United States Environmental Protection Agency

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LIGHTING MAINTENANCE

Proper lighting system maintenance is essential to high quality, efficient lighting. Systematic lighting management methods and services from lighting specialists can help organize the process and assure continued high performance of any lighting system.

CONTENTS

ACTION CHECKLIST

- ✔ Group relamp to reduce lumen depreciation and maintenance costs.
- ✔ Clean fixtures at the time of relamping, more often in dirty locations.
- ✔ Write a lighting maintenance policy.
- ✔ Design your lighting upgrade projects to incorporate effective maintenance.
- ✔ Get help when needed from the following resources:
  - ★ lighting management companies
  - ★ consultants
  - ★ distributors
  - ★ manufacturers

INTRODUCTION

Lighting maintenance is more than simply replacing lamps and ballasts when they fail. Facility managers today must manage their lighting resources (i.e., fixtures, lamp/ballast inventory, labor, energy) to sustain the quality of a lighting system.

The light output of a luminaire decreases with age and use, yet the energy input remains unchanged. (See Exhibit 1 on the next page.) Because the human eye is extremely adaptive to gradually changing lighting conditions, most occupants do not notice the gradual decline in light levels. Eventually, however, the reduction will affect the appearance of the space and the productivity and safety of the occupants.

In the past, lighting designers have dealt with this problem by increasing the number of fixtures or lamps to compensate for the future light loss. While this simplifies maintenance, it is not an acceptable solution due to the added initial equipment cost, energy cost, and energy-related pollution.

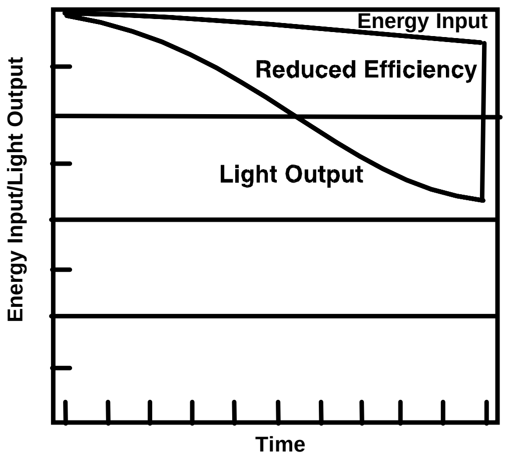
LIGHT LOSS FACTORS

Three factors cause light loss.

- lamp and ballast failure
- lamp lumen depreciation
- luminaire dirt depreciation

Light loss gradually decreases system efficiency over time. In combination, these factors commonly reduce light output by 20-60%. No corresponding energy reduction is associated with light loss, except with lamp and ballast failure.

EXHIBIT 1
LOST EFFICIENCY OVER TIME



Lamp and Ballast Failures

When lamps and ballasts fail, they no longer provide light for the space. Often, failed lamps and ballasts remain in fixtures for months.

Lamp Failures

Lamp manufacturers list the "average rated life" for their products. The average rated life is the number of operating hours after which one-half of the lamps can be expected to have failed. A few lamps may fail soon after installation, and the rate of failure will increase as the time in use increases (see Exhibit 2). Several factors affect lamp life.

- average operating time between starts
- type of ballast circuit
- improper installation

Based on the type of lamps in use and the operating conditions, it is possible to predict lamp failure rate accurately. Such predictions enable you to schedule the replacement of all the lamps just before substantial failures begin. This group replacement of lamps at 70% of rated life will reduce the light loss caused by lamp failure and will reduce the time, effort, and complaints associated with spot replacement of lamps. In addition, expired lamps left in the luminaire can cause ballasts to fail prematurely. The few lamps that fail between group replacements can be tolerated or spot-replaced as needed.

