Performing a

Lighting System Audit

Revised Edition

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PREFACE

This guide has been prepared to help you conduct the lighting system audit which should be performed prior to modifying an existing lighting system. Those who perform the audit should account for more than the energy consumed by lighting. They also should be aware of the benefits which good lighting provides and the manner in which proposed lighting system modifications may affect these benefits, including productivity, retail sales stimulation, safety and security, among others. It is not prudent to sacrifice these benefits, especially so because recent technological advances now make attainment of lighting’s many benefits and energy saving fully compatible, through application of effective lighting energy management options.
# Take This Simple Test

1. Have you determined how much light the Illuminating Engineering Society of North America (IES/NA) recommends for the visual tasks being performed inside and/or outside your facility?

2. Have you conducted a study within the past two years to determine how much light your lighting system provides for the visual tasks being performed?

3. If you have removed lamps (light bulbs or tubes) or disconnected fixtures, did you perform a study first to evaluate the impact on factors such as productivity, safety, security, or sales (if applicable)?

4. Have you developed a lighting use schedule for both indoor and outdoor lighting?

5. Have you converted from standard fluorescent lamps to reduced-wattage high-efficiency fluorescent lamps?

6. Have you converted from standard fluorescent ballasts to energy-saving fluorescent ballasts?

7. Do you use metal halide, high-pressure sodium, or low-pressure sodium lamps for outdoor lighting?

8. Have you considered changing your lighting controls, by using techniques such as localized switching or installation of timers, dimmers, photocells or other control devices?

9. If the tasks performed in different areas have changed, and/or if desks or other workstations have been relocated, have fixtures been modified to accommodate these changes?

10. Do you change lamps on a group relamping basis, that is, are all lamps in a large area changed at the same time even though all or most of them are still operating?

If you have answered "no" to any one of the above questions, conduct a lighting system audit. You will probably be able to identify serious shortcomings in your present lighting system. By eliminating these shortcomings, you will have a better lighting system, one which costs less to operate and maintain, and—even more important—one which gives you more of what it originally was installed to provide.
CONDUCTING A LIGHTING SYSTEM AUDIT

Lighting is one of the most important of all building systems.

Indoors, good lighting is required to support maximum worker productivity, for attractive eye-catching displays which stimulate retail sales, to provide good visibility for consumer evaluations, to achieve the desired appearance and ambience in a space, and to meet many other important functional and psychological needs.

Outdoors, lighting is required mostly for safety and security. In fact, the absence of adequate outdoor lighting has led to liability problems and lawsuits. Outdoor lighting is also used to create a nighttime environment. In many cases, safety, security and aesthetic needs can all be met by one well-designed system.

As important as lighting is, it often is taken for granted. As long as new lamps—light bulbs and tubes—are installed when the old ones burn out, many people assume their lighting system is being properly operated and maintained. And if lamps are removed or fixtures are disconnected to save energy, they assume they are doing the right thing. But it may be the wrong thing. It may cause productivity to fall or retail sales to slump, or it may result in an accident or injury. Not only that, it may actually cause consumption of more energy rather than less, because lighting systems are far more complex than most people realize. This complexity must be considered before any change is made to determine which modification is likely to work best. This kind of approach pays off. Due to innovations developed by manufacturers of lighting system components, lighting energy consumption and operating cost can be reduced by as much as 50% or more and the value of new benefits derived may be many times the value of operating and maintenance savings alone.

Getting the Facts

To get the most from lighting system changes, it’s best to develop a plan indicating what will be done, when it will be done, how much it will cost to make a change, how much energy will be saved, and how much the energy savings and other benefits (more productivity, increased retail sales, etc.) will be worth. To develop such a plan, start by gathering facts about the lighting system which is installed right now, that is, by conducting a lighting system audit.

The basic information required for a lighting system audit is indicated by the form on pages 4 and 5. A detailed explanation of how to complete the form is also provided. It is not difficult. In general, for each space inside the building you need to know what kind of lighting is installed, how much power (wattage) is needed to operate it, average daily hours of operation, the kinds of control devices which are used and where they are located, and the kinds of tasks that are performed in various spaces. The amount of light provided at task locations should be measured using a lightmeter, following the directions which come with it.

It’s also important to find out how well the lighting system supports the work being done by comparing actual lighting levels with those recommended for the tasks involved. It also will be helpful to obtain comments from those who use the lighting. For example, do they notice that light tends to bounce off what they’re reading or working with and into their eyes, making it difficult to see? Does light come in through windows, causing glare and discomfort? You can also ask, “Is it too bright in here?” If the answer is “yes,” it does not usually indicate there is “too much light,” meaning higher footcandles than necessary. It could mean (among other things) that there is glare in the space, coming directly from a lighting fixture or window, or indirectly through reflection off another surface in the room.

Generally speaking, when people sense the lighting system is causing visual discomfort, the problem is lighting quality, not lighting quantity. In such cases it is best to rely on a lighting professional for guidance.

Fact-finding procedures should be used for outdoor lighting, too, to determine the type of system installed, its power requirements, how often it is used and the amount of light provided. If records are kept on the number of accidents which occur on building grounds or in a parking lot, it may be wise to glance through them to see how many are nighttime incidents which feasibly could be prevented by better lighting. A call to your insurance agent may reveal better lighting will result in reduced premiums. In some cases this may apply indoors, too.

