ORNL/TM-9981

ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Recommended Lighting Maintenance Practices for Army Installations

R. J. Kedl

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A04 Microfiche A01

ORNL/TM-9981

Energy Division

RECOMMENDED LIGHTING MAINTENANCE PRACTICES FOR ARMY INSTALLATIONS

R. J. Kedl

Date Published - August 1987

Prepared for the
U.S. ARMY FACILITIES ENGINEERING SUPPORT AGENCY
Fort Belvoir, Virginia 22060
under
ARMY CONSERVATION EQUIPMENT TESTING PROGRAM
TASK ORDER/WORK DIRECTIVE NO. 0002

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

EXECUTIVE SUMMARY

Properly maintained lighting can yield dividends in several ways. First, and probably most important, an adequate and well-maintained lighting system contributes to the efficiency and safety of the work force. In addition, if lighting fixtures are maintained so that the illumination level approaches its "new" condition, then the possibility exists that some lamps may be removed while an adequate level of illumination is still maintained.

This report makes recommendations concerning routine lighting maintenance. In the context of this document, "routine lighting maintenance" primarily means relamping and fixture cleaning; however, window cleaning and ceiling and wall painting are also addressed. Ballasts are not included because their maintenance requires a greater level of skill than is required for "routine" maintenance in the sense of this document. Most common sources of interior and exterior lighting are considered: fluorescent, incandescent, and high-intensity discharge. To develop a background for lighting maintenance, the first section of this report describes operating characteristics of the major lamp types; those characteristics that result in light deterioration are emphasized. In addition, light deterioration that results from dirt accumulation on the fixture (lens and reflector) is discussed, and correlations are presented.

To develop these recommendations, a number of sources of information were used:

1. a literature search was conducted,
2. information was requested from the major lamp manufacturers and the industries' professional and trade associations,
3. two Army posts were visited to determine current lighting maintenance practices, and
4. discussions were held with the maintenance supervisors of two large entities in the nonmilitary sector (a city and a university) to determine their practices.

With information derived from the above sources, a comparative economic analysis based on an office-type building containing 1000

fluorescent tubes was conducted on various lighting maintenance practices. Various combinations of spot relamping (either by central maintenance or a utility person in the building), scheduled relamping (semiannually and annually), group relamping, and fixture cleaning (annually and every 2 years) were considered.

The recommendations are based on the availability of a central maintenance staff, such as that available through the Army's Directorate of Engineering and Housing (DEH). Also, they are influenced by the comparative economic analysis and by acceptable practices in the Army and the nonmilitary sector. Their objective is to achieve acceptable lighting at a minimum cost.

1. FLUORESCENT FIXTURES

It is recommended that, typically, fixtures be inspected and relamped (replace burned-out tubes) semiannually by DEH and that they (including windows) be cleaned annually by custodial subcontract. Certain buildings may require a greater or lesser level of maintenance because of their environment, mission, public exposure, or frequency of use. For those cases, the level of maintenance should be jointly acceptable to the supervisor of the building involved and DEH. Spot relamping should be discouraged except for a few special cases. Group relamping (periodic replacement of *all* lamps) is not recommended as a dedicated practice for a large installation with a central maintenance staff.

2. INCANDESCENT LAMPS

The only widespread use of incandescent lamps in the Army is in military housing and barracks. It is recommended that personnel who live in military housing be responsible for their own lighting maintenance, including the purchase of bulbs. It is recommended that occupants of barracks be responsible for their own lamp replacement but that a supply of bulbs be maintained in the barracks for that purpose.

3. HIGH-INTENSITY DISCHARGE LAMPS

Because of their nature (widely spaced and high above the floor), it is recommended that high-intensity discharge (HID) lamps be replaced by DEH at the building supervisor's request. This recommendation is the same for both interior and exterior lights. However, roadway, walkway, and parking-lot lights are a special case; on many large installations, there are a sufficient number to warrant annual inspection and relamping. Typically, HID fixtures are relatively well sealed and high off the floor; thus, they require little cleaning except in special cases.

4. EMERGENCY LIGHTS

Army regulations dictate the maintenance policy for emergency lighting systems. These should continue to be followed.

RECOMMENDED LIGHTING MAINTENANCE PRACTICES FOR ARMY INSTALLATIONS

R. J. Kedl

ABSTRACT

A well-maintained lighting system contributes to workforce efficiency and safety. This report recommends routine lighting maintenance practices (primarily relamping and fixture cleaning) for Army installations. The recommendations are derived from consideration of a comparative economic analysis, current maintenance practices in the military and nonmilitary sectors, and information obtained from industry trade and professional associations. Most common sources of interior and exterior illumination are considered: fluorescent, incandescent, and high-intensity discharge. Recommendations concerning window cleaning and wall and ceiling paint are included.

---

1. PURPOSE

The purpose of this investigation is to evaluate current routine lighting maintenance practices at major Army installations and to make recommendations concerning how these maintenance practices may be improved or their costs reduced.

2. SCOPE

Maintenance practices for major Army installations are recommended for all forms of lighting: fluorescent, incandescent, and high-intensity discharge (HID), both interior and exterior. In the context of this study, "lighting maintenance" means routine maintenance and is limited to lamp replacement and cleaning of fixtures and windows. Ballasts are not included because their maintenance requires a greater level of skill than is required for "routine" maintenance. Painting of walls and ceilings is also discussed.

3. BACKGROUND

The U.S. Army Facilities Engineering Support Agency (FESA), Fort Belvoir, Virginia, issued Task Order No. 0005 on July 25, 1985,[1] requesting that lighting maintenance practices at Army installations be reviewed and evaluated and that recommendations be made to improve them. To meet the objective of this task, the following actions were taken.

1. A DIALOG search of COMPENDEX, ENGINEERING MEETINGS, and NTIS data bases and a DOE/RECON search of the ENERGY data base were conducted. The search identified 215 references of which 31 reprints were requested for review.
2. Letters describing the task and requesting appropriate information were sent to the major lamp manufacturers.[2-4]
3. Letters describing the task and requesting appropriate information were sent to the industry professional and trade associations.[5,6]
4. Two Army posts — one a FORSCOM and the other an AMC — were visited to determine current lighting maintenance practices.[7]
5. The maintenance supervisors of two large, nonmilitary entities were contacted to determine the maintenance practices of large nonmilitary organizations.[8,9]

The data-base search disclosed that the U.S. Navy has developed a computer code (RELAMP) that determines annual cost for various lighting maintenance practices.[10] Associated with this code is a document that specifies detailed labor time requirements for various components of relamping and cleaning operations.[11] The computer code was not used by Oak Ridge National Laboratory (ORNL) in this study nor was it used extensively by the Navy. However, the labor requirements for relamping and fixture cleaning form the basis for the comparative economic analysis presented in Sect. 5.4 and are included in the appendix.

The recommended lighting maintenance practices are based on input from all of the above sources of information. In general, the recommendations strive to maintain adequate lighting at a minimum cost and assume the existence of a central maintenance staff, such as the Directorate of Engineering and Housing (DEH). They are influenced by existing maintenance practices at Army facilities, existing practices in the nonmilitary sector, and recommendations reported in the literature.

4. CHARACTERISTICS OF LIGHTING SYSTEMS

An understanding of how lamps work, what the variables are that affect their operation, how their light output deteriorates with time, and how they fail is important in determining a meaningful maintenance policy. There are many different types of lamps, and within each type, there are many variations. It is beyond the scope of this study to describe all these kinds and variations. Fortunately, it is only important to understand the basic operation and behavioral characteristics of the major types. Thus, this section will concentrate on general characteristics of incandescent, fluorescent, and HID lamps that would be of interest to a maintenance supervisor. Much of the information in this section was extracted from the Illuminating Engineering Society (IES) lighting handbooks.[12,13] When presented, data will be typical for the class of lamps under discussion. Information for specific lamps is available from the manufacturer.

Note that the deterioration of lamps and light is directly applicable to spaces that are totally illuminated with artificial light. Light deterioration would not be nearly as noticeable in spaces that have windows and are only occupied during the daylight hours.

4.1 INCANDESCENT LAMPS

Light is generated in an incandescent lamp by electric resistance heating of this filament until it glows white hot. The filament temperature in a vacuum lamp operates at about 4000°F and in a gas-filled lamp, about 4700°F. Tungsten is selected for the filament material because of its high melting point, low vapor pressure, and adequate strength at high temperature. Of the total radiant energy emitted by the filament, only a small part is in the visible light range; most is in the infrared region. The quality of light produced is good, but incandescent lamps are the least efficient of all common lights; they typically deliver between 10 to 20 lm/W. Their life is also low, and the most commonly available bulbs have a rated life of 750 or 1000 h. On the other hand, they have the advantage that they do not require a ballast.

The effect of applied voltage on an incandescent bulb is shown in Fig. 1. Note particularly that lamp life is an extremely strong function of the voltage. For example, 5% decrease in voltage will result in a 100% increase in life but only a 10% decrease in light level. Similarly, a 5% increase in voltage will reduce the lamp life to one-half of its rated life.

The operational deterioration of a general-purpose incandescent lamp, as a function of burning time, is shown in Fig. 2. While the lamp is burning, the filament evaporates very slowly. Thus, the diameter of the filament decreases with time, and its electrical resistance increases. The increased resistance causes a reduction in current, power, and light generated. A further reduction in light output results from condensation of evaporated tungsten (and other materials) on the bulb. These two effects can result in an almost 20% reduction in light at its rated life.

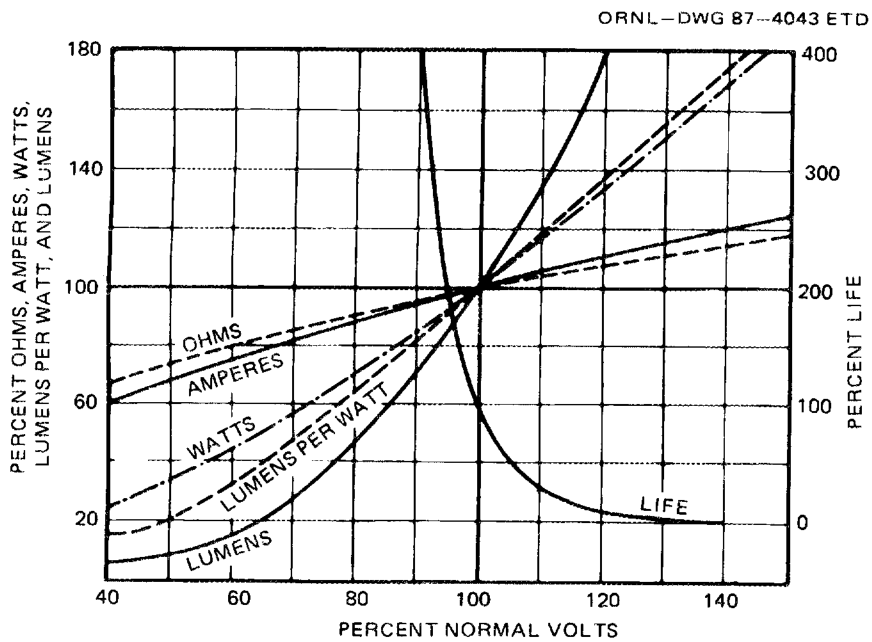


Fig. 1. Effect of voltage on operating characteristics of incandescent lamps in general light circuits. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-12(*a*), p. 8-9.

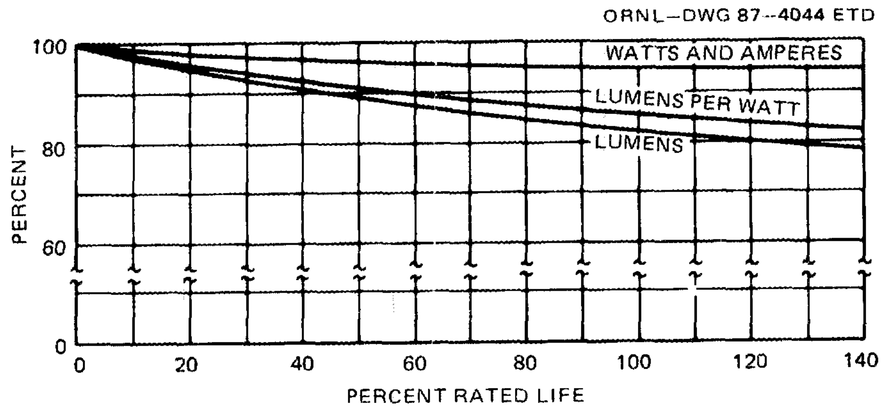


Fig. 2. Typical operating characteristics of general purpose incandescent lamps as function of burning time. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-13(*a*), p. 8-10.

The filament continues to evaporate and becomes thinner and thinner, eventually breaking. This is the most common mechanism for incandescent bulb failure. In a large population of bulbs, all of the filaments evaporate at about the same rate, and, therefore, they all break at more or less the same time. This is illustrated in Fig. 3 in which the percent of survival is plotted against time. Note that at 50% of the design life, <5% of the bulbs have burned out and that the highest mortality *rate* (steepest part of the curve) occurs at the rated life. Another observation is that 60% of the lights burn out during the relatively short period between 80 and 120% of the rated life. These mortality characteristics form the technical basis for group-relamping, in which a population of bulbs that were installed at the same time and have the same burn schedule are allowed to remain installed for about 80% of their rated lives. At this time, about 20% of the lamps have burned out. The failure rate of the remaining lamps is increasing rapidly, and they have short additional life expectancies. Therefore, *all* bulbs are replaced at this time. Maintenance costs are kept low because in group relamping the time required to replace a single lamp is low when compared with lamp replacement on request.

