increasing competition.
- **Frequent on-off cycling can dramatically reduce the operating life** of CFLs, so they shouldn't be used with occupancy sensors or where frequent switching is expected.
- **Some electronically ballasted CFLs emit infrared radiation** that can interfere with the remote controls for televisions, stereos, and video players. Care should be taken when specifying CFLs for such settings.

Field Observations to Assess Feasibility

This section describes field observations that can indicate where compact fluorescent lamps can achieve energy savings with good visual quality. Certain fixtures are more readily retrofitted than others, and both fixture design and duty factor affect energy savings and implementation cost .

Related to Applicability

CFLs can be used in most applications where incandescent lamps are found. The key field observations are to notice what types of fixtures and lamps are in

current use. Here are some of the fixtures to look for:

- **Downlight can fixtures** with incandescent A-lamps (normal frosted screw-ins) or R-lamps (reflector lamps) are candidates for retrofit kits that use CFLs. The specific kit will depend on ceiling height, desired lumen output, and desired light distribution.
- **Incandescent desk lamps** can be replaced with CFL task lamps, many of which are inexpensive (under \$50) and use the small 13W twin-tube lamps.
- **Table lamps** can be retrofitted with circline or 2D lamps—some of which now are available in 3-way designs that have three different light output levels.
- **Sconces** (lights affixed to the wall) can be difficult to retrofit, although many varieties of new fixtures with CFL lamps are available.
- **Pendant** or other fixtures with recessed lamps may be retrofitted with screw-in CFLs.

Related to Energy Savings

Nearly any incandescent-to-CFL retrofit in an application with sufficient burn hours will save significant energy. To assess the potential of CFL retrofits, the main question is: How many hours per day or per year is the lamp in use? Incandescent lamps that operate 24 hours per day—such as hotel hallway lights—are usually sure winners. Closet lamps probably aren't worth considering, however. Any lamp that operates more than 1500 hours per year is probably a good bet for a CFL retrofit.

Related to Implementation Cost

Some CFL retrofits are much easier and less expensive than others. Screw-in retrofits are the easiest. Because there are so many fixture types, crafting retrofits can take considerable ingenuity (and expense). Custom fixtures can sometimes be ordered from manufacturers, especially if the order is large (see case study). A careful economic analysis should be made, however, to be sure that the energy savings can cover the cost of custom fixtures. Perhaps the best approach is to keep track of the different types of CFL fixtures and retrofit kits that have been successfully applied for unique fixture types.

Case Study: A Custom Reflector for a CFL

At Columbia University, energy managers often worked with manufacturers to create solutions that benefited both parties. A good example was the need for a downlight reflector that took full advantage of the 28-watt quad-tube compact fluorescent lamp. At the time, there was no satisfactory retrofit reflector for that lamp.

A company that manufactures lighting equipment was asked to provide pricing for a large metal reflector that could clip on to a 28-watt screw-in CFL base, and approximate the intensity and beam-spread of a 150-watt long-life incandescent floodlamp. After some early stumbling, the vendor and energy manager derived a shape that produced the desired results and could be produced by a metal fabrication shop. As always, it came down to economics: \$12,000 was needed to make a mold for the first

prototype.

When lighting audits indicated that at least 1,000 fixtures could use the new reflector, the university committed to buy the first 1,000 devices at \$12 each, completely covering development cost. The vendor agreed to put up the necessary funding to fabricate the first lot, providing he could maintain exclusive rights to the product. The total cost for each installation (including lamp, ballast, reflector, and labor) was about \$65. The units saved over \$30 a year per retrofit, yielding a payback of about two years. The units soon became popular at many other facilities.

Estimation of Energy Savings

CFLs typically use 60 to 75 percent less energy than the incandescents they replace. Table 2 provides a typical example.

Standard Savings Calculation

The following equation is recommended for estimating energy savings from changes to the capacity of a lighting system. Alternative equations and further information can be found in the CEE program documentation, filed with the CPUC.

	Baseline Incandescent 75W	CFL Option 1 18W triple-twin	CFL Option 2 21W 2D
Performance			
Light output (lumens)	1,190	1,200	1,350
Lamp lifetime (hours)	1,000	10,000	10,000
Power input (W)	75	18	21
Efficacy (lumens/W)	15.9	66.7	64.3
Energy			
Annual energy use (kWh/year)	187.5	45.0	52.5
Annual energy use (\$/year)	\$ 18.75	\$ 4.50	\$ 5.25
Annual energy savings (\$/year)	n/a	\$ 14.25	\$ 13.50
Maintenance			
Lamp cost (\$/lamp)	\$ 1.00	\$ 5.00	\$ 20.00
Relamping labor cost (\$/lamp)	\$ 5.00	\$ 5.00	\$ 5.00
Annual lamp cost	\$ 2.50	\$ 5.00	\$ 5.00
Annual labor cost	\$ 12.50	\$ 1.25	\$ 1.25
Annual maintenance savings (lamp+labor) (\$/year)	n/a	\$ 8.75	\$ 8.75
Summary			
Annual operating cost (energy+maintenance) (\$/year)	\$ 33.75	\$ 10.75	\$ 11.50
Annual operating cost savings (\$/year)	n/a	\$ 23.00	\$ 22.25
Payback on first CFL installed (years)	n/a	1.1	1.1

Table Notes: Annual operating time = 2500 hours
Electricity cost = \$0.10/kWh
Paybacks do not include PG&E rebates. Paybacks will be shorter if rebates are available.