Equipment and Materials Needed

It takes little to conduct a lighting system audit. Equipment and materials include a high-quality lightmeter (this can be rented; contact an electrical distributor for guidance), a stepladder (a taller ladder may be needed for outdoor lighting), notepad and pencils (or a tape recorder), an instant-developing camera and graph paper (to indicate where lighting fixtures and workstations such as desks are located in a space, as shown in Figure 1). It also will be appropriate to have some written references for your use. One of the most important is the latest edition of the IES Lighting Handbook which contains the most current recommendations for lighting levels (amount of footcandles) which are most appropriate for hundreds of specific tasks. You may be able to borrow a Handbook from your library or other local source. For purchasing details, contact the Illuminating Engineering Society of North America, 345 East 47th Street, New York, N.Y. 10017. You will also find it useful to obtain other publications from the National Lighting Bureau. Re-
quest a free directory of publications from the Bureau.

**Obtaining Information on Requirements and Restrictions**

It's also important to have a thorough understanding of any requirements or restrictions that affect your lighting system. These include governmental restrictions such as local codes affecting outdoor and emergency lighting, among others, as well as those which relate to OSHA (Occupational Safety and Health Administration) and other federal programs. Contact local or state building officials for details.

If your building includes rented space, be familiar with any restrictions or requirements indicated in lease agreements. In most cases it will be possible to modify leases providing there is an equitable sharing of the benefits which will result from changes made.

**Instructions for Completing the Lighting System Audit Form**

One copy of the lighting system audit form (shown on pages 4 and 5) should be used for each space or unit involved, indoors and outside.

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**FOOTCANDLE**

Footcandle is the unit used to measure how much light is falling upon a surface. One footcandle is equal to one unit of light (one lumen) distributed evenly over a one-square-foot surface. Lighting quantity in footcandles is measured using a lightmeter.

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**Figure 1: Room Sketch Indicating Locations of Workstations and Fixtures**
Figure 2:
LIGHTING SYSTEM AUDIT FORM

(See Instructions)

UNIT OR SPACE SERVED ____________________________________________

SQUARE FOOTAGE __________________________

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<td>Input Watts per Luminaire Type</td>
<td>Number of Luminaires by Type</td>
<td>Total Watts</td>
<td>Watts per Square Foot</td>
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<td>Visual Tasks Performed</td>
<td>IES/NA Illuminance Recommendations</td>
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<td>(8) Lighting Energy Cost</td>
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Unit or Space Served

Indicate the unit or space for which the form is being completed. Be specific. You may wish to coordinate the form with a plan of the building, so that “Lab #3” or “Lobby Area #6” can be found by quick reference to the building layout. The same technique may be applicable for outdoor lighting (Walkway #1, Parking Lot #5, etc.).

Square Footage

Indicate the square footage of the space involved. This can be obtained by measurement or by reference to plans. Do not include large nonilluminated areas such as elevator shafts, closets, etc.

(1) Types of Luminaires

A luminaire is a lighting fixture. (Technically speaking, a luminaire is a lighting fixture ready for installation, including one or more lamps, wiring connections, and, when appropriate, ballast(s), lampholders, and lens.) The type of lamps used generally indicates the kind of luminaire installed. Incandescent lamps are used with incandescent fixtures, fluorescent lamps with fluorescent fixtures, and so on with mercury vapor, metal halide, high-pressure sodium and low-pressure sodium. Note that innovations have resulted in exceptions. For example, certain types of self-ballasted fluorescent and mercury vapor lamps can be used in incandescent luminaires, and specific models of metal halide and high-pressure sodium lamps have been developed for use in certain types of mercury vapor fixtures.

In some cases a given space may have two or more types of luminaires using the same or different type of lamps. All types must be accounted for.

(2) Input Watts per Luminaire Type

The input watts per luminaire calculation should be based on the specific types luminaires installed. In other words, if there are five different types of luminaires in a space, say three different types of fluorescent and two different types of incandescent, watts per luminaire must be computed for each of the five different types.

Watts per luminaire is determined principally by the wattage of the lamps installed. For example, if a luminaire contains six 25W incandescent lamps, luminaire wattage would be (25W/lamp x 6 lamps = ) 150W.

Except for incandescent lamps and fixtures, a factor must be added to account for the power needed by the ballast. (A ballast is a small transformer-like device which conditions incoming voltage and current to make them suitable for a gas-discharge lamp.) A factor of 1.1 is generally applied as a “rule of thumb” for fluorescent luminaires. Accordingly, if a fluorescent luminaire has four 40W lamps installed, watts per luminaire would be (4 lamps x 40W/lamp x 1.1 = ) 176W. A factor of 1.2 is usually applied to high-pressure sodium lamps which are smaller than 1,000W. Exact ballast power requirements can be obtained by consulting the ballast or luminaire manufacturer.

(3) Number of Luminaires by Type

Indicate the number of identical luminaires in a space. For example, if there are five different types of luminaires, indicate how many of each type are installed.

(4) Total Watts

Total watts refers to the total power requirements for each type of luminaire and for the space itself. If there are ten fluorescent luminaires each having a 176W power requirement, total watts would be (176W/luminaire x 10 luminaires = ) 1,760W. If the space also has ten incandescent fixtures each requiring 180W to operate, total watts for the space would be (1,760W + 1,800W = ) 3,560W.

(5) Watts/Ft²

Watts per square foot (watts/ft² or W/ft²) is determined by dividing total lighting watts in a space by total square footage. The watts-per-square-foot measure in and of itself does not indicate the energy efficiency of a lighting system. Watts relate to power requirements, not energy consumption.