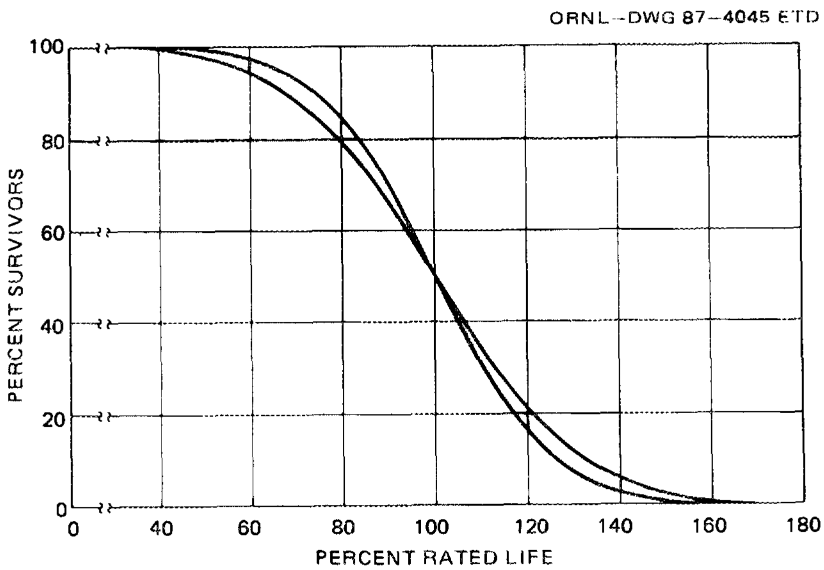


Fig. 3. Range of typical mortality curves for good-quality incandescent lamps. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-14(*a*), p. 8-11.

4.2 FLUORESCENT LAMPS

Light is generated in a fluorescent lamp predominately by fluorescent phosphor powder on the inside tube surface that is activated by ultraviolet energy generated from a mercury arc within the tube. Some visible light is generated by the mercury arc. Fluorescent lamps must be operated in series with a ballast that provides the required starting and operating voltage and limits the current to the design value. The ballast typically requires 12 to 24% of the electrical power required by the fixture. Most common fluorescent lamps are the hot-cathode type, which implies that they contain a tungsten cathode filament coated with alkaline earth oxides to enhance electron emission. The cathode operates at about 2000°F, and the tube contains a small amount of liquid mercury. The amount of mercury in the gas phase is controlled by its vapor pressure which, in turn, is controlled by the lamp temperature. In addition, the tube contains some combination of argon, krypton, neon, or xenon at low pressure. Variation in color (shades of white) of the light may be achieved by phosphor control. Lights can be made "warm" by increasing the proportion of red in the spectrum or "cool" by increasing the proportion of blue in the spectrum. In recent years a variety of new fluorescent lamps that feature reduced electrical power requirements have been developed; however, these lamps often have reduced light output. Fluorescent lamps have a much higher efficiency than incandescent bulbs and typically deliver from 35 to 90 lm/W. Their rated life is also much higher than incandescent bulbs, typically ranging from 10,000 to 20,000 h.

The overall efficiency of a fluorescent lamp increases with tube length (Fig. 4) because the electrical requirements of the electrodes, which do not generate light, are essentially constant. As the tube increases in length, it becomes a smaller component of the total electrical requirements of the light.

Light deterioration with time and ultimate failure of a fluorescent lamp are dependent on many factors, including the frequency of on/off cycles, electrical current loading, compatibility of lamp and ballast,

ORNL–DWG 87–4046 ETD

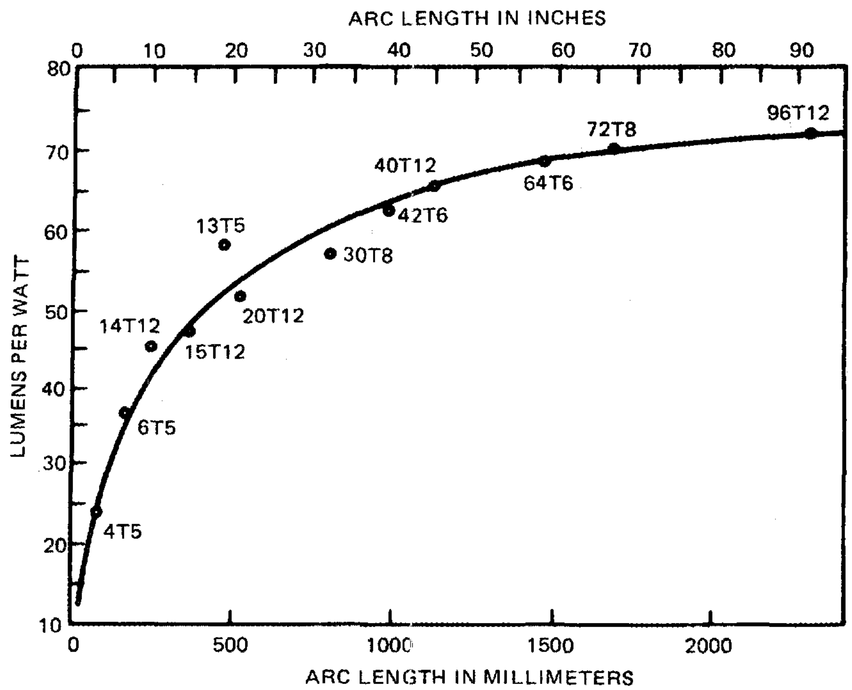


Fig. 4. Light generation efficiency of typical fluorescent lamps as function of lamp length. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-26(*a*), p. 8-26.

and temperature. The deterioration of light output with time for typical fluorescent lamps is shown in Fig. 5. The mechanisms for this deterioration are not fully understood. At least one mechanism is evaporation of the hot-cathode material and subsequent condensation on the tube surface (as with incandescent lamps). Figure 5 shows that light reduction with age can be quite high for a heavily loaded lamp. Most commonly available tubes are lightly loaded. The hot-cathode is designed to minimize evaporation of its materials; nevertheless, the materials do evaporate during the starting sequence and during normal operation. When coating evaporates from the electrodes to the point that they become nonemissive, the lamp burns out. As with incandescent lamps, the evaporation rate is fairly constant; thus, failure of a large number of fluorescent tubes subject to the same operating conditions occurs at more or less the same time. This is shown in Fig. 6 for typical fluorescent lamps of good quality. Note that the average life of fluorescent tubes is usually based on 3 h of operation per start. The number of starts can have a considerable effect on the life. For

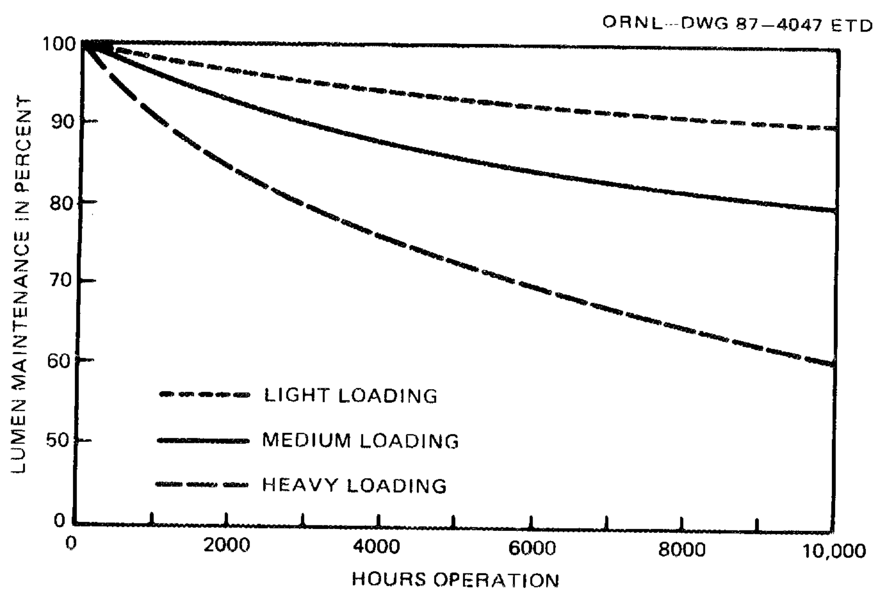


Fig. 5. Deterioration of light output for typical fluorescent lamps as function of operating time. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-32(*a*), p. 8-29.

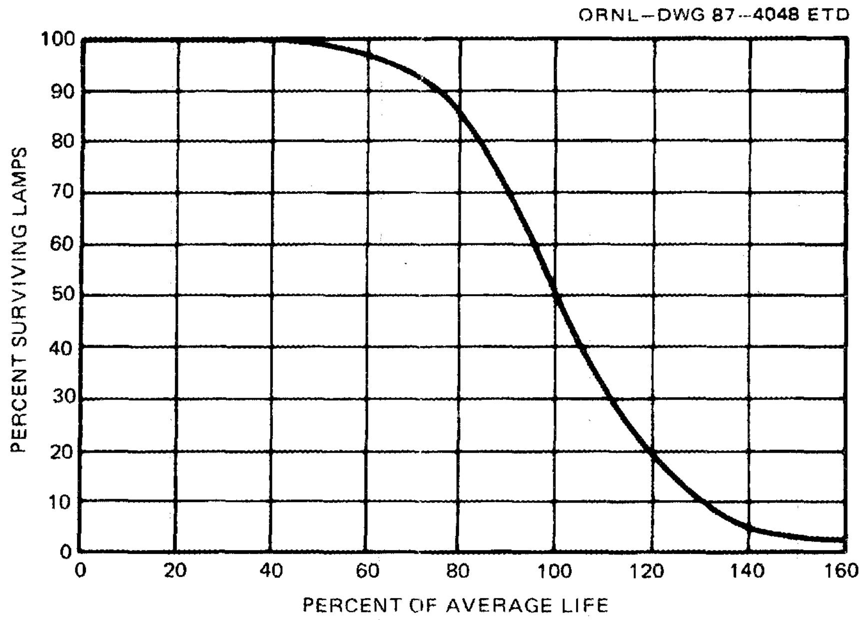
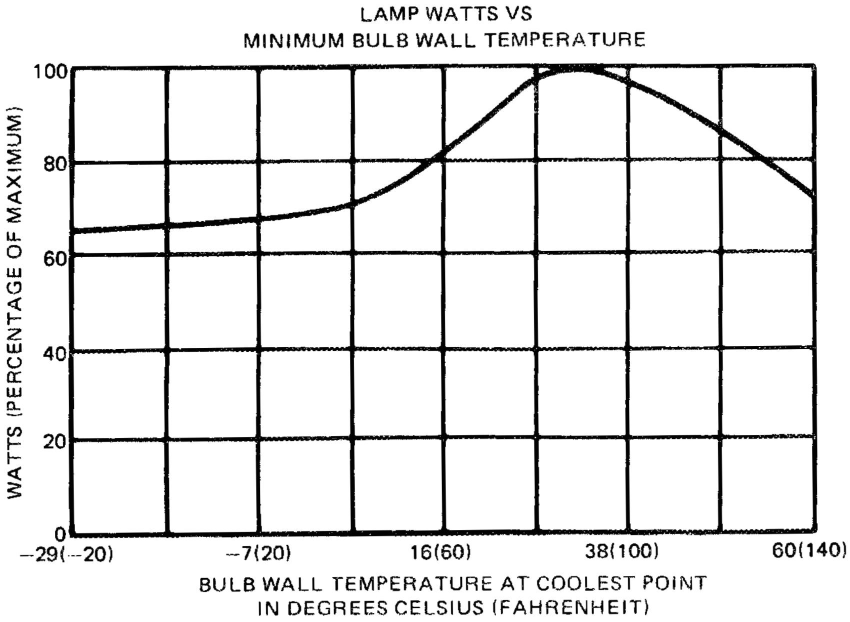


Fig. 6. Typical mortality curve for a statistically large group of fluorescent lamps (at three operating hours between starts). *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-31(*a*), p. 8-28.

example, the life of a fluorescent tube can almost double if it is burned continuously until failure. Note the similarity between the mortality curves for fluorescent lamps (Fig. 6) and incandescent lamps (Fig. 3). Virtually the same comments made on the shape of the curve and group relamping for incandescent bulbs can be made for fluorescent tubes. The average life of a ballast, operating at a 50% duty cycle and a proper temperature, is normally estimated to be about 12 years.

