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LIGHTING CONTROLS COUNCIL
NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

CONSTRUCTION ENGINEERING RESEARCH LABORATORY, U.S. ARMY CORPS OF ENGINEERS

U.S. GENERAL SERVICES ADMINISTRATION

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This guide has been prepared for property managers, facility managers, building managers, resident managers, and others who have responsibility for lighting systems, but who do not possess in-depth technical knowledge about electric illumination. It is not the intention of this guide to relate highly detailed technical information. Instead, its purpose is to convey some “lighting basics” that should help facilitate discussion between the individual in charge and whomever is relied upon to provide the technical input required for effective decision-making. Note that, in any event, lighting decisions tend to be facility-specific. The approach used in one building may not be appropriate for another. Indeed, the methods used for a given space in a building may be inappropriate for another space in the same building, even though the two spaces are used for the same or similar functions.

In all cases, the goal of a lighting retrofit should be better lighting, that is, lighting whose quality and quantity have been optimized, while energy consumption has been minimized. As pointed out in the Introduction, the benefits derived by the lighting system owner or user can be substantial, but these benefits can be matched on a national scale through creation of more electrical generating capacity, less pollution, and less reliance on foreign sources to meet domestic needs.

Understanding the Purpose of Lighting provides more information about lighting’s many benefits, including increased productivity, fewer errors and rejects, better quality control, more real sales, less absenteeism, more safety and security, etc. Particularly when lighting decisions will be based on financial factors, it is important to consider the value of a benefit such as improved worker productivity.

Analyzing the Existing System gives more details about the energized, nonenergized, and human systems, how they interact, and how they can be modified to achieve better results. If you are not a lighting professional yourself, it would be wise to rely on one to help in this critically important assessment. Guidance may be available at little or no cost, through manufacturers, contractors, distributors, utilities, and state energy offices, among other sources.

Lighting System Maintenance: The Essential Option points out the importance of effective maintenance. In fact, no change should be made until the impact of improved maintenance can be assessed. In many instances, improving maintenance can result in significant energy savings, in addition to better quality lighting.

Nonenergized System Considerations provides information on specific steps that can be taken to lower energy consumption, as through repainting or otherwise recovering major surfaces, relying on daylighting, and modifying the physical make-up of a space. The following chapter — Lighting System Retrofit/Replacement Options — goes on to create specific replacement options for various types of lighting systems, relying on the existing luminaire’s
"footprint." The chapter discusses lamps, luminaires, ballasts, shielding and diffusing media, and controls. As its title implies, Retrofit/Replacement Planning Considerations covers a variety of factors that should be considered before finalizing a retrofit plan. Issues such as quantity and quality of illumination, codes, use of existing components, operation, and maintenance are reviewed, along with information on their impact.

Evaluating and Accepting Options presents several of the economic factors that commonly are used in considering various options, as well as different evaluation techniques, such as simple payback and savings-to-investment ratio. Also considered are preparation of drawings and specifications, monitoring the installation, and on-site debugging and fine-tuning, all of which are significant elements of acquiring and accepting lighting systems.

Organizations that can provide assistance are identified in Sources of Assistance, and the Glossary of Terms explains a number of the words and phrases used throughout the text.

Many other texts and guides are available from the National Lighting Bureau, and all follow much the same approach. Reliance on a nontechnical format to relate information decision-makers need to know in order to make effective technical decisions. An illustrated directory of National Lighting Bureau publications can be obtained by writing the Bureau at 2101 L Street, N.W., Suite 300, Washington, D.C. 20037, or by calling the Bureau at 202/457-8437.
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National Lighting Bureau
Illuminating Engineering Society of North America
National Electrical Contractors Association
National Association of Electrical Distributors
International Association of Lighting Management Companies
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Glossary of Terms
INTRODUCTION

The United States consumes more energy per capita than any other nation on Earth. This high level of consumption causes the nation to rely substantially on others to meet its domestic energy needs. This dependency was a principal factor leading to the OPEC nations' petroleum embargo of 1973-74 and the meteoric rise in energy prices that followed. Now, almost two decades later, 50 percent of all petroleum consumed in the United States is imported, and per capita consumption, after trending downward for a number of years, has started to climb.

Will America's seemingly insatiable energy appetite once again make the nation subject to international politics? While experts debate that issue, another has arisen and it is not subject to debate: the link between energy consumption and environmental degradation.

The nature of the problem can be seen almost any day in cities such as Los Angeles, whose air has been fouled by vehicle emissions. In other cities, industry can be blamed. And no locale can afford to overlook the environmental degradation that can occur due to energy use in buildings.

When fossil fuels such as oil and natural gas are consumed in buildings, carbon dioxide (CO$_2$) is emitted to the atmosphere. The generation of electricity also contributes to environmental problems since it results in the emission of CO$_2$, sulfur dioxide (SO$_2$), and nitrogen oxides (NO$_x$).

ENERGY USE IN BUILDINGS

In buildings, electricity is used principally for purposes of space cooling and lighting. Opportunities for reducing the space cooling are somewhat limited, because the base systems themselves are not readily modified, and the cost of system replacement eliminates that option for most owners. Even the most cost-conscious owners are interested in the bottom-line benefits of energy conservation, however, and thus many have taken steps to improve system efficiency. Controls can be of particular value in this respect, because they help assure comfort while minimizing energy consumption.

THE ROLE OF LIGHTING

Lighting can account for 35-50 percent of a building's total electrical demand. In most instances, it is put to good use. Nonetheless, much of America's electric illumination is ineffective, inefficient, or both, and could greatly benefit from upgrading. And, because lighting in buildings is segregated into discrete systems, each one serving a specific area, it is relatively easy to modify lighting in one space without affecting others. This permits a phased approach to lighting modernization in order to accommodate budgeting needs. These needs also have been addressed by the many utilities that provide economic incentive programs to encourage lighting retrofit and replacement. By
encouraging users to invest in more energy-efficient lighting, utilities can serve more customers from existing capacity, to forestall the need for new generating plants. Shared energy savings and leasing programs also can be applied to make acquisition of energy-efficient lighting systems less costly.

Even buildings whose lighting has been upgraded over the years are likely to benefit from new lighting systems, due to the extraordinary advances made by manufacturers. New types of lamps, luminaires, ballasts, shielding and diffusing media, controls, and other devices can help make electric illumination more efficient than ever before. Those who apply them effectively can contribute to an

UNDERSTANDING EFFICIENCY

The overall efficiency of a lighting system depends both on the individual efficiencies of the system's components and the extent to which the components work together to produce the end result: electric illumination. Relying on energy-efficient components does not in and of itself assure energy efficiency. In fact, when existing components are mixed with new ones, the most efficient result may be derived by using something less than the most efficient new component, due to compatibility issues.

LAMP EFFICACY

Efficacy is the technical term used to indicate a lamp's efficiency, in terms of lumens (a measure of light output) per watt (of power required to operate the lamp). The efficacies of the six different lamp families is indicated in Table 1. There is significant variance within and between them. Specifying high-efficacy lamps is no guarantee the system will be efficient.

LUMINAIRE EFFICIENCY AND CU

A luminaire's efficiency is determined as the ratio between its light output and the light output of the lamps it houses. As such, a luminaire that emits 20,000 lumens using lamps that produce 25,000 lumens is 80 percent efficient; 20 percent of the lamp's light is absorbed. But the amount of light a luminaire produces is not as important a concern as the amount of light it directs to the workplane, a factor considered by coefficient of utilization (CU):

<table>
<thead>
<tr>
<th>Type of Lamp</th>
<th>Wattage Range</th>
<th>Initial Lumens per Watt Including Ballast Losses^2</th>
<th>Average Rated Life (Hours)</th>
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<tbody>
<tr>
<td>Low-Pressure Sodium</td>
<td>18 - 180</td>
<td>62 - 150</td>
<td>12,000 - 18,000</td>
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<td>High-Pressure Sodium</td>
<td>35 - 1,000</td>
<td>51 - 130</td>
<td>7,500 - 24,000+</td>
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<td>Metal Halide</td>
<td>70 - 2,000</td>
<td>69 - 115</td>
<td>5,000 - 20,000</td>
</tr>
<tr>
<td>Mercury Vapor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>40 - 1,000</td>
<td>24 - 60</td>
<td>12,000 - 24,000+</td>
</tr>
<tr>
<td>Self-Ballasted</td>
<td>160 - 1,250</td>
<td>14 - 25</td>
<td>12,000 - 20,000</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>4 - 2,15</td>
<td>14 - 95</td>
<td>6,000 - 20,000+</td>
</tr>
<tr>
<td>Incandescent</td>
<td>15 - 1,500</td>
<td>8 - 24</td>
<td>750 - 4000</td>
</tr>
</tbody>
</table>

^1Datos are based on the more commonly used lamps and are provided for comparison purposes only. Actual results to be derived depend on factors unique to the specific products and installation involved. Consult manufacturers for guidance.

^2Lumens (of light output) per watt (of power input) is a common measure of lamp efficiency (efficacy). Initial lumens-per-watt data are based upon the light output of lamps when new. The light output of most lamps declines with use. The actual efficacy to be derived from a lamp depends on factors unique to an installation. The actual efficiency of a lighting system depends upon far more than efficiency of lamps or lamps/ballasts alone. More than efficiency should be considered when evaluating a lighting system.
America that relies less on foreign sources to meet domestic needs, and to a cleaner environment.

Of course, the economic savings derived from reduced energy consumption also can be significant, including lower space cooling costs due to reduced heat gains from lighting. In addition, and of even more financial consequence, are the many often-overlooked benefits that better lighting can provide, including improved worker productivity, increased retail sales, and enhanced safety and security, among others.

The following discussion provides some of the basic information you need to better understand what lighting can do for you and how it can do it.

\[
CU = \frac{\text{Lumens Reaching the Work Plane}}{\text{Lumens Generated by the Lamps}}
\]

As such, a luminaire that delivers 14,000 lumens to the workplane using lamps that produce 20,000 lumens has a CU of 0.70. The CU of a fixture can have a pronounced effect on both initial and life-cycle costs. For example, consider a situation where plans call for 100 luminaires, each with a CU of 0.60. Assuming an installed cost of $200 per luminaire, the total initial cost would amount to $20,000. Assuming each fixture houses four 34W fluorescent lamps and is operated 3,000 hours per year, energy costs (at $0.08/kWh) would amount to $3,500 per year. The average annual (annualized) cost of replacement lamps, group relamping labor, periodic cleaning, and ballast replacement would bring the overall annual cost to some $4,200.

Where similar luminaires with a CU of 0.70 are employed, initial costs possibly could be reduced to $17,000 (a savings of $3,000), and overall annual costs likely would not exceed $3,200, because fewer luminaires would be needed to attain the same light output.

Luminaire manufacturers establish the CUs of their products by using standardized procedures. Note, however, that a luminaire's CU rating will vary depending on the size and shape of the space involved and the reflectances of its surfaces. Using light-colored, reflective finishes can therefore have a dramatic impact on lighting efficiency and initial and life-cycle lighting costs. In some situations, however, light, reflective finishes that elevate CUs can create serious viewing problems, necessitating close consideration of quality factors before a decision is made.

**VISUAL COMFORT PROBABILITY**

Visual comfort probability, or VCP, is a rating used to indicate how much direct glare an indoor luminaire is likely to produce. A VCP of 70 indicates that 70 percent of the people seated in the least desirable location of a space would not be bothered by direct glare produced by a system comprising identical fixtures mounted in a uniform pattern. Historically, VCPs of 70 have been considered good for most offices. Offices that rely heavily on VDTs require luminaires with VCPs of 80 or more.

As with CU, VCP ratings are application-dependent; a luminaire that provides adequate comfort in a small space may be completely inappropriate for a larger one.

**BALLAST FACTOR**

Ballast factor defines the relative light output provided by a lamp/ballast system with respect to the manufacturer's rated light output for the lamp specified. It is important because it determines the applications for which a given ballast is most appropriate. A high ballast factor may be the most economical for renovations and new construction because fewer ballasts and lamps will be required to provide a specific level of illumination. A low ballast factor can be useful in retrofitting spaces that are overilluminated.
more effectively and efficiently than ever before. But make no mistake: This is not a how-to guide. Its purpose is to familiarize you with key concerns and opportunities to help you work more effectively with the expert you need to maximize your results.

**EIGHT STEPS TO LIGHTING EFFICIENCY AND EFFECTIVENESS**

1. Survey existing lighting systems to determine what you have, condition of equipment, and quantity and quality of lighting provided. (See *Performing a Lighting System Audit* available from the National Lighting Bureau.)

2. Given the tasks now performed and those planned, as well as the people performing these tasks, determine actual illumination needs.

3. Identify lighting system retrofit/replacement options available to improve energy-efficiency and better support performance of the functions for which electric illumination is used.

4. Determine the value of benefits to be derived from application of each option, including utility cost savings, improved productivity, reduced vandalism, etc.

5. Perform economic evaluations to determine which changes will be made.


7. Monitor modifications and results to help assure objectives are achieved. If they are not achieved or are surpassed significantly, determine why.

8. Maintain knowledge of new technology through reading and seminar participation.
UNDERSTANDING THE PURPOSE OF LIGHTING

Lighting is installed for specific purposes that have nothing to do with energy consumption. Foremost among these is providing the light people need to perform visual tasks. Others include providing the light required to improve safety and security, to enhance aesthetics, to attract and direct people at night, and to stimulate retail sales.

Every effort should be made to help eliminate lighting energy waste. However, in all cases, the functionality of the lighting involved should be at least maintained if not improved, particularly so because of lighting's leveraging effects. If the amount of energy consumed by the lighting system used by a 100-person work force is reduced by 50 percent, savings might amount to $5,000 annually. However, if the changes made cause that work force to lose five percent of its productivity, the net loss could exceed $100,000 annually. In short, the common goal should be to maximize the energy efficiency of that lighting system which is most compatible with the needs of the people involved. Toward that end, the people involved need to understand how lighting contributes to the attainment of various objectives. These are termed the benefits of lighting. They are summarized in Table 2, and some of the major benefits are discussed more fully below.

INCREASED PRODUCTIVITY

Good lighting is essential for performance of visual tasks. (All tasks except those that people can perform with their eyes closed are visual tasks.) More than three decades of research and numerous case histories show that better lighting permits people to work faster and with fewer errors. The value of even relatively small productivity increases can be substantial.

For those who own and occupy their buildings, good lighting that improves productivity can be an extremely cost-effective investment. The same is true for those who lease space in their buildings, because any building feature that enhances tenant productivity can be a significant factor in space marketing.

FEWER ERRORS AND REJECTS; BETTER QUALITY CONTROL

Errors sap productivity because additional time must be spent to redo what should have been done properly the first time. In fabricating operations, errors also can result in waste of source material and energy. And should an error not be caught through quality control operations, the result can be soured customer relations, damaged image, and other costly problems. Better lighting can help minimize errors and also increase the effectiveness of all visually oriented quality control procedures. In some cases, just a small investment in better lighting can save hundreds of thousands of dollars annually.
MORE RETAIL SALES

The lighting best suited to increase retail sales is selected based on the types of merchandise being displayed, the image that a store wishes to convey, and many other factors unique to a given setting. Lighting can make a bottom-line difference, by creating the proper ambience for a given display, highlighting a carousel of impulse-purchase merchandise, bringing out the color and texture of fabrics, or lending sparkle to crystal and jewelry. Lighting also can be used to complement other measures used to establish an image commensurate with what the store offers for sale. Outdoor lighting can be used for image purposes, too, but its importance to retail operations can go far beyond that. When a retail facility depends on nighttime shopping, effective lighting in parking lots and along walkways comprises a form of conspicuous security. It can help overcome the fear of crime that could otherwise keep people away.