Energy consumption is measured in kilowatt-hours (kWh) which is derived as power requirement in kilowatts (thousands of watts) multiplied by hours of use. Nonetheless, in some areas government programs use the W/ft² measure to indicate lighting system efficiency, despite the fact that a system having a 3W/ft² connected load may be more efficient and consume less energy than a system having a 2 W/ft² connected load.

(6) Annual Hours of Use

Annual hours of use are determined by identifying when lights are turned on and off Monday-Friday, Saturday, Sunday and holidays. An accurate determination is needed because, in many instances, large amounts of energy and energy dollars are wasted by keeping lights on when they don’t have to be. Do not assume that lighting in a building is used eight hours a day just because the building is typically occupied from 9AM-5PM. In many cases lighting will be activated early in the morning at the convenience of operating personnel and left on late at night for cleaning crews. In some cases a great deal of office lighting will be kept on for just a few people who are working late. Inspect your building during other-than-normally occupied periods. It will be a good investment of your time.

(7) Energy Consumption (kWh)

The amount of energy consumed for lighting a space each year is determined by multiplying total watts (column 4) by annual hours of use (column 6). Thus, if a
space has a connected lighting load of 3,560 watts (3.56 kW) and the lighting system is on for 2,800 hours per year, total energy consumption would be (3.56 kW x 2,800 hrs/yr = ) 9,968 kWh/yr.

(8) Lighting Energy Cost

Annual lighting energy cost is generally determined by multiplying annual kWh (energy consumption) by the cost per kWh. You may need some assistance to develop accurate figures. Many electrical utility rate structures are incremental in nature, for example, $0.09/kWh for 1-500 kWh, $0.08/kWh for 501-1500 kWh, and so on. In addition, lighting use affects electrical demand charges and/or low power factor penalty charges which a utility may impose. In the case of small buildings, the amount of time required to make calculations “to-the-penny” precise may not be worthwhile. However, when larger buildings are involved, it often will be worthwhile to compute demand charges and energy charges separately, to obtain more definition of how much is being spent and why, thus to provide better guidance in the selection of lighting energy management options (LEMOs). (Demand charges reflect the rate at which energy is consumed as opposed to the amount of energy consumed. Although two buildings may consume identical amounts of energy, it will cost the utility more to meet the needs of the one which consumes energy at a faster rate, in that more energy must be available to meet demand at any time, larger distribution and transmission facilities are required, etc. Reducing demand can often save more money than reducing energy consumption by an equivalent percentage, especially when the utility imposes a “ratchet clause.” Such a clause in the rate structure requires the customer to pay for demand no less than a certain percentage (e.g., 70%) of the maximum recorded sometime earlier in the year.)

Generally speaking, it is best to speak with a utility representative or some other reliable source to determine whether or not an overall average number should be used and, in either case, the specific rates which should be applied.

(9) Replacement Lamp Cost

To determine the annual average cost of replacement lamps, you first must determine how many replacement lamps are used on average each year. If lamps are left in place until they burn out, this can be determined by dividing the annual hours of use by the rated life of the lamp. (A lamp's rated life is the number of hours which elapse before half the lamps in a large group of lamps burn out.) Thus, if a lamp is used 4,000 hours per year and its rated life is 20,000 hours, (4,000 hrs/yr ÷ 20,000 hrs/lamp = ) 0.2 lamp/yr would be used. If a system employs 400 identical lamps, it would require—on average—about (0.2 lamp/yr × 400 lamps = ) 80 new lamps/yr. If each lamp cost $2, the annual average cost would be (80 lamps/yr × $2/lamp = ) $160/yr. Lamp manufacturers list rated lives in their catalogs. These life ratings often vary according to how many hours a lamp customarily is burned after each start (fewer starts mean longer life). Lamp manufacturers or electrical distributors usually can provide assistance. Note: If all lamps in a system are replaced at the same time at a predetermined interval (group relamping), determine replacement lamp requirements based on the interval, rather than rated life.

(10) Lamp Replacement Labor Cost

Determine lamp replacement labor cost by multiplying the average number of new lamps installed each year by the time (in hours) required to install each. Then multiply the product by the hourly rate of the persons who customarily install replacement lamps. If lamps are replaced one at a time, as they burn out (spot relamping), it may take a half-hour (0.5 hr) or more to replace each, considering the time required to fetch lamp-changing equipment and a lamp, move to the fixture involved, move furniture, set up lamp-changing equipment, and so on. Obtain an accurate estimate by walking through the process with a person who customarily performs it. In determining hourly labor cost, consider not only a person's hourly wage or salary, but also the taxes and fringe benefits which the employer pays on that person's behalf. Generally speaking, the overall amount paid is from 1.3 to 1.4 times the hourly salary or wage.

(11) Ballast Replacement Cost

Most conventional indoor and outdoor ballasts last from 12 to 15 years; less if they operate under hot conditions. Energy-saving fluorescent ballasts—which operate cooler—may last two to three times longer than their conventional counterparts. Determine the anticipated life of the types of ballasts you have installed, and divide it into the cost to effect a replacement (labor and materials included). Multiply the result by the number of ballasts (of each type of luminaire) installed. For example, if you will have to pay an electrical contractor $50 to replace a ballast which will last 15 years, the annual cost is ($50/ballast ÷ 15 yrs/ballast = ) $3.33/yr. If the system comprises 100 four-lamp fluorescent luminaires, with each luminaire housing two ballasts, the total cost would be (100 luminaires × 2 ballasts/luminaire × $3.33/yr = ) $666/yr. Note: Only a qualified electrician should attempt ballast replacement. Faulty replacement can create safety hazards and other problems.