Temperature has an extremely strong effect on the performance of fluorescent lamps. The light output depends on the amount of mercury in the gas phase of the tube, which is a function of the mercury vapor pressure and, thus, the ambient temperature. Electrical characteristics are also affected by temperature (Fig. 7). Note that the light output peaks at a tube temperature of about 100°F and decreases at higher and lower temperatures. At a tube temperature of 60°F, probably not uncommon in warehouses and shops, the light output is almost one-half of the output at 80°F. The electrical power requirements also drop but not

ORNL–DWG 87–4049 ETD



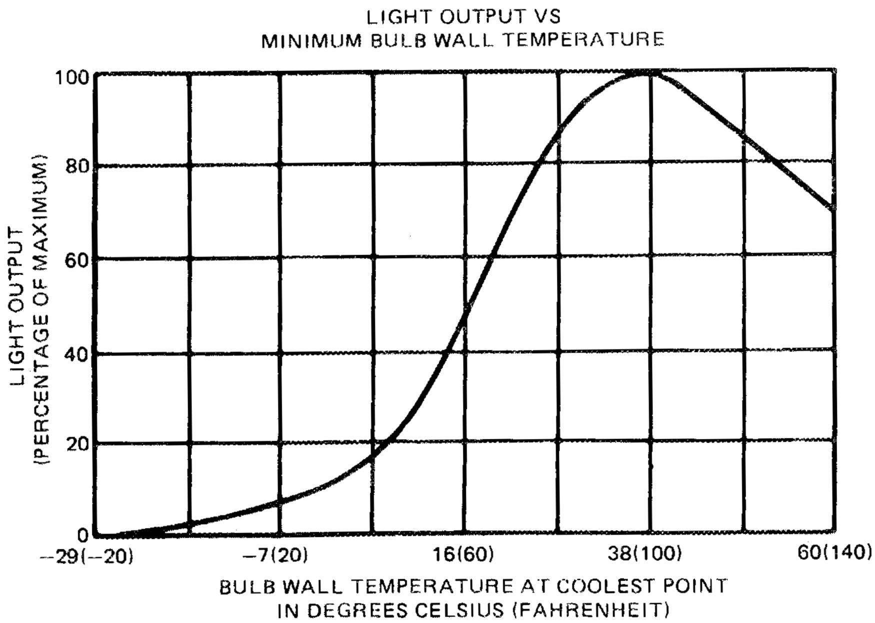


Fig. 7. Typical fluorescent lamp temperature characteristics. Exact shape of curves will depend upon lamp and ballast type; however, all fluorescent lamps have curves of the same general shape. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-34, p. 8-29.

nearly as much; thus, the overall efficiency of the tube decreases considerably. At temperatures of 0 to 10°F, the lamp is almost out. Jacketed lamps and fixtures and slip-on jackets are available for fluorescent lamps to conserve heat and, thus, raise the tube temperature. In addition, special ballasts are available for reliable low-temperature operation. Special lamps containing a mercury amalgam, which reduces the mercury vapor pressure, are available for high-temperature services.

4.3 HIGH-INTENSITY DISCHARGE LAMPS

HID is a generic term for a group of lamps that include mercury vapor, metal halide, low-pressure sodium, and high-pressure sodium. The characteristic common to this group is that they produce light by a stabilized arc discharge contained within an arc tube. All HID lamps require a ballast.

In mercury vapor lamps, light is produced by passing an electric current through mercury vapor. Once the arc is struck, its heat vaporizes all of the mercury present, usually to a final operating pressure of 2 to 4 atm. A significant portion of the light energy generated in the arc is in the ultraviolet region. As with fluorescent lights, this radiation is converted to visible light by use of phosphor coating. Light quality is good and can be controlled to an extent with the phosphor. After a cold start, several minutes are required to vaporize the pool of mercury and reach full light output, typically 3 to 7 min. Restarting a hot lamp when the arc is extinguished takes about the same amount of time. In this case, the lamp must be cooled to lower the mercury vapor pressure to a point where the arc can be restruck with the voltage available. Mercury vapor lamps have a fairly low efficiency, and their output ranges from about 30 to 65 lm/W (excluding ballast losses). Power requirements for the ballast are usually 5 to 15% of the power required by the lamp. Mercury vapor lamps are little affected by ambient temperature. Some lamps are equipped to extinguish automatically the arc if the outer bulb is broken and, thus, minimize the potential exposure to ultraviolet radiation. Deterioration and ultimate failure of mercury vapor lamps are a result of electrode evaporation and condensation, similar to other lamps previously discussed. Figure 8 shows the deterioration of a 400-W mercury vapor lamp as a function of time. The expected life of a mercury vapor lamp is commonly in excess of 24,000 h. After this period of time, its light output has decreased by about 40%.

Metal halide lamps operate very similarly to mercury vapor lamps, the major difference being that the arc tube contains various metal halides in addition to mercury. Metal halides are added to the arc tube surface. When the lamp is hot, some of the halide evaporates, and when the vaporized halide enters the arc, it dissociates into a metal plus

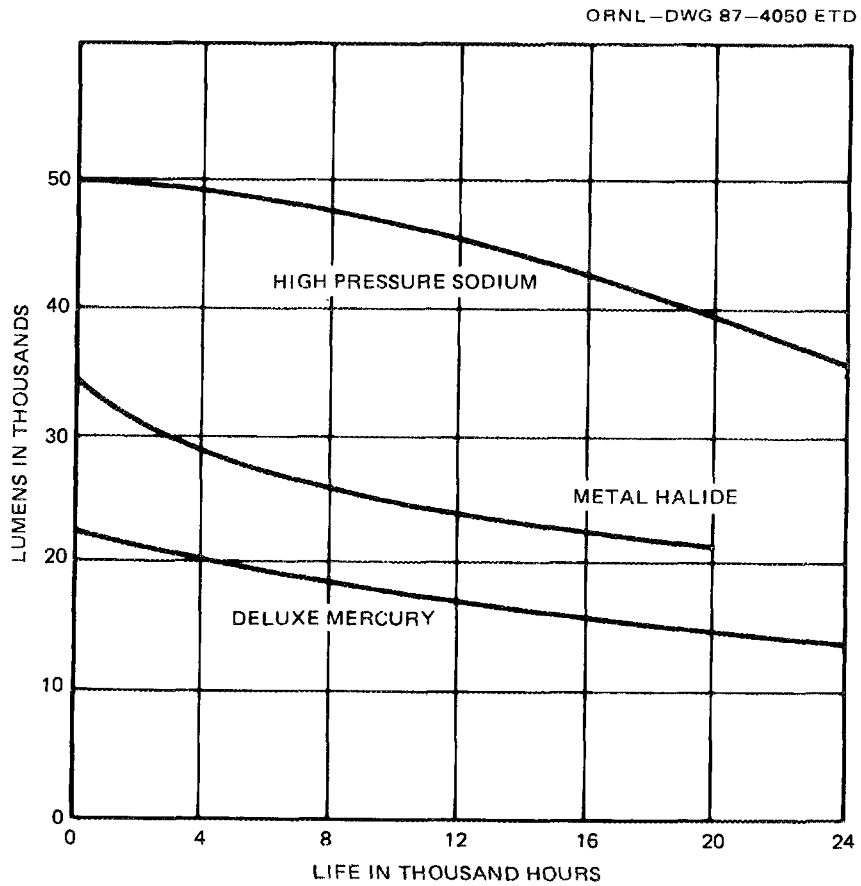


Fig. 8. Typical deterioration of light output for 400-W HID lamps. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 8-52, p. 8-44.

the halide. Radiation from the arc is then determined by two metals, mercury plus the metal introduced as a halide. Thus, the metal halide concept can be considered as a technique for introducing a second metal to the arc. The light output from a metal halide lamp is increased considerably from a mercury vapor lamp and commonly ranges from 75 to 125 lm/V (excluding ballast losses). Starting characteristics are similar to a mercury vapor lamp. As the lamp warms up, it may go through several color changes as the various halides begin to vaporize. Metal halide lamps operate at higher temperatures than mercury vapor lamps and require more time to cool. Restrike time for a metal halide lamp may be as long as 15 min. Halide lamps are more sensitive to orientation than mercury lamps. When the lamp is operated horizontally, the arc bows up. The metal halides tend to condense below the arc (coldest spot) and no longer contribute to the lamp operation. The light output is reduced and its color changed. Reactions between the halide (iodine) and electrode materials preclude the use of the same electrode materials as in mercury lamps. The alternate materials evaporate at a greater rate. Thus, the deterioration of output from a metal halide lamp (see Fig. 8) is somewhat greater than for a mercury lamp, and the expected life is shorter. The rated life of a metal halide lamp ranges from 10,000 to 20,000 h. After 20,000 h the light output has decreased about 40%. Although most metal halide lamps require a ballast specifically designed for them, certain halide lamp designs can be operated with some mercury ballasts for retrofit situations.

In high-pressure sodium lamps, light is produced by passing an electric current through a sodium vapor. These lamps are constructed with two envelopes: an inner alumina arc tube and an outer glass containment bulb. The outer glass tube is evacuated to isolate it from ambient temperature effects and drafts. Most high-pressure sodium lamps can burn in any position, and all radiate energy across the visible spectrum although the light has a marked golden-white color. These lamps have a high efficiency and typically deliver 60 to 140 lm/W. Once started, it takes ~10 min for the lamp to reach full light output. It will usually restrike in <1 min after it is extinguished and reaches full output in 3 to 4 min. Though to a lesser extent, the deterioration of light output follows a similar pattern as other HID lamps. Figure 8 shows that for a typical high-pressure sodium lamp the decrease in output is about 30% after 24,000 h. The rated life of high-pressure sodium lamps is as great as 24,000 h; however, replacement is often necessary because one characteristic of these lamps is a slow rise in operating voltage over the lamp's life. This rise is caused by blackening of the arc tube (electrode evaporation and condensation) that, in turn, heats up the tube ends and causes additional sodium vaporization. The resulting increase in pressure in the arc tube causes a voltage increase. When the ballast can no longer supply the required voltage, the lamp will extinguish. When it cools down, the lamp will again ignite and warm up until the ballast again can no longer support the arc. This cycling continues until the lamp fails completely or is replaced.

In low-pressure sodium lamps, light is produced in almost exactly the same way as in a high-pressure sodium lamp. The difference is that the sodium concentration in the arc is several orders of magnitude less, resulting in the light produced by a low-pressure sodium lamp being almost pure monochromatic yellow. Color rendition with this light is extremely poor. It takes 7 to 15 min to reach full light output after the arc is struck; however, reignition is good, and these lights can be restarted almost immediately after power interruption. Low-pressure sodium lamps are among the most efficient lamps available, and outputs in excess of 180 lm/W, excluding ballast losses (~150 lm/W including ballast losses), are available. The rated life of these lamps is usually 18,000 h. Low-pressure sodium lights are not common in the United States because of their poor light quality.

4.4 INSTALLED LAMPS AND FIXTURES

The light output from installed lamps will deteriorate with time for a number of reasons. Some light deterioration is recoverable, and some is not. Nonrecoverable light losses are defined as those that result from aging of the lamp and permanent changes to the lenses (yellowing) and reflectors (surface corrosion). Recoverable losses are defined as those that result from dirt accumulation on the lenses and reflectors, dirt accumulation on the room surfaces, and lamp burnout.

Nonrecoverable losses caused by lamp aging have been described in Sects. 4.1—4.3. Within the lighting industry this kind of light deterioration is referred to as lamp lumen depreciation (LLD).

Light reduction that results from dirt accumulation on the fixture is a complex phenomenon and is difficult to predict. Nevertheless, to approximate this effect, the *IES Lighting Handbook* presents a correlation that takes into consideration the degree to which the fixture is sealed or louvered against outside air drafts and the kind and amount of dirt that may be transported to the fixture. Within the lighting industry this kind of light deterioration is referred to as luminair dirt depreciation (LDD), and the correlations involved are shown in Figs. 9—11. The characteristics of the fixtures are factored into the approximation by the maintenance category selected in Fig. 9. The characteristics of the dirt are factored into the approximation with Fig. 10, in which the degree of dirtiness is selected. Having selected the appropriate maintenance category and degree of dirtiness, a reasonable approximation of the recoverable light deterioration with time (LDD) from Fig. 11 can be obtained. This correlation is only for removable dirt and does not include permanent effects, such as reflector corrosion and lens yellowing.

A method of approximating the decreased light that results from dirt accumulation on the room surfaces is also presented by IES. The method involves estimating the degree of dirtiness from Fig. 10 and then factoring in the effect of the relative proportions of the room or space cavity dimensions (length, width, and height). The actual calculation is quite complex, especially the part that considers the effect of space dimensions. Because in most cases the effect of dirty walls on lighting is not great, the results of this correlation will be summarized as follows.

1. For office, classroom, dining, and similar settings (clean air, direct fluorescent lights, low ceilings, or low-hung lights), the effect

ORNL–DWG 87–4051 ETD

To assist in determining Luminaire Dirt Depreciation (LDD) factors, luminaires are separated into six maintenance categories (I through VI). To arrive at categories luminaires are arbitrarily divided into sections, a *Top Enclosure* and a *Bottom Enclosure*, by drawing a horizontal line through the light center of the lamp or lamps. The characteristics listed for the enclosures are then selected as best describing the luminaire. Only one characteristic for the top enclosure and one for the bottom enclosure should be used in determining the category of a luminaire. Percentage of uplight is based on 100 percent for the luminaire.

The maintenance category is determined when there are characteristics in both enclosure columns. If a luminaire falls into more than one category, the lower numbered category is used.