LESS ABSENTEEISM

Employee absenteeism is a growing concern to American business. National Lighting Bureau case histories suggest improper lighting may be far more of a causal factor than previously supposed. Improper lighting often is characterized by glare, typically caused by ineffectively shielded lighting fixtures (luminaires) or a bright light source surrounded by a dark background. Muscles cause the eye to adapt to such conditions and, over a period of time, these muscles may become strained, leading to visual fatigue, headaches, and "eye-strain." Effective lighting may help eliminate such problems and the absenteeism they may cause.

HEIGHTENED SAFETY AND SECURITY

The darkness caused by insufficient outdoor lighting at night, and the shadows created by lighting that is improperly positioned, can mask hazards that otherwise would be self-evident: steps along a walkway, fallen branches, or pavement cracks. In parking lots, along access roads and at entrances and exits, effective lighting can help reduce the likelihood of vehicle-vehicle and vehicle-pedestrian accidents. Effective lighting also can eliminate the "safe harbors" needed by vandals, muggers, and

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<td><strong>INCREASED PRODUCTIVITY</strong></td>
</tr>
<tr>
<td>• Reduces visual fatigue and absenteeism.</td>
</tr>
<tr>
<td>• Reduces errors and improves work performance.</td>
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<tr>
<td>• Saves time spent on reworking work.</td>
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<tr>
<td><strong>BETTER QUALITY CONTROL</strong></td>
</tr>
<tr>
<td>• Decreases waste of source materials and energy due to lower error rate.</td>
</tr>
<tr>
<td>• Increases effectiveness of visually oriented quality control procedures.</td>
</tr>
<tr>
<td><strong>INCREASED RETAIL SALES</strong></td>
</tr>
<tr>
<td>• Creates the proper ambience for a given display.</td>
</tr>
<tr>
<td>• Brings out color and texture of fashions.</td>
</tr>
<tr>
<td>• Lends sparkle to crystal and jewelry.</td>
</tr>
<tr>
<td>• Reveals features, details, colors, and wholesomeness of displayed products.</td>
</tr>
<tr>
<td>• Motivates larger quantity, higher-priced purchases.</td>
</tr>
<tr>
<td>• Prompts confident buying decisions and reduces returns.</td>
</tr>
<tr>
<td>• Triggers impulse and seasonal sales.</td>
</tr>
<tr>
<td><strong>ENHANCED BUSINESS IMAGE</strong></td>
</tr>
<tr>
<td>• Improves appearance of &quot;first impression&quot; lobby areas.</td>
</tr>
<tr>
<td>• Highlights paintings, sculpture, and other art objects.</td>
</tr>
<tr>
<td><strong>HEIGHTENED SAFETY AND SECURITY</strong></td>
</tr>
<tr>
<td>• Reduces safe harbors for vandals, muggers, and other lawbreakers.</td>
</tr>
<tr>
<td>• Eliminates shadows that can mask hazards.</td>
</tr>
<tr>
<td>• Highlights particular hazards or provides more illumination where people must work with sharp or heavy objects, near exposed moving equipment, or in areas subject to liquid spills.</td>
</tr>
<tr>
<td><strong>GREATER ATTRACTION</strong></td>
</tr>
<tr>
<td>• Attracts customers to the store itself, departments, and products.</td>
</tr>
<tr>
<td>• Guides customers along preferred routes.</td>
</tr>
<tr>
<td><strong>IMPROVED VISUAL ENVIRONMENT</strong></td>
</tr>
<tr>
<td>• Creates lively visual environment.</td>
</tr>
<tr>
<td>• Improves working conditions.</td>
</tr>
<tr>
<td>• Establishes brightness variations that match merchandising objectives.</td>
</tr>
<tr>
<td>• Lets customers enjoy and extend stay in stores.</td>
</tr>
<tr>
<td>• Instills confidence in store's fashion or quality awareness.</td>
</tr>
<tr>
<td>• Makes image statement.</td>
</tr>
<tr>
<td><strong>REDUCED OPERATING COSTS</strong></td>
</tr>
<tr>
<td>• Reduces energy and demand costs because of improvement in energy efficiency.</td>
</tr>
<tr>
<td>• Lowers insurance costs due to risk reduction.</td>
</tr>
<tr>
<td><strong>OTHER BENEFITS</strong></td>
</tr>
<tr>
<td>• Enhances curbside appeal.</td>
</tr>
<tr>
<td>• Creates mood-affecting ambience.</td>
</tr>
<tr>
<td>• Improves profitability.</td>
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</tbody>
</table>
other lawbreakers. The lighting used to improve security can perform additional lighting functions at the same time. For example, facade lighting can be as effective for beautification as it is for detecting the presence of unauthorized personnel. Lighting can be of value in maintaining indoor security, too, e.g., by integrating certain lighting and security controls, all lighting in a given area can be illuminated when a security breach occurs. Similarly, electric illumination can be valuable in maintaining indoor safety, by highlighting particular hazards or by providing more illumination where people must work with sharp or heavy objects, near exposed moving equipment, or in areas subject to liquid spills.

**LOW-COST SPACE DIFFERENTIATION**

In open landscaped offices, department stores, and similar facilities, there often is a need to differentiate one space from another without erecting a partition or wall. Lighting can meet this need by means of different luminaires, different lighting levels, and/or different colors of light.

**ACCOMMODATION OF FREQUENT SPATIAL CHANGES**

Experience suggests that most office areas are rearranged once every two years; larger retail stores and many other display-oriented facilities are rearranged even more frequently. If their lighting systems cannot be easily and inexpensively adjusted to accommodate spatial changes, inferior — and thus costly — illumination may result, making flexibility of illumination a key concern. Numerous techniques now are available to achieve this flexibility, including luminaires that are easily repositioned or re-aimed, and controls that change luminaire light output. Although a modest premium may be necessary to achieve flexibility, long-term benefits generally make it an extremely wise investment, for both leased and owner-occupied space.

**EFFECTIVE MOOD-SETTING**

Lighting is known to have an impact on mood, an important consideration in restaurants, conference rooms, and other spaces and facilities. By selecting the level of light suitable for the mood, and by choosing lamps that will produce desired color effects, the likelihood of attaining the desired mood-affecting ambience is greatly enhanced. Flexibility is often an important concern in this regard, as in conference rooms, where controls can be used to adjust lighting to complement the nature of discussion.

**IMPROVED EMPLOYEE MORALE**

Improved morale is a frequent result of better lighting, in that many employees view improved illumination as a demonstration of management’s concern. Better morale also can result because of lighting’s ability to promote faster, more accurate, and thus more satisfying work performance, safer
conditions, or more attractive space appearance.

**ENHANCED CORPORATE IMAGE**

Most businesses are concerned about their image; lighting can be used to enhance it. Indoors, lighting can dramatically improve the appearance of “first impression” lobby areas as well as work areas and executive offices. Outdoors, lighting can be used to create a nighttime environment, and some of the equipment used is so well-designed that, during daylight hours, it takes on a sculptural appearance.

**LOWER UTILITY COSTS**

Both energy and electric demand costs can be trimmed when more efficient lighting is installed. But consider, too, how lighting’s impact on other functions may be able to lower utility costs. For example, when productivity is improved or errors reduced, fewer overtime hours are necessary to get a job done. When people work overtime, the building’s energy systems must work overtime, too. As another example, the heat generated by lighting systems often can be used to reduce the amount of space heating otherwise required to maintain comfort. Alternatively, a substantial portion of lighting system heat can be captured before it enters a space, to reduce cooling requirements. In some cases, the captured “heat of light” can be employed for other energy-saving purposes, such as preheating domestic hot water.

**POLLUTION PREVENTION**

Energy-efficient lighting offers the potential for saving electricity which, in turn, prevents air pollution caused by electricity generation. If energy-efficient lighting were used everywhere it were profitable, the Environmental Protection Agency estimates that electric use for lighting would be cut by 50 percent, and aggregate national electricity demand would be reduced by 10 percent. This reduction would free $18.6 billion from ratepayer bills for useful investment and reduce annual carbon dioxide emissions by 232 million tons (4 percent of the national total). It also would reduce sulfur dioxide emissions by 1.7 million tons, or 7 percent of the national total; and nitrogen oxide emissions by 900,000 tons, or 4 percent of the national total. Other forms of pollution — boiler ash, scrubber waste, acidic drainage and waste from coal mining, radioactive waste, and natural gas leakage — also would be reduced.
THE AMOUNT OF ENERGY A BUILDING CONSUMES
Depends upon the nature of its human systems,
nonenergized systems, and energized systems, and
the interrelationships between them. To improve
energy efficiency, then, one must examine each of
the three systems to identify the shortcomings and
the options available to overcome them. The same
approach can be taken with electric illumination.

While much of the work involved can be per-
formed by experienced personnel, procedures
such as evaluating the condition and effectiveness
of the existing system, evaluating the illumination
needs of the task and workers involved, and rec-
ommending system modifications are steps best
taken in conjunction with a qualified lighting pro-
fessional. The assistance is important because more
than energy is at stake. The manner in which a light-
ing system is modified also affects productivity,
safety, security, and a number of other important
concerns. The qualified help needed in some cases
may be available at little or no cost from sources
such as a local utility, a state energy office, or a
manufacturer. Even when a cost is involved, how-
ever, it should be justifiable given the importance
of the system involved.

The existing lighting system also is composed
of human systems, nonenergized systems, and ener-
gized systems. It is absolutely essential to develop a
"fix" on these systems and their interrelationships
before opting for any specific change.

HUMAN SYSTEMS

The human systems associated with electric
illumination include, in particular, those who oper-
ate and maintain the lighting systems, and those
who rely on it in order to get their work done.

To some extent, a lighting professional can
evaluate the ability of lighting systems to support
human activity by determining the extent to which
the quantity and quality provided by a system agree
with recommended values. More information will
be obtained during a walk-through, however, by
observing the conditions that exist. Discussions with
users will provide even more insight. While these
discussions will tend to focus on quality issues, they
also should consider others, such as usage of con-
trols or the manner in which certain spaces are
used, by whom, and when.

Human systems concerns also should address
lighting maintenance. The physical review of ener-
gized systems will indicate the quality of mainte-
nance being provided. Discussions with mainte-
nance personnel should help determine what their
instructions have been, the training they have re-
ceived, and so on.

NONENERGIZED SYSTEMS

Nonenergized systems include sources of day-
light and principal reflective surfaces in a space. To
what extent can or does daylighting contribute to overall illumination? What is the quality of daylighting given the manner in which windows and skylights are located and maintained, the nature of the tasks being performed, and the orientation of workstations to daylight sources?

With respect to the surfaces in a space, to what extent do they reflect light and what occurs with respect to the quality of light? In some instances, light-colored walls can be a tremendous benefit by contributing to energy efficiency without any negative impacts. In other cases, light-colored walls might be a source of glare that leads to a degradation of lighting quality that, in turn, leads to productivity or other losses.

The lighting professional should be able to develop an overall assessment that identifies existing equipment and conditions, and the impacts that would occur due to modification of existing conditions as part of the general routine, e.g., cleaning and painting.

**ENERGIZED SYSTEMS**

Energized systems include lamps, luminaires, and controls. (Technically speaking, a luminaire is a complete lighting unit that includes lamps, ballasts, and shielding/diffusing media. For purposes of this discussion, these are treated as separate entities.) It is necessary to identify what already exists, that is, the type of controls used, the types of luminaires installed, and the types of ballasts, lenses or louvers, and lamps.

Once the components of the existing energized system have been identified, they need to be depicted graphically to indicate where they are located with respect to other elements of a space. One approach to doing this is indicated in Figure 1.

Based on the tasks being performed in a space, a lighting professional will be able to indicate the quantity and quality of lighting needed to optimize task performance. Quantity needs can be determined easily, through simple reference to data developed by the Illuminating Engineering Society of North America (IES/NA). Quality actually being delivered also can be determined easily, by applying a lightmeter. Quality factors are not so easily determined, however, and often they can be crucial. In fact, quality often is more important than quantity, and — unlike quantity — energy conservation is not necessary to provide it.

Based on review of the existing system, one of the first things that should be done is to analyze the quality of maintenance being provided for the
lighting system. The concern is not so much the amount of illumination the system now is delivering as it is the quantity and quality of light the system is capable of delivering. All too often this important step is not taken and, as a consequence, managers authorize changes that are not needed or which are of no help.

**REPORT AND RECOMMENDATIONS**

The end result of the examination should be a report of what was found and what is recommended. Recommendations should be accompanied by estimates of investment requirements and likely savings to be achieved. It also would be appropriate to indicate the types of performance changes that should or could result, and the extent to which savings or other benefits may be available.

In recommending modifications to the existing energized system, it is essential for the individual developing the report to consider not what conditions actually are, but what they could or should be through application of routine maintenance. For that reason, the following section focuses on the issue of lighting systems maintenance.

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**CASE IN POINT**

**COMPACT FLUORESCENT LAMPS REDUCE ENERGY AND MAINTAIN COSTS AT MILWAUKEE COURTHOUSE**

The General Services Administration's Milwaukee Field Office contacted the Madison Gas and Electric Company and discovered the utility willing to conduct a free energy survey report of the U.S. Courthouse in Madison, Wisconsin. The survey report recommended replacing the 60-watt incandescent lamps that illuminated the courtrooms and hallways with 18-watt compact fluorescent lamps. The field office accomplished this retrofit at a cost of approximately $5,000. This lighting retrofit was estimated to save about $980 in annual energy costs. The retrofit also reduced maintenance costs by $2,604 per year, due to the longer life of the fluorescent lamps — 10,000 hours compared to 1,000 hours. The project achieved a simple payback of 1.9 years and a savings-to-investment ratio of 1.77. In addition to the energy and maintenance savings, the GSA received an $860 rebate from the Madison Gas and Electric Company.

All of these savings were achieved without a decrease in light levels, demonstrating that energy retrofit projects can result in an aesthetically pleasing building environment while simultaneously saving energy and money. On October 26, 1990, the Federal Interagency Energy Policy Committee and the Department of Energy presented the Federal Energy Efficiency Award to the U.S. Courthouse in Madison, Wisconsin in special recognition of this lighting retrofit project.
LIGHTING SYSTEM MAINTENANCE: THE ESSENTIAL OPTION

To some, discussing lighting system maintenance before discussing specific changes that can be made to lamps and luminaires may seem somewhat odd. In fact, however, no specific lighting system change should be considered until after the impact of system maintenance has been assessed. This occurs because many lighting systems, possibly most, are poorly maintained. As a consequence, they consume far more energy than necessary and, more often than not, produce lighting that is less than optimal. While it may be inappropriate to perform comprehensive maintenance, including relamping, before initiating other options, such as lamp retrofit, it frequently would be an error to consider other actions before considering the impact of improved maintenance. In that way, owners/managers can avoid the potential of retrofitting luminaires that effective lighting maintenance would make expendable.