(12) Other Maintenance Costs

Other maintenance costs typically include the cost of regular lamp and fixture cleaning. Alternatively, if lamps are maintained on an annual basis by a lighting maintenance contractor, it may be appropriate to insert
the dollars involved in this column, and not fill in the other columns affected. If large quantities of lamps are stored in-house, it may be appropriate to include the value of the space in which they are stored, as well as the estimated value of breakage, inventorying, "inventory shrinkage," and similar "numbers." In some cases no lamps are stored and someone must make a trip to a supplier each time new lamps are needed. In such instances the value of that time could be inserted in this column or in column 10 (Lamp Replacement Labor Cost).

(13) Annual O&M Costs
The annual operating and maintenance (O&M) cost of the system involved is the sum of energy cost (column 8), replacement lamp cost (column 9), lamp replacement labor cost (column 10), ballast replacement cost (column 11) and other maintenance costs (column 12). As should be readily evident, the overall operating and maintenance costs are substantially more than the cost of energy alone.

(14) Method of Control
In this column indicate how the lighting in each space is controlled, for example, by one or more local switches, a master switch (circuit breaker) at the central panelboard, time clocks, dimmers, etc. Indicate on a diagram where controls are located.

(15) Visual Tasks Performed
Visual tasks are all tasks performed in a space except those which can be done—literally—with eyes closed. How effectively visual tasks are performed depends substantially on the visibility provided. In many cases a given worker will perform several visual tasks. For example, a word processor often will read from handwritten copy and then look into the video display terminal (VDT) screen. Identify the principal tasks for each worker or each group of workers. Do the same in the case of other settings. For example, in retail areas, salespersons will have one set of functions; customers will have other visual needs. (Familiarity with the requirements associated with completing the next column will help facilitate this process.)

(16) IES/NA Illuminance Recommendations
The IES Lighting Handbook identifies hundreds of different visual tasks and provides a method for establishing how much light (illuminance) should be provided for each. This method may be too complex for some nontechnical personnel to apply and, if so, a source of assistance should be relied upon. Do not bypass this step. Comparing results of data inserted in this column with that inserted in column 17 is an absolutely crucial step for effective lighting system evaluation. It helps identify how well your lighting system is doing what it’s supposed to be doing. If it is not doing it well, you or your company could be wasting thousands of dollars each year. Note: IES/NA recommendations are the only recommendations accepted by the nation’s illuminating engineering community. They also are the only recommendations based on more than three decades of research. In most cases they are task-specific. In some cases, however, they indicate how much light should be provided in a space.

(17) Illuminance on Tasks
A lightmeter is required to measure the amount of light which falls on a task. Follow the instructions which should accompany the lightmeter, and be certain to take measurements where the visual tasks are actually performed. It may be best to rely on an outside source for assistance, to help assure accuracy of measurements. An experienced individual can take other meaningful measurements, too, relative to brightness ratios and similar factors which are useful in evaluating a lighting system, but whose complexity goes beyond the scope of this publication. If the amount of light provided for a task exceeds the amount recommended, the lighting system may be wasting energy. However, if less light than recommended is being provided, far more costly outcomes may be involved. Workers’ productivity may be less than otherwise attainable; they may be making a large number of visual errors. In the case of a store, visual appeal may be affected, thus affecting sales. Outdoors and indoors as well, inadequate lighting could mean that safety or security is being compromised. How many dollars are involved? This requires an expert’s opinion. However, to obtain an idea of potential impact, consider a small manufacturing facility that employs 35 people on each of two shifts. Assuming the company pays each worker $18,000 per year (including company contributions for taxes, fringe benefits, etc.), just a 1% productivity improvement would be worth ($35 workers × 2 shifts × $18,000/worker/yr × 1% = ) $12,600/yr. That amount would probably be about twice the annual cost of all lighting energy those workers would need to get their work done!

(18) User Comments
User comments can be particularly important concerns, because they represent the reactions of those who use the lighting system every day. Is it "easy on their eyes," or do they sometimes feel symptoms of eyestrain, such as headaches or fatigue? Do they believe "there’s too much light in here"? Such a comment almost always means they are bothered by glare, a quality factor which has little to do with quantity. Do they believe that better lighting is needed? If user comments are negative, and if a comparison of columns 16 and 17 indicates insuf-
ficient lighting quantities are being provided, chances are
new lighting will have a dramatic impact on human per-
formance. Some consideration should be given to this
improved performance when evaluating how much
benefit will be derived from applying lighting energy
management options (LEMOs).

(19) Overall Appearance

A lighting professional can use several different tech-
niques to quantify the appearance of lighting. However, if
professional assistance is not obtained, at least subjective
judgements are needed. In fact, how does the lighted
environment appear? Is it visually comfortable while being
somewhat stimulating, or is it dull, flat and visually bor-
ing? Is it doing all it can to enhance the aesthetics of a
space, or could more be done? Could it be rated excel-
ent? Good? Fair? Poor? What about outdoor lighting?
Does that used for safety create a feeling of safety, or
are there dark spots and shadows which create areas
where people could easily trip or fall? Does the lighting
trespass onto neighboring property or into other areas
where it is not wanted? Does it enhance the appearance
of a facility and its surroundings at night? Does it draw
attention to a facility and identify it to passers-by?
Remember, lighting can be used to create a predeter-
mined nighttime environment. Assuming that would be
beneficial, does your present lighting do it?