Maintenance Category	Top Enclosure	Bottom Enclosure
I	1. None	1. None
II	1. None 2. Transparent with 15 percent or more uplight through apertures. 3. Translucent with 15 percent or more uplight through apertures. 4. Opaque with 15 percent or more uplight through apertures.	1. None 2. Louvers or baffles
III	1. Transparent with less than 15 percent upward light through apertures. 2. Translucent with less than 15 percent upward light through apertures. 3. Opaque with less than 15 percent uplight through apertures.	1. None 2. Louvers or baffles
IV	1. Transparent unapertured. 2. Translucent unapertured. 3. Opaque unapertured.	1. None 2. Louvers
V	1. Transparent unapertured. 2. Translucent unapertured. 3. Opaque unapertured.	1. Transparent unapertured 2. Translucent unapertured
VI	1. None 2. Transparent unapertured. 3. Translucent unapertured. 4. Opaque unapertured.	1. Transparent unapertured 2. Translucent unapertured 3. Opaque unapertured

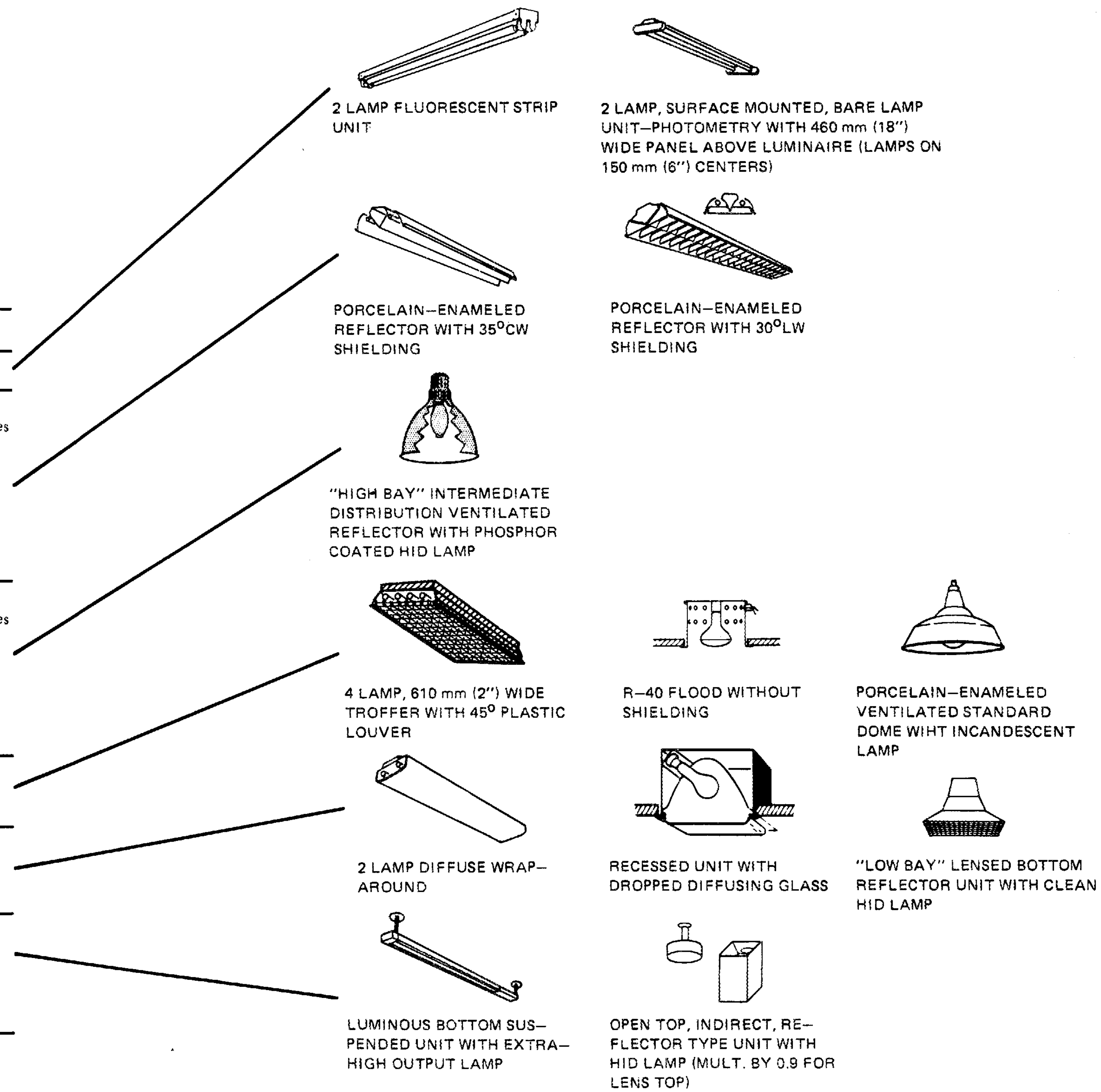


Fig. 9. Procedure for determining luminaire maintenance categories. *Source:* J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 9-2 and 9-12 (Nos. 3, 5, 12, 19, 22, 24, 25, 27, 32, 33, 37, 38, and 48) pp. 9-3 and 9-14–9-28.

ORNL-DWG 87-4052 ETD

	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

Fig. 10. Five degrees of dirt conditions. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 9-4, p. 9-4.

of dirty walls is minimal. The correlations show that, typically, if the interior room surfaces are not cleaned or repainted for 3 years, the general lighting level will decrease by <5% from this effect.

2. For a maintenance shop with dirty air and low-hung fluorescent lights, after 3 years the dirty walls may result in a decrease in light level of about 10%. Many maintenance shops are quite spacious, and only the operations being carried out near the wall would be affected.

3. For a high-bay shop with dirty air and HID lights near the ceiling, after 3 years the dirty walls may result in a decrease in light level of about 15%.

An approximation of light deterioration for roadway and parking-lot lights is shown in Fig. 12. This correlation may also be appropriate for other outside lights, such as for loading docks, piers, and sporting fields.

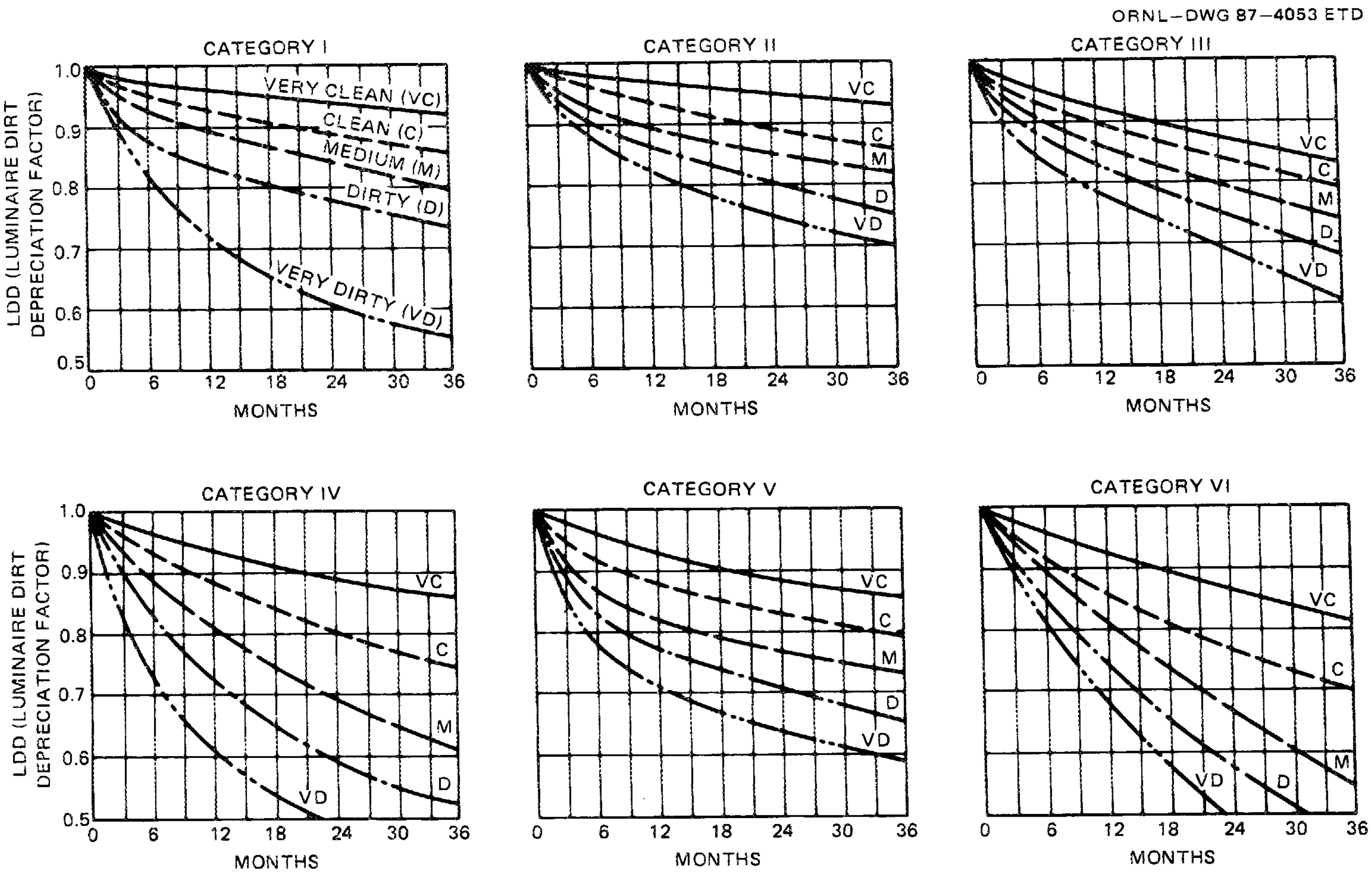


Fig. 11. Luminaire dirt depreciation (LDD) factors for six luminaire categories (I to VI) and for five degrees of dirtiness (as determined from either Fig. 9 or 10. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 9-5, p. 9-5.

ORNL--DWG 87--4054 ETD

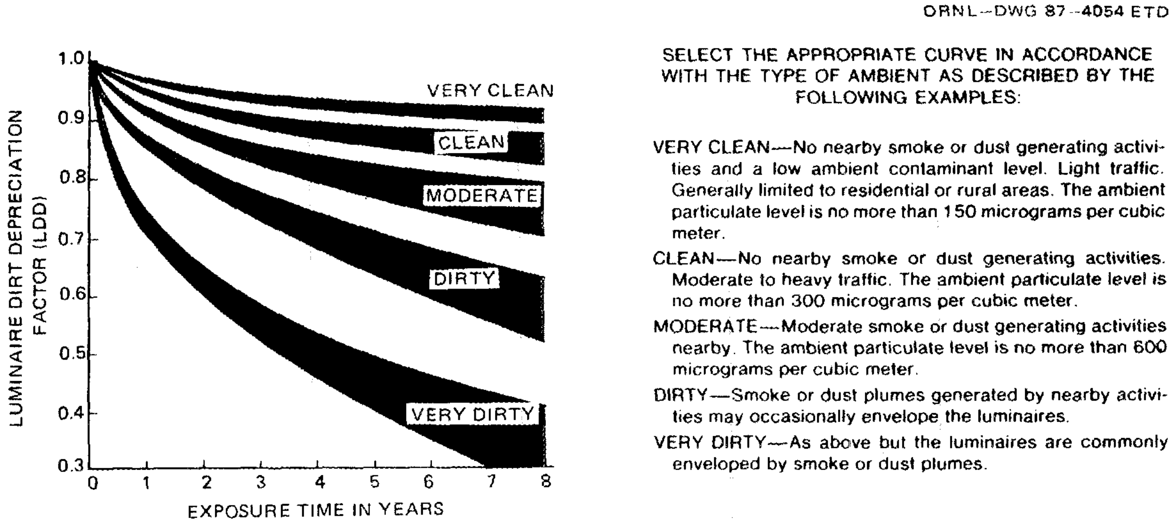


Fig. 12. Chart for estimating roadway luminaire dirt depreciation factors for enclosed and gasketed luminaires. *Source*: J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981, Fig. 14-20, p. 14-26.

5. LIGHTING MAINTENANCE PRACTICES

5.1 INTRODUCTION

A large Army post is a complex installation. In terms of buildings and other physical features that require lighting, it may have private and multifamily housing, barracks and dining halls, administration and office buildings, maintenance buildings, warehouses, shopping malls, inside and outside recreational areas, medical buildings, streets and parking lots, and many special-purpose facilities that are unique to the military. Similarly, the number of kinds of lighting systems are extensive and include general-purpose fluorescent and incandescent lights, interior and exterior HID lamps, safety and emergency lights, and many special-purpose lighting systems (e.g., runaway lights and baseball field lights). The relative composition of an Army installation, in terms of the types of buildings and their personnel, depends on its mission. For example, a FORSCOM post will have a relatively greater number of military personnel and, thus, a greater number of required buildings (housing, barracks, dining halls, etc.) than an AMC post, which may have only a few military personnel but a large number of civilian employees, maintenance shops, laboratories, and warehouses. These differences in composition have an influence on lighting maintenance practices.

Section 5.2 outlines lighting maintenance practices that currently exist at large Army installations. This is followed in Sect. 5.3 by a discussion of lighting maintenance practices at large nonmilitary entities, such as universities and cities. Finally, Sect. 5.4 presents the results of a comparative economic analysis of fluorescent fixture maintenance.

5.2 LIGHTING MAINTENANCE PRACTICES AT ARMY INSTALLATIONS

Two Army installations, a FORSCOM post and an AMC post, were visited during the course of this study.[7] The FORSCOM post can be characterized as having a high density of permanent military personnel and associated buildings (residences, barracks, dining halls, maintenance buildings, and on-site shopping and recreational facilities). The AMC post, with a primary mission of conducting major repairs and overhauls of wheeled military vehicles, can be characterized as having a high density of civilian personnel. Its physical features are mainly heavy maintenance shops and warehouses. Although two Army posts cannot be considered a large sample, it is felt that a great deal has been learned about lighting maintenance at Army installations, and this information is summarized here.

