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Fluorescent Lamp Retrofits: Savings or Fantasy?

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This Tech Tip evaluates lighting controls and the real-world savings from retrofitting standard 4-foot F40T12 fluorescent lamps and magnetic ballasts in Forest Service offices.

The Energy Policy Act of 1992, Executive Order 13123, and the Federal Acquisition Regulation, Part 23, Section 704 (48 CFR 23.704) institute guidelines for Federal agencies to purchase energy-efficient products. Lighting accounts for 20 to 25 percent of the United States' electricity consumption. Forest Service installations should consider various means of saving energy when retrofitting old lighting systems. Retrofitting with automatic controls and energy-efficient fluorescent lamps and ballasts yields paybacks within 2 to 5 years. However, the best reason for retrofitting an old lighting system—increasing the productivity of workers—is often overlooked.

Background on Costs

With electricity costing 8 cents per kilowatt hour, a typical 40-watt T12 fluorescent lamp will use $64 worth of electricity over its life. The purchase price of the bulb ($2) accounts for just 3 percent of the life-cycle costs of owning and operating the lighting system. Energy accounts for 86 percent of the cost (figure 1). These calculations readily justify the cost of more expensive lamps that produce better quality light, save energy, and increase productivity.

The effect of lighting on human performance and productivity is complex. Direct effects of poor lighting include the inability to resolve detail, fatigue, and headaches. Lighting may indirectly affect someone's mood or hormonal balance.

A small change in human performance dwarfs all costs associated with lighting. The typical annual costs of 1 square foot of office space are:

- Heating and cooling $2
- Lighting $0.50
- Floor space $100
- Employee salary and benefits ... $400

Cutting lighting consumption in half saves about 25 cents per square foot each year. A 1-percent increase in human productivity would save $4 per square foot each year. Forest Service costs may be different. Costs will vary from facility to facility, but the relative magnitudes of these costs aren't likely to change. The focus needs to be on providing quality lighting to meet occupants' needs. However, it is possible to improve lighting quality while reducing energy costs thanks to improvements in lighting technology.

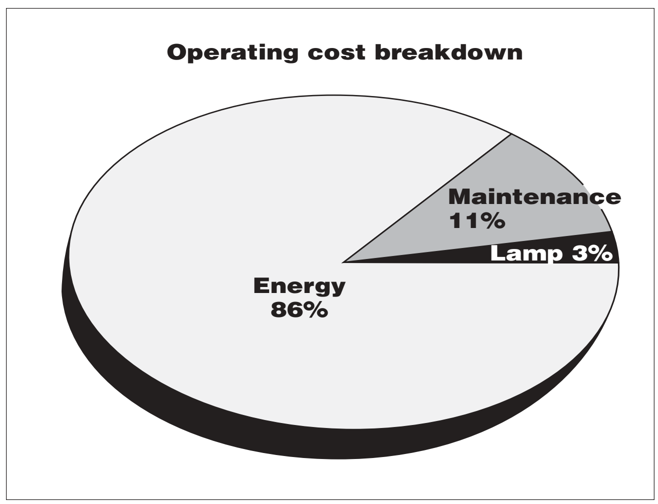

Figure 1—Operating cost breakdown for F40T12 fluorescent lamps with standard magnetic ballast and electricity costing 8 cents per kilowatt-hour.

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Choosing the Best Fluorescent Lamp and Ballast

A light's "warmness" is determined by its color temperature, expressed in degrees Kelvin. The higher the correlated color temperature, the cooler the light. Offices should use intermediate or neutral light. This light creates a friendly, yet businesslike environment. Neutral light sources have a correlated color temperature of 3,500 °K. The color rendition index measures the quality of light. The higher the color rendition index, the better people see for a given amount of light. Currently available 4-foot fluorescent lamps (figure 2) have indexes of 70 to 98. Lamps with different correlated color temperatures and color rendition indexes should not be used in the same space. Specify the correlated color temperature and color rendition index when lamps are purchased.

Figure 2—Typical 4-foot fluorescent lamp fixtures.

Table 1 lists typical fixtures for 4-foot fluorescent lamps and various ballasts that are commonly found in office buildings. The best lighting system for each operating dollar is realized with T8 fluorescent lamps that have a color rendition index of 80 or higher. Compared to standard T12 fluorescent lamps, T8 lamps have better balance between the surface area containing the phosphors that fluoresce and the arc stream that excites them. This means that T8 lamps produce more light for a given amount of energy. In Europe, T5 lamps are popular. The T5 lamps are more efficient than T8 lamps, but cost more than twice as much. The availability of T5 lamps and fixtures is limited in the United States. T8 lamps are currently preferred.