Other Helpful Information

Additional information should be recorded and re-
ferred to, to help assure important factors are con-
sidered. The more you know, the more you can save.
For example, notes should be made about the condition
of lighting equipment. Are lamps and fixture surfaces be-
ing cleaned often enough? If not, the dust and dirt which
build up absorbs light.

Have fixture lenses yellowed due to age? If so, they
are robbing you of light and should be replaced.

Are fluorescent lamps flickering? If they are it's usually
because they are approaching burn-out. Replace them to
reduce the high per-footcandle cost of lighting and
energy waste they cause, as well as the distraction,
discomfort and annoyance. Note that flickering fluo-
rescent lamps can damage some ballasts, resulting in an
expensive repair.

Examine maintenance records or speak with mainte-
nance personnel to determine when lamps were last
changed. Also, determine how old the fixtures are and
whether or not they have ever been reballasted.

Examine the ceiling. If fluorescent lamps are used, do
they have different colors? If so, inadequate lamp pur-
chasing controls or poor maintenance may be the cause.
Use of higher efficiency, better-color lamps will improve
the appearance of the space.

Examine the windows which let in natural light (day-
lighting). Are they kept clean? If not, dust and smudges
can aggravate the problems of glare. Inspect the cleanli-
ness of walls and ceilings as well. Dirt on walls and ceil-
ings absorbs light and the money paid for it.

If it is time for repainting, consider use of lighter colors
which are better reflectors.

Do You Need Help?

Can you perform a lighting system analysis on your
own, or do you need assistance? Can you select lighting
energy management options (LEMOs) on your own, or
do you need assistance? If one assumes that it will be
necessary to pay for assistance, a decision about obtaining
it usually will be based on how much additional value
will be derived from that assistance in comparison to its
cost. To evaluate this potential value in terms of poten-
tial lighting energy or lighting operation and maintenance
(O&M) cost savings alone would be an error. Why? Ask
yourself this question: "Why do we have lighting here?"
Consider everything you need the lighting for and, where
appropriate, the dollar value of just a modest improve-
ment in performance of the activities which lighting sup-
ports. In retail operations, one must consider the impact
on customer appeal and sales, as well as the productivity
of workers responsible for inventorying, stocking and
retrieval from storage. In office and other production
areas, including industrial production areas, consider the
impact on productivity, error rates and employee
morale. In sports facilities, consider the impact on eye-
hand coordination and overall athletic performance. And
outdoors, consider the impact on safety, security and
appearance.

In fact, it takes relatively little expertise to reduce the
amount of energy which your lighting system consumes.
But to assume that the most important benefit you can
derive from a lighting system modification is less energy
consumption is to assume the system's purpose is energy
consumption. Such faulty assumptions could result in
costly errors. In many instances, the real value of better
lighting is its ability to support increased productivity,
lower error rates, more retail sales, decreased accident rates,
and so on. It almost always requires an experienced pro-
fessional to design the type of lighting necessary to
realize these benefits, and their value is such that it
usually justifies the fee or fee premium required to ob-
tain such guidance. Note, however, that effective
guidance is available from many sources and, in some in-
stances, this assistance is available for a very modest
change or none at all. Sources of assistance are discussed
on page 24.
Lighting energy conservation and lighting energy management are not synonymous terms. Lighting energy conservation implies an undue concentration on energy savings, without consideration of lighting’s purpose or the techniques available to attain lighting which better fulfills that purpose. By contrast, lighting energy management implies full consideration of the activities lighting is installed to illuminate, and lighting principles which can be applied to help people perform these activities better. By relying on energy-efficient lighting system components, as well as effective controls and maintenance, all integrated into one well-designed system, reduced lighting system operating and maintenance (O&M) costs can be a valuable additional benefit of lighting energy management.

The techniques which can be applied to reduce lighting O&M costs within a context of lighting energy management are called lighting energy management options or LEMOs. They are discussed in this section in a general nature and the examples used, although completely realistic and based on actual experience, are hypothetical. It is essential to consider all possible LEMOs and to evaluate each before making a final decision on which ones to apply and the order in which those applicable should be implemented.

**Reduce Usage**

The most direct way of reducing lighting energy consumption is through usage reduction. Recognize, however, that keeping lights off when they’re needed is often more neglectful than keeping them on when they’re not needed. Remember, too, that even if more effective use of lighting does result in substantial savings, you should not stop there. Any energy-consuming system which is wasteful by design will continue to waste energy every time it is turned on.

Usage reduction generally is accomplished most effectively through the application of automatic controls, because they bring results which are far more reliable and effective than those derived by trying to change long-standing habits. Nonetheless, in some smaller buildings, controls may not be cost-effective. In such instances it may be necessary to rely on the human element and take steps to instruct and encourage people to use lighting more wisely. One of these steps involves application of lighting reminder stickers (Figure 2) to wall switches. It may also be appropriate to campaign for better usage by creating posters (Figure 3) for mounting in strategic locations.

Some people still believe fluorescent lighting should not be extinguished when leaving a room. This is not the case today. Frequent on-off switching of fluorescent lamps does not increase energy cost; it reduces it. Frequent on-off switching will reduce the usable life of fluorescent lamps, but with today’s long-life lamps, the value of the energy saved almost always exceeds the value of the lamp life lost.

If your building has cleaning personnel who report before of after normal operating hours, determine how they use the lighting. All too often all fixtures on a floor are illuminated and kept on even though lighting use could be staggered, with lights being turned on and off when needed. Also determine when lighting is normally turned on in the morning and off at night. It may be found that some systems in a building are turned on at 6:30 AM when they don’t have to be on until 8:00 or 8:30 AM. Observe outdoor lighting usage, too. Be certain that there is having on when it is needed. However, it may be wasteful to illuminate an empty parking lot from 11 PM-7 AM.