Typical Lamp Life	
Incandescent	1-2,000 hrs
Halogen	2-3,000 hrs
Fluorescent	12-20,000 hrs
Sodium	12-24,000+ hrs
Metal Halide	8-20,000 hrs
Mercury	20-24,000+ hrs

Ballast Failures

Ballasts last much longer than lamps. The operating temperature of the ballast primarily determines ballast life. But operating temperature varies with the type of ballast, the heat retention characteristics of the luminaire enclosure, and the fixture mounting method. This variation makes ballast life more difficult to predict than lamp life. Electronic ballasts can be expected to operate longer than magnetic ballasts because electronic ballasts produce less heat. While there are no reliable long-term test data available, ballast life is generally described by ballast manufacturers as shown in the box below.

Similar to lamps, the ballast failure rate can be expected to be small in the first 70% of average life and increase beyond that point. By monitoring ballast failures in a facility, it may be possible to predict the value of the potential maintenance savings achievable by replacing ballasts before failure.

Typical Ballast Life	
Magnetic	10 -14 yrs
Efficient Magnetic	12 -15 yrs
Cathode Cutout	15 -17 yrs
Electronic	15 - 20 yrs

EXHIBIT 2
LAMP FAILURE RATES

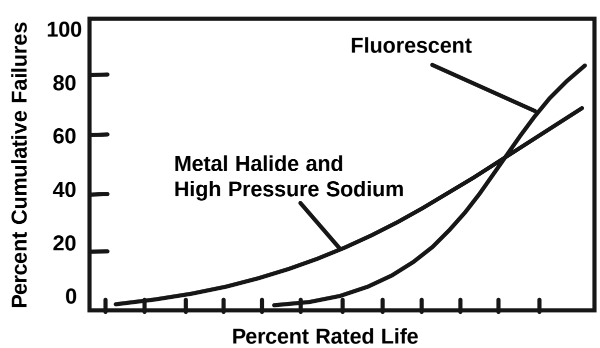


EXHIBIT 3
LAMP LUMEN DEPRECIATION

Source: US Department of Energy

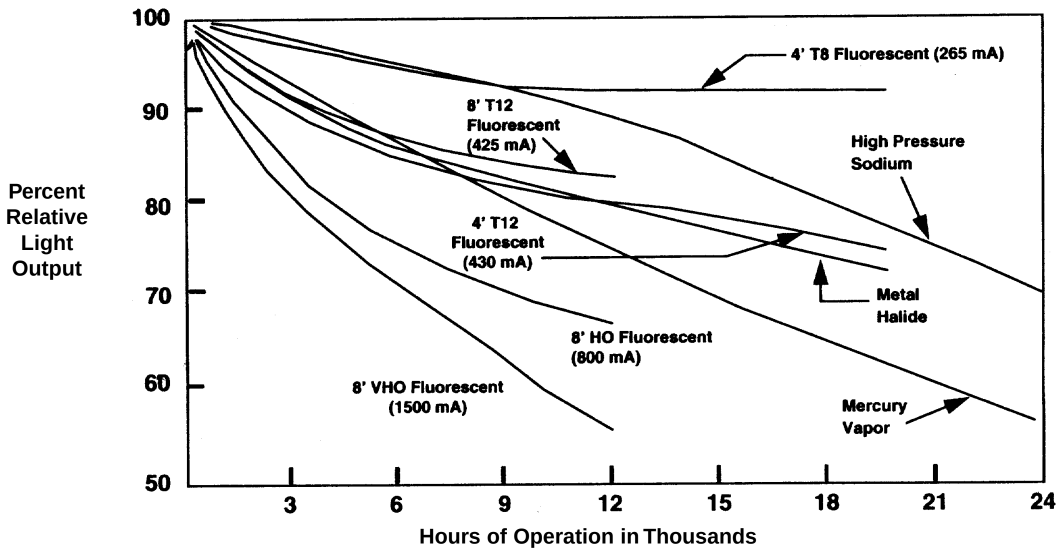


EXHIBIT 4
PROCEDURES FOR DETERMINING LUMINAIRE MAINTENANCE CATEGORIES

Source: IESNA

Maint. Category	Top Enclosure	Bottom Enclosure
I	• None	• None
II	• None • Transparent with 15% or more uplight through apertures • Opaque with 15% or more uplight through apertures	• None • Louvers or baffles
III	• Transparent with less than 15% upward light through apertures • Translucent with less than 15% upward light through apertures • Opaque with less than 15% uplight through apertures	• None • Louvers or baffles
IV	• Transparent unapertured • Translucent unapertured • Opaque unapertured	• None • Louvers
V	• Transparent unapertured • Translucent unapertured • Opaque unapertured	• Transparent unapertured • Translucent unapertured