First, it is necessary to note two active Army programs that have an impact on routine lighting maintenance procedures. One, the Army-wide Commercial Activities (CA) program, represents an effort to transfer operation and maintenance (O&M) functions from the federal to the private sector. The CA program is still in the implementation stage; some Army installations are fairly far along while others have only begun. The second, the self-help program, is an effort to require military to be more responsible for their own minor maintenance. For example, the various units on an Army post may be required to obtain their own fluorescent tubes from the supply warehouse and relamp their own fixtures. The self-help program is handled differently throughout the Army. Some installations have a well-developed program; others have none at all.

Four observations relating to current routine lighting maintenance practices of these two installation are made here.

1. Both installations have a DEH and, thus, their own lighting maintenance personnel. These personnel have the necessary expertise, skills, and equipment to undertake virtually any lighting maintenance task that may be required.

2. Lighting systems were adequately maintained at both installations. During a "walk through" visit of a large number of buildings at both installations, few lamps were found burned out. The fixtures and lenses were adequately clean although they were relatively cleaner at the FORSCOM post than at the AMC post. This undoubtedly reflects the nature of the work carried out at the AMC post.

3. Costs associated with routine lighting maintenance are virtually impossible to extract from existing cost accounting records.

4. Although not directly related to maintenance, lighting modifications for energy conservation have been widely incorporated at the FORSCOM post. For example, many fluorescent fixtures there were built for four tubes. In many, if not most, of these fixtures, two tubes have been removed. Additionally, for large sections of roadway, every other HID lamp had been turned off. Similar modifications are being initiated at the AMC post.

A summary of current routine lighting maintenance practices at these installations is listed below. The maintenance practices at the FORSCOM post are strongly influenced by its advanced implementation of the CA program and a well-developed self-help program.

1. Personnel who live in military housing are required to purchase and install their own fluorescent and incandescent lamps. Thus, there are no routine lighting maintenance costs associated with this sector. At a FORSCOM post and similar installations with extensive military housing, such as TRADOC posts, this represents a considerable fraction of the total installed lighting. At an AMC installation, it may represent only a small fraction of the installed lighting.

2. The self-help program at the FORSCOM post has resulted in an innovative minor maintenance procedure involving repair and utility (R&U) personnel. Attached to each unit on the post is a designated R&U person who is responsible for minor maintenance in the one or more buildings assigned to him. For routine lighting maintenance, he has a storage area where he keeps spare fluorescent tubes and incandescent bulbs. Thus, if a necessary lamp burns out, a request to the unit R&U will result in a new lamp. The R&U would clean the fixture at the same time, if needed. The FORSCOM post DEH estimated that roughly 80% of the nonresidential fluorescent and incandescent bulbs are replaced by R&U personnel. Routine lighting maintenance conducted in this manner is accomplished at very little cost to the maintenance program but not necessarily to the Army. It will be seen in Sect. 5.4 that spot replacement of lamps can be the most expensive of the various relamping practices. However, in barracks and certain other military buildings, this kind of lighting maintenance may be considered free (except for the cost of the lamp) because the soldier would probably replace lamps when

he is off duty. There are certain limitations to this kind of lighting maintenance; for example, the light must be 8 ft above the floor and require no special knowledge or equipment.

Some buildings may not lend themselves to effective lighting maintenance by the R&U. Buildings without permanent residents, such as offices, classrooms, and libraries fall into this category. Usually, several lights must burn out in these areas before they are reported.

3. A considerable amount of routine maintenance at the FORSCOM post is accomplished by subcontract issued by the Custodial Contract Administrator. Windows and light fixtures in buildings without permanent residents are cleaned annually by outside personnel under a custodial subcontract. The custodians are required to report burned-out lamps and other problems that they encounter while cleaning the fixtures. The Custodial Contract Administrator then reports the burned-out lamps to the appropriate R&U for replacement.

4. Lighting for the various shops at the AMC post is either HID or fluorescent, and lighting for the warehouses is exclusively fluorescent. Virtually all lamp replacement and fixture cleaning are accomplished by the Electrical Section. HIDs are replaced on request by shop personnel. Fixtures are cleaned at the same time. Fluorescent fixtures are cleaned and relamped on a schedule of once every 1 to 3 years, depending on the shop or warehouse involved. Only the burned-out tubes are replaced during this maintenance period. Many of the machine tools, such as lathes, have their own incandescent task lights attached. Replacement bulbs for these lights are available to the machinist in the shop toolroom.

The Preventive Maintenance (PM) shop at the AMC post replaces fluorescent and incandescent bulbs on request in all buildings on the post. The PM shop has divided the post into four areas. Two men and a vehicle are assigned to each area for maintenance, which includes lamp replacement. Spare lamps are carried in their truck.

A novel feature that will be tried at the AMC post this year (for the first time) is a shutdown of the installation between Christmas and New Years. However, even though the post will be "officially" shut down, a number of personnel with insufficient leave will be working. This remaining work force will be assigned to various maintenance tasks, one of which will be fluorescent tube replacement and fixture cleaning in some of the shops.

5. The CA program is well under way at the FORSCOM post. A direct result of this program is the Performance Work Schedule (PWS), a large document that schedules maintenance activities of all forms. An example concerning lighting maintenance is that the outside lights (street, parking lot, and sidewalk) will be surveyed every 6 months and repaired and cleaned as necessary. The maintenance personnel follow this schedule rigorously. Thus, outside lights at the FORSCOM post are maintained on a 6-month schedule. In certain critical areas, outside lights are repaired on request.

The AMC post has no scheduled maintenance for outside lights. Most lamp replacement results from a request by the night security forces or other personnel who travel the post at night.

6. Group replacement of lights is practiced in situations where economics are judged favorable. For example, the lights in a gymnasium are difficult to reach, and scaffolding may be required. When sufficient lights are burned out to warrant replacement, all lights are replaced and lenses cleaned at the same time.

5.3 COMMON RELAMPING AND CLEANING PRACTICES

With reference to relamping, common routine lighting maintenance practices today fall into three general categories. Each has its own advantages, disadvantages, and applications where it is the most appropriate.

1. Spot replacement or replacement on request — implies that lights are replaced individually, or a few at a time, at the request of the light user. The fixture may be cleaned at the same time. This form of lighting maintenance is considered to be the best practice in situations where relatively few lamps are used to light a large area: high-bay maintenance buildings, auditoriums, roadways and parking lots, security lights, etc. Usually, these areas are lighted with widely spaced HID

lamps. If one lamp burns out, a significant area may be affected, and replacing the lamp immediately may be necessary for security, safety, or work-related reasons. Special equipment, such as high lifts or scaffolding, is usually required. The maintenance crew would normally replace in that area other lamps that require the same special equipment at the same time. Most municipal street lamps are in residential areas and are replaced on request. Because most street lamps are sealed, they are not usually cleaned except when they are being relamped.[9,14]

Certain entities, such as universities and some government buildings, have a utility person assigned permanently to individual (or a few) buildings. In situations like this, the utility person commonly replaces fluorescent tubes on request. The logic is that "the utility person has to be there anyway, so he might as well relamp on request."

2. Scheduled relamping and cleaning — implies that burned-out lamps are replaced and fixtures cleaned in accordance with a schedule that is predetermined by environmental dirtiness and the necessity of the lights. In public buildings with considerable exposure (e.g., city hall and library), fixtures are commonly cleaned semiannually.[8,9] In the more-commonplace offices, fixtures are cleaned annually.[7,9] Industrial buildings fall on the other end of the dirtiness scale. For a large fraction of these buildings, cleaning the fluorescent fixtures semiannually is recommended.[15] In buildings with low ceilings, fluorescent fixtures are often cleaned under a custodial contract. The contractors are identified under "Janitor Service" in the yellow pages of the phone book. Economics dictates this approach because the custodian worker's salary is usually close to the minimum wage. In addition, cleaning operations can be scheduled during nonworking hours, thus minimizing disruption of the normal work force. For higher ceilings, a professional lighting maintenance contractor may be required.[16] Although this contractor's wage scale is higher than the janitorial service, the cost of cleaning fixtures may still be reasonable because he may have high-speed cleaning equipment and rolling scaffolding to do the job rapidly. Professional lighting maintenance contractors are identified under "Lighting Fixtures — Repair and Maintenance" in the yellow pages or by writing to the International Association of Lighting Maintenance Contractors.[6]

Burned-out lamps are always replaced during cleaning operations. Often, when fixtures are cleaned and relamped annually, an additional relamping is scheduled at 6 months.

The level of maintenance in municipal buildings is always determined by consultation between the maintenance supervisor and the building occupant.

Scheduled lighting maintenance, or a variation of it, is probably most common for institutions that are large enough to have a central maintenance staff.

3. Group relamping — is really a special variation of the scheduled relamping technique. The difference is that in group relamping *all* lamps, even those not burned out, are replaced at the same time. The technical basis for group relamping, explained in Sect. 4.1, is that a large fraction (>50%) of a population of lamps installed at the same time and having the same operation schedule can be expected to burn out during a relatively short period of time (at the lamp's rated life). Group relamping applies equally well to incandescent and fluorescent lamps but is most applicable to fluorescent tubes because of their widespread use. When group relamping is practiced, it is recommended that fluorescent tubes be replaced when 10 to 30% have burned out, depending on lighting requirements.[9,15,17,18] For fluorescent tubes, about 10% will have burned out at 75% of their rated lives and about 30% at 90% of their rated lives.

The basic requirement for group relamping to be effective is that most of the lamps in a large population burn out during a relatively short period of time near the end of their expected lives. For this to happen, all lamps in this population must be exposed to approximately the same operating conditions that affect their life expectancy. Specifically, all lamps in the population should be

1. installed at the same time;
2. subjected to the same operating schedule, concerning both the number of on-off cycles and the total on-time;
3. rated the same type (same life expectancy) and possibly even be from the same manufacturer;
4. associated with the same or an equivalent ballast, and the ballast should be expected to outlive the lamp;

5. exposed to the same line voltage; and
6. exposed to the same ambient temperature.

Obviously, some of the above conditions will affect the life expectancy of a lamp more than others. Nevertheless, if any of these conditions are not met, the steep part of the mortality curve will be smeared out, making group relamping less attractive. A group relamping program is particularly difficult to initiate in an existing building or area where the lamps represent a variety of ages. Statistically, only about one-half of the lights will have reached the midpoint of their lives at any one time. In addition, there is a certain resistance by the business manager or the maintenance supervisor to discard a large number of good lamps to start a group relamping program. Thus, group relamping is most suitable for new buildings.[9,18]

In recent years, group relamping of fluorescent tubes has increased in popularity in commercial buildings, such as large retail stores and office buildings. These establishments do not normally have a permanent maintenance staff, and lighting maintenance is not a well-organized operation. Replacement of burned-out lamps is considered a nuisance and is usually accomplished as needed or on a spot-replacement basis. Section 5.4 shows that spot replacement of lamps is the most expensive of all lighting maintenance options. Thus, for commercial buildings, group replacement is a reasonable and economic option. However, a large Army installation has the DEH with a well-equipped and trained staff. For this situation, the economic justification for a dedicated group relamping program is not nearly so obvious.

When fixtures are very difficult to reach, group replacement of lamps is appropriate. If extensive scaffolding is required, such as in an auditorium, then group relamping is often practiced. This decision is usually based on the maintenance supervisor's judgment.

5.4 COMPARATIVE ECONOMICS OF FLUORESCENT LIGHTING MAINTENANCE PRACTICES

The annual cost of various lighting maintenance practices is developed in this section. In the context of this analysis, lighting maintenance consists of relamping and fixture cleaning. The basis for the economic comparison is an office area containing 500 fluorescent fixtures, each containing two 4-ft-long lamps (1000 lamps total). Such an area is probably representative of many office situations in the military. Two cases are considered. In the first case, the building is considered to be existing (or "old"). The distinctive feature of this case is that because of past lighting maintenance practices (spot relamping or scheduled relamping), the existing lamps represent a mixture of ages and possibly a mixture of types and manufacturers. Thus, the fluorescent tubes are burning out continuously and at approximately a constant rate. In the second case, in which the building is considered "new," the distinctive features are that all lamps are assumed to be installed at the same time, all lamps and fixtures are identical, and all lamps have the same operating schedule. Thus, all lamps may be expected to follow cumulatively the same mortality curve. For this case, group relamping is appropriate.

In the case of the existing building, various combinations of scheduled relamping, spot relamping (relamping on request), and 1- or 2-year cleaning cycles are included in the analysis. Spot relamping by DEH is also compared with spot relamping by a utility person located in the building involved. As noted previously, group relamping is probably not appropriate for this case because the first time the lamps are replaced, many good lamps will be discarded. At any one time, only about one-half of the tubes will have reached the midpoint of their expected lives. In the case of the new building, only group relamping is considered. Spot relamping and scheduled relamping are not considered because in the long term, the annual costs will approach those for the existing building case.

All information required for this analysis was obtained from correlations contained in this report. The LLD factor was obtained from Fig. 5 (light loading was assumed). Lamp mortality characteristics were determined from Fig. 6. The LDD factor was obtained from Fig. 9 (maintenance category — V), Fig. 10 (dirt conditions — clean), and Fig. 11. Time requirements for maintenance personnel to perform the relamping and cleaning tasks were those developed by the Navy[11] and included here as the appendix. Note that the appendix also includes an example of how to make the calculations. Thus, the reader may conduct his own analysis for a different kind of building (e.g., a maintenance shop) or a different set of parameters if he desires.