If you find lighting use is resulting in lighting waste, develop lighting schedules which tell people when to turn certain lights on and off. Consider color-coding switches to make the schedule easier to follow. Explain each schedule to those who will be using it. Tell them why it is important. Monitor their progress and provide remedial guidance as needed. The dollars involved will make the effort worthwhile.

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**Figure 2: Lighting Switch Sticker**

**Figure 3: Lighting Campaign Poster**
Improve Controls

There are many different types of controls available. The most basic control is a simple on/off switch. In many cases as many as 25 fixtures are controlled by just one switch or circuit breaker located at a central panelboard. As a result, all of these fixtures will often be energized at times when only five or six are needed. In cases such as this it is wise to install additional switches located conveniently so users can apply lighting more discriminatingly. Four-lamp fluorescent fixtures can be rewired so one switch controls the two outboard lamps of luminaires while another controls the two inboard lamps (split-ballasting). In this way lighting energy consumption can be cut in half during those periods when 50% of full lighting output is all that is needed, as during cleaning periods. When three-lamp fixtures are installed, reductions to 66% or 33% of light output can be obtained using this split-ballasting technique.

Time clocks (time switches) have been in use for many years, especially for outdoor applications. Both electromechanical and electronic time clocks have a variety of features, such as the "astronomic feature" which causes the control to adjust automatically for changing hours of light and darkness during the year. Programmable time clocks permit the user to schedule lighting for a week at a time. Time clocks also can be applied indoors so all lighting (except emergency lighting) is turned off and on at preset times. Local switches can act

Case History

Central Michigan University performed a comprehensive analysis of the 244 high-security walkway fixtures it was using. Fixtures were fitted with 250W mercury vapor lamps which, by contemporary standards, are not particularly efficient. Accordingly, Robert F. Ringel, AIA, CMU director of plant extension, decided to convert to high-pressure sodium (HPS) lighting. He had a choice. If 150W HPS lamps were installed, light output would have increased by almost 30% and energy consumption would have been cut by one-third. If 250W HPS lamps were installed, light output would have more than doubled, but energy consumption would have increased. Nonetheless, Mr. Ringel decided to go with the 250W HPS lamps and his decision saved the college more than $10,000 per year. Why? Because the much higher illuminances provided permitted a reduction in security patrols, thus creating substantial labor savings.

Example

A ten-story office building has 100 fixtures on each floor, each fixture containing four 40W lamps. Cleaning crews work from 7PM-7PM each evening Monday-Friday, cleaning all floors simultaneously. All lamps are illuminated all the time.

The building’s connected lighting load is:

100 fixture x 4 lamp fixture x 40W/lamp x 11 ballast factor x 10 floors = 176,000W = 176kW

Annual lighting energy consumption for cleaning purposes is:

4 hrs/week x 5 eyes/week x 52 weeks/yr x 176kW = 183,040kWh/yr

The annual cost of the lighting energy used for cleaning purposes is, at an average of $0.08/kWh:

183,040kWh/yr x $0.08/kWh = $14,643/yr

By reassigning cleaning crews, all are active on one floor at a time. After they are done with lighting the floor, lighting is turned off. No additional time is required using this approach, so the lighting system on each floor is on for no more than 24 minutes (0.4 hrs) at a time. The connected load for each floor is (176kW + 10 = 176kW). Accordingly, total lighting energy consumed for cleaning purposes becomes:

0.4 hrs/week x 10 floors x 5 eyes/week x 52 weeks/yr x 176kW = 183,040kWh/yr

The annual cost drops to:

183,040kWh/yr x $0.08/kWh = $14,643/yr.

The amount of energy saved is:

183,040kWh/yr (before) - 183,040kWh/yr (after) = 164,736kWh/yr (saved)

Percentage energy savings are:

164,736kWh/yr / 183,040kWh/yr = 0.90/yr = 90%/yr

Annual dollars saved amount to:

$14,643/yr (before) - $14,643/yr (after) = $13,790/yr (saved)

Percentage dollar savings amount to:

$13,790/yr / $14,643/yr = 0.90/yr = 90%/yr
as overrides.

**Photocell controls** activate and deactivate lighting depending on the amount of ambient lighting which exists, be it from the sun or some other source. When the amount of ambient lighting falls to a certain level, lighting is automatically turned on. When ambient lighting rises to a certain level the electric illumination is automatically turned off. Some systems have a delay feature to prevent continual on-off operation which otherwise would occur on a “sunshiny-but-cloudy” day. Photocells are particularly useful outdoors; they also are applied indoors to control lighting near windows.

**Photocell-timeclock controls** are used mostly for outdoor applications. The time clock keeps lighting off for a given period, say midnight to 6:00 AM. From 6:00 AM-11:59 PM, the photocell control would activate lighting when needed.

Energy-saving solid-state dimmers and dimming systems are available for use with all incandescent, most fluorescent, and some mercury vapor, metal halide, and high-pressure sodium fixtures. In each case, reducing light output also reduces energy consumption. The amount of energy saved depends on the type of dimming system employed and the types of luminaires and lamps used.

**Dimmer-photocell controls** maintain a given lighting level through combined use of electrical illumination and daylighting. Applied for fixtures near windows and skylights, they automatically reduce luminaire light output as more daylighting enters a space, then increase light output as the amount of available daylighting diminishes.