VI	• None • Transparent unapertured • Translucent unapertured • Opaque unapertured	• Transparent unapertured • Translucent unapertured • Opaque unapertured

Lamp Lumen Depreciation (LLD)

As a lamp ages (through use), the amount of light it produces declines. This change is called lamp lumen depreciation (LLD) and is expressed as a percentage of initial lamp light output. Several factors can cause LLD, such as carbon deposits inside the bulb wall or deterioration of the phosphor coating inside the bulb. Incandescent and high pressure sodium lamps have minimal LLD (i.e., they maintain a high percentage of their initial output throughout their useful life). Fluorescent, mercury and metal halide lamps, however, exhibit significant lumen depreciation (See Exhibit 3).

To calculate average light levels, a lighting designer considers the light output of a lamp at the average age the lamp is expected to reach in use. By replacing lamps earlier, it is possible to achieve the same light levels with fewer lamps and less energy.

Luminaire Dirt Depreciation (LDD)

Dust, smoke film, oil and dirt accumulate on the reflective surfaces of fixtures, lenses and lamps. As a result, less of the light produced by the lamps is delivered into the room. This depreciation can be very minor in closed fixtures located in clean rooms, but it can be very severe in open fixtures in dirty environments. Estimating the effect of dirt depreciation is important for determining fixture cleaning schedules.

The following Illuminating Engineering Society of North America (IESNA) tables and graphs are used for determining LDD.

- Use Exhibit 4 to identify the luminaire category.
- Use Exhibit 5 to identify the dirt condition for the space.
- Use Exhibit 6 to estimate the luminaire dirt depreciation factor once the luminaire category, dirt conditions, and cleaning cycle have been established.

MAINTENANCE PLANNING

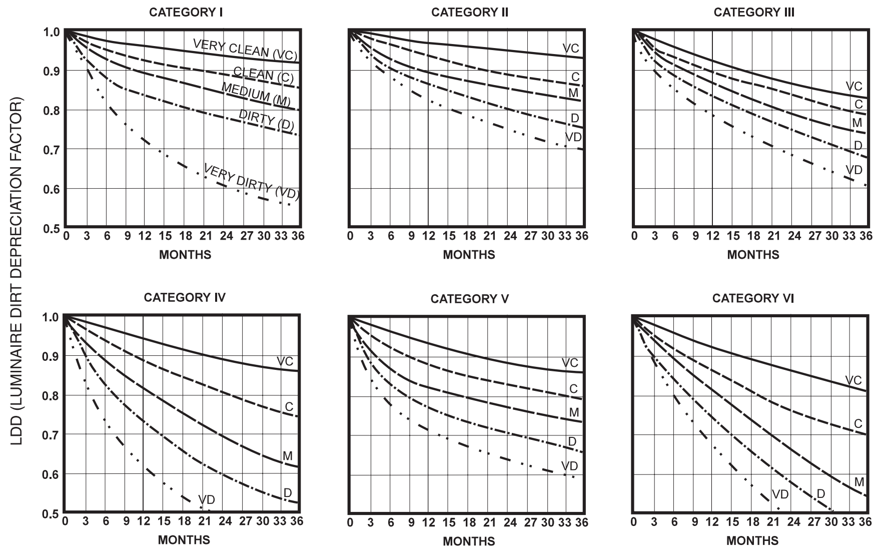
Many maintenance managers are hesitant to replace lamps that are still operating. But group relamping and cleaning can be less expensive than sporadic spot maintenance. Through strategic planning and performance management of the overall lighting system, costs can be reduced and lighting quality improved.