A quick comparison of light output shows how important it is to specify ballast factor and whether the ballast is electronic or magnetic (table 1). Electronic ballasts last twice as long as magnetic ballasts, use less energy, have a lower life-cycle cost, and operate the lamp at much higher frequencies. Operating fluorescent lamps at higher frequencies improves their efficiency and eliminates the characteristic 60-cycle buzz and strobe-lighting effect associated with fluorescent lights. The 60-cycle strobe-lighting effect may cause eye fatigue and headaches. Electronic ballasts are especially desirable in shops with rotating equipment. The 60-cycle strobe-lighting effect produced by magnetic ballasts can cause rotating equipment to appear stationary. All new buildings and retrofits should use electronic ballasts.

Fluorescent Lamp and Ballast Life

Most fluorescent lamps have a rated life of 12,000 to 20,000 hours. The rated life is the time it takes for half of the bulbs to fail when they are cycled on for 3 hours and off for 20 minutes. Cycling fluorescent lamps off and on will reduce lamp life. On the other hand, turning a lamp off when it is not needed will reduce its operating hours and increase its useful life. Electricity—not lamps—accounts for the largest percentage of the operating cost of a lighting system. It is economical to turn off fluorescent lights if they are not being used.

According to the Certified Ballast Manufacturers Association, the average magnetic ballast lasts about 75,000 hours, or 12 to 15 years with normal use. The optimum economic life of a fluorescent lighting system with magnetic ballasts is usually about 15 years. At this point, ballast failures proliferate, the system is on its third or fourth round of lamp replacements, and dirt on reflectors and lenses has significantly reduced light output. Other factors may make it desirable to retrofit a lighting system before the end of the 12- to 15-year life cycle. Those factors include increased productivity, utility rebates, and high energy costs.

Table 1—Fluorescent lamp and ballast performance for standard fixtures.

No. lamps -type[1]	Ballast type[2]	Ballast factor	Fixture lumens[3]	Lumens per watt[3]	Fixture watts	kWh/yr[4]	kWh[5] saved/yr	Dollars saved/yr[6]
4-F40T12	Std	0.88	9,126	47.53	192	499	0	$0
4-F40T12	Hi-Eff	0.88	9,126	53.06	172	447	52	$4.16
4-F40T12 ES	Std	0.88	7,929	47.53	164	426	73	$5.84
4-F40T12 ES	Hi-Eff	0.88	7,929	55.06	144	374	125	$10.00
4-F32T8	Elec	0.87	8,926	78.30	114	338	161	$12.88
4-F32T8	Elec	0.83	8,516	78.85	108	281	218	$17.44
3-F40T12	Std	0.88	6,844	48.89	140	364	0	$0
3-F40T12	Hi-Eff	0.88	6,844	58.00	118	307	57	$4.56
3-F40T12 ES	Std	0.88	5,947	48.75	122	317	47	$3.76
3-F40T12 ES	Hi-Eff	0.88	5,947	59.47	100	260	104	$8.32
3-F32T8	Elec	0.87	6,695	76.95	87	226	138	$11.04
3-F32T8	Elec	0.8	6,156	76.95	80	208	156	$12.48
2-F40T12	Std	0.94	4,874	50.77	96	250	0	$0
2-F40T12	Hi-Eff	0.87	4,511	52.45	86	224	26	$2.08
2-F40T12 ES	Std	0.87	3,919	47.79	82	213	37	$2.96
2-F40T12 ES	Hi-Eff	0.87	3.919	54.43	72	187	63	$5.04
2-F32T8	Elec	1.29	6,618	118.18	56	146	104	$8.32
2-F32T8	Elec	0.77	3,950	75.96	52	135	115	$9.20
1-F40T12	Std	0.94	2,437	42.75	57	148	0	$0
1-F40T12	Hi-Eff	0.87	2,255	45.1	50	130	18	$1.44
1-F40T12 ES	Std	0.87	1,960	39.2	50	130	18	$1.44
1-F40T12 ES	Hi-Eff	0.87	1,960	45.58	43	112	36	$2.88
1-F32T8	Elec	0.87	2,232	74.4	30	78	70	$5.60
1-F32T8	Elec	0.75	1,924	71.26	27	70	78	$6.24

—Information courtesy of Steve Leinweber, the Lighting Design Lab, Seattle, WA.