**Personnel detection controls** sense the presence of people (by motion, sound, heat or other means) and immediately turn lighting on. After a predetermined interval during which people are no longer detected, lighting is automatically extinguished. Such controls are particularly applicable for spaces which are used irregularly during the day. Note that personnel detection controls can be integrated with certain types of heating and cooling units, as well as building security systems.

**Telephone-activated controls** permit users of push-button telephones to call a control center and, typically after hearing an acknowledging tone, to “punch in” a simple code which turns lighting off or on or increases or decreases light output. In some cases the phone can be used to permit manual activation of local controls, such as those that would be used for a tennis court or a recreational center.

**Centralized control systems** are designed principally for larger buildings or groups of buildings. They permit programmable control of all lighting inside and outside, in some cases also permitting use of both telephone-activated and local overrides and/or providing hard-copy print-outs of lighting actions taken. Some of these systems require dedicated hard-wiring; others use existing power wiring (line-carrier control systems) or no wiring at all (radio frequency control systems).

**Other control LEMOs** include door-jamb controls which activate lighting when the door is open and keep it on until the door is closed. These are particularly useful for closets of different types. Time-based switches turn lighting on when a wall switch is manually activated, and then turn it off within a predetermined time unless manual deactivation occurs first. A number of other devices also is available, and electrical distributors—among others—can provide more details. Note that lighting can also be integrated into multifunction programmable controllers as well as centralized building control systems.

### Use More Efficient Lamps

The efficiency of lamps (known technically as lamp efficacy) is rated in terms of lumens per watt (LW), meaning the amount of light output derived from the lamps alone for each unit of power (watt) required to operate them. The more lumens produced per watt, the more

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**Example**

A large parking lot is illuminated from 6 PM-6 AM every day of the year. Illumination is provided by 24 1,000W high-pressure sodium lamps, mounted in four six-lamp clusters. Annual energy consumption is:

$$24 \text{lamps} \times 1,000W/\text{lamp} \times 1.1 \text{ballast factor} \times 12 \text{hrs/day} \times 365 \text{days/yr} = 115,632\text{kWh/yr}$$

At an average of $0.08/kWh, annual energy cost amounts to:

$$115,632\text{kWh/yr} \times 0.08\text{kWh} = 9,250\text{$/yr}$$

A time clock with an astronomic feature is installed to control the lighting. As a result, an average of two hours is saved each day. The amount of energy saved is:

$$24 \text{lamps} \times 1,000W/\text{lamp} \times 1.1 \text{ballast factor} \times 2 \text{hrs/day} \times 365 \text{days/yr} = 19,272\text{kWh/yr}$$

The value of this savings is:

$$19,272\text{kWh/yr} \times 0.08\text{kWh} = 1,542\text{$/yr}$$
efficient a lamp is.

Table 1 indicates the efficiency of different types of lamps, including ballast losses.

Two types of lamp LEMOs generally are considered. One of these involves direct substitution (lamp retrofit), where one lamp is removed from a fixture and a more efficient one is installed in its place. Some of the typical substitutions possible are shown in Table 2. In some cases the retrofit lamp provides the same amount of light as the original, but consumes far less energy. In other cases a retrofit lamp will consume the same amount of energy but produce far more light, possibly permitting the use of fewer fixtures and lamps to obtain the same lighting levels (illuminances). When the latter approach is taken, however, guidance is needed to help assure acceptable system geometry results. In all cases, guidance should be obtained from manufacturers or other sources to help assure the existing fixture and ballast can operate the new lamp safely and efficiently.

The alternative to direct substitution comprises reliance on both new lamps and new fixtures. Although this requires more capital investment, the results which can be obtained usually justify it. It helps assure fixtures, ballasts and lamps are optimally compatible with one another and the applications for which they are installed.

In all cases, a thorough study should be made to obtain accurate estimates which relate to the specific building or area in question. Do not select a lamp purely on the basis of its efficiency. Rather, select the most efficient lamp appropriate for the application. Some of the factors to consider, among others, include:

**Color and Color Rendition**

A lamp’s color and color rendition refer to the color of its light and the impact of that color on illuminated objects, respectively. Numerous color variants are available, ranging from incandescent-like to the blue of northern sky light. Others produce “color shifts” ranging from minor to major. For example, low-pressure sodium

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**Table 1: General Lighting Lamp/Ballast Characteristics**

<table>
<thead>
<tr>
<th>Type of Lamp</th>
<th>Wattage Range</th>
<th>Initial Lumens per Watt Including Ballast Losses</th>
<th>Average Rated Life (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Pressure Sodium</td>
<td>18-180</td>
<td>62-150</td>
<td>12,000-18,000</td>
</tr>
<tr>
<td>High-Pressure Sodium</td>
<td>35-1,000</td>
<td>51-130</td>
<td>7,500-24,000+</td>
</tr>
<tr>
<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>60-1,250</td>
<td>14-25</td>
<td>2,000-20,000</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>4-215</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>750-3,500</td>
</tr>
</tbody>
</table>

**Notes:**

1. Data are based on 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.
2. Luminous or light output per watt (of power input) is a common measure of lamp efficiency (efficiency). Initial lumens per watt data are based upon the output of lamps when new. The light output of most lamps declines with use. The actual efficiency to be derived from a lamp depends on factors unique to an installation.
3. The actual efficiency of a lighting system depends on far more than the efficiency of lamps or lamps/ballasts alone. More than efficiency should be considered when evaluating a lighting system.
### Table 2: Interchangeability of Several Selected Lamps