To understand the role of lighting system maintenance, it first is necessary to understand two key phenomena that affect the performance of energized systems. One of these is lamp lumen depreciation or LLD, the steady lessening of light output from commonly used lamps while their energy consumption remains constant (Figure 2). When effective maintenance is performed, most lamps are removed before they burn out, to help assure that the amount of lighting provided by a system is adequate for the tasks being performed. Adequate maintenance also helps assure that dust and dirt on lamp and reflective surfaces of luminaires are removed before they have an opportunity to absorb light.

Luminaire dirt depreciation (LDD) also can affect energized system performance. LDD indicates a fixture’s ability to resist dirt build-up on light-reflecting surfaces and lamps. The better a luminaire resists dirt build-up, the fewer luminaires are required to maintain a given amount of illumination averaged over time.

PLANNED LIGHTING MAINTENANCE

The goal of a lighting system designer is to help assure that the lighting system achieves the objective for which it was designed in an energy-efficient and cost-effective manner. Knowing that many systems are not well maintained, lighting designers often include compensatory lighting — additional lamps and luminaires — in their designs to help assure adequate lighting despite poor maintenance; e.g., lamps left in place long after their diminished light output warrants replacement, and luminaires that are not cleaned often enough.

If those responsible for a lighting system can assure that planned lighting maintenance (PLM) will be performed, compensatory lighting can be reduced.

Regular cleaning and timely lamp replacement are two key elements of PLM. Regular cleaning helps assure dust and dirt do not build up to such
a degree that they absorb excessive quantities of light. It may increase average light output over time by 50 percent or more. For purposes of economy, all luminaires in a system or large area should be cleaned at the same time (group cleaning), usually during nonoccupied hours. (Lighting system maintenance contractors can be hired to perform this function.)

With timely lamp replacement (TLR), lamps are replaced at some optimal point before they burn out based on the lamp lumen depreciation characteristics of the lighting. As a result of replacing lamps on a timely basis, the average amount of light they produce while in place is higher than it otherwise would be. Accordingly, when all lamps are replaced on the same timely basis, the average light output of the entire system is higher than it otherwise would be. In many instances, maintenance of higher system light output through timely lamp replacement permits a designer to use up to 25 percent fewer fixtures and lamps in the initial installation, depending on lamp type.

Although TLR is a proven money-saver, misdirected “common sense” can sometimes be an obstacle. This occurs when some individuals find it unacceptable to discard lamps that are still serviceable. That can be an expensive attitude. Consider the hypothetical installation shown in Table 3. It comprises 200 four-lamp fluorescent luminaires operated 3,000 hours per year, each lamp having a rated life of 20,000 hours. At an assumed cost of $3 per lamp, the annualized cost of replacement lamps is $360.

With TLR, the number of fixtures is reduced a conservative 10 percent to 180, but lamps are replaced at 75 percent of rated life or every 15,000 hours instead of every 20,000 hours. As such, the cost of replacement lamps increases by $72, from $360 per year to $432 per year. However, this premium is offset by an energy cost savings of $720 per year; assuming a connected load of 150W/ luminaire and an energy rate of $0.08/kWh (averaged to include demand). The annualized cost of cleaning and rebalasting also would be reduced by 10 percent, and the benefits of group relamping also would be attained.

GROUP RELAMPING

Group relamping means that all lamps in a system are changed at the same time. Typically, all lamps, lamp-changing equipment, and personnel are assembled at a preplanned time when lamp-changing operations will not affect others’ activities. Assuming the time required to change a lamp on this basis is approximately three minutes (0.05 hr), and also assuming a labor rate of $15 per hour (in-

![Figure 2: Lamp Lumen Depreciation (LLD) of Commonly Used Lamps](image-url)
clusive), the cost of replacing 720 lamps would amount to $540 (assuming no additional costs for proper lamp and ballast disposal). Since this would be done once every five years, the annualized cost would be $108 per year.

If lamps are left in place until they burn out, they must be changed on an individual basis. The time required to do this, all things considered, generally averages about 30 minutes (0.50 hr) per lamp or longer. The cost of relamping labor on this basis would be $6,000. Since, on average, a complete changeover would become effective every 6.67 years, the annualized cost would be $900. As such, the premium that would have to be paid for discarding lamps only after they burn out would amount to $1,530.

Although group relamping does not eliminate the need for some spot relamping, it does require maintenance of a far smaller inventory of lamps. This means fewer dollars tied up on material sitting on a shelf, less space required for lamp inventory, less breakage, and less “inventory shrinkage.” In addition, substantial discounts may be attainable when lamps are purchased on a bulk basis. Group relamping also makes contract lighting maintenance practical (in the private sector, the cost is amortized monthly over the length of the contract) and that can lead to reduced demand for staff time. Note, however, that federal law and some state laws affect the manner in which many types of lamps and certain ballasts are disposed of. These laws and their attendant regulations must be followed and doing so may elevate lighting maintenance costs. Nonetheless, group relamping should remain a cost-effective option, particularly because it helps assure the lighting system continuously provides the quantity and quality of illumination needed to attain high levels of productivity and other valuable lighting benefits.

**ESTABLISHING THE IMPACT OF PLM**

It is essential to determine the extent to which PLM is applicable to an existing lighting system. Obviously, if 20 percent of the existing lamps and luminaires can be disconnected or removed altogether, without affecting lighting quality, significant

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**TABLE 3: OFFICE LIGHTING WITHOUT AND WITH PLANNED LIGHTING MAINTENANCE**

<table>
<thead>
<tr>
<th></th>
<th>WITHOUT PLM</th>
<th>WITH PLM</th>
<th>SAVINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminaires</td>
<td>200</td>
<td>180</td>
<td>20</td>
</tr>
<tr>
<td>Lamps/Luminaire</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Load/Luminaire</td>
<td>150 W</td>
<td>150 W</td>
<td></td>
</tr>
<tr>
<td>System Load</td>
<td>30 kW</td>
<td>27 kW</td>
<td>3 kW</td>
</tr>
<tr>
<td>Hours of Use</td>
<td>3,000 hrs/yr</td>
<td>3,000 hrs/yr</td>
<td>9,000 kWh/yr</td>
</tr>
<tr>
<td>Energy Use</td>
<td>90,000 kWh/yr</td>
<td>81,000 kWh/yr</td>
<td>9,000 kWh/yr</td>
</tr>
<tr>
<td>Cost/kWh</td>
<td>$0.08/kWh</td>
<td>$0.09/kWh</td>
<td></td>
</tr>
<tr>
<td>Energy Cost</td>
<td>$7.20/yr</td>
<td>$6.49/yr</td>
<td>$720/yr</td>
</tr>
<tr>
<td>Lamp Usage</td>
<td>20,000 hrs</td>
<td>15,000 hrs</td>
<td>(5,000 hrs)</td>
</tr>
<tr>
<td>Lamps Replaced</td>
<td>120 lamps/yr</td>
<td>144 lamps/yr</td>
<td>(22 lamps/yr)</td>
</tr>
<tr>
<td>Cost/Lamp</td>
<td>$3</td>
<td>$3</td>
<td></td>
</tr>
<tr>
<td>Replacement Lamp Cost</td>
<td>$360/yr</td>
<td>$432/yr</td>
<td>($72/yr)</td>
</tr>
<tr>
<td>Time to Replace One Lamp</td>
<td>0.5 hr/lamp</td>
<td>0.05 hr/lamp</td>
<td>0.45 hr/lamp</td>
</tr>
<tr>
<td>Relamping Labor Time</td>
<td>60 hrs/yr</td>
<td>7.2 hrs/yr</td>
<td>52.8 hrs/yr</td>
</tr>
<tr>
<td>Labor Cost</td>
<td>$15/hr</td>
<td>$15/hr</td>
<td></td>
</tr>
<tr>
<td>Lamp Install Cost</td>
<td>$900/yr</td>
<td>$108/yr</td>
<td></td>
</tr>
<tr>
<td>Cleaning Time</td>
<td>0.1 hr/lxd</td>
<td>18 hr/lxd</td>
<td></td>
</tr>
<tr>
<td>Cleaning Costs/Year</td>
<td>$300/yr</td>
<td>$270/yr</td>
<td></td>
</tr>
<tr>
<td>Ballast Replacement Cost</td>
<td>$45/ballast</td>
<td>$45/ballast</td>
<td></td>
</tr>
<tr>
<td>Ballast Life</td>
<td>30 yrs</td>
<td>30 yrs</td>
<td></td>
</tr>
<tr>
<td>Reballasting Cost</td>
<td>$600/yr</td>
<td>$540/yr</td>
<td>$60/yr</td>
</tr>
<tr>
<td>Total O&amp;M Costs</td>
<td>$9,360/yr</td>
<td>$7,830/yr</td>
<td>$1,530/yr</td>
</tr>
</tbody>
</table>
savings can be achieved. This is not to say that one should stop at this point. In fact, it is more than likely that you will want to integrate other activities with this process. For example, why relamp existing luminaires with the same type of lamp if a new alternative will reduce energy consumption further? Also consider the impact of maintenance, to avoid the assumption that the existing number of luminaires is appropriate. If fewer can be utilized, now is the time you would want to know about it, to prevent the modernization of luminaires that are not needed.

In essence, before making a decision about how to modify the existing system, it is essential to know what the existing system can do.

**CASE IN POINT**

**HISTORIC ENERGY SAVINGS**

The Federal Building and U.S. Courthouse in Milwaukee, Wisconsin was built in two phases — at the turn of the century and 1940 — and is listed in the National Register of Historic Places. The older portion of the building has a large, central, skylit atrium that extends from the ground floor to above the fifth floor. The corridor chandeliers, wall-mounted fixtures, and corridor column fixtures surrounding the atrium utilized 135-watt incandescent lamps before the GSA’s Milwaukee Field Office performed a lighting retrofit. The incandescent lamps were replaced with nine-, eleven-, and thirteen-watt compact fluorescent lamps. This lighting retrofit resulted in an annual energy savings of about $10,911 and a rebate of $6,675 from the Wisconsin Electric Power Company.
NONENERGIZED SYSTEM CONSIDERATIONS

Nonenergized systems refer to reflective surfaces in a space and daylighting sources. As with maintenance, modifications of the energized systems should not be specified until the impact of any proposed changes to the nonenergized systems are detailed. If that step is not taken, an opportunity to use paint instead of energy may go overlooked, or both paint and energy will be applied to provide more lighting than is beneficial, in addition to energy waste.

REFLECTANCE VALUES

Due to reflection, the ceiling, walls, and floor of a space act as large secondary light sources. As such, they are important factors in determining how much energy is required to attain a given illuminance, and in determining brightness ratios between the lighting equipment and its surroundings and between the task and its more remote surroundings. Figure 3 indicates recommended reflectances for room surfaces. Many different colors will meet the recommended reflectances, and most manufacturers can provide reflectance information.

Under certain conditions, higher or lower wall reflectances are satisfactory or even desirable. Utilization of the upper wall surface in this manner could result in as much as 10 percent more illuminance on the workplane. Finishes with reflectances higher or lower than those recommended also can be used for accents. As long as they do not occupy more than 10 percent of any person's visual field, they will not affect lighting system efficiency or brightness ratios significantly.

Window shielding media should have approximately the same reflectance as that recommended for the walls.

DAYLIGHTING

Daylighting is the intentional use of light entering a space through windows or skylights to reduce the amount of energy required to provide specific visual conditions and to improve the quality of lighting in the space. Reliance on daylighting does not reduce requirements for luminaires or other electric illumination system components. These still must be available because daylighting is unreliable and is not available at night.

The amount of daylighting available in a space depends upon the time of year, the time of day, geographic location, and weather conditions. Building design also influences the amount of daylighting available. It includes the location and size of windows and skylights; the shape of the building and corresponding ratio of interior and perimeter areas (properly oriented abia, bays, doughnuts, Ls, Us, Zs, and other plans can increase daylighting); and position, shape, and color of interior partitions, ceilings, floors, and furnishings.

If an existing building was not designed to provide daylighting, its ability to do so will be limited.
Its viability must be closely assessed, particularly with respect to actual energy savings. While daylighting may help reduce the amount of energy needed for electric illumination, it may have a more significant impact on the need for cooling. As such, a careful review of the pros and cons is needed, along with the cost of items such as window films, window cleaning (to reduce the glare that can be caused by dirt and smudges), and so on. Obviously, where daylighting will have a net positive value, it should be used.

Close analysis also is required to determine whether or not daylighting will be cost-effective in new building design. For example, reliance on daylighting requires more glazing (windows and skylights) to increase the transmission and infiltration of light. Depending on the type of glass used, this may increase heating loads significantly in winter. Large expanses of glass can create radiant heat losses which produce discomfort, leading to higher thermostat settings. Furthermore, in hot weather these solar gains added to infiltration of hot air and transmission loads can significantly increase demands on the cooling system. Certain initial costs are associated with the use of daylighting. These include additional design fees for analysis, the possibility of additional construction costs, and/or less usable space. In addition, the large areas of glazing commonly associated with daylighting generally require an investment in extensive controls. These include thermal barriers for the windows at night or during other unoccupied periods, glare controls (interior or exterior shading systems that can be adjusted according to need), and a system to integrate electric and daylight sources so they complement rather than duplicate one another.

Daylighting seems to be most effective in warm or mild climates where heat loss is not a major problem. In these areas and elsewhere, the following suggestions might help designers maximize the benefits derived from daylighting while minimizing the drawbacks:

- Design fenestration to minimize direct sunlight while taking maximum advantage of daylight components direct from the sky and reflected from the ground. In this regard, northern exposures are suitable at all times. Southern exposures may be suitable most of the year without additional screening, depending on the latitude and on screening by adjacent struc-

**FIGURE 3:** Reflectances Recommended for Room Surfaces
tures. Eastern and western exposures may require different treatment, depending on the time of day and screening due to adjacent structures.

- Incorporate daylight-diffusing fenestration above vision panels in new buildings to extend natural light further into the interior space.
- Use translucent insulating panels in walls or ceilings where appropriate. Those constructed of two layers of fiber-reinforced plastic with an insulating air space have proved effective.
- Reduce glare or undesirable heat gain at the window by using devices such as Venetian blinds, exterior screening or shades, reflective glass, metalized plastic shades, or solar screen material.
- Provide a control mechanism — preferably automatic — that deactivates or dims electric illumination when adequate illumination from daylight is available.
- Orient workers so daylight comes from the side or rear of their line of sight.
- Compensate for the effects of additional radiation during daylight hours and minimize losses through the building envelope during other hours by incorporating energy-saving features into the HVAC system. Drapes, blinds, or shutters may be used.

**PHYSICAL MAKE-UP OF THE SPACE**

It also is essential, in planning retrofits, to consider the physical make-up of a space as it now exists, and as it likely will exist in the future. In essence, it makes little sense to optimize energy use for a space that will soon undergo change and require new or different lighting. Accordingly, if space is to be redesigned, or if new tasks will be performed in the space, or if the physical layout of the space is to change, the recommendations made for modification of maintenance, nonenergized systems, and energized systems all should be geared to what will exist, and changes should be coordinated with respect to timing.
This section identifies typical retrofit opportunities for incandescent, fluorescent, and high-intensity discharge (HID) indoor lighting systems. The focus is on the most commonly made retrofits and replacements.

The nature of retrofits fall into several categories, depending on the type of lighting involved. With incandescent lighting, the issues center principally on lamp replacement and system replacement. In the case of fluorescent and HID systems, modifications center on lamp replacement, lamp/ballast replacement, and reliance on new luminaires (including new lamps and ballasts) that will fit into the same space as the luminaire being replaced.