Group relamping is analogous to changing the spark plugs in your car. All of the spark plugs are changed at the same maintenance interval. This saves time and money and improves the overall efficiency of your car. As the spark plugs age, gas mileage of the car declines. Similarly with lighting, the efficiency and output of the system will decrease as lamps age. This change could decrease worker productivity. The most efficient maintenance method is to group-replace your lamps, just as you would group-replace the spark plugs in your car.

EXHIBIT 5
FIVE DEGREES OF DIRT CONDITIONS
Source: IESNA

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

EXHIBIT 6
DIRT DEPRECIATION GRAPHS
Source: IESNA



Advantages of Group Relamping and Cleaning

- ★ Saves money, time, and energy
- ★ Improves overall system efficiency
- ★ Reduces maintenance time and costs
- ★ Technician does not have to wait for service requests
- ★ Technician does not have to 'search' for a lamp and ladder
- ★ Technician does not have to travel to two or more remote sites to replace only a few lamps
- ★ Technician does not have to return the ladder and dispose of the lamps, one-by-one
- ★ Efficiently utilizes maintenance personnel
- ★ Reduces lamp and ballast inventory
- ★ Reduces material costs through bulk purchasing practices
- ★ Provides higher maintained light levels
- ★ Prevents unnecessary ballast degradation caused by ballasts trying to start expired lamps

Step 1: Define Existing Condition

The first step in planning a lighting maintenance strategy is to define the existing condition of the lighting systems. You must evaluate the following.

- type of lamps and ballasts in use
- average age of the lamps/ballasts
- total annual hours of lighting operation
- product costs
- spot replacement labor costs
- group replacement labor costs
- energy costs
- the rate of dirt accumulation

Step 2: Establish a Relamping Interval

You can identify an appropriate time to group relamp the lighting system. First, you must determine an acceptable level of light loss and an acceptable number of lamp failures (or spot replacements). Exhibit 2 shows that after 70 percent of rated life, the mortality rate of fluorescent lamps sharply increases. Therefore, group relamping traditionally occurs at 70 percent of the lamps' rated life. For example, suppose a lamp is rated at 20,000 hours and is operated 4,000 hrs per year. Then relamping should take place at 14,000 hours of lamp life, or at approximately three-year intervals.

EXHIBIT 7
CALCULATING MAINTAINED LIGHT LEVEL

$$\mathbf{fc} = \frac{\text{rated lumens} \times CU \times BF \times LSD \times RSDD \times \mathbf{LLD} \times \mathbf{LDD} \times \mathbf{LBO}}{\text{area of room (ft}^2\text{)}}$$

CU	=	coefficient of utilization
BF	=	ballast factor
LSD	=	luminaire surface depreciation
RSDD	=	room surface dirt depreciation
LLD	**=**	**lamp luminaire depreciation**
LDD	**=**	**luminaire dirt depreciation**
LBO	**=**	**lamp burnouts (%)**

Step 3: Predict Light Loss Factor

Armed with the above information, it is possible to evaluate existing and future light loss. The mortality, lumen depreciation, and dirt depreciation curves are used to determine the maintained illumination, which is the average illumination expected over time. An overall light loss factor is applied to initial illumination value to obtain the maintained illumination value. The formula for light loss factor (LLF) follows.

LLF = LLD x LDD x LBO

Where,
LLD = Lamp lumen depreciation
LDD = Luminaire dirt depreciation
LBO = Lamp burnout, or lamp mortality rate

These are three of the *recoverable* components of light loss that a good maintenance program can minimize. The equation for maintained illuminance on horizontal surfaces, shows the significant impact these factors have on light levels (see Exhibit 7). These factors are *multiplied*, typically resulting in lumen output reductions of over 40% in poorly maintained systems.