The following additional assumptions were made:

1. The light operating schedule is 12 h/d, 6 d/week, and 3744 h/year.
2. The rated lamp life is 18,000 h. This was selected so that after 4 years (15,000 h of lamp on-time), ~15% of the tubes would be burned out. Thus, group relamping could be practiced on a 4-year cycle. This corresponds to an annual lamp replacement rate of (1000/4) = 250/year. For other relamping practices, the average number of lamps replaced per year is (1,000) (3,744/18,000) = 208/year.
3. Spot relamping, either by DEH or by a utility person located in the building involved, is conducted by a single person.
4. Scheduled relamping, group relamping, and fixture cleaning operations are conducted by a team of two persons from the DEH maintenance shop.
5. The time required to relamp a single tube by a utility person located in the building involved is 10 min.
6. Round-trip travel time from the DEH maintenance shop to the building involved is 30 min.
7. The cost of a new fluorescent tube is $1.00.
8. The cost of labor, including overhead, is $20.00/h.
9. The cost of electricity is $0.05/kWh, which includes an electric demand charge.

Results of these calculations are shown in Table 1 for the existing building and in Table 2 for the new building. The "Total light retention" in the tables — the product of the LLD, lamp outage, and LDD factor — represents the amount of illumination computed as a percentage of the illumination when the lighting system was new. In each case, two values are listed: the first is the illumination retention just before relamping and fixture cleaning; the second is the illumination retention just after relamping and fixture cleaning. The total average annual maintenance cost is the sum of the annual cost of lamps, relamping, and fixture cleaning. When the costs can be singled out, they are shown

Table 1. Lighting retention and annual costs of lighting maintenance practices for an existing (old) building or area[a]

Lighting-retention or maintenance parameter	Maintenance practice							
	Spot relamping by DEH; annual fixture cleaning	Spot relamping by DEH; fixture cleaning every 2 years	Spot relamping by local person; fixture cleaning annually	Spot relamping by local person; fixture cleaning every 2 years	Scheduled semiannually; fixture cleaning annually	Scheduled semiannually; fixture cleaning every 2 years	Scheduled annually; fixture cleaning annually	Scheduled annually; fixture cleaning every 2 years
	Light retention from new condition (%)							
Lamp lumen depreciation (LLD) factor	89.0/89.0[b]	89.0/89.0[b]	89.0/89.0[b]	89.0/89.0[b]	89.0/90.1[b]	89.0/90.1[b]	89.0/91.3[b]	89.0/91.3[b]
Lamp outage factor	100/100	100/100	100/100	100/100	89.6/100	89.6/100	79.2/100	79.2/100
Luminaire dirt depreciation (LDD) factor	88.0/100	83.0/100	88.0/100	83.0/100	88.0/100	83.0/100	88.0/100	83.0/100
Total (three factors multiplied)	78.3/89.0	73.9/89.0	78.3/89.0	73.9/89.0	70.2/90.1	66.2/90.1	62.0/91.3	58.5/91.3
	Average annual maintenance costs ($)							
Lamps	208	208	208	208	208	208	208	208
Relamping	2234	2234	695	695				
Fixture cleaning	1750	875	1750	875				
Relamping and fixture cleaning combined					1964	1108	1838	1028
Total (four cost added)	4192	3317	2653	1778	2172	1316	2046	1236

[a]The annual cost of electricity for all lights in this building or area is $9000 (at $0.05/kWh).

[b]Before maintenance/after maintenance.

Table 2. Lighting retention and annual costs of lighting maintenance practices for a new building or area[a]

Lighting-retention or maintenance parameter	Maintenance practice: Spot relamping; scheduled fixture cleaning	Scheduled relamping; scheduled fixture cleaning	Group relamp — 4-year cycle[b] and relamp annually; annual fixture cleaning	Group relamp — 4-year cycle and relamp annually; fixture cleaning every 2 years	Variable scheduled;[c] annual fixture cleaning
Light retention from new condition (%)					
Lamp lumen depreciation (LLD) factor	In the long term, light depreciation factors and annual maintenance costs will approach those of existing buildings (Table 1); initially, these values may cycle substantially.	In the long term, light depreciation factors and annual maintenance costs will approach those of existing buildings (Table 1); initially, these values may cycle substantially.	88.0/100[c]	88.0/100[c]	89.7/92.3[c]
Lamp outage factor			87.0/100	86.0/100	80.0/100
Luminaire dirt depreciation (LDD) factor			88.0/100	83.0/100	88.0/100
Total (three factors multiplied)			67.4/100	62.8/100	63.1/92.3
Average annual maintenance costs ($)					
Lamps			250	250	132
Relamping					
Fixture cleaning					
Relamping and fixture cleaning combined			1810	934	1860
Total (four costs added)			2060	1184	1992

[a]The annual cost of electricity for these lights, at $0.05/kWh, is $9000.

[b]It is assumed that light fixture cleaning crews will replace lamps that they observe to be burned out.

[c]Before maintenance/after maintenance.

separately. Note that the costs are annualized and do not necessarily represent the yearly cost. For example, consider group relamping on a 4-year cycle with fixture cleaning every 2 years. The maintenance costs for years 1 and 3 will be very low, but for years 2 and 4 will be almost twice the value shown in the table. Finally, calculations of this nature are, by necessity, highly idealized. Changes in the assumptions can make changes in the annual costs. Therefore, small differences in the annual costs should not be regarded as significant. Nevertheless, in a broader sense, these calculations do represent reasonable estimates of annual maintenance costs (consistent with assumptions and parameters selected) and can be used for comparative purposes.

First, consider lighting maintenance in the existing building (Table 1). The principal comparison to be made for this building is spot maintenance vs scheduled maintenance. For equal fixture cleaning cycles, the estimated cost for spot relamping by DEH is, by far, the most-expensive maintenance practice. Even spot maintenance by a person located in the same building is significantly more expensive than scheduled maintenance. Spot maintenance has the advantage of somewhat higher maintained light retention because lamps are replaced as they burn out (lamp outage factor = 100%). On the average, 208 lamps out of 1000 (20.8%) burn out each year. Thus, the lamp outage factor for scheduled relamping on an annual cycle is 100 – 20.8 = 79.2% and 89.6% on a semiannual cycle.

For scheduled maintenance the fixtures are relamped at the same time that they are cleaned (when the cycles coincide); therefore, it is not possible to isolate the individual relamping and cleaning costs. For spot relamping, fixture cleaning is a separate operation, and its cost can be extracted. The estimated cost of a complete fixture cleaning operation is $1750. When fixtures are cleaned every 2 years, the annual cost is one-half of this value or $875. Now consider annual scheduled relamping with annual cleaning. The combined annual maintenance cost for relamping and fixture cleaning is $1838. Thus, the incremental cost for relamping is $1838 – $1750 = $88. This is very low compared with the cost for spot relamping of $2234 by DEH or $695 by a person in the building. For the case of relamping semiannually with cleaning annually, the incremental cost for relamping is \$1964 — \$1750 = \$214, which is still very low compared with spot relamping. The difference in incremental relamping costs between semiannual relamping and annual relamping is \$214 — \$88 = \$126. This is a very small cost for ~10% more retained illumination (before maintenance).

The estimated annual lighting maintenance costs and light retention characteristics for the new building are shown in Table 2. Spot relamping and regularly scheduled relamping are not included. In the long term, maintenance costs and light retention for spot relamping and scheduled relamping would approach those of the existing building. However, in the short term they would cycle substantially. For example, the mortality curve used in this analysis shows that <5 lamps will burn out the first year but ~350 will fail during the fifth year. Thus, the cost of spot relamping would be very low the first year but would be considerable the fifth year.

The estimated annual maintenance costs for group relamping in the new building are similar to the estimated costs for the equivalent case of scheduled relamping in the existing building. However, any conclusions from this comparison may be unwarranted because regularly scheduled relamping is inappropriate in a new building where the initial lamp burnout rate is very low but increases rapidly near the lights' rated lives. For the building considered here, only about 150 lamps burn out during the first 4 years, but about 650 burn out during the next 2 years. Annual relamping (during annual cleaning) would be quite adequate for the first 4 years, but semiannual relamping would be required for the next 2 years to maintain adequate lighting. This increased maintenance would probably take place because of either prior planning by DEH or complaints by the building occupants. Following this 2-year period, the relamping schedule could then revert back to annual relamping. Annualized maintenance costs were estimated for this scenario and are shown in Table 2 as "Variable scheduled" relamping. The calculation covered an 8-year period with semiannual relamping during the fifth and sixth years and annual relamping for all other years. Eight years was selected because all of the original tubes can be expected to have failed by then. After this period of time, only about 56 of the second generation of tubes will have burned out; thus, the annualized cost of lamps is (\$1000 + \$56)/8 = \$132. Light retention values in the table are for the end of the fifth year, which is the year of greatest lamp outage. For this special case, the average annual cost of lighting maintenance is approximately the same as for group relamping. Thus, the annual cost of group relamping is approximately the same as for scheduled relamping. If cost is the only consideration, there seems to be no particular economic incentive to develop a dedicated group relamping program. The choice between scheduled relamping and group relamping must be based on other considerations.

The basic requirement for efficient group relamping is that all lamps in a given area or building be identical and operate on the same schedule. There are many reasons why all lamps do not operate on the same schedule. For example, in office buildings, some of the personnel may work different hours than others, or cleanup crews turn lights off at different times; in dining halls, kitchen lights may have different operating schedules than in eating areas. The use of local switches (turn out the lights when the area is not in use) is being encouraged by the military for energy conservation. In general, the active use of local switches is contrary to the requirements of efficient group relamping. The problem, then, is that DEH will not know when the lights in a given area/room/building meet the requirements for efficient group relamping. An extensive inspection and recordkeeping procedure would be required for DEH to decide when to group-relamp and which lamps should be included in the replacement group. Thus, for a large military installation with a DEH, a dedicated effort toward developing a group-relamping program for new buildings is not recommended. If, in retrospect, DEH recognizes that a well-defined group of lamps may be reaching their rated lives, they may elect to replace them as a group or temporarily schedule relamping of burned-out tubes at shorter intervals.

6. RECOMMENDED LIGHTING MAINTENANCE PRACTICES

6.1 INTRODUCTION

In this section, lighting maintenance practices are recommended for large Army installations. In the context of these recommendations, lighting maintenance means relamping and fixture cleaning. Window cleaning and wall and ceiling painting are also considered. The recommendations are largely procedural and are based on the availability of a central maintenance staff, such as that available in DEH, and any specialized equipment that may be necessary. These recommendations are, furthermore, influenced by the comparative economic analysis and by currently acceptable practices in the Army and in equivalent large entities in the nonmilitary sector. The objective of these recommendations is to achieve adequate lighting with minimum procedures and minimum costs.

The recommendations are made of what is considered to be a typical case and are, therefore, appropriate for most installations. However, deviations from typical can be expected. A level of lighting maintenance greater than recommended may be required for buildings in a particularly dirty environment where lighting is critical to the task being performed or where the building has a high public or military exposure. A level of maintenance less than recommended may be adequate for buildings that are superclean with relatively sealed fixtures, buildings that are seldom used, or buildings that have windows and are only used during daylight hours. The level of lighting maintenance that is required for specific buildings should be determined jointly by DEH and the building work area supervisor.

6.2 RECOMMENDATIONS

6.2.1 Fluorescent and Incandescent Lights

1. General administration and operational buildings (e.g., offices, classrooms, dining halls, medical facilities, laboratories, and minor maintenance shops) are virtually always illuminated with fluorescent

lights. On many Army posts, these buildings may constitute the greatest lighting load. For this class of buildings, it is recommended that spot relamping be discouraged and that scheduled lighting maintenance be conducted and coordinated by DEH. It is recommended that fixtures be cleaned and relamped annually with an intermediate relamping scheduled for 6 months after cleaning. Based on calculations performed in Sect. 5.4 ("Comparative Economics of Fluorescent Lighting Maintenance Practices"), ~20% of the fluorescent tubes burn out annually. Thus, annual relamping results in an excessive lamp outage factor. An intermediate lamping at 6 months resolves this problem at a very small additional cost. Of course, DEH must be responsive to the situation where a critical lamp fails and must be replaced immediately. Annual fixture cleaning is a common practice at Army installations and large nonmilitary entities, and this practice should continue.

Group relamping of fluorescent fixtures (by subcontract with a lighting maintenance company) is becoming a more common commercial practice. Group relamping is appropriate in this sector because the businesses involved do not normally have a permanent maintenance staff with adequate training and equipment. By contrast, a large Army installation has a DEH with a well-equipped and trained staff. The economic analysis in Sect. 5.4 shows that the annual cost of lighting maintenance based on group relamping is about the same as lighting maintenance based on scheduled relamping. However, to conduct an effective group relamping program, DEH would be required to make considerably more building inspections and keep considerably more records than now required. In addition, the basic requirement for group relamping, that all lamps in a large group be operated the same number of hours, is contrary to the active use of local light switches for energy conservation. Thus, a dedicated group-relamping program is not recommended for large Army installations.