[1] ES stands for energy saving.
[2] Standard refers to standard magnetic ballast. Hi-Eff refers to high-efficiency magnetic ballast. Elec refers to electronic ballast.
[3] These values include average lumen depreciation at the end of a lamp's life. Average lumen depreciation is the fractional loss of lamp lumens that progressively occurs over the life of the lamp. T12 lamps have at least 15-percent lumen depreciation, while T8 lamps average 10-percent lumen depreciation.
[4] kWh/yr is the kilowatt-hours consumed per year, assuming the lights are on 2,600 hours per year (10 hours per day, 5 days per week, 52 weeks per year).
[5] kWh saved/yr is the energy saved per fixture compared to the first fixture of each group with the same number of lamps.
[6] Money saved/yr is dollars saved per fixture with electricity costing 8 cents per kilowatt-hour compared to the first fixture of each group with the same number of lamps.

Economic Analysis

When considering the benefits of retrofitting, more lamps per existing fixture yield more energy savings per fixture, and a better payback. Higher than average energy or demand costs or a utility rebate will also produce a faster payback.

Ballast factor can be used to adjust light levels. A high ballast factor increases lumens (a measure of light output), allowing fewer lamps to provide the same amount of light. For example, when electronic ballasts with a high ballast factor are used, two-lamp fixtures will produce as much light as three-lamp fixtures. This reduces the cost of the fixtures and improves the payback. An economic analysis of retrofitting three-lamp fixtures and magnetic ballasts with two-lamp fixtures with a high-ballast-factor electronic ballast yields a payback of slightly more than 2 years. The payback is calculated using MTDC's electricity rates, which are among the lowest in the country.

A glossary of lighting terminology and detailed information on calculating energy savings, heating and cooling savings, and simple payback for the lighting system retrofit at the Missoula Technology and Development Center (MTDC) are available on the Forest Service and Bureau of Land Management's internal computer network at the MTDC web site: *http://fsweb.mtdc.wo.fs.fed.us/pubs/htmlpubs/htm01712310/fluorescent_summary.htm*

Lighting Controls

Lighting controls are another means of reducing energy consumption. When used correctly, they can lengthen the operating life of lamps and ballasts. Of all lighting controls, automatic occupancy sensors usually save the most energy. Manual override controls are the next best. Automatic and manual dimming can have a good payback, but the savings are usually smaller. The two main types of automatic-occupancy sensor controllers are passive infrared and ultrasonic. Some hybrid controllers are available.

Ultrasonic sensors send out sound waves that bounce off objects. Moving objects change the frequency of the reflected waves, which the sensors interpret as occupancy. Ultrasonic sensors are preferred in areas with many obstructions where the sensor does not have a clear line of sight of the occupants. They are sensitive to any moving object, not just people. A sensor that is installed or adjusted incorrectly can cycle the lights on and off in an unoccupied room. To prevent this problem, ultrasonic sensors have a sensitivity adjustment that can be tuned after installation. Ultrasonic sensors are also equipped with a time delay (usually adjustable) that will shut off the lights when the sensor does not detect movement for a predetermined time.

Passive infrared sensors differentiate between the heat of a person and the background heat of the room. They function by tracking a heat source from one area to another. Unlike ultrasonic sensors, passive infrared sensors must have a direct line of sight to the occupants. When the sensor does not see a moving heat source after a certain period (usually adjustable), the sensor turns off the lights. Obstructing the sensor's field of view can turn off the lights, irritating employees.

Hybrid sensors usually contain a passive infrared sensor and an ultrasonic sensor. They will activate the lighting system when sensors detect movement. A typical hybrid sensor will continue to provide power to the lights so long as at least one sensor detects movement. When neither sensor detects movement, the lights are turned off after a set time delay. Hybrid sensors reduce the chance that lights will be turned on when no one is in the building, or turned off when someone is in the building.

Improperly installed occupancy sensors and overly complicated controls have limited the acceptance of automatic lighting controls. In most cases, lighting control problems are due to human errors in positioning, adjusting, and programming sensors and controls. Qualified persons should design and install the controls. The entire system should be thoroughly tested before it is accepted. See *Commissioning Existing Buildings* (9871-2301-MTDC) for further information. Incompatibility of components can lead to problems. It is best to select a complete system from a single manufacturer that integrates all control components. It is also important to meet State and local requirements.