The need to consider dollar factors cannot be stressed strongly enough, especially when a number of alternatives exist. Do not assume that a retrofit of component parts will be more economical than a new luminaire. In fact, the cost of retrofitting can in some cases exceed the cost of luminaire replacement.

INCANDESCENT LIGHTING

Incandescent lighting is popular because of its low initial cost and good color-rendering properties. However, incandescent lamps have the shortest lives of all lamps and are the least efficient. Approximately 90 percent of the energy they consume is converted to heat; the other 10 percent produces visible light.

RETROFIT/REPLACEMENT OPTIONS

Tables 4 and 5 summarize retrofit/replacement options for commonly used incandescent lighting. Note that these and other tables do not address the additional savings available through application of appropriate controls. Some systems can be controlled more cost-effectively than others and this may influence the selection of the best suited lamp/ballast retrofit option. Controls are discussed more fully later in this chapter.

A brief description of the various energy-efficient retrofit options follows.

ENERGY-EFFICIENT LAMPS

Energy-conserving incandescent lamps are filled with krypton gas and have modified filaments. Krypton reduces filament evaporation, permitting the filament to achieve higher temperatures, increasing the lamp's efficacy (the technical term for lamp efficiency) and/or life. A-shaped energy-conserving incandescent lamps are from one to five percent more efficient than their conventional counterparts.

ELLIPSOIDAL REFLECTOR (ER) LAMPS

Ellipsoidal reflectors (ERs) focus light a few inches in front of the lens, rather than behind it, therefore trapping less light and heat in recessed fixtures. They are effective for deeply recessed fixtures where they can match the light of an R-lamp with as little as half the wattage. Similar to ERs, "BR"
lamps use a parabolic silver reflector with the filament mounted further forward.

HALOGEN LAMPS

Four types of tungsten-halogen incandescent lamps have been introduced to replace standard incandescent lamps used for general lighting, spot- and floodlighting, reflector applications, and accent lighting. The tungsten-halogen lamps that were introduced to replace medium base, A-line incandescent lamps for general lighting have rated lives of 3,500 hours, as opposed to the 750-2,500-hour rated life (depending on their design) of standard incandescents. They achieve energy savings of up to 31% and are available in 42-, 52-, and 72-watt versions, all with excellent color-rendering properties.

Another group of PAR halogen lamps has been introduced to replace PAR lamps used for spot lighting and floodlighting. The halogen lamps are available in 45-, 75-, 90-, and 150-watt versions, replacing standard lamps of 75, 100, 150, and 250 watts, respectively, without loss of light output or rated life. Smaller PAR halogen capsule reflector lamps also have been introduced. They produce a more brilliant and efficient white light than any other lamps of comparable size. PAR 20 and PAR 30 lamps replace R20 and R30 reflector incandescent lamps.

A low-voltage, compact-filament 36-watt PAR 36 lamp (popular for merchandising) also is available. Its light output is equivalent to that of a 50-watt standard lamp while consuming 28% less energy. It also permits better light control and has a rated life of 4,000 hours compared to 2,000 hours for a 50-watt PAR lamp. Also used for displays and accents are 2-inch-diameter mini-reflector lamps called MR-16s. They are available in a

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**TABLE 4: RETROFIT OPTIONS FOR INCANDESCENT Fixture**

<table>
<thead>
<tr>
<th>Existing Lamp</th>
<th>Retrofit/Replacement Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LAMP RETROFIT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60W Standard Lamp</td>
<td>52W Energy-Saving</td>
<td>8</td>
<td>85%</td>
<td>$2.00</td>
</tr>
<tr>
<td></td>
<td>13W Compact Fluorescent</td>
<td>44</td>
<td>92%</td>
<td>$14.00</td>
</tr>
<tr>
<td></td>
<td>18W Compact Fluorescent</td>
<td>42</td>
<td>12%</td>
<td>$13.00</td>
</tr>
<tr>
<td>75W Standard Lamp</td>
<td>18W Compact Fluorescent</td>
<td>57</td>
<td>100%</td>
<td>$18.00</td>
</tr>
<tr>
<td>150W Standard Lamp</td>
<td>135W Energy-Saving</td>
<td>15</td>
<td>91%</td>
<td>$5.00</td>
</tr>
<tr>
<td></td>
<td>90W Halogen</td>
<td>60</td>
<td>61%</td>
<td>$19.00</td>
</tr>
<tr>
<td>500W</td>
<td>450W Self-Ballasted Mercury Vapor</td>
<td>50</td>
<td>84%</td>
<td>$16.00</td>
</tr>
<tr>
<td>1000W</td>
<td>750W Self-Ballasted Mercury Vapor</td>
<td>250</td>
<td>59%</td>
<td>$80.00</td>
</tr>
<tr>
<td><strong>SYSTEM REPLACEMENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500W</td>
<td>175W Metal Halide</td>
<td>290</td>
<td>121%</td>
<td>$93.00</td>
</tr>
<tr>
<td>1000W</td>
<td>250W High-Pressure Sodium</td>
<td>695</td>
<td>119%</td>
<td>$222.00</td>
</tr>
</tbody>
</table>

*The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.

**Value of Annual Energy Savings**

$Assuming 6,000 hrs. of operation at $0.084/kWh.
variety of beam patterns with wattages of 20, 35, 42, 50, 65, and 75.

COMPACT FLUORESCENT LAMPS

Compact fluorescent lamps are four times more efficient than incandescent lamps and have rated lives up to 13 times as long. Three principal families of compact fluorescent lamps currently are available. These are:

- Twin-tube preheat lamps with starter devices in the base of the lamp. These lamps can use inexpensive reactor ballasts resulting in an economical alternative to incandescent lighting.
- Quad-tube preheat lamps (couble twin-tube and four-finger) also having plug bases and integral starters. Some of these lamps use reactor ballasts; others require high-reactance autotransformer types. These are designed to be a more compact, higher lumen output variation of the twin-tube.
- Special twin and quad rapid start lamps without an integral starter in the base of the lamp. These can be used with special dimming, low-temperature, or electronic ballasts.

Compact fluorescent lamps are available as either a single unit (Figure 4) consisting of a starter, ballast, and lamp, or a screwbase socket adapter that includes the ballast and a separate lamp. The adapter unit permits replacing the lamp when it burns out, whereas the single unit must be replaced entirely.

Compact fluorescent lamps have good color-rendering properties, and many choices of color temperature (warmth or coolness) are available. Like full-size fluorescent lamps, compacts typically are controlled by switching the ballast and lamp circuit on and off. Certain versions can be dimmed. These require specialized dimmers and ballasts in order to work properly. Dimming range is typically down to 5 percent of lamp output.

---

### TABLE 5:
RETROFIT OPTIONS FOR RECESSED BAFFLED INCANDESCENT DOWNLIGHT

<table>
<thead>
<tr>
<th>Existing Lamp</th>
<th>Retrofit Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings $</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>75W R30</td>
<td>18W Compact Fluorescent</td>
<td>57</td>
<td>96%</td>
<td>$18.00</td>
<td></td>
</tr>
<tr>
<td>150W R40</td>
<td>120W Energy-Saving</td>
<td>30</td>
<td>Same</td>
<td>$10.00</td>
<td></td>
</tr>
<tr>
<td>75W PAR</td>
<td>65W Energy-Saving PAR</td>
<td>10</td>
<td>Same</td>
<td>$3.00</td>
<td></td>
</tr>
<tr>
<td>300W R</td>
<td>120E R40</td>
<td>180</td>
<td>Same</td>
<td>$58.00</td>
<td></td>
</tr>
<tr>
<td>150W PAR</td>
<td>120W Energy-Saving PAR</td>
<td>30</td>
<td>Same</td>
<td>$10.00</td>
<td></td>
</tr>
<tr>
<td>90W Halogen PAR</td>
<td>60W Halogen PAR</td>
<td>60</td>
<td>Same</td>
<td>$19.00</td>
<td></td>
</tr>
</tbody>
</table>

1The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.

2Assuming 4,000 hrs. of operation at $0.08/kWh.
SYSTEM REPLACEMENT OPTIONS

In the case of flush-mounted incandescent fixtures, almost any type of fluorescent, metal halide, or high-pressure sodium source will be a cost-effective substitute depending upon the specific application.

FLUORESCENT LIGHTING

Fluorescent lighting has overtaken incandescent as the most widely used, providing more than two-thirds of all the electric illumination (and almost all the general office lighting) in the United States. The most common fluorescent tubes vary in length from six inches to eight feet. They are available as linear, circular, U-shaped, compact twin, and quad tube forms (Figure 5). They also are available as preheat, instant-start, or rapid-start. Preheat/rapid-start (which can operate on either preheat or rapid-start circuits) are the most common. Preheat lamps require a few seconds to start after they have been activated. Instant-start lamps need no preheating because they use ballasts that provide a high starting voltage (400-1,000 volts). Rapid-start lamps require less starting voltage than instant-start because the ballast heats the lamps' cathodes to facilitate start-up almost as quickly as instant-start lamps.

RETROFIT/REPLACEMENT OPTIONS

Various four-foot fluorescent lamps have been developed to replace standard 40W T-12 lamps. ("T" refers to "tubular" and the numerical designation indicates envelope diameter in eightths of an inch. As such, a T-12 lamp is tubular and has a diameter of 12/8" or 1.5" inches.) Some of the retrofit lamps include: energy-saving 34W T-12 lamps, energy-saving 32W T-12 lamps, 40W T-10 lamps, and 32W T-8 lamps. The latter two lamps have higher lamp/ballast system efficacies. They also are smaller in diameter than the standard 40W T-12 lamps, as shown in Figure 6. Note, however, that the T-8 lamp requires a compatible ballast.

Tables 6 through 9 summarize retrofit/replacement options for commonly used fluorescent lighting. A brief description of these options follows. Although many existing fluorescent installations still rely upon standard core-coil magnetic ballasts, the existing systems identified in the tables all assume use of energy-saving high-efficiency magnetic ballasts. If your existing installation relies on standard ballasts, the savings to be derived from retrofit will be higher than those indicated in the tables.

ENERGY-SAVING 34W T-12 LAMPS

Energy-saving 34W T-12 lamps are filled with an argon-krypton gas mixture rather than argon alone (as used in standard 40W T-12 lamps). The lamps are compatible with the ballasts used to operate standard lamps, but they produce less light. As such, they normally are used to provide energy savings in areas that generally are overilluminated. When combined with standard magnetic ballasts, the lamp/ballast system has a slightly higher efficacy than a standard argon-filled fluorescent lamp/ballast system.

ENERGY-SAVING 32W T-12 LAMPS

Energy-saving 32W T-12 lamps also are filled with an argon-krypton gas mixture. They have a heater cutout device that disconnects the lamp filament heater reducing total lamp wattage with no
loss in light output when compared to the 34-watt type. Note that this lamp has a one- to two-minute restart time; i.e., it takes one to two minutes to achieve full brightness when it is turned on immediately after being turned off.

HIGH-EFFICIENCY PHOSPHOR T-12 LAMPS

New types of fluorescent lamps are available that use tri-phosphors instead of the halophosphate phosphors traditionally used in standard fluorescent lamps. Whereas halophosphate phosphors emit broadly throughout the electromagnetic spectrum, tri-phosphors emit in fairly narrow regions of the red, green, and blue portions of the spectrum. Lamps now are being manufactured with layers of both types of phosphors. These double-layer coatings provide improved color-rendering and efficacy. Table 10 lists some representative values.

40W T-10 LAMPS

40W T-10 lamps provide higher efficacies, longer lives, and more light output than standard fluorescent lamps. They are used to best advantage as retrofits for T-12 lamps in areas that are underilluminated. No ballast change is needed and they provide increased light output.

32W T-8 LAMPS

The 32W T-8 fluorescent lamps are one inch in diameter and are available in 2-foot (17-watt), 3-foot (25-watt), 4-foot (32-watt), and 5-foot (40-watt) lengths, as well as U-shaped tubes. Because they are incompatible with T-12 lamp ballasts, they require the use of special ballasts. A summary of the characteristics of the T-8 lamp family is provided in Table 11. The largest U-shaped lamp is ideally suited for 2' x 2' luminaires. Two of the smallest U-shaped lamps can be installed in a 1' x 1' luminaire to provide light output equivalent to that of a 150-watt incandescent luminaire while requiring only 42 watts of power.

BALLAST RETROFIT OPTIONS

Fluorescent ballasts are designed to operate preheat, instant-start, or rapid-start fluorescent lamps. Magnetic core-coil ballasts are most commonly used. Also known as electromagnetic or magnetic ballasts, they operate lamps at the nominal power distribution frequency of 60 Hz.

Federal regulations established in 1988 and
**TABLE 6: FOUR-LAMP FLUORESCENT 2' X 4' LUMINAIRE WITH FLAT PRISMATIC LENS**

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Retrofit/Replacement Option¹</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 40WT12, 2 Mag Hi-Eff Bal</td>
<td>4 34WT12</td>
<td>22</td>
<td>88%</td>
<td>$ 7.00</td>
</tr>
<tr>
<td></td>
<td>2 Mag Hi-Eff Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 32WT12</td>
<td>30</td>
<td>88%</td>
<td>$ 10.00</td>
</tr>
<tr>
<td></td>
<td>2 Mag Hi-Eff Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LAMP RETROFIT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 40WT12, 2 Mag Hi-Eff Bal</td>
<td>4 40WT12</td>
<td>22</td>
<td>86%</td>
<td>$ 7.00</td>
</tr>
<tr>
<td></td>
<td>2 Cath Cutout Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 34WT12</td>
<td>41</td>
<td>79%</td>
<td>$ 13.00</td>
</tr>
<tr>
<td></td>
<td>2 Cath Cutout Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 32WT8</td>
<td>28</td>
<td>95%</td>
<td>$ 9.00</td>
</tr>
<tr>
<td></td>
<td>2 Mag Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 40WT12</td>
<td>22-34</td>
<td>101-98%</td>
<td>$ 7.00-$ 11.00</td>
</tr>
<tr>
<td></td>
<td>2 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 34WT12</td>
<td>38-51</td>
<td>91-79%</td>
<td>$ 12.00-$ 16.00</td>
</tr>
<tr>
<td></td>
<td>2 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 40WT10</td>
<td>16-17</td>
<td>110%</td>
<td>$ 5.00-$ 6.00</td>
</tr>
<tr>
<td></td>
<td>2 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 32WT8</td>
<td>45-49</td>
<td>97-101%</td>
<td>$ 14.00-$ 16.00</td>
</tr>
<tr>
<td></td>
<td>2 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 32WT8</td>
<td>45-49</td>
<td>97-101%</td>
<td>$ 14.00-$ 16.00</td>
</tr>
<tr>
<td></td>
<td>1 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LAMP AND BALLAST REPLACEMENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 40WT12, 2 Mag Hi-Eff Bal</td>
<td>3 40WT12</td>
<td>50-53</td>
<td>76-72%</td>
<td>$ 16.00-$ 17.00</td>
</tr>
<tr>
<td></td>
<td>1 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 34WT12</td>
<td>65-73</td>
<td>67-61%</td>
<td>$ 21.00-$ 23.00</td>
</tr>
<tr>
<td></td>
<td>1 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 40WT10</td>
<td>53</td>
<td>84%</td>
<td>$ 17.00</td>
</tr>
<tr>
<td></td>
<td>1 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 32WT8</td>
<td>63-76</td>
<td>73-65%</td>
<td>$ 20.00-$ 24.00</td>
</tr>
<tr>
<td></td>
<td>1 Elec Bal</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.