An option available to DEH is to conduct the fixture cleaning (and concurrent relamping) with the internal maintenance staff or by custodial subcontract to a janitorial service. Fixture cleaning is a labor-intensive process, and its cost is strongly influenced by labor rates. Janitorial laborers typically receive wages only modestly above the minimum wage; thus, the economics of this option would probably be favorable. Unless special equipment or knowledge is required, it is suggested that DEH consider a custodial subcontract for light fixture cleaning (and relamping, as required). The appropriate organizations can be located under "Janitor Service" in the yellow pages of the phone book. Subcontracted fixture cleaning has the additional advantage that it may be scheduled during nonworking hours, resulting in a minimum disruption of the normal work force.

As a general practice, it is recommended that windows should be washed at the same time that fixtures are cleaned.

2. Barracks have characteristics that make them a special case. They are probably the only type of military building (excluding housing) that contains large quantities of incandescent bulbs. The rated life of an incandescent bulb is one-tenth to one-twentieth of that for a fluorescent tube. Barracks are also regarded as private quarters, and many barracks have private rooms. Because of these characteristics, lighting maintenance by DEH is impractical. It is recommended that the occupants of the barracks be responsible for their own lighting maintenance and that a supply of spare lamps and certain fixture parts (lenses and shades) be kept in the barracks for this purpose. Relamping should be conducted on request, either by the person needing the lamp or by a barracks R&U person. Light fixtures can be cleaned at the same time or at a time when the officer in charge decides they need cleaning. Most relamping will probably be conducted during off-duty hours and, thus, can be considered as free maintenance except for lamp cost.

3. Heavy-maintenance shops, warehouses, and similar buildings are highly variable regarding the kinds of lights they use and the degree of dirtiness of the work conducted. Most warehouses and many heavy-maintenance shops are illuminated with fluorescent lights. Incandescent bulbs are sometimes used, for example, as task lights on lathes and milling machines. Many heavy-maintenance shops feature HID lamps, but these will be discussed in the next section. As in the case of administration and operational buildings (No. 1 above), it is recommended that lighting maintenance be coordinated by DEH. Under normal conditions it

is recommended that scheduled relamping be conducted at 6-month intervals. However, in some cases, such as warehouses that are only used occasionally, the relamping interval could be increased to a year or more. Similarly, under normal conditions it is recommended that fixture cleaning be conducted annually, but, again, this is highly variable. In warehouses that are only used occasionally, fixture cleaning could be at 2-year intervals or longer. For buildings that have dirty working conditions and critically need good lighting because of the work involved, fixture cleaning may be required semiannually. For this latter class of buildings, it is essential that the level of lighting maintenance be mutually agreed to by DEH and the work area supervisor.

As in the case of general administration and operational buildings (No. 1 above), DEH has the option to conduct fixture cleaning (and concurrent relamping) with the internal maintenance staff of by custodial subcontract. The situation is somewhat different, however, because special equipment and skills may be required for these buildings. The light fixtures may be higher and require scaffolding to reach, and special solvents may be required for cleaning. Janitorial services may not have the equipment and skills for this class of buildings. If not, then professional lighting maintenance contractors are available. They can be found under "Lighting Fixtures — Repair and Maintenance" in the yellow pages of the phone book or by writing to the International Association of Lighting Maintenance Contractors.[6] These companies have the knowledge and equipment for difficult fixture cleaning jobs and might not be much more expensive than janitorial services because they have more-advanced equipment, such as rolling scaffolds and power-driven cleaners. Professional lighting maintenance contractors have the additional advantage that they can identify opportunities for cost-effective ways to increase the efficiency of the lighting system.

It is recommended that, as a general practice, windows should be washed at the same time that light fixtures are cleaned.

The same comments concerning group relamping apply to this class of buildings as apply to the general administration and operational buildings (No. 1 above).

In some cases, task lights are necessary for a worker to perform his job (e.g., the incandescent task lamp on a lathe and the lamps in sandblasting or painting booths). For these situations, it is recommended that spare lamps be made an integral part of the equipment and material supply cage used by these workers so that they can replace their own lamps as necessary.

At the end of the year, a situation sometimes exists that may be capitalized on in some cases. Most workers take some leave during the Christmas-to-New Year period. The few who remain at work may not be able to do their jobs efficiently because interaction with others is required. These personnel could be assembled to conduct periodic labor-intensive maintenance that does not require a special task. Fixture cleaning and relamping is one such maintenance task. This procedure is being used on at least one Army AMC post.

4. It is recommended that the occupants in military housing and in commercial establishments located on the post be responsible for their own lighting maintenance, including purchase of lamps.

6.2.2 High-Intensity Discharge Lights

1. HID lights are commonly used for interior illumination of buildings that feature high ceilings, such as heavy-maintenance buildings, aircraft hangars, recreational buildings (e.g., basketball courts), and auditoriums. In these applications, the lights are positioned high above the floor and are spaced fairly far apart. Often, a single or a few lamps are critical and must be replaced soon after they burn out. The light output of mercury and metal halide lamps can decrease substantially by end-of-life (LLD — 60 to 65%), and replacement may be necessary before they fail. Because special skills and equipment are required to replace HID lamps, it is recommended that these lamps be maintained only by DEH. It is also recommended that relamping be conducted basically at the request of the supervisor of the building involved. He, more than any other, is the best judge of when the available light is inadequate.

When a crew is sent out in response to a relamping request, DEH must decide how extensive the relamping should be. Perhaps other buildings in the area feature HID lights and require the same special equipment (scaffolding or lift trucks). It would be appropriate to inspect and relamp these buildings at the same time. In some cases, extensive scaffolding is required (e.g., for access to lights located above a swimming pool). For extreme cases like this, it is common practice to replace all of the lamps, even those that are not burned out. Fixtures should be cleaned when lamps are replaced. A dedicated fixture-cleaning schedule for HID lights may not be required. HID fixtures are relatively better sealed than fluorescent tube fixtures and do not allow the free movement of air and dirt into the fixture. Some building environments may feature airborne materials (e.g., oil) that will stick to the outside of the lens and reduce illumination. For these cases, scheduled cleaning operations may be necessary.

2. HID lights are commonly used for exterior illumination in a wide variety of applications, such as roadways, parking lots, docking facilities, sporting facilities, airports, and security. As in the case of interior HID lights, and for the same reasons, it is recommended that these lights be relamped by DEH at the request of an authoritative person who has reported a problem. In addition, the same comments apply to the extent of relamping and fixture cleaning.

Roadway, parking-lot, and walkway lights are a special case, particularly on a large post with many personnel (e.g., a FORSCOM or TRADOC post). Inadequate or poorly maintained lighting in high-population areas is often associated with vandalism, robbery, assault, and other similar crimes. In addition, there will be a sufficient number of lights to warrant a scheduled inspection and relamping program. In addition to relamping on request (probably by the post security force), it is recommended that the entire system be inspected and relamped annually. Roadway and parking-lot light fixtures are usually sealed and require cleaning only when they are relamped. Some communities find that traffic lights need periodic cleaning of the lens outer surface. The protective sun shield over these lights prevents rain from washing the lens outer surface, and dirt accumulation can be quite high.

6.2.3 Emergency Lights

Emergency lights are separate lighting systems intended to automatically supply illumination in the event of failure of normal lighting systems. Emergency lighting systems are complete within themselves and contain their own power source (batteries). Thus, maintenance of these lights means maintenance of the entire system (lamps, batteries, sensors, etc.). Army regulations specify the maintenance policy for emergency lights:

> The facilities engineer will maintain, repair, and replace interior storage battery-type automatic lights, both unit and central battery-type. These lights will be checked at intervals not to exceed 12 months if they are equipped with maintenance-free batteries; otherwise, they will be checked monthly.[19]

No changes are recommended for this maintenance policy.

6.2.4 Painting and Cleaning of Walls and Ceilings

The reflectance and, thus, the color and cleanliness of walls and ceilings have an impact on lighting quality. Walls and ceilings must be painted or cleaned periodically. However, the usual motivation to clean or paint interior surfaces is not the quality of light (surface reflectance) but, rather, such discriminating and aesthetic concerns as pride of ownership, pride of quality maintenance, and the need for a desirable work-force environment (higher morale and efficiency). This procedure is probably acceptable because when DEH, in conjunction with the building supervisor, determine that a room needs to be painted or cleaned, they are reacting, at least in part, to the reduced surface reflectance. Therefore, it is recommended that interior surface painting or cleaning requirements be determined jointly by DEH and the supervisor or foreman of the space involved.

IES has addressed the subject of interior surface painting.[13] The following brief extracts concerning painting as it relates to lighting may be of assistance to the maintenance supervisor.

1. The recommended ceiling reflectance for almost all building types is in the range of 80 to 90%. The consequence of this recommendation is that ceilings are usually painted white or a white that is lightly tinted with the wall color.
2. The recommended reflectance for walls and other internal structures (space dividers) covers a wider range, depending on the building type, but 50 to 70% encompasses most situations. The general consequence of this recommendation is that walls may be painted with a variety of light colors as determined by personal taste, color coordination within the space, and current fashion.
3. In general, paint should leave a matte finish to avoid glare.
4. A general rule is that yellows, yellow-reds, reds, and red-purples are warm colors and that greens, blue-greens, blues, and purple-blues are cool colors. All grey colors approach neutrality, whether from the warm or cool side. The warm colors are most appropriate in rooms with a northern exposure, cool temperatures, and low noise element. The cool colors are most appropriate in a room with a southern exposure, warm temperatures, and high noise element.

7. SUMMARY AND CONCLUSIONS

Operating characteristics of the major lamp types (incandescent, fluorescent, and HID) are described; the emphasis is on those characteristics that result in light deterioration. In addition, light deterioration that results from dirt accumulation in the fixture (lens and reflector) is described. Current lighting maintenance practices at Army installations and also at large nonmilitary entities (universities and cities) are described. A comparative economic analysis was conducted on routine lighting maintenance practices (relamping and fixture cleaning) in a simulated office building that contains 500 fluorescent fixtures (two 4-ft lamps per fixture). The analysis considered various combinations of spot relamping (either by control maintenance or by a utility person in the building), scheduled relamping (annually and semiannually), group relamping, and fixture cleaning (annually and every 2 years). The analysis was conducted using light deterioration correlations contained within this report. Based on the results of the economic analysis and other considerations, the following recommendations are summarized.

7.1 FLUORESCENT FIXTURES

Typically, it is recommended that fixtures be inspected and relamped (replace burned-out tubes) semiannually by DEH and that they (including windows) be cleaned annually by custodial subcontract. Certain buildings may require a greater or lesser level of maintenance because of their environment, mission, public exposure, or frequency of use. For these cases, the level of maintenance should be jointly acceptable to the supervisor of the building involved and DEH. Spot relamping should be discouraged except for a few special cases. Group relamping (periodic replacement of all lamps) is not recommended as a dedicated practice for a large installation with a central maintenance staff.

7.2 INCANDESCENT LAMPS

The only widespread use of incandescent lamps in the Army is in military housing and barracks. It is recommended that personnel who live in military housing be responsible for their own lighting maintenance, including the purchase of bulbs. It is recommended that occupants of barracks be responsible for their own lamp replacement but that a supply of bulbs be maintained in the barracks for that purpose.

7.3 HIGH-INTENSITY DISCHARGE LAMPS

Because of their nature (widely spaced and high above the floor), it is recommended that HID lamps be replaced by DEH at the request of the building supervisor. This recommendation is the same for both interior and exterior lights. However, roadway, walkway, and parking-lot lights are a special case. On many large installations, there are a sufficient number to warrant annual inspection and relamping. Typically, HID fixtures are relatively well sealed and high off the floor; thus, they require little cleaning except in special cases.

7.4 EMERGENCY LIGHTS

Army regulations dictate the maintenance policy for emergency lighting systems. These should continue to be followed.

REFERENCES

1. J. J. Krajewski, U.S. Army Facilities Engineering Support Agency, Ft. Belvoir, Va., letter to M. A. Broders, Oak Ridge Natl. Lab., July 25, 1985; subject: U.S. Army Conservation Equipment Testing Program with attached Task Order No. 0005.

2. J. Kedl, Oak Ridge Natl. Lab., letter to General Electric Corp., Lighting Business Group, Nela Park, Cleveland, August 9, 1985.

3. R. J. Kedl, Oak Ridge Natl. Lab., letter to North American Philips Lighting Corp., One Westinghouse Plaza, Bloomfield, N.J., August 9, 1985.

4. R. J. Kedl, Oak Ridge Natl. Lab., letter to GTE Corp., Lighting Products Group (Sylvania), 10-T Hutchinson Drive, Danvers, Mass., August 9, 1985.

5. R. J. Kedl, Oak Ridge Natl. Lab., letter to Illuminating Engineering Society of North America, 345 East 47th St., New York, August 9, 1985.

6. R. J. Kedl, Oak Ridge Natl. Lab., letter to International Association of Lighting Maintenance Contractors, 2017 Walnut St., Philadelphia, August 9, 1985.

7. R. J. Kedl, "Trip Report to Ft. Carson, CO, and Tooele Army Depot, UT, Concerning Lighting Maintenance," letter trip report, November 12, 1985.

8. R. J. Kedl, Oak Ridge Natl. Lab., phone call to Electrical Maintenance Supervisor, University of Tennessee, Knoxville, August 28, 1985.

9. R. J. Kedl, Oak Ridge Natl. Lab., phone call to Electrical Maintenance Supervisor, City of Oak Ridge, Tenn., February 3, 1986.

10. W. Pierpoint, *Optimizing the Operation and Maintenance of Lighting Systems*, TM No. M-62-78-06, U.S. Navy Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, Calif., April 1978.