Although room surface dirt depreciation (RSDD) is a recoverable factor, it is often ignored in lighting calculations and maintenance programs. Since most offices today are smoke-free, the RSDD is minimal relative to the other light loss factors. However, in manufacturing and other dirty environments, RSDD can have a significant effect and should not be ignored. Refer to the 8th edition of the *IES Lighting Handbook* for more information on calculating RSDD.

Step 4: Develop a Maintenance Method

There are several factors to consider when planning a lighting maintenance strategy.

- Use existing staff, hire new staff, or use a contractor.
- Complete during regular hours, nights, weekends.
- Manage quality control.
- Dispose of lamps and ballasts responsibly.
- Re-lamp building-wide or in stages.
- Establish product types.
- Establish testing procedures for exit and emergency lighting.

Step 5: Budget for Maintenance

Budgeting is the most difficult part of planning a maintenance program. Spot maintenance of a lighting system can be sporadic on a daily basis, but the annual cost will be constant after the first few years. Strategic maintenance, on the other hand, is easier to manage on a daily basis and may cost less overall, but the cost fluctuates each year.

Suppose you want to maintain the fluorescent lighting on a spot basis in a facility that operates 4,000 hours per year. This approach would require replacing about 20% of the lamps every year. To maintain the same facility on a group basis would require minimal replacement for two years, and then 100% replacement every third year.

Because budgets are often established a year in advance, it is necessary to predict relamp timing and budget accordingly. As an alternative, lighting maintenance budgets can be leveled by completing an equal portion of the group maintenance each year. In the example above, for instance, completing a group relamp of 33% of the facility each year will level the annual cost.

Step 6: Write a Lighting Maintenance Policy

For a lighting maintenance program to be most effective, it needs to be carried out regularly over the life of the lighting system. You can write a lighting maintenance policy once you have completed a lighting management analysis, developed a method, and established a budget. This will help in getting the program approved and will enable the plan to be carried out by other personnel in the future or in other facilities. Include justification for the maintenance plan, so that future managers can understand the importance of effective maintenance. Most important, it will assure a systematic continuation of the program.

Step 7: Implement the Strategy

A well-planned strategy can be easy to implement. Many companies use outside contractors to complete major tasks and then use inside staff to provide spot maintenance. Others contract with an outside lighting or electrical company to completely manage the lighting. Similarly, an outside company can designate and train a lighting management team within the company.

Whichever method you select, strategic lighting will also make lighting maintenance a predictable task and reduce unscheduled maintenance requirements.

GETTING HELP

As the demand for planned lighting maintenance has increased, so have the services offered by the lighting industry. The following are some resources available to help analyze, plan and implement efficient lighting maintenance.

Lamp Manufacturers

Although strategic lighting management can save energy and labor costs, group maintenance will usually require the use of more lamps. As a result, lamp manufacturers have an interest in providing assistance in analyzing lighting management strategies. Most of this assistance is valuable and reliable and offered free (or at low cost). Contact your lamp supplier or manufacturer for information. Many manufacturers are also Green Lights Manufacturer Allies. Assistance from lamp manufacturers is available from several sources.

- local factory representatives
- distributors
- software tools
- training programs

Lighting Management Companies

Lighting management companies (LMCs) are maintenance or electrical contractors that specialize in lighting installation, upgrade, management, and maintenance. Many offer a free or low cost service to identify optimum lighting maintenance programs. Some LMCs may offer consulting services to help develop in-house lighting management programs, but most are interested in providing upgrade installation and maintenance contract services. Many of these are Green Lights Lighting Management Company Allies.

EXAMPLE

The following example shows how strategically planned lighting maintenance can reduce energy consumption, prevent pollution, and control costs. The assumptions for this example are as follows.