²Electronic ballast data are given in ranges to accommodate the industry variation in design. In general, the higher input power savings match the lower relative light output listings.

³Conversion requires recalibration of sockets.

⁴Assuming 4000 hrs. of operation at $0.08/kWh.
fully implemented in April 1991 set the minimum energy standards for the fluorescent ballasts most commonly used in commercial lighting applications. These standards generally preclude use of yesterday's "conventional" ballasts with F40 T-12 four-foot rapid-start, F96 T-12 eight-foot slimline, and F96 T-12 high-output rapid-start lamps. Instead, high-efficiency, energy-saving electromagnetic or high-frequency ballasts must be used.

HIGH-EFFICIENCY ELECTROMAGNETIC BALLASTS

Compared to conventional electromagnetic ballasts, energy-saving electromagnetic ballasts can cut fluorescent lighting energy consumption by as much as 10 percent. The life of these ballasts is approximately twice that of the 12-15 years of their conventional counterparts.

| TABLE 7: RETROFIT OPTIONS FOR THREE-LAMP FLUORESCENT 2' X 4' PARABOLIC FIXTURE |

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Retrofit Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (In Tandem - 3 Bal Operate 6 Lamps)</td>
<td>3 34WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>23</td>
<td>85%</td>
<td>$ 7.00</td>
</tr>
<tr>
<td>LAMP RETROFIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Retrofit Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>3 34WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>27</td>
<td>92%</td>
<td>$ 9.00</td>
</tr>
<tr>
<td>LAMP AND BALLAST RETROFIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>15</td>
<td>92%</td>
<td>$ 5.00</td>
</tr>
<tr>
<td></td>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>30</td>
<td>78%</td>
<td>$ 10.00</td>
</tr>
<tr>
<td></td>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>20-26</td>
<td>106-93%</td>
<td>$ 6.00-$ 8.00</td>
</tr>
<tr>
<td></td>
<td>3 40WT12, 1.5 Mag Hi-Eff Bal (Tandem)</td>
<td>35-41</td>
<td>92-88%</td>
<td>$11.00-$13.00</td>
</tr>
<tr>
<td></td>
<td>3 40WT10, 1 Mag Hi-Eff Bal (Tandem)</td>
<td>23</td>
<td>114%</td>
<td>$ 7.00</td>
</tr>
<tr>
<td></td>
<td>3 32WT12, 1 Mag Hi-Eff Bal (Tandem)</td>
<td>23</td>
<td>87%</td>
<td>$ 7.00</td>
</tr>
<tr>
<td></td>
<td>3 32WT8, 1 Mag Hi-Eff Bal (Tandem)</td>
<td>33-46</td>
<td>99-86%</td>
<td>$11.00-$15.00</td>
</tr>
</tbody>
</table>

¹The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.

²Electronic ballast data are given in ranges to accommodate the industry variation in design. In general, the higher input power savings match the lower relative light output figures.

³Assuming 4,000 hrs. of operation at $.083/kWh.
HEATER-CUTOUT BALLASTS

Heater-cutout (or hybrid) ballasts are equipped with a cutout device that turns off the cathode heaters in fluorescent lamps once the lamps illuminate, creating an approximate 5 watt savings per ballast. These ballasts are cost-effective and can be used with 34W T-12, 40W T-12, and 40W T-10 lamps.

ELECTRONIC BALLASTS

Electronic ballasts incorporate advanced solid-state circuitry that converts 60 Hz input frequency to a higher frequency, typically 25-40 kHz. They can improve lamp/ballast system efficacy by 25 percent or more, emit significantly less heat, operate more quietly, and reduce flicker.

Some electronic ballasts have the additional capability of regulating light output. These can be especially advantageous, because they make a lighting system more flexible while permitting energy savings of 50 percent or more when used in conjunction with certain control strategies.

REFLECTOR REPLACEMENT OPTIONS

Highly polished retrofit reflectors are being

---

### TABLE 8:
LENSED FLUORESCENT 2' X 2' TROFFER
WITH 2 U LAMPS (6.0")

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Retrofit/Replacement Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.40WT12U 1 Mag Hi-Eff Bal</td>
<td>2.34WT12U 1 Mag Hi-Eff Bal</td>
<td>11</td>
<td>88%</td>
<td>$4.00</td>
</tr>
<tr>
<td></td>
<td>2.31WTBU 1 Mag Bal</td>
<td>12</td>
<td>97%</td>
<td>$4.00</td>
</tr>
<tr>
<td></td>
<td>2.40WT12U 1 Elec Bal</td>
<td>11-17</td>
<td>99.88%</td>
<td>$4.00-$5.00</td>
</tr>
<tr>
<td></td>
<td>2.34WT12U 1 Elec Bal</td>
<td>19-25</td>
<td>91.79%</td>
<td>$6.00-$8.00</td>
</tr>
<tr>
<td></td>
<td>2.31WTBU 1 Elec Bal</td>
<td>9-21</td>
<td>115.97%</td>
<td>$3.00-$7.00</td>
</tr>
</tbody>
</table>

**LAMP AND BALLAST RETROFIT**

**SYSTEM REPLACEMENT**

T-5 System with 1 Elec Bal

1 The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.

2 Electronic ballast data are given in ranges to accommodate the industry variation in design. In general, the higher input power savings match the lower relative light output ratings.

3 Retrofit lighting is needed to convert to T-8 U lamps.

4 Assuming 4000 hrs. of operation at $0.10/kWh.
marketed for use with existing fluorescent luminaires. Typically, they are promoted for application to four-lamp fixtures, with claims suggesting that retrofit permits elimination of two lamps with no significant light loss directly below the fixture.

Retrofit reflectors come in a variety of shapes (Figure 7). Most are designed to hide the fact that lamps have been removed by diffusing the light or by creating an illusion of four lamps where there really are only two. Common reflector materials are anodized aluminum, aluminum with an aluminum film, or aluminum with a silver film.

Analyze data closely before investing in a specific type of reflector retrofit. Consider the cost of the reflector and installing it, the cost of restoring the existing fixtures, and the cost of new fixtures. In some cases, manufacturer claims about savings are based on “before” conditions that assume lu-

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Retrofit Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (%)</th>
<th>Value of Annual Energy Savings</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>75W/96T12/12</td>
<td>60W/96T12</td>
<td>35</td>
<td>83%</td>
<td>$11.00</td>
<td></td>
</tr>
<tr>
<td>Mag Hi-Eff</td>
<td>60W/96T12</td>
<td>46</td>
<td>83%</td>
<td>$15.00</td>
<td></td>
</tr>
<tr>
<td>Mag Hi-Eff</td>
<td>75W/96T12</td>
<td>24</td>
<td>Same</td>
<td>$8.00</td>
<td></td>
</tr>
<tr>
<td>110W/96T12/HO</td>
<td>95W/96T12/HO</td>
<td>30</td>
<td>87%</td>
<td>$10.00</td>
<td></td>
</tr>
<tr>
<td>Mag Hi-Eff</td>
<td>Mag Hi-Eff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.
2Assuming 4,000 hrs. of operation at $0.10/kWh.

<table>
<thead>
<tr>
<th>STANDARD HALOPHOSPHOR</th>
<th>RARE EARTH PHOSPHOR RE70</th>
<th>RE80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Lumens</td>
<td>3050</td>
<td>3200</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>88%</td>
<td>88%</td>
</tr>
<tr>
<td>Lumens/Watt</td>
<td>76 lwp</td>
<td>80 lwp</td>
</tr>
<tr>
<td>Life Hours</td>
<td>— 20,000 @ 3 hours/start —</td>
<td>70.79</td>
</tr>
<tr>
<td>Color Rendering Index</td>
<td>62</td>
<td>70.79</td>
</tr>
</tbody>
</table>

1The table values apply to a 40-watt rapid-start fluorescent lamp. Chromaticity (apparent color temperature), which is a measure of the visual warmth or coolness or a particular lamp, is rated the same for the three designs.
minaires and lamps have not been cleaned on a regular basis. In fact, published test data suggest that a four-lamp luminaire re-lamped to two-lamp operation and fitted with a retrofit reflector will produce 30-40 percent less light than a fully lamped, recently cleaned four-lamp luminaire with new lamps.

It also is important to note that retrofit reflectors can change the optical qualities of a luminaire. Such changes can result in inferior lighting due not only to less light, but also to “hot spots” beneath the fixture, dark areas between luminaires, and darkened, “gloomy” walls. Higher maintenance costs also may result, since highly polished surfaces require more frequent and rigorous cleaning to maintain their effectiveness, and because their installation makes it more difficult to service luminaires, especially for ballast replacement.

Another concern to address is the possibility that installation of a retrofit reflector could void the Underwriters’ Laboratories (UL) or other listing of a luminaire, resulting in a code violation. It also could void the manufacturer’s warranty on the fixture.

If analysis shows that reflector retrofits will be cost-effective, proper selection of the retrofit is important. Partial reflectors are needed when luminaires are part of the HVAC system, to assure vents are not covered. Partial reflectors also may be a wise choice if ballasts are to be kept accessible for easy maintenance. In all cases, the optics should be reviewed closely, to help assure the new lighting scheme does not produce undesirable effects, such as glare.

It often makes sense to consider installation of new ballasts when luminaires are being modified with new reflective material. However, the cost of new ballasts added to the cost of new reflectors can exceed the cost of installing new fixtures. Recognize that luminaires now available offer many more options than before. The benefits to be derived may be more than sufficient to justify the additional cost, especially so since new luminaires may use three lamps rather than four, produce the proper level of illumination, and offer dimming and other optional features.

**SHIELDING AND DIFFUSING MEDIA REPLACEMENT OPTIONS**

Modifying a luminaire’s shielding and/or diffusing media can be an effective and low-cost luminaire modification. Many manufacturers offer

<table>
<thead>
<tr>
<th>TABLE II: T-8 LAMPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watts</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td><strong>STRAIGHT LAMPS</strong></td>
</tr>
<tr>
<td>17</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>32</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td><strong>U-SHAPED LAMPS</strong></td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td>31</td>
</tr>
</tbody>
</table>
a broad range of products for use in retrofit, and new media can be custom-fitted to almost any existing fixture.

Plastic lenses that have become yellowed with age, or that have deteriorated due to improper maintenance procedures, should be replaced. When a replacement is called for, consider the application carefully. For example, if the space involved has been equipped with video display terminals (VDTs), use of media designed specifically to reduce VDT screen glare is called for. Note, however, that some of these retrofits may not be energy-efficient. For example, reflective-coated small-cell parabolic louvers may provide excellent performance, but at considerable sacrifice to the illumination level.

**HID LIGHTING**

High-intensity discharge (HID) lighting refers to lighting provided by mercury vapor, metal halide, and high-pressure sodium lamps. Mercury vapor lamps are the least efficient HID lamps and, generally speaking, are only slightly more efficient than incandescent lamps. Their principal advantage is long life. Mercury vapor lamps can be replaced with either metal halide or high-pressure sodium lamps, which in most instances also require a ballast system retrofit. Some common retrofit/system replacement options are shown in Table 12.

Another somewhat common retrofit is to rely on energy-efficient metal halide lamps or color-corrected high-pressure sodium lamps in place of

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**CASE IN POINT**

**CONTROL DATA SAVES MORE THAN $235,000 DUE TO BENEFITS OF NEW LIGHTING**

The lighting system used by Control Data’s Operations Group, in Sunnyvale, CA, was inadequate. It consumed far more energy than necessary. Even more important, however, the quality of the illumination was inadequate for the work being performed. Reflected glare on VDT screens and computer keyboards was causing performance and causing input errors. Working with Control Data’s engineering staff, Frank J. Arroyo, an energy management engineer employed by Pacific Gas and Electric, designed a new lighting system for the Operations Group. The cost of the new system — which relied on fluorescent lighting — was $14,890. Although it was installed principally to provide better illumination, it also was inherently efficient. In fact, it was predicted to lower overall operating and maintenance (O&M) costs by some 60 percent per year; from $1,120 annually to $4,830, with energy consumption alone being reduced by 65 percent. As significant as these savings may sound, however, they are almost inconsequential compared to the bottom-line values derived from better performance. Records show that computer downtime was reduced by three to four hours annually. Because no one dependent on the system could use it when the Operations Group’s computers were inoperative, downtime avoidance was worth an average of $200,000 per year to Control Data. The better-quality illumination that permitted downtime avoidance also resulted in Operations Group members being able to work faster. The estimated 6 percent productivity improvement exhibited by the ten members of the Operations Group rewarded Control Data with additional savings worth an estimated $28,000 annually. The improved performance and more aesthetic appearance of the space also resulted in a significant morale boost for the Operations Group. Although the dollar value of the improved morale could not be calculated, the other benefits could be, and they create an impressive sum: $235,290 saved per year as a consequence of a $14,890 investment in good lighting, creating a simple payback of 23 days.
their respective standard counterparts. This retro-fit is made principally to obtain better color, typically because some change in operations has made more accurate color rendering essential. The color-corrected HPS lamps are not as efficient nor do they last as long as their standard counterparts.

LOW-PRESSURE SODIUM LIGHTING

Often used for security purposes, low-pressure sodium (LPS) lighting is the most efficient of all, with LPS systems attaining efficacies as high as 150 lumens/watt. The principal drawback of these lamps is their color-rendering properties. In many instances, the colors they illuminate appear as black, white, or shades of grey. Should the operations they illuminate change, or should better color-rendering be required for any reason, a new type of lighting is needed. No retrofit lamps are available for use in existing low-pressure sodium luminaires.

TABLE 12:
HIGH-BAY INDUSTRIAL LIGHTING FIXTURE

<table>
<thead>
<tr>
<th>Existing System</th>
<th>Retrofit Option</th>
<th>Input Power Savings (Watts)</th>
<th>Relative Light Output (Mean Lumens)</th>
<th>Value of Annual Energy Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>175W Mercury Vapor</td>
<td>70W HPS</td>
<td>105</td>
<td>79%</td>
<td>$34.00</td>
</tr>
<tr>
<td>100W HPS</td>
<td>70</td>
<td>112%</td>
<td>$22.00</td>
<td></td>
</tr>
<tr>
<td>100W MH</td>
<td>71</td>
<td>106%</td>
<td>$23.00</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>87%</td>
<td>$50.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>250W Mercury Vapor</td>
<td>150W HPS</td>
<td>97</td>
<td>147%</td>
<td>$31.00</td>
</tr>
<tr>
<td>150W MH</td>
<td>100</td>
<td>104%</td>
<td>$32.00</td>
<td></td>
</tr>
<tr>
<td>175W MH</td>
<td>70</td>
<td>106%</td>
<td>$22.00</td>
<td></td>
</tr>
<tr>
<td>400W Mercury Vapor</td>
<td>150W HPS</td>
<td>266</td>
<td>82%</td>
<td>$85.00</td>
</tr>
<tr>
<td>250W HPS</td>
<td>150</td>
<td>141%</td>
<td>$48.00</td>
<td></td>
</tr>
<tr>
<td>250W MH</td>
<td>159</td>
<td>97%</td>
<td>$51.00</td>
<td></td>
</tr>
<tr>
<td>325W Energy Saving Metal Halide</td>
<td>70</td>
<td>100%</td>
<td>$22.00</td>
<td></td>
</tr>
<tr>
<td>1000W Mercury Vapor</td>
<td>250W HPS</td>
<td>775</td>
<td>62%</td>
<td>$248.00</td>
</tr>
<tr>
<td>400W HPS</td>
<td>610</td>
<td>79%</td>
<td>$195.00</td>
<td></td>
</tr>
<tr>
<td>950W Energy Saving Metal Halide</td>
<td>50</td>
<td>200%</td>
<td>$16.00</td>
<td></td>
</tr>
</tbody>
</table>

1 The data presented in this table are extrapolated from several sources and therefore must be considered approximate. In choosing between different systems or similar systems offered by different manufacturers, data relating to the specific installation should be obtained.