Maintenance

In general, the lighting installation and all materials must meet applicable local codes and the National Electric Code. Lamps and ballasts must be compatible. It is extremely important to specify ballast factor, ballast type, correlated color temperature, and color rendition index.

The Environmental Protection Agency assumes all ballasts contain PCBs (polychlorinated biphenyls, a hazardous material) unless they have labels stating that they do not contain PCBs (figure 3). All ballasts manufactured before January 1, 1979, contain PCBs. Ballasts with PCBs cannot be disposed of at landfills. They must be recycled or disposed of at facilities approved by the U.S. Environmental Protection Agency.

Conclusions

When specifying or maintaining lighting systems, design engineers and facility managers need to focus on providing high-quality, energy-efficient light. Maintenance personnel are responsible for maintaining the lighting system. End users must ask for good lighting and turn off lights when they are not in use.

Automatic occupancy sensors with readily available manual overrides typically have the best payback of all control strategies. New T8 fluorescent lamps with a high color rendition index and electronic ballasts should be used in all new buildings and retrofits. Such lighting systems improve productivity, and also save energy and money, a worthwhile bonus.

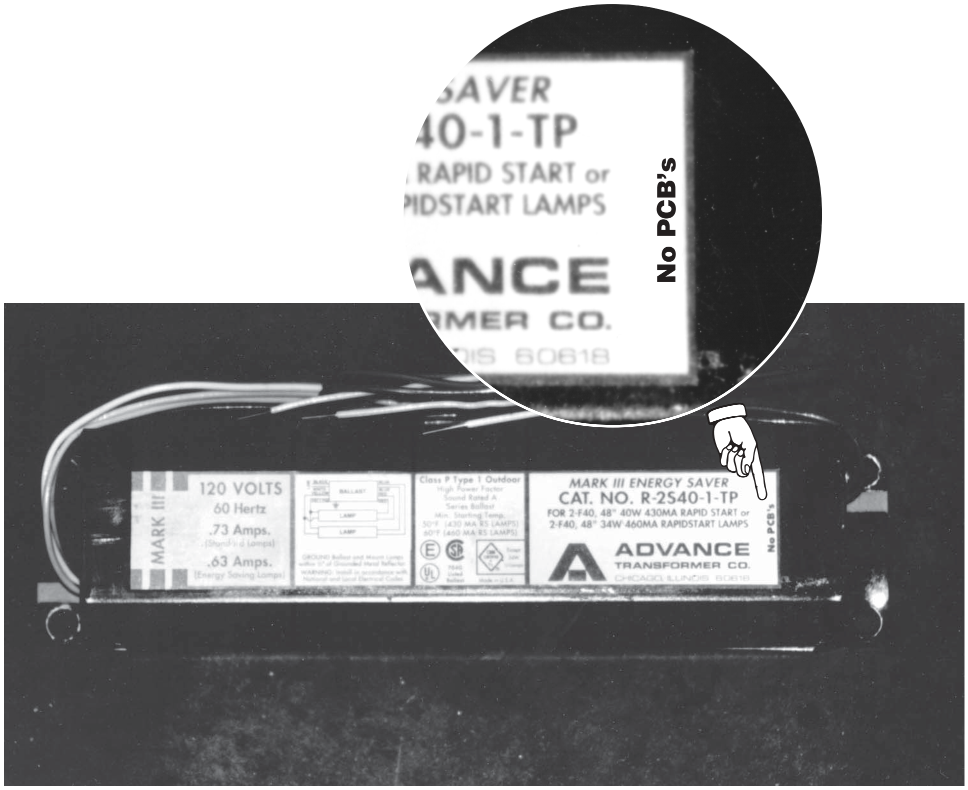

Figure 3—Fluorescent lamp ballast without PCBs (polychlorinated biphenyls, a hazardous material).

Additional Information on Fluorescent Lighting

Evaluating Fluorescent Lamp Options Under EPACT
February 1994, *Plant Engineering*

Lighting And Human Performance: A Review
National Electrical Manufacturers Association
2101 L St. NW.
Washington, DC 20037

Lighting Maintenance
November 1998, *Energy & Engineered Systems*

The Lighting Management Handbook
Craig DiLouie
The Fairmont Press, Inc., 1967

Lighting Control Web Sites—

National Lighting Project Information Program
http://www.lrc.rpi.edu/NLPIP/Online/sensors.html

EPA's Energystar Label for Buildings Program
http://www.energystar.gov

Federal Energy Management Program
http://www.eren.doe.gov/femp/greenfed/index.html

Fluorescent Lighting Nomenclature

The pattern for interpreting fluorescent lamp names is FWWCCTDD where:

F....... Fluorescent lamp.