11. Director, NAVFAC Industrial Engineering Center, Naval Facilities Engineering Command, Norfolk, Va., letter to Officer in Charge, Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, Calif., enclosing Engineered Performance Standards Time Values for Working and Relamping Light Fixtures, August 29, 1978.

12. J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Reference Volume*, Illuminating Engineering Society of North America, New York, 1981.

13. J. E. Kaufman and H. Haynes, eds., *IES Lighting Handbook: Application Volume*, Illuminating Engineering Society of North America, New York, 1981.

14. C. F. Scholz, "Reducing Theory to Practice — Luminaire Dirt Depreciation and Maintenance," *J. Illum. Eng. Soc.* 4(3), 177–82 (April 1975).

15. D. Brooker, "Reaping the Benefits of Lighting Maintenance," *Electr. Rev.* 215, 27–28 (November 1984).

16. R. E. Mann, "Cutting Lighting Energy Costs with Proper Maintenance," *Plant Eng.*, pp. 81–84 (September 16, 1982).

17. D. B. Mathews, "Maintenance for Commercial and Industrial Lighting," *Light Light. Environ. Des.* 70(3), 124–26 (1977).

18. R. A. McCully, "The Benefits of Group Relamping Fluorescent Systems," *Plant Eng.*, pp. 117–20 (February 17, 1977).

19. *Facilities Engineering-Electrical Services,* Army Regulation AR420-43, October 1982, p. 4-3.

Appendix

ENGINEERED PERFORMANCE STANDARDS TIME VALUES FOR WASHING AND RELAMPING LIGHT FIXTURES

ENGINEERED PERFORMANCE STANDARDS TIME VALUES FOR WASHING AND RELAMPING LIGHT FIXTURES

I. General

A. A summary of Engineered Performance Standards (EPS) time values for washing and relamping various types of light fixtures is provided below. These time values have been extracted from appropriate EPS craft handbooks and are called "craft time" values since they provide only for the direct productive effort required to accomplish any given task.

B. Travel time, job preparation time, and craft delay allowances must be added to the craft time values in order to determine the total allowed time for any given task. A nomograph is normally used in easily adding such allowances. Difficulties in explaining use of the nomograph outside of a formal classroom setting preclude such explanation for purposes of this enclosure.

C. As an alternate to the nomograph, a mathematical procedure for this application of EPS craft delay allowances, travel times and job preparation times is provided by attachment (A). Additionally, attachment (A) provides the appropriate EPS craft delay allowances and job preparation times for crafts normally involved in washing and relamping fixtures.

D. Several examples of calculations using the mathematical procedure for the nomograph are provided by attachment (B).

II. Craft Time

A. Wash Light Fixtures (Based on NAVFAC P-706.0, Janitorial Handbook) — Washing includes disassemble (where possible), clean, dry and reassemble fixtures at 8' height. Washing involves removing and replacing tubes/light bulbs and therefore old bulbs/tubes can be replaced by new (in total or in spots) with the only additional time needed for material handling of boxes of bulbs to and from the job site. Times include necessary travel within the particular building.

1. Fluorescent

   a. Strip light (4 ft., 1 tube) (Based on JT-82) — .0363 hrs./fixture

   b. Industrial (4 ft., 2 tube) (Based on JT-83) — .0848 hrs./fixture

   c. Finned louver

      (1) (4 ft., 2 tube) (Based on JT-84) — .1399 hrs./fixture

      (2) (4 ft., 4 tube) or (8 ft., 2 tube) (Based on JT-85) — .1695 hrs./fixture

   d. Recessed (4 ft., 4 tube) or (8 ft., 2 tube) (Based on JT-86) — .1364 hrs./fixture

   e. Egg crate (4 ft., 4 tube) or (8 ft., 2 tube) (Based on JT-87) — .1916 hrs./fixture

2. Incandescent

   a. Vapor or explosive proof

      (1) Without shade (Based on JT-88) — .0409 hrs./fixture

      (2) With shade (Based on JT-89) — .0886 hrs./fixture

   b. Open glass globe (up to 300 watts) (Based on JT-90) — .0455 hrs./fixture

   c. RLM open (warehouse/storage area, porcelain shade)

      (1) In place (Based on JT-91) — .0477 hrs./fixture

      (2) Removable shade (Based on JT-92) — .0572 hrs./fixture

3. Combination (1 mercury vapor and 3 incandescent) (Based on JT-93) — .1088 hrs./fixture

4. Each occasion forklift truck is used add (Based on JT-80) — .0346 hrs./fixture

5. Each occasion extension ladder is used add (Based on JT-81) — .0480 hrs./fixture

B. Relamp Light Fixtures (Based on NAVFAC P-703.0, Electrical Handbook) - for work at one building (or jobsite):

1. Fluorescent

   a. Standard; glass diffused type (Based on GT-280)

1 tube/fixture	=	.0374 hrs./fixture
2 tubes/fixture	=	.0435 hrs./fixture
3 tubes/fixture	=	.0496 hrs./fixture
4 tubes/fixture	=	.0557 hrs./fixture

   b. Standard; open reflector type (Based on GT-281)

1 tube/fixture	=	.0294 hrs./fixture
2 tubes/fixture	=	.0355 hrs./fixture
3 tubes/fixture	=	.0416 hrs./fixture
4 tubes/fixture	=	.0477 hrs./fixture

   c. Vapor sealed type (Based on GT-282)

1 tube/fixture	=	.0687 hrs./fixture
2 tubes/fixture	=	.0748 hrs./fixture
3 tubes/fixture	=	.0809 hrs./fixture
4 tubes/fixture	=	.0870 hrs./fixture

   d. Each occasion forklift truck is used add .0346 hrs./fixture
   (Based on JT-80 of P-706.0)

   e. Each occasion extension ladder is used add .0480 hrs./fixture
   (Based on JT-81 of P-706.0)

2. Incandescent

   a. Explosion-proof (up to 300 watts) = .0391 hrs./bulb
   (Based on GT-283)

   b. Frosted globe (up to 300 watts) = .0342 hrs./bulb
   (Based on GT-285)

   c. Vapor proof (up to 300 watts) = .0303 hrs./bulb
   (Based on GT-286)

   d. Flush mounted (glass diffused) = .0527 hrs./bulb
   (Based on GT-287)

   e. Open reflector (up to 300 watts) = .0252 hrs./bulb
   (Based on GT-288)

   f. With bulb changer (up to 750 watts)

      (1) 9' changer = .0221 hrs./bulb
      (Based on GT-289)

      (2) 18' changer = .0294 hrs./bulb
      (Based on GT-290)

      (3) 27' changer = .0368 hrs./bulb
      (Based on GT-291)

3. Floodlamps on 60' to 80' tower (with extension ladder) (Based on GT-292) = .2280 hrs./tower + .0384 hrs./box of bulbs + .0276 hrs./bulb

4. Floodlamps on poles or buildings (with bucket truck) (Based on GT-293) = .1646 hrs./bulb

C. Material Handling (Reference NAVFAC P-701.0, PWA-5-I):

1. To include an appropriate amount of material handling time, assume one man carries one box of light bulbs or tubes at a time and calculate based on the following figures:

.069 hrs./box of bulbs where: No. of boxes of bulbs =

$$\frac{\text{No bulbs}}{\text{No. bulbs/box}}$$

2. Material handling times should be added directly to the craft time. The .069 hours value includes loading box of bulbs on truck, rearrange and unload at job site; and load old bulbs on truck, rearrange and unload at shop; and walk a total of 360 paces.

MATHEMATICAL PROCEDURE FOR APPLICATION OF EPS CRAFT DELAY ALLOWANCES, TRAVEL TIMES, AND JOB PREPARATION TIMES TO EPS CRAFT TIMES

I. Mathematical Procedure

- Total allowed working time = total craft time x craft delay allowance factor, where craft delay allowance factor = $1 + \frac{\text{\% craft delay allowance}}{100}$

- Available working time per man per day =

$$\left(\frac{\text{8 hrs.}}{\text{day}} - \frac{\text{travel time}}{\text{day}} - \frac{\text{job preparation time}}{\text{day}}\right) \times \text{craft delay allowance factor}$$

- Number of days required for allowed working time =

$$\frac{\text{Total allowed working time}}{\text{Available working time per man per day} \times (\text{\# men})}.$$

- Number of round trips = 1 for first half day + 1 for each whole day thereafter + 1 for the remaining fractional day (assumes average job starting time to be 12 noon).

- Total adjusted time = total allowed working time + (# round trips) x (no. men) x $\left[\frac{\text{travel time}}{\text{day}} + \frac{\text{job preparation time}}{\text{day}} \times \text{craft delay allowance factor}\right]$,

II. Appropriate Craft Delay Allowance and Job Preparation Times for Washing and Relamping Fixtures

A. Janitorial Craft Workers (for cleaning jobs):

1. Craft Delay Allowance = 13%
2. Job Preparation Time = .2 hrs. per man per day

B. Electrical Craft Workers (for relamping jobs):

1. Craft Delay Allowance = 21%
2. Job Preparation Time = .3 hrs. per man per day.

Attachment (A)

EXAMPLES OF APPLICATIONS OF EPS CRAFT DELAY ALLOWANCES TRAVEL TIMES, AND JOB PREPARATION TIMES TO EPS CRAFT TIMES FOR WASHING AND RELAMPING LIGHT FIXTURES

I. Washing Light Fixtures

Two Janitorial craft workers wash 460 recessed 4 ft., 4 tube fluorescent fixtures in one building (round trip travel time = .45 hrs.)

- Craft time = $\frac{.1364 \text{ hrs.}}{\text{fixture}}$ x 460 fixtures = 62.744 hrs.
- Total allowed working time = 62.744 hrs. x 1.13 = 70.9 hrs.
- Available working time per man per day = 8 - .45 - .226 = 7.324 hrs.
- No. of days = $\frac{70.9}{7.324 \text{ x } 2 \text{ men}}$ = 4.84
- No. of round trips = 6 per man
- Total adjusted time = 70.9 + 6 x 2 x (.45 + .226) = 79.0 hrs.

II. Relamping Light Fixtures

Two electrical craft workers relamp 60 Standard (glass diffused type) fluorescent fixtures (4 tubes/fixture) in one building. (Round trip travel time = .45 hours). 10 tubes per box.

- Craft time = $\frac{.0557 \text{ hrs.}}{\text{fixture}}$ x 60 fixtures + $\frac{.0690 \text{ hrs.}}{\text{box}}$ x $\frac{1 \text{ box}}{10 \text{ tubes}}$ x 60 fixtures x $\frac{4 \text{ tubes}}{\text{fixture}}$ = 4.998 hrs.
- Total allowed working time 4.998 hrs. x 1.21 = 6.05 hrs.
- Available working time per man per day = 8 - .45 - .363 = 7.187 hrs.
- No. of days = $\frac{6.05}{7.187 \text{ x } 2 \text{ men}}$ = .4207
- Number of round trips = 1 per man
- Total adjusted time = 6.05 + 1 x 2 x (.45 + .363) = 7.7 hrs.

Attachment (B)

ORNL/TM-9981

INTERNAL DISTRIBUTION

1. F. D. Boercker
2-6. M. A. Broders
7. R. S. Carlsmith
8. W. Fulkerson
9. J. A. Getsi
10. H. W. Hoffman
11. L. Jung
12-16. R. J. Kedl
17. M. A. Kuliasha
18. F. C. Maienschein
19. J. A. McEvers
20. M. P. Ternes
21. J. J. Tomlinson
22. T. Wilbanks
23. R. S. Wiltshire
24. ORNL Patent Office
25. Central Research Library
26. Document Reference Section
27-28. Laboratory Records Department
29. Laboratory Records — RC

EXTERNAL DISTRIBUTION

30. J. Bouldin, U.S. Army Facilities Engineering Support Agency, Engineering Division Energy Branch/EN, Fort Belvoir, VA 22060-5516
31. J. G. Carbonell, Associate Professor of Computer Science, Carnegie-Mellon University, Pittsburgh, PA 15213 (ORNL Energy Division Advisory Committee Member)
32. Stephen M. Gillis, Dean, Graduate School, Duke University, 4875 Duke Station, Durham, NC 27706 (ORNL Energy Division Advisory Committee Member)
33. Fritz R. Kalhammer, Vice President, Energy Management and Utilization Division, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303 (ORNL Energy Division Advisory Committee Member)
34. R. H. Karney, U.S. Army Facilities Engineering Support Agency, Engineering Division, Mechanical Branch/EM, Fort Belvoir, VA 22060-5516
35. R. E. Kasperson, Professor of Government and Geography, Graduate School of Geography, Clark University Worchester, MA 01610 (ORNL Energy Division Advisory Committee Member)
36-42. C. A. Kotas, U.S. Army Facilities Engineering Support Agency, Engineering Division, Energy Branch/EN, Fort Belvoir, VA 22060-5516
43. J. J. Krajewski, U.S. Army Facilities Engineering Support Agency, Engineering Division, Fort Belvoir, VA 22060-5516
44. Martin Lessen, Consulting Engineer, 12 Country Club Drive, Rochester, NY 14618 (ORNL Energy Division Advisory Committee Member)
45. B. S. Wasserman, Department of the Army, Office of Chief of Engineers, Attn: DAEN-ZCF-U, 20 Massachusetts Avenue, N.W., Washington, DC 20314-1000
46. Office of Assistant Manager for Energy Research and Development, U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37831
47-48. Technical Information Center, Department of Energy, Oak Ridge, TN 37831