Table 2: Example Savings Calculations

$$kW_{savings} = \# fixtures \times \left[\left(\frac{Watts / fixture_{base}}{-Watts / fixture_{as-built}} \right) \div 1,000 \right] \times Utilization_factor$$

$$kWh_{savings} = kW_{savings} \times hours_{as-built} \times HCIF_{kW}$$

$$therm_{takeback} = kW_{savings} \times 0.034 \times hours \times HCIF_{heat} / heating_efficiency$$

HCIF_{kW} and HCIF_{heat} are the heat/cool interaction factors which account for reduced electric air conditioning loads and increased gas heating loads, respectively, due to the decreased lighting energy. A table of these factors is in the

program documentation.

Utilization_factor is the ratio of “on” fixtures to total installed fixtures. This factor accounts for fixtures or lamps which are not operational due to: burned out lamps, failed ballasts, or not turned on.

Cost and Service Life

Factors That Influence Service Life and First Cost

The first cost of CFL equipment is high compared to incandescents, but the en-



ergy savings and reduced labor costs for relamping mean that they pay back very rapidly in applications over 2,000 operating hours per year. In fact, avoided lamp replacement and labor costs give the CFL a lower lifecycle cost. The more annual operating hours, the more attractive CFLs become, because more incandescent relamping costs are being avoided.

Typical Service Life

CFL lifetime is highly sensitive to lamp cycling. On the basis of three-hour duty cycle, three hours on and 20 minutes off, most CFLs have rated lifetimes of about 10,000 hours. But this can be dramatically reduced by frequent cycling—or doubled in continuous operation. Figure 9 illustrates the reduction associated with short cycling times. The impact of cycling should be part of the economic analysis of occupancy sensors, which may cause frequent cycling in areas alternately occupied and unoccupied many times a day.

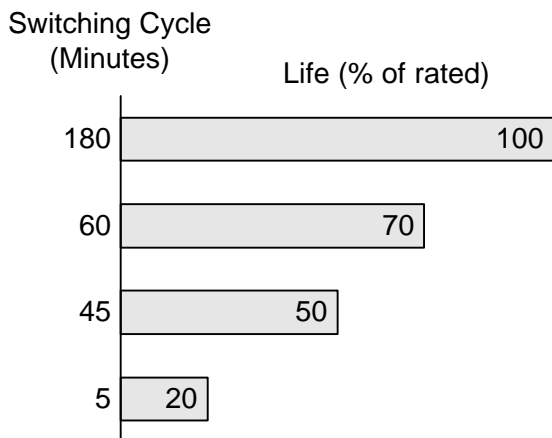


Figure 9: CFL Lifetime vs. Switching Cycle (Source: Delux CFL Handbook)

The PG&E CEE program assumption for service life is 8,000 hours for integral lamps and 16,000 hours for modular (replaceable) lamps.

Laws, Codes, and Regulations

Few laws regulate the use of compact fluorescents, and most energy codes tend to encourage their use. They must meet requirements of the Federal Communications Commission to limit their potential for electromagnetic interference with other devices, but this issue is addressed by manufacturers before selling their products.

Definitions of Key Terms

- **Ballast:** An electrical device that supplies the proper voltage, amperage, and waveform to start and operate a fluorescent lamp.
- **Electronically Ballasted:** Having a ballast that provides high-frequency arc voltage to improve lamp efficiency.
- **Halogen Infrared:** A relatively-high-efficiency incandescent lamp with a halogen gas capsule surrounding the filament, and an infrared-reflective coating on the capsule.
- **HID:** High-Intensity Discharge, a light source using a short arc in a glass enclosure, often with very high light output. Includes metal halide, sodium, and mercury vapor lamps.

- **Lumens per Watt:** A measure of the efficiency of a light source, in terms of light output in lumens divided by power input in watts.

- **Rare Earth Phosphor:** a blend of coating for the inside of a fluorescent lamp that produces high-quality light with excellent color rendering.

References to More Information

1. E Source, "Lighting Technology Atlas," September 1994.
2. E Source, "Success at Zero Net Cost: Columbia University's Achievements in Energy Efficiency," 1994.
3. GE Lighting, "Spectrum 9200 Lamp Catalog," 22nd edition, 1996.
4. Illuminating Engineering Society of North America, "Lighting Handbook—Reference and Application," 8th edition, 1993.
5. Osram Sylvania, "1996 Lighting Catalog," 1996.
6. Philips Lighting Company, "Lamp Specification and Application Guide," 1996.

Major Manufacturers

GE Lighting
Nela Park
Cleveland, OH 44112
Tel (800) 255-1200
Fax (216) 266-2900

Osram Sylvania
100 Endicott Street
Danvers, MA 01923
Tel (508) 777-1900
Fax (508) 750-2152

Philips Lighting
200 Franklin Square Dr.
Somerset, NJ. 08875-6800
Tel (908) 563-3000
Fax (908) 563-3641

For more information on manufacturers and distributors, see References 4, 6 and 7. Information can also be obtained from relevant trade organizations, such as the National Electrical Manufacturers' Association and the Illuminating Engineering Society of North America.

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