WW.. Nominal power in watts (4, 5, 8, 12, 15, 20, 33, and so forth).

CC.... The color. W = white, CW =cool white, WW = warm white, and so forth.

T....... Tubular bulb.

DD.... Diameter of the tube in eighths of an inch. A T8 bulb has a diameter of 1 inch, a T12 bulb has a diameter of $1\frac{1}{2}$ inches, and so forth.

For example, an F40T12 lamp is a 40-watt fluorescent lamp with a $1\frac{1}{2}$-inch tubular bulb.

Maintenance, Performance, and Safety Tips for Fluorescent Lighting

General

- Always meet applicable electric codes for the installation: National Electric Code, State, and local codes. All fixtures must comply with applicable Underwriter's Laboratory, Canadian Standards Association, and American National Standards Institute requirements.
- Install fixtures to prevent damage from excessive heat. Consult the manufacturer or dealer for specific application.
- Install new lamps in groups at manufacturer's recommended life.
- Clean lamps and fixtures annually.

Lamps

- Make sure the replacement lamps have the same correlated color temperature (CCT) and color rendering index (CRI) as the original lamps.
- Only use lamps of the same wattage rating as the ballast.
- Disconnect rapid-start lamp ballasts when removing lamps.
- Replace lamps when replacing ballasts.
- Replace failed lamps immediately. A failed lamp left in its socket will cause magnetic or electronic ballasts to fail.
- Replace lamps in sets. Do not operate a new lamp with an old ballast.
- Consult your lighting dealer if installing lamps where the ambient temperature is below 50 °F.
- Never install fluorescent lamps on conventional voltage reduction dimming circuits.
- To avoid radio interference, position fluorescent lamps more than 10 feet from radio equipment.

Ballasts

- Make sure replacement ballasts have the same ballast factor.
- Do not replace defective electronic ballasts with magnetic ballasts.
- Encased ballasts should be protected from weather if they are installed outside.
- Fixtures and ballasts must be grounded properly. Always use high power-factor ballasts (90 percent). Electronic ballasts are available for dimming fluorescent lamps.
- If noise levels are considered important in an application, be sure to use ballasts with class "A" sound rating.
- Ballasts manufactured before 1978 may contain polychlorinated byphenyls (PCBs). Ballasts made without PCBs will have ***No PCBs*** printed on them. PCBs are a human carcinogen and must be handled and disposed of as a hazardous waste.

High-Intensity Lighting

- Fixtures in high-temperature areas should have high-temperature rated ballasts or core and coil ballasts. Fixtures should never exceed 356 °F.
- High-intensity discharge (high-pressure sodium vapor, quartz halogen, and metal halide) lamps should be mounted vertically (some models are available for horizontal mounting applications).
- Use diffused-type high-pressure sodium vapor lamps for longer lamp life.
- Tungsten-halogen lamps (quartz and ultrapure glass) fail early if marred by fingerprints. Handle lamps with soft cloth or gloves.

—Information courtesy of the Montana Power Co.

About the Author

Dave Dieziger came to MTDC from the Northern Region fleet management staff in 1999. He has a bachelor's degree in mechanical engineering from the University of Idaho and is a licensed professional engineer. Other experience includes American Society of Mechanical Engineers certification as a certified boiler inspector, energy conservation work for the Navy, enlisted service in the Navy, and work as a city fireman.

Library Card

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Evaluates the savings from retrofitting standard 4-foot F40T12 fluorescent lamps and magnetic ballasts in Forest Service buildings. Modern fluorescent lamps may pay for themselves through energy savings in a couple of years or less, depending on the cost of electricity. The modern lamps also provide a higher quality light. New T8 fluorescent lamps with a high color rendition and electronic ballasts should be used in all new buildings and retrofits. Information on the nomenclature used for fluorescent lights and tips for maintenance, performance, and safety are included. A glossary of lighting terminology and detailed information on calculating energy savings, heating and cooling savings, and simple payback for the lighting system retrofit at the Missoula Technology and Development Center are available on the Forest Service and Bureau of Land Management's internal computer network at the MTDC web site: *http://fsweb.mtdc.wo.fs.fed.us/pubs/htmlpubs/htm01712310/fluorescent_summary.htm*

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