2 Assuming 4000 hrs. of operations at $0.08/kWh.
designers of new construction are available to those who are planning a retrofit. The principal difference relates to limitations imposed by the system exclusive of controls (e.g., type of lighting involved or ballast types used), limitations on space (some control modules take more room than others), and budget. Nonetheless, for the most part, the issue does not revolve around, “Can we attain this function?” so much as it revolves around, “What specific method should we use to attain this function?”

(A comprehensive guide to contemporary lighting controls has been published by the Lighting Control Council of the National Electrical Manufacturers Association (NEMA). Titled NEMA Guide to Lighting Controls, it examines all types of lighting controls currently available, both for new construction and retrofit, and the functions they perform.)

Typical functions performed by lighting controls include on/off, occupancy recognition, scheduling, task tuning, daylight harvesting, lumen depreciation compensation, and demand control. A brief discussion of these is as follows:

- **On/Off** — is turning lighting on or off. The degree to which this function is performed depends on other variables or control functions such as occupancy recognition and scheduling, as described below.

- **Occupancy recognition** — is commonly used in intermittently occupied areas or rooms, typically to turn lights on when people are present, and then turn them off automatically after a certain amount of time when they are no longer present. Experience indicates that occupancy detection can save significant amounts of energy and money by preventing the waste caused by keeping lights on when they are not needed.

- **Scheduling** — involves providing exactly the light level required at specific areas at specific times of the day, night, week, or month. This reduces electricity waste. Rather than having full light output in a particular area when it is normally not in use, or when the task requirement changes, such as during lunch hour or evening clean-up, the control system will automatically schedule programmed lighting levels that are optimum for the varying tasks.

- **Task Tuning** — provides the ability to adjust the light output of any or all light fixtures for the actual task being performed. It also compensates for factors that affect light levels, such as the reflective characteristics of floors, ceilings, walls, and other major surfaces, or to compensate for the age of the worker.

- **Daylight Harvesting** — is taking advantage of the light available from windows, skylights, daylight atriums, and other daylight systems now used by designers. Depending on how much daylight area can be utilized, savings of up to 15 percent in lighting energy consumption can be realized through the use of daylight compensation control, while maintaining a visually comfortable working environment.

- **Lumen Depreciation Compensation** — compensates for light loss experienced by the lighting system with use over time. A number of factors affect the actual footcandle level the lighting system delivers. As lamps age, they

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**FIGURE 8**

Occupancy Sensors
produce less light (lamp lumen depreciation). As lamps, lighting fixtures, and room surfaces become dirty, they deliver less light (luminaire dirt depreciation). Line voltage fluctuations, ambient and lamp wall temperature variations, component production tolerances, and burnouts also have an effect on light output. To compensate for this light loss, the common practice has been to initially provide a higher footcandle level than the targeted design level or to overlight with additional luminaires. With modern lighting controls, such overdesign is not necessary.

- **Demand Control** — involves dimming or turning off certain luminaires during the brief daily period of peak electrical demand in order to reduce utility demand charges.

Lighting controls can be generally classified as manual or automatic. Manual controls turn lighting systems on or off, or adjust light output, in direct response to manual adjustment, e.g., flicking a switch or moving a dimmer slide. Manual lighting controls include lighting panelboard controls (circuit breakers) and contactors for controlling large numbers of fixtures, wall switches for flexible control of small groups of fixtures, key-activated switches for applications where lighting control security is important, and solid-state manual dimmers.

Automatic controls are either programmed to take a certain action at a specific time, or the action is event-initiated. Examples of automatic controls include time-based programmable controls for indoor and outdoor switching, photocell controls that respond to changes in light levels, occupancy sensor controls (Figure 8) that operate by sensing the presence of people, and microprocessor-based programmable and network control systems that provide flexible lighting systems control and integration.

**RETROFIT OPTIONS**

Retrofit options for lighting controls include: switching, dimming, and integrated microprocessor-based controls. A brief discussion of major control devices and systems follows.

**SWITCHING CONTROLS**

Switching controls turn lights on and off, with some units performing other functions as well. They work effectively with any light source and can provide the right amount of light when and where it is needed. For example, the lights in a building can be turned off during unoccupied hours automati-
cally (at night, on weekends, on holidays, or at any other time when no one is present). And, when a building’s unnecessary lights are off, the heat buildup that otherwise would have to be removed with air conditioning is prevented. This reduces energy consumption even further, to provide even more savings.

Many manual and automatic switching controls are available. These include lighting contactors, local wall switches, on/off local intelligent devices (receiving inputs from a timer, clock, occupancy sensors, photocells, etc.), low-voltage switching systems, power-line-carrier control, and two-level HID lighting controls.

**DIMMING CONTROLS**

Dimming controls are available for most types of lighting. They provide variable light output and can be integrated into automatic lighting control systems. An example of an automatic photocell-activated lighting control system is shown in Figure 9. Some dimming controls require use of standard or electronic dimming ballasts, while others employ an electronics package installed in the panelboard or elsewhere within the system.

Dimming control technologies typically rely on either voltage reduction or waveform management. Through voltage reduction, line voltage to the lighting system is lowered without affecting the shape of the AC line voltage to any significant extent. The voltage reduction permits full-range control of most incandescent lighting. It also is effective for most low-voltage lighting, except some solid-state transformers may not be capable of full-range dimming. Although voltage reduction can be used with gas-discharge lighting (fluorescent, mercury vapor, metal halide, and high- and low-pressure sodium), its effectiveness is limited unless it is combined with special ballasts.

Waveform management systems effect dimming by modifying the shape of the AC line voltage. The most popular type of waveform management is phase control. This type of control permits dimming of the initial portion of each AC waveform half-cycle. The amount of dimming achieved is determined by the amount of each half-cycle that is eliminated. When applied to waveform management, devices permit control from 20 percent to more than 90 percent of nominal light output (100 percent output usually cannot be obtained due to a small voltage drop across control elements.)
Phase control also can be used with gas-discharge systems, providing special magnetic dimming ballasts are applied. In such cases, fluorescent lighting output can be controlled from 5 percent or less to full nominal output.

Phase control dimming equipment is available in a variety of shapes, sizes, and functions. Wallbox controls are available with ratings from 600 to 2,000 watts and larger modular and system dimmer packs can handle essentially any load. Control schemes can include timer or photocell arrangements, as well as a wide range of manual controls and the ability to interface with the building automation equipment. Even wallbox dimmers, which generally have been considered stand-alone devices, now can be interfaced and controlled by external systems.

New types of waveform management controls permit dimming of gas-discharge sources without use of special ballasts, but the low end of their output range tends to be 15-50 percent, depending on the specific device employed. Luminaire, ballasts, and wiring do not have to be modified to gain the advantage of dimming controls. Their low initial cost makes them attractive for new construction as well. Although these newer controls are not yet available in wallbox-size, they can be obtained as fixture-mounted devices that control a single ballast; subcircuit devices that control up to eight ballasts; and 20- to 100-amp circuit control devices. They are available as stand-alone units, for manual or photocell control, and as modules designed for integration with other building controls systems.

In general, both voltage reduction and waveform management systems are compatible with electronic ballasts, to the extent there is circuit compatibility (manufacturers' circuit designs vary). Note, however, that voltage reduction control's dimming range is limited when used in conjunction with ballasts. The specific unit depends on factors inherent in control and ballast design. Manufacturers should be contacted. Note, too, that significantly reduced lamp life and lamp color property changes might result if the voltage reduction is carried too far.

A variety of dimming controls is available from various manufacturers. These include manual, modular, preset, and integrated dimmers.

INTEGRATED MICROPROCESSOR-BASED CONTROLS

Several types of microprocessor-based lighting control systems are available that integrate switching and dimming controls into a facilitywide control system (Figure 10). They can be configured in many ways, depending upon the application involved. Examples of these systems include microprocessor-based centralized programmable lighting controls, networked lighting control systems, and building automation controls.
A wide array of options is available for purposes of lighting system retrofit or replacement. The planning process can be simplified somewhat by identifying certain key parameters. But even that task may be more complex than some may suppose, given the various financing options available. As examples, a number of electric utilities provide rebates to lower the cost of purchasing certain types of energy-efficient components. Shared energy savings and financing programs also are available, and leasing also may be an option. As such, it may be possible to obtain the desired lighting for less than expected or, alternatively, owners may be able to derive a much better system than they thought the budget could support.

Other key considerations to take into account include factors such as quantity and quality of illumination, codes, use of existing components, operation, and maintenance.

These and other issues are addressed below. One issue not discussed is the interrelationship between quality of lighting and lighting energy consumption. Given today’s technology, it is possible to achieve high-quality lighting from systems that are highly energy-efficient. By the same token, it is possible to reduce lighting energy consumption considerably by removing lamps, disconnecting luminaires, eliminating lenses and louvers, installing highly reflective materials inside luminaires, and applying similar measures to produce more light for the same amount of energy, or produce the same amount of light with far less energy. Unfortunately, such procedures can have a significantly negative effect on lighting's ability to achieve its purpose.

To achieve the bottom-line benefits of lighting — to achieve the advantages that can be achieved only through effective lighting management — it is necessary to give serious consideration to lighting quality and how that quality affects the ability of lighting to do its job, that is, to support the work being performed in the space. Light is for people. Light that creates glare or that casts undesirable shadows cannot be considered good lighting, no matter how much or how little energy it consumes. First and foremost, lighting must do its job. Energy managers really “earn their stripes” when the systems that provide the light that’s needed do so in a manner that also minimizes energy consumption.

QUANTITY OF ILLUMINATION

The quantity of illumination — the amount of illumination, or lighting level — is properly referred to as illuminance, measured in footcandles (fc). Illuminance requirements depend not only on the task itself, but also on the age of the worker (older eyes require more light), the importance of the task (how critical or expensive is a visual mistake?), and the reflectance of the task background (the greater the difference between task and background, the easier it is to see).
Several sets of illuminance recommendations or requirements have been developed by various organizations, including the Illuminating Engineering Society of North America (IESNA), the federal government, and state and local governments as well. The only generally accepted illuminance recommendations are those developed by the IESNA. Most of the other guidelines consider IESNA recommendations, but tend to be somewhat more stringent for purposes of energy conservation.

For many years, the IESNA published its illuminance recommendations in a simple tabular format. Today's approach is somewhat more complex, taking into account the key variables that affect illuminance requirements.

There is far more to selecting the appropriate illuminances than developing numbers from a set of tables. For example, it is common for several different tasks to be performed at a given workstation. A word-processing operator must read printed or written material of variable quality, and must look at both an input device and a video display screen. Each of these subtasks requires a different illuminance. Likewise, many different tasks will be performed in a large space, and the overall visual environment created by lighting in that space also must be considered. It is virtually impossible to develop a lighting system that will be all things to all people; compromises are necessary. Generally speaking, these compromises should favor the most important tasks and the somewhat more demanding visual requirements of older workers.

QUALITY OF ILLUMINATION

The amount of energy required to achieve a given illuminance can be minimized when good quality lighting is provided. Moreover, good quality lighting is essential if maximum benefit is to be obtained from the lighting system and the energy it uses. Simply providing whatever illuminances may be appropriate is not sufficient to ensure good lighting. The quality of illumination depends on the proper distribution, color, and control of light to achieve a proper balance in the whole visual environment as well as to provide adequate lighting for each task.

VISUAL COMFORT

A lighting system that provides good visual comfort is relatively free of conditions that make seeing and performing visual tasks difficult.

Glare is a general term used to indicate too much light impinging on the eye. Disability glare indicates that the light is so concentrated that a person must look in another direction. For example, the oncoming high beams of an automobile at night can create disability glare. Disability glare is seldom a problem inside buildings, but it can occur outside, due to improper aiming of fixtures.

Discomfort glare is a common problem indoors and one that can seriously erode productivity. It is not a harsh or obvious glare, but rather a general sensation of too much brightness in the general area of view, seen by peripheral vision or normal movement of the eye. It is usually caused by misdirected light coming from excessively bright fixtures or windows that are not properly shielded for normal angles of view. This type of glare is also known as direct glare, as opposed to indirect glare or reflected glare, which is brightness reflected from a surface into the eyes of a viewer.

Direct glare is relatively easy to control. Glare that comes from windows can be controlled
through proper use of interior shading devices. Direct glare from luminaires is minimized by providing shielding in the glare zone, i.e., a zone of 45 degrees from the horizontal plane.

Indirect glare reflected from sources such as mirrors, picture frames, and similar sources can often be controlled through rearrangement. In other cases, control is far more difficult, particularly when veiling reflections are involved.

Veiling reflections consist of light that bounces off the task or workstation surface into the eyes, thus veiling details of the task. Veiling reflections commonly occur when there is a light source directly above and in front of the line of sight, in the “offending zone.” Because the reflected glare comes from below eye level or so close to the line of vision that the eye cannot avoid it, it frequently is more disturbing than direct glare. The contrast reductions it creates can drastically reduce visual performance.

SHADOWS

When properly used, shadows have a positive impact on overall lighting quality. For example, clearly defined shadows may assist the performance of certain specialized industrial tasks. They also accent the depth and form of various objects, which can be an important merchandising consideration. On the other hand, the shadows cast on most visual tasks reduce the brightness of the task, obscure important details, and thereby impair effective visual performance (Figure 11). In addition, shadows that are sharply defined on or near a task can be a source of visual discomfort. These tend to occur when the light on the task comes primarily from relatively small light sources in a few scattered locations. They can be avoided by using large diffusing luminaires or by employing many sources for task illumination. Shadows also can be reduced by using high-reflectance matte finishes on room surfaces because they reflect light into shadowed areas.

VISUAL AESTHETICS

In addition to providing visual comfort, a good lighting system contributes to visual aesthetics by being integrated with and becoming integral to architecture and interior design. In this role, lighting has a psychological impact and functions almost as an art form. Factors such as color, texture, form, shadow, and depth become important design considerations. New data from ongoing research, as well as an abundance of new lighting system components, now make it possible to derive significant aesthetic value from a lighting system while still minimizing energy consumption and demand.

Atmosphere, or the “feeling” of a space, is influenced by prevailing brightness patterns and color that, in turn, are influenced by light distribution and room reflectances. An atmosphere of restfulness can be attained by using low-brightness patterns, no visible light sources, subdued color, dark upper ceiling, and a low wall brightness that decreases upward to the ceiling. When lower illuminances are used, an atmosphere of restfulness becomes one of intimacy. At higher illuminances, however, the same pattern may be regarded as confining or cheerless. Such variances illustrate the point that sometimes mood is more important than the task, as on a dance floor, and adhering strictly to appropriate brightness ratios may result in less than desirable effects. Similarly, it may be appropriate to violate brightness ratio guidelines to create a visual environment conducive to task performance, as in a church. In any event, levels, movement, and patterns of light are essential aesthetic considerations.

Color is another significant aspect of visual aesthetics. People are emotionally responsive to their surroundings and color is one of the chief characteristics of an environment.