- old office building
- 25,000 square feet
- 250 luminaires (category V, CU = 0.70)
- 4 F40T12/CW lamps per luminaire
- no luminaire cleaning for the existing system
- 20,000 hr lamp life
- 4,000 hr/yr operation

Step 1: Calculating Relamping Frequency

The first step is to determine the average number of lamps replaced per year. This will depend on the type of relamping practice chosen.

Average Annual Relamps for Spot Relamping

The average annual relamps for spot relamping is calculated as follows.

- 20,000 hrs life/4,000 hrs per yr = 5 year life
- 1,000 lamps/5 years = ***200 average annual relamps***

Average Annual Relamps for Group Relamping

The average annual relamps for group relamping is calculated as follows.

- (20,000 hrs life)x(0.70 group relamping factor) /4,000 hrs per yr = 3.5 years
- use 3 year relamping interval
- 1,000 lamps/3 years = 333 relamps per year
- (1,000 lamps)x(0.07 premature spot failures) /3 year interval = 23 spot failures per year
- 333 + 23 = ***356 average annual relamps***

Step 2: Determining Light Loss Factors

The next step is determining the light loss factors — LLD and LDD. A value of 1.0 will be used for LBO, which assumes that lamps that burn out will be spot-replaced without a long delay. Exhibit 8 summarizes the light loss factors used in this example. Following is the rationale for the use of the various factors. Note that group versus spot relamping practices will affect these factors significantly.

LLD

Spot Relamping

LLD for spot relamping is the average value of the lumen depreciation. The value for this example is chosen from the graph in Exhibit 3 at 40% rated life (or 8,000 hours). The T12 graph indicates that the LLD value is 0.82 at 8,000 hours.

Group Relamping

LLD for group relamping is the lumen depreciation at the time of the group relamp. This is at 14,000 (20,000 x 0.70) hours life for both the T8 and the T12 lamps. Referring to Exhibit 3, the lamp lumen depreciation at 14,000 hours for the T8 is 0.93, and for the T12 is 0.78.

LBO

Spot Relamping

After 20,000 hours, half of the lamps will have failed. The LBO for spot relamping can vary significantly depending on the promptness of the maintenance staff. For this example the LBO is 1.0 which assumes prompt replacement of failed lamps.

Group Relamping

According to Exhibit 2, approximately seven percent of the lamps will fail at 70 percent of their rated life. However, again an LBO factor of 1.0 is used. Note the spot replacement costs of the 7% premature failures is accounted for in the financial analysis of Exhibit 9.

LDD

Spot Relamping

Fixture cleaning is not typically included in spot relamping practices. This example assumes that the fixtures will be cleaned at least once during their 20 year expected life. Therefore, a ten year cleaning cycle is used. To find the LDD for this extended period, the luminaire dirt depreciation equation is used. For simplicity reasons, the equation is not presented in this text but can be found in the 1993 *IES Lighting Handbook*. For this example a value of 0.65 was calculated.

Group Relamping

Refer to the graphs in Exhibit 6 to determine the LDD, based on the following assumptions.

- a three-year cleaning cycle
- luminaire type V
- a clean environment

The LDD is 0.80 for both the T12 and T8 systems.

Step 3: Calculating Light Levels

The following light level calculations are based on the equation in Exhibit 7 and the factors for LLD, LDD, and LBO are tabulated in Exhibit 8. These factors were determined in the previous step.

T12 Spot Relamping

✍ 3,050 lumens per lamp x 250 luminaires x 4 lamps per luminaire x 0.70 CU x 0.53 LLF/25,000 SF = 45 fc

T12 Group Relamping

✍ 3,050 lumens per lamp x 250 luminaires x 4 lamps per luminaire x 0.70 CU x 0.62 LLF/25,000 SF = 53 fc

T8 Group Relamping

✍ 2,900 lumens per lamp x 250 luminaires x 4 lamps per luminaire x 0.70 CU x 0.74 LLF/25,000 SF = 60 fc

EXHIBIT 8
LIGHT LOSS FACTORS

	T12 Spot	T12 Group	T8 Group
LLD	0.82	0.78	0.93
LBO	1.00	1.00	1.00
LDD	0.65	0.80	0.80
Total LLF*	0.53	0.62	0.74

* LLF = LLD x LDD x LBO

Results

Group relamping and fixture cleaning can reduce maintenance and energy costs (see Exhibit 9). The T8 system has increased light levels while reducing energy consumption and pollution.