Colors at the red end of the spectrum are psychologically warm and stimulating, while those at the blue end create a mood of coolness and repose. Generally speaking, warm-colored surfaces seem to make a room appear smaller than it actually is. Conversely, cool colors generally appear to recede, so their use may increase the apparent size of a room, but also may create an impersonal atmosphere. Gradations, variations, and accents of color are frequently used to break up monotonous continuity in larger areas.

Each light source produces light with distinctive spectral characteristics, causing surfaces to look different. When selecting or comparing colors for any purpose, it is important to use the type of light source under which the colors ultimately will be seen.

The color of a light source also affects the reflectance of the surface it illuminates. This occurs because a colored surface does not reflect all wavelengths of light energy equally. The muted, neutral,
or pastel colors usually selected for large interior surfaces have reflectances that vary only slightly with the color of the light source. By contrast, the reflectance value of a highly saturated color will vary significantly with the color of the light source. Since these are customarily used as accents in small areas, the impact on overall reflectance values tends to be minor. But when these colors are used in large areas, considerable variations can occur. For example, a highly saturated red with little or no reflectance in the yellow, green, and blue portions of the spectrum may have a reflectance of 20 percent to incandescent light, but a reflectance near zero to a clear mercury vapor source, because such lamps generate no energy in the red or orange regions.

**UNIFORMITY OF ILLUMINATION**

Uniform and nonuniform illumination are terms used to describe the layout of fixtures on a ceiling. Uniform illumination implies that luminaires are laid out in a uniform grid pattern, regardless of task locations. Nonuniform illumination indicates that selection of the fixture locations is based on

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**FIGURE 12:**
A nonuniform layout of 4-lamp 2-ft. x 4-ft. fluorescent fixtures is shown for an office. The numbers shown are footcandles.

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**FIGURE 13:**
Flexible (Modular) Branch Wiring System
the location of the work stations they illuminate (Figure 12).

Until recent years, locating luminaires with respect to workstations was not practical given the relatively high cost of moving a Luminaire and the extent to which workstation locations and tasks changed with time. Use of uniform illumination helped ensure adequate illumination in a space no matter where a given task was performed. The amount of illuminance provided was that required for the most difficult commonly occurring task.

Although uniform illumination is still regarded as the best approach for illuminating densely occupied areas (100 sq. ft. or less per worker), for other applications it has serious drawbacks, energy waste in particular.

Nonuniform illumination is practical today as a result of new equipment. One of the most significant advances in this regard is flexible or modular branch wiring. As shown in Figure 13, one end of a factory-assembled wiring module plugs into the power source while the other plugs into the fixture. The plugs are designed to make misconnections impossible, and to accommodate quick and easy luminaire relocation. This approach allows positioning of luminaires after occupancy, permitting a level of fine-tuning not otherwise available. Note, however, that use of flexible branch wiring is not permitted by all local codes. Modular wiring also allows tandem wiring of luminaires which offers unique opportunities for “ballast sharing.” In this case, 2-lamp or 3-lamp luminaires can “share” portions of 4-lamp ballasts, thereby reducing total energy use. Track lighting also provides flexibility in locating fixtures. Long used in retail areas, this approach uses fixtures plugged into an electrified track.

The installation of dimming controls in an existing uniform system will also permit nonuniformity. The light output of a given fixture or a small group of fixtures can be adjusted according to needs.

TASK LIGHTING

Task lighting is a term commonly used to describe what could more accurately be called furniture-integrated lighting (Figure 14). Furniture-integrated lighting systems incorporate task lighting into the workstation. Ambient illumination is provided by overhead fixtures, an upward component of the integrated task lighting fixture that directs all its output toward the ceiling for indirect ambient light distribution, or a combination of these.

Although some furniture-integrated lighting systems permit effective adjustments to accommodate the needs of any given user, they are far more difficult than other systems to control from a central source. As a result, it is far more difficult to integrate such lighting into demand control operations. In addition, furniture-integrated lighting converts all of its power consumption to heat within the working space. Comparison with a system of overhead air-handling or heat-removing luminaires shows that use of furniture-integrated lighting may require larger air-handling system motors as well as more air changes.

**FIGURE 14:**
Ambient office illumination from uplight is achieved through ceiling-directed lighting and elimination of typical open office system partitions, as shown at left. Location of task lighting, shown at right, eliminates shadows.
Task lighting also can be provided by overhead fixtures located correctly with respect to the workstation as well as by local desk-mounted lighting units.

No matter what type of task lighting is employed, it should minimize direct glare, provide uniform and shadowless illumination, and minimize veiling reflections. To minimize veiling reflections, task lighting should increase light from the side. When overhead fixtures are employed, they should be located out of the offending zone. In large open offices, however, this is sometimes difficult. Also, high dividing screens, overhanging shelves, or cabinets near the workstation can block ceiling light, causing shadows to fall on the task.

CODES

Most states and many local jurisdictions have building codes that incorporate the energy-efficient guidelines included in ASHRAE/IES Standard 90.1. Some state codes are more stringent than others. In all cases, the applicable code must be followed.

USE OF EXISTING COMPONENTS

It may be possible to reuse certain existing components when modernizing a lighting system. Such reuse is completely acceptable provided that it does not impose limitations. For example, existing fixtures may be suitable for a new system, but it would be unwise to use them if they require extensive modernization or if they are inefficient in comparison to contemporary ones. Likewise, it may be possible to reuse existing poles outdoors. If they are taller than desired, they can probably be cut to the appropriate length. If they are shorter than desired, however, smaller and less efficient lighting sources probably would be required, and it may be impossible to obtain the desired lighting distribution. Also, one must consider the appearance of outdoor lighting poles and other equipment during daytime hours.

If reuse of the existing lighting system would make it difficult to attain the desired results, it is best simply to dispose of the existing equipment.

OPERATION

No matter how efficient a lighting system may be by design, it will waste energy if it is used unnecessarily. Unnecessary use can be minimized through proper control. Automatic controls are preferable because they eliminate the unreliability of human memory. Controls may be particularly important with daylighting. In order to derive maximum cost-effectiveness, adjustable shading devices for windows and skylights generally are needed. Fairly sophisticated sensors and actuators may be required to automate such devices. Otherwise, the designer should develop a schedule to indicate when manual controls should be operated. The cost of labor associated with manual controls should be calculated when analyzing various automatic and manual options.

MAINTENANCE

As already noted, maintenance can be one of the most cost-effective aspects of lighting system ownership. When the designer can rely on less compensatory lighting, fewer luminaires and lamps will be required initially—reducing first cost—and the resulting energy consumption, demand, and other operating and maintenance costs will be that much less.

Maintenance should go beyond the lighting system itself. Since the amount of lighting required to provide a given illuminance depends upon surface reflectances in a space, it is important to maintain the surfaces properly. Maintenance of windows and skylights also is an important consideration when daylighting is used. Dirt build-up can restrict the amount of daylighting available; it also can lead to reflections that create glare and thus erode overall lighting quality.

The lighting system designer should make general maintenance recommendations for the system as well as for other elements of the building that affect the lighting system. Maintenance of controls is an important consideration as well.
EVALUATING AND ACCEPTING OPTIONS

The general approach to evaluating and accepting options is to first determine which will be most effective, all things considered, and then proceed with procurement. It is important to realize that, as important as lowering energy consumption may be, other factors also should be evaluated with respect to the purpose of the lighting and the function of the illuminated space. In other words, a change that lowers energy cost at the expense of safety or productivity would not be wise. The simplest approach to making the evaluations is to reduce as many as possible to a common denominator: In the case of lighting, it is simplest to rely on dollars, because they comprise a common base to which the value of energy savings, productivity increases, safety enhancements, and so on, all can be converted. Accordingly, much of this section focuses on these issues, as follows.

EVALUATING COST-EFFECTIVENESS OF LIGHTING SYSTEM OPTIONS

Major cost criteria in selecting a system include the budget provided, the initial system cost, its projected life-cycle costs, and the dollar value of benefits to the customer. Other important cost-related criteria are the energy efficiency of the lighting system, its overall energy consumption, its relationship to other building systems, and its flexibility with respect to modification or rearrangement. Still other considerations include existing limitations in modernization projects and building code requirements.

Numerous factors must be addressed specifically when evaluating the economics of lighting system options. These include the design, components, and the method of payment that contribute to the initial system cost; alternative methods of acquiring the system hardware; utility incentives and rebates; operating and maintenance costs, including energy, parts, and labor; inflation; interest rates; tax considerations; the economic life of the system; the discount rate; and the value of tangible and intangible benefits to be derived from the system.

In some cases, the procedures to be used to conduct an evaluation already have been developed. As an example, the federal government has established methodologies for economic analysis utilizing life-cycle costing procedures. These are described in the Life-Cycle Cost Manual for the Federal Energy Management Program (order No. PB88138227) available from the U.S. Department of Energy (DOE), Washington, DC. Also available from DOE is the Building Life-Cycle Cost (BLCC) Software.

ECONOMIC FACTORS

Economic evaluations must consider a variety of factors, such as those indicated below.

INITIAL COSTS

Initial costs includes the cost of design, system components, shipping system components, the
taxes involved, and the cost of installation. In existing situations, the initial cost also must include any associated modifications needed to accommodate lighting system components or layout.

Initial costs will be reduced by any incentives or rebates offered by the local utility. In addition, in modernization work, initial costs should be reduced by the value of income derived from selling existing components for scrap, or tax benefits derived by donating them to a charitable organization.

Several options for hardware acquisition other than purchasing are available. When flexible or modular branch wiring systems are used, for example, it is possible for the owner to lease the branch wiring as well as the fixtures for outdoor lighting. It also may be feasible for the owner to provide the flexible branch wiring, but require tenants to purchase or lease the fixtures they prefer.

Under a lease agreement, an investor (lessor) completely finances the purchase and installation of lighting control improvements in a facility. The building owner (lessee) makes monthly payments to the lessor (owner of equipment) for the use of the equipment. The building owner also is responsible for maintaining the equipment. At the end of the lease agreement, the building owner can purchase the equipment at a predetermined residual value, extend the lease, or have the equipment removed. (Lease/purchase agreements are different in that the lessee is considered the owner of

CASE IN POINT

Pennsylvania Power & Light Sees Savings of $250,000 Annually Because of Better Lighting

Drafters located in Pennsylvania Power & Light company's (PP&L's) N3 Drafting Room in Allentown (PA) were experiencing frustration. They were unable to work up to their potential, and were making too many errors, because of inadequate illumination. Light from the overhead fixtures was bouncing off the surface of the task and into their eyes, creating a form of indirect glare known as a veiling reflection. PP&L management determined that a change was in order, and that the new lighting selected could also be more energy-efficient than that which comprised the existing system. Before implementing the comprehensive change-over called for, it was decided to convert only a portion of the overall space to assess impact. Results were impressive. Overall operating and maintenance (O&M) costs experienced before conversion amounted to $1,247 annually. After the modernization, it was projected, these costs would be trimmed by 76 percent, to just over $3,000 per year. As significant as the O&M cost reduction was, it took on the appearance of being minor by virtue of productivity improvements. Actual measurement showed that the new lighting, which virtually eliminated veiling reflections, permitted workers to perform their tasks more than 1.3 percent faster. For purposes of projections, however, management decided to rely on a 7.5 percent “number.” Even at that rate, however, the productivity benefit was projected to be worth $235,290 per year. It was known that a number of errors were avoided as a result of the new lighting, but the value of these could not be quantified. Even a relatively minor error could have major dollar implications, especially when it is not discovered until construction, or even later. It was noted, too, that absenteeism seemed to decline after the new lighting was installed, a result, some said, of less eyestrain and fewer headaches. All told, the bottom line benefits of better lighting were projected to save PP&L $255,929 per year. The cost of the new lighting was projected at $48,882, for a simple payback of 73 days.
the equipment and thus can obtain tax benefits from depreciation.) Typical lease contracts last from five to ten years.

In retrofit and replacement situations, shared energy savings (SES) contracts may be a viable option. Under an SES arrangement, a third party — usually an energy service company (ESCO) — designs, installs, and owns the lighting equipment at the owner’s facility, with the ESCO receiving a share of the energy savings that result. The actual energy use after the improvements usually is subtracted from a baseline estimate, and the savings are then adjusted to reflect current energy prices. For example, if the improvements saved 15,000 kWh and the current rate of electricity is $0.08 per kWh, the cost of energy savings is calculated as $1,200. If the same amount of energy was saved but the cost of energy increased to $0.10 per kWh, the savings would be calculated as $1,500. Sometimes the savings split between the contractor and the owner remain constant for the duration of the contract, and sometimes they vary. When they vary, they usually begin with a larger percentage for the contractor (such as 80-20) to enable the contractor to regain the capital spent on energy efficiency improvements, then is reduced to a more even split.

Outright financing by banks or other third parties also is an option. In that case, initial costs are split into equal monthly payments and paid over a period of years. In many cases, the energy savings on utility bills exceed the monthly time payment, resulting in a positive cash flow.

OPERATING COSTS

Operating costs are treated principally to energy and demand. These can be calculated manually although, in many cases, it is more appropriate to use computer programs. The latter approach helps assure adequate consideration of the impact of controls, as well as the effects of summer versus winter demand rates and time-of-use rates. A number of computer programs have been developed on a proprietary basis. Many utilities and manufacturers provide computer analyses for their customers without charge. The federal government also has developed computer programs, such as ASEAM, developed by the U.S. Department of Energy. With daylighting, one should consider the savings derived from lack of electric illumination, as well as the expense of employing daylighting. For example, it may be necessary to spend far more than otherwise required to keep windows and skylights clean, to prevent the specular reflections and glare which can occur due to dirt buildup and smudges.

In making long-term calculations, it is important to consider the energy rates likely to be in effect. Energy rate projections are available from the Energy Information Administration of the U.S. Department of Energy. Most utilities also can make projections available.

ECONOMIC LIFE

The economic life of a lighting system can be determined in a variety of ways. One is to base it on the anticipated life of the system itself. Another is to base it on the anticipated life or remaining life of the building involved. Another is to use the amount of time during which the owner anticipates staying in the building, or — when a tenant is involved — to base it on the length of the lease. Depending on the economic life involved, it may be appropriate to alter certain other calculations. For example, the life expectancy of an energy-saving ballast is about twice the 12-15 years of its standard counterpart. If the economic life of the system is 10 years, it would be improper to include the annualized cost of ballast replacement in long-term (10-year) maintenance costs because, in all probability, no ballasts will have to be replaced during that period.

MAINTENANCE COSTS

Most maintenance costs can be projected on an annualized basis. They include the cost of replacement lamps, lamp replacement labor, lamp and fixture cleaning labor, ballast replacement, and lamp and ballast disposal. One would also consider the cost of maintaining control systems, including those used in conjunction with daylighting. If an evaluation of cost differences between group relamping and spot relamping is performed, one should consider not only labor costs, but also those associated with lamp quantity discounts and lamp storage, breakage, and pilferage.

INFLATION

Inflation is not likely to affect all factors equally; energy costs may rise at a rate that exceeds the
general rate of inflation. The extent to which energy costs will increase faster than general inflation is referred to as the differential inflation rate. A 2-3 percent energy differential inflation rate is commonly assumed for life-cycle costing analysis, but this will vary from utility to utility and owner to owner.

INTEREST RATE

Because almost all construction is financed, the interest rate paid for borrowed funds determines the real cost of a system and its components. An owner may be more interested in knowing how much a system will cost per month or per year than what it costs initially. When looked at in these terms, the premium paid for good lighting may be of relatively little consequence.

DISCOUNT RATE

The discount rate is an interest rate applied in reverse to determine the present value of future money. One dollar received today is more valuable than one dollar received a year from today because today's dollar can be invested in a secure, insured account. It will have grown to more than a dollar by the end of a year. For example, if one assumes a 10 percent interest rate can be earned, then one dollar received today will be worth $1.10 in one year.

The discount rate is applied to determine how much future money (income or expense) is worth today. Once again, the rate applied is that which can be earned easily and safely. Thus, assuming the rate is 10 percent, $1.10 received one year from today would be worth $1.00 today:

\[ \frac{1.10}{1.10} = 1.00 \]

Likewise, $1.00 received one year from today would be worth only $0.909 now, and $1.00 received two years from today would have a present value of $0.826 ($1.00 \times 1.10 + 1.10 = 0.826$).

Using this approach, one can take all future expenses associated with a system, adjust for inflation, and apply a discount rate to determine the present value. The present value then can be divided by the economic life of the proposed system to develop annualized cost data in present-value dollars.

Most texts on engineering economics provide comprehensive charts of factors that can be used to determine the present value of future money quickly and easily using a number of different discount rates.

In retrofit applications, this approach is frequently applied to determine whether it is worthwhile to make an investment in energy conservation. Using this approach, one computes the future value of savings in terms of present-value dollars. If the present value of this future savings is less than the investment required, obviously it would be wiser to invest the money in something other than the energy conservation option.

VALUE OF BENEFITS

It is sometimes difficult to assign dollar values to some of the benefits of lighting. Nonetheless, it is appropriate to apply at least conservative approximations when they are warranted. For example, if the existing system is plagued by veiling reflections and other quality problems and the work involved is highly dependent on effective lighting, some conservative assumptions about productivity enhancement should be included. This applies also to factors such as retail sales, safety and security, and insurance rates.

EVALUATING ECONOMIC FACTORS

Simple payback is the most common economic analysis method in use and is also the easiest to compute. It sometimes is accompanied by analysis of simple return on investment (ROI), which is the reciprocal of simple payback. When life-cycle costing is employed, internal rate of return (IRR) and savings-to-investment ratio (SIR) often are used. These four methods are discussed below. Note that many other techniques also are employed. These are discussed in various engineering economics handbooks.

SIMPLE PAYBACK

Simple payback is used to determine how quickly the savings generated by a modification will pay for its cost. It is expressed as:

\[
\text{Simple Payback} = \frac{\text{Initial Cost}}{\text{Annual Savings}}
\]

If a system that costs $2,000 to install saves $1,200 per year, its simple payback is 1.7 years. If it saves $1,500 per year, payback occurs in 1.3 years, or 16 months.

Simple payback also can be applied in new
construction, for evaluation of alternatives. Accordingly, it may be found that investing an additional $1,000 in a better system will create energy savings or other benefits whose value will pay for the additional investment in a relatively short period of time, or whose annualized value exceeds the additional principal, interest, taxes, and insurance (PTTI) payment associated with the higher first cost.

SIMPLE RETURN ON INVESTMENT (SROI)

Simple ROI is the reciprocal of simple payback. It is expressed as:

\[ \text{Simple ROI} = \frac{\text{Annual Savings}}{\text{Initial Cost}} \]

Accordingly, a system that costs $2,000 to install and saves $1,200 per year has an SROI of:

\[ \frac{\$1,200/\text{yr}}{\$2,000} = 0.60/\text{yr} = 60\%/\text{yr} \]

INTERNAL RATE OF RETURN (IRR)

The internal rate of return (IRR) method is more complex than simple payback or SROI. IRR is the interest rate stated as a percent for which the life-cycle savings are just equal to the life-cycle costs. It is calculated using a trial-and-error process. Selected compound rates of interest are used to discount the cash flows until a rate is found for which the net value of the investment is zero or close to zero. The calculated IRR is compared to the investor’s minimum acceptable rate of return to determine if the investment is desirable.

SAVINGS-TO-INVESTMENT RATIO (SIR)

A savings-to-investment ratio (SIR), also known as benefit-cost ratio, compares the present value of savings to be obtained over an investment’s economic life to what it costs today to make the investment. It is expressed as the formula:

\[ \text{SIR} = \frac{\text{Present Value of Future Savings}}{\text{Initial Cost}} \]

If the SIR is equal to 1.0, it means the present value of future savings is equal to the dollars required today to achieve those savings. If the ratio is less than 1.0, it means the investment will not generate as much money as an easy, safe investment would. A ratio that exceeds 1.0 indicates the investment will yield a return that is better than the easily obtained return.

SIR is an effective means for evaluating relative merits of alternative systems.

ACQUIRING AND ACCEPTING LIGHTING SYSTEMS

Certain general procedures apply to the acquisition of any lighting system. Drawings and specifications must be clear and complete. Installation schedules should be carefully coordinated with other activities in the same space. After installation, the system should be thoroughly checked and adjusted to function as planned under actual working conditions.

PREPARING DRAWINGS AND SPECIFICATIONS

No matter what approach is used, the importance of comprehensive, well-prepared drawings and specifications cannot be overstressed. Drawings should indicate both indoor and outdoor lighting, floor plans, fixture schedules, and control schematics. In the case of modernization, information should be provided to indicate which fixtures and controls are to be removed, and who has responsibility for disposing of them; effective schedules are needed to minimize interruption of functions in the occupied space.

Problems have occurred in the past when specifications have not been properly coordinated with drawings, or when plans and specifications have not been properly integrated with overall electrical, mechanical, and structural plans and specifications. Computer-aided design and drafting can help minimize such problems, especially when all design professionals associated with a project are using compatible programs.

Given the abundance of fixtures now available, and the special operating characteristics of each, many consulting engineers find it difficult to write performance specifications for them. Specific fixtures from certain manufacturers often will be cited instead. To avoid any problems in this regard, specifications should make clear whether or not fixtures
include lamps, and, where applicable, what type of ballast is to be installed.

It is in the owner's best interest to have available information about the proper operation and maintenance of the entire lighting system. This can be provided by the manufacturers of the equipment, the contractors involved, the design professionals, or a combination. If more than one source is used for this information, however, someone should be appointed to coordinate it. When sophisticated controls are used, some training may be required to help ensure that building personnel understand their proper use.

**INSTALLATION MONITORING**

Most standard contracts between owners and design professionals call for the design professionals to visit the construction site on occasion to see that the construction is proceeding according to the overall intent of the plans. Unfortunately, plans and specifications are seldom as well executed as they could be, and this leaves a great deal of decision-making to contractors. Even when plans and specifications are well detailed, they still may be subject to interpretation. Full-time comprehensive observation by the design professional or a representative during construction is the owner's best assurance that what has been designed and specified will in fact be delivered. In addition, on-site observation means that any unexpected conditions can be dealt with quickly, thus minimizing rework requirements, change orders, delays, and disputes.

**INSPECTION, ACCEPTANCE, AND COMMISSIONING**

When the installation is almost complete, facility staff should inspect, accept, and commission the new lighting system. This is an important step, because it may be the last chance to help assure that the new system performs as intended and to correct any installation errors. The contractor should be responsible for on-site debugging and fine-tuning after the installation is complete, principally to check that the system works as it is supposed to. Fine-tuning generally assures not only that controls work properly and are correctly calibrated, but also that the conditions provided by the lighting are appropriate — free from glare, unwanted shadows, and so on. Fine-tuning thus may require repositioning of luminaires or workstations, particularly when video display terminals (VDTs) are involved.

Fine-tuning also means monitoring the use of the lighting system by those who customarily will be operating it for at least several days. This is done to make sure they are familiar with the control system, a particularly important factor when electronic control or daylighting is employed.
Lighting should be considered a long-term investment. Even if it is the intent to sell a building quickly, long-term considerations are important because most prospective purchasers will want to "see the numbers." Some sources of assistance are indicated below. When it comes to obtaining design input, however, it is essential to select individuals and organizations with care. A great deal is at stake. Be sure to determine the names of others whom a given source has served, and contact those clients to assess their satisfaction. Also consider visiting their facilities.

**NATIONAL LIGHTING BUREAU**

The NLB has for many years worked to make lighting system decision-makers more aware of the many benefits available from effective lighting, and some of the many options available to derive these benefits at minimal expense. The Bureau has many other publications available and will provide a directory of its publications without charge. (National Lighting Bureau, 2101 L Street, N.W., Suite 300, Washington, DC 20037)

**ILLUMINATING ENGINEERING SOCIETY OF NORTH AMERICA**

The IESNA is a national membership organization with chapters (sections) throughout the United States. Many of its members are independent illuminating engineers. Others are affiliated with utilities, manufacturers, and other organizations. The IESNA publishes the *IES Lighting Handbook*, a two-volume set that most lighting professionals consider the "Bible of the industry." IESNA also publishes some less technical materials which can be of substantial help. (Illuminating Engineering Society of North America, 345 East 47th Street, New York, NY 10017)

**NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION**

NECA is a national association of electrical contractors. The organization has chapters throughout the United States. Many electrical contractors, in addition to installing lighting systems, have complete design departments. Some also are active in the area of equipment leasing and contract maintenance. NECA offers a computerized service that can match specific lighting needs with qualified contractors in all areas of the country. To access this service, call 1-800-888-NECA (6322). (National Electrical Contractors Association, 3 Bethesda Metro Center, Suite 1100, Bethesda, MD 20814)

**NATIONAL ASSOCIATION OF ELECTRICAL DISTRIBUTORS**

NAED is a national association of electrical distributors, those who stock and sell lighting sys-
INTERNATIONAL ASSOCIATION OF LIGHTING MANAGEMENT COMPANIES

Known as NALMCO, the organization comprises lighting system maintenance contractors, that is, firms that provide contract lighting maintenance such as scheduled lamp replacement and luminaire cleaning. Many NALMCO members also perform rebalancing and luminaire modernization, among other services. NALMCO sponsors seminars and other training activities for its members and offers two certification programs, for Certified Lighting Management Contractors and Certified Lighting Management Consultants. (International Association of Lighting Management Companies, 34-C Washington Road, Princeton Junction, NJ 08550)

DEPARTMENT OF ENERGY

The U.S. Department of Energy (DOE) sponsors a variety of ongoing research studies in the area of lighting energy conservation, and it has developed or sponsored development of many instructional materials, as well as computer software, training materials, etc. DOE’s Office of Federal Energy Management Programs (Forrestal Building, 1000 Independence Ave., SE, Washington, DC 20585; 202/586-5772) also is responsible for coordinating the Federal Relighting Initiative.

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) has initiated an innovative, voluntary, nonregulatory program called Green Lights which encourages major U.S. corporations to install energy-efficient lighting technologies. Under this program, EPA commits to help Green Lights participants with technical support projects (e.g., computerized decision support system, national lighting product information program, and guide to financing sources for energy-efficient lighting), help strengthen the infrastructure of the energy-efficient lighting industry, and lower the barriers to energy-efficient lighting. (Green Lights Program, Environmental Protection Agency, 401 M Street, SW (ANR-445), Washington, DC 20460)

MANUFACTURERS

Manufacturers can provide catalogs and other materials that provide information on their products. Many also have a number of guides available that provide some general information on lighting, specific types of components, and so on. In addition, manufacturers, through their representatives and application engineers, can provide valuable assistance in the design and specification process. Most use sophisticated computer programs for these purposes, and some also have computer programs that can provide data relative to life-cycle costs.

OTHERS

Other sources of assistance include your local electric utility. Many have energy conservation or energy management departments, some staffed by specialists in lighting. The degree of assistance they can provide varies from utility to utility. Many electric utility companies offer rebates and other financial incentives for lighting modernization projects that can result in substantial cost savings. These usually are conducted under demand-side management programs. For a detailed listing of the electric utilities providing incentives for retrofit, contact the Association of Demand-Side Management Professionals (P.O. Box 4658 Berkeley, CA 94704; 415/528-5566).

A state’s energy office may be of value. Some also have incentive programs they can make available. Most have publications that can be of assistance.

Especially in major metropolitan areas, there likely will be a number of chapters of national groups that can be of help, at least by providing referrals to its members. Many of these are listed in the local telephone company’s yellow pages directory.
GLOSSARY OF TERMS

Many terms are used in discussions of indoor and outdoor lighting. Some of the more commonly used words and phrases are defined below.

**Ballast:** A device that modifies incoming voltage and current to provide the circuit conditions necessary to start and operate electric discharge lamps.

**Brightness:** As commonly applied, brightness (or luminance) is the intensity of the sensation that results from viewing a surface or space that directs light into the eyes. The foot-lambert is a measure of brightness.

**Coefficient of Utilization:** A measure commonly applied to indicate the efficiency of a luminaire in a given space. Coefficient of utilization (CU) comprises a ratio of the light delivered to the work surface by a luminaire compared to the total light output of the lamp(s) alone. This ratio changes with room size, shape, and surface reflectances.

**Contrast:** The relationship between the brightness of an object and its immediate background. An example of this would be the relationship between the letters printed on this page and the paper itself. An example of poor contrast would be a third or fourth carbon copy of a purchase order or computer printout.

**Diffuser:** A device commonly put on the bottom or sides of a luminaire to redirect or spread the light from a source. It is used to reduce brightness from the source.

**Footcandle:** The basic measure used to indicate illuminance (level of illumination). One footcandle is equal to one unit of light flux (one lumen) distributed evenly over a one-square-foot surface area. The metric equivalent to footcandle is lux, where one lux (lx) is equal to one lumen per square meter.

**Glare:** A discomforting or disabling condition that occurs when a high-brightness source contrasts with a low-brightness background, making it difficult for eyes to adjust. High brightness alone does not cause glare.

**HID:** High-intensity discharge lighting, including mercury vapor, metal halide, and high-pressure sodium light sources. Although low-pressure sodium lamps are sometimes included in the HID category, they are not HID sources.

**Lamp:** A light source, commonly called a bulb or tube.
**Lens**: A glass or plastic shield that covers the bottom, and sometimes sides, of a luminaire to control the direction and brightness of the light as it comes out of the luminaire.

**Light Loss Factor**: A multiplier applied to account for temperature and voltage variations, lamp aging, and dirt build-up on lamp, luminaire, and room surfaces, factors that reduce light output over time. In common practice, light loss factors are applied to initial footcandles to determine the light level that will be maintained in a given area.

**Light Trespass**: A situation that occurs when, due to lack of adequate beam control, light from an outdoor source is distributed onto areas where the illumination is not wanted.

**Louver**: A series of baffles arranged in a geometric pattern used to shield a lamp from view at certain angles, to avoid glare from the bare lamp.

**Luminaire**: A complete lighting fixture including one or more lamps and a means for connection to a power source. Many luminaires also include one or more ballasts and elements to position and protect lamps and distribute their light.

**Lux**: Unit of illuminance equal to one lumen per square meter.

**Nonuniform Illumination**: A system that has lighting located with respect to the tasks, including displays, so more lighting falls on these tasks than on surrounding areas.

**Reflector**: A device used to redirect the light from a lamp or luminaire by the process of reflection.

**Task Lighting**: The lighting, or amount of light, that falls on a given visual task.

**Veiling Reflection**: Also known as reflected glare, a reflection of a light source that partially or totally obscures details by reducing the contrast between task details and their background.