A further measure to reduce energy consumption would be to delamp the T8 option from four to three lamps per fixture. This would produce approximately 44 maintained footcandles, and decrease energy costs by an additional 10 percent. There would also be additional material and labor savings due to the fewer number of lamps.

★ A T8 and T12 system with group relamping and cleaning provides **18 to 33 percent more light** than the T12 base case of spot relamping only.

★ The T8 system **reduces energy consumption by 35 percent** as compared to both T12 systems.

★ The T8 system **reduces O&M costs by 31 percent** as compared to the T12 group relamping case.

★ Group relamping and fixture cleaning **save $811 annually** in labor costs.

EXHIBIT 9
AVERAGE ANNUAL O&M COSTS

	T12 Spot Relamping	T12 Group Relamping	T8 Group Relamping
Lamp Costs			
T12 Lamps (spot) 200 @ $1.50/lamp	$300	----	----
T12 Lamps (group) 356 lamps @ $1.50/lamp	----	$534	----
+ spot relamping of premature failures, 23 @$1.50		$34	
T8 Lamp (group) 356 lamps @ $2.00/lamp	----	----	$712
+ spot relamping of premature failures, 23 @$2.00			$46
Labor Costs			
T12 Relamp Labor (spot) 200 @ $7.50/lamp	$1500	----	----
T12 Relamp Labor (group) 356 lamps @ $0.75/lamp	----	$267	----
+ spot relamping of premature failures, 23 @$7.50		$172	
T8 Relamp Labor (group) 356 lamps @ $0.75/lamp	----	----	$267
+ spot relamping of premature failures, 23 @$7.50			$172
Fixture Cleaning Costs			
Fixture Cleaning (group) 333 @ $0.75/fix.	----	$250	$250
Energy Costs			
T12 Energy, 192W/fix. @$.07/kWh (assumes LBO=1)	$13,440	$13,440	----
T8 Energy, 124W/fix. @$.07/kWh (assumes LBO=1)	----	----	$8,680
TOTAL ANNUAL O&M COST	**$15,240**	**$14,697**	**$10,127**
ANNUAL O&M SAVINGS	**BASE**	**$543**	**$5,113**

NOTES:

GREEN LIGHTS
A Bright Investment in the Environment

Green Lights is an exciting and innovative program sponsored by the US Environmental Protection Agency (EPA) that encourages major US corporations and other organizations to install energy-efficient lighting technologies.

Organizations that make the commitment to Green Lights will profit by lowering their electricity bills, improving lighting quality, and increasing worker productivity. They will also reduce the air pollution caused by electricity generation.

For more information contact the Green Lights program office.

Green Lights Program
US EPA
401 M Street, SW (6202J)
Washington, DC 20460

Green Lights Information Hotline

☎ (202) 775-6650
Fax: (202) 775-6680

Lighting Maintenance is one of a series of documents known collectively as the *Lighting Upgrade Manual.* Other documents in the Manual are Listed below.

Lighting Upgrade Manual

PLANNING

- *Green Lights Program*
- *Implementation Planning Guidebook*
- *Financial Considerations*
- *Lighting Waste Disposal*
- *Progress Reporting*
- *Communicating Green Lights Success*

TECHNICAL

- *Lighting Fundamentals*
- *Lighting Upgrade Technologies*
- *Lighting Maintenance*
- *Lighting Evaluations*
- *The Lighting Survey*

☞ To order other documents or appendices in this series, contact the Green Lights Hotline at (202) 775-6650. Look in the monthly Green Lights *Update* newsletter for announcements of new publications.

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