<table>
<thead>
<tr>
<th>Standard Lamp</th>
<th>Replacement Lamp</th>
<th>Wattage Savings</th>
<th>Comparative Light Output of Replacement Lamp</th>
<th>Value of Energy Savings over Life of Replacement Lamp at $0.08/kWh</th>
<th>Other Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>60W Incandescent</td>
<td>35W Reduced-Wattage Incandescent</td>
<td>3</td>
<td>=</td>
<td>=</td>
<td>$0.40</td>
</tr>
<tr>
<td>75W Incandescent</td>
<td>70W Reduced-Wattage Incandescent</td>
<td>5</td>
<td>=</td>
<td>=</td>
<td>$0.40</td>
</tr>
<tr>
<td>22W Cool White Fluorescent</td>
<td>28W Cool White Fluorescent</td>
<td>4</td>
<td>=</td>
<td>=</td>
<td>$43.20</td>
</tr>
<tr>
<td>18W Compact Fluorescent</td>
<td>22W Compact Fluorescent</td>
<td>6</td>
<td>=</td>
<td>=</td>
<td>$34.20</td>
</tr>
<tr>
<td>100W Incandescent</td>
<td>95W Reduced-Wattage Incandescent</td>
<td>5</td>
<td>=</td>
<td>=</td>
<td>$0.40</td>
</tr>
<tr>
<td>150W Incandescent</td>
<td>145W Reduced-Wattage Incandescent</td>
<td>6</td>
<td>=</td>
<td>=</td>
<td>$33.60</td>
</tr>
<tr>
<td>75W PAR38 Spot or Flood Incandescent</td>
<td>65W PAR38 Spot or Flood Incandescent</td>
<td>0</td>
<td>=</td>
<td>=</td>
<td>$1.60</td>
</tr>
<tr>
<td>45W Incandescent</td>
<td>40W Incandescent (Halogen)</td>
<td>30</td>
<td>=</td>
<td>=</td>
<td>$4.80</td>
</tr>
<tr>
<td>50W R40 Flood Incandescent</td>
<td>45W ER-40 Incandescent1</td>
<td>75</td>
<td>=</td>
<td>=</td>
<td>$12.00</td>
</tr>
<tr>
<td>50W G40 Incandescent</td>
<td>45W ER-40 Incandescent2</td>
<td>0</td>
<td>=</td>
<td>=</td>
<td>$4.80</td>
</tr>
<tr>
<td>65W PAR38 Spot or Flood Incandescent</td>
<td>50W PAR38 Incandescent</td>
<td>60</td>
<td>=</td>
<td>=</td>
<td>$9.60</td>
</tr>
<tr>
<td>300W PAR46 Flood Incandescent</td>
<td>200W ER-40 Incandescent3</td>
<td>60</td>
<td>=</td>
<td>=</td>
<td>$28.80</td>
</tr>
<tr>
<td>500W Incandescent</td>
<td>450W Self-Ballasted Mercury Vap</td>
<td>30</td>
<td>=</td>
<td>=</td>
<td>$6.00</td>
</tr>
<tr>
<td>1000W Incandescent</td>
<td>750W Self-Ballasted Mercury Vap</td>
<td>250</td>
<td>=</td>
<td>=</td>
<td>$32.00</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 Reduced-Wattage, High-Efficiency Fluorescent</td>
<td>7</td>
<td>=</td>
<td>=</td>
<td>$11.20</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 Reduced-Wattage, High-Efficiency, Cathode Disconnect Fluorescent</td>
<td>6</td>
<td>=</td>
<td>=</td>
<td>$15.20</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 Reduced-Wattage, High-Efficiency, Color-Improved Fluorescent</td>
<td>7</td>
<td>=</td>
<td>=</td>
<td>$11.20</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 Reduced-Wattage, High-Efficiency, Color-Improved, Cathode-Disconnect Fluorescent</td>
<td>7</td>
<td>=</td>
<td>=</td>
<td>$15.20</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 High-Brightness Fluorescent</td>
<td>6</td>
<td>=</td>
<td>=</td>
<td>$9.00</td>
</tr>
<tr>
<td>F40 Fluorescent (U-Shape)</td>
<td>F40 Reduced-Wattage, High-Efficiency Fluorescent (U-Shape)</td>
<td>7</td>
<td>=</td>
<td>=</td>
<td>$11.20</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 Reduced-Wattage, High-Efficiency Fluorescent</td>
<td>17</td>
<td>=</td>
<td>=</td>
<td>$16.80</td>
</tr>
<tr>
<td>F40 Fluorescent</td>
<td>F40 Reduced-Wattage, High-Efficiency Fluorescent</td>
<td>7</td>
<td>=</td>
<td>=</td>
<td>$15.20</td>
</tr>
<tr>
<td>75W Mercury Vapor</td>
<td>100W Retrofit High-Pressure Sodium</td>
<td>40</td>
<td>=</td>
<td>=</td>
<td>$38.40</td>
</tr>
<tr>
<td>250W Mercury Vapor</td>
<td>200W Retrofit High-Pressure Sodium</td>
<td>80</td>
<td>=</td>
<td>=</td>
<td>$62.40</td>
</tr>
<tr>
<td>400W Mercury Vapor</td>
<td>325W Retrofit Metal Halide</td>
<td>70</td>
<td>=</td>
<td>=</td>
<td>$12.00</td>
</tr>
<tr>
<td>400W Mercury Vapor</td>
<td>400W Retrofit Metal Halide</td>
<td>0</td>
<td>=</td>
<td>=</td>
<td>$0.00</td>
</tr>
<tr>
<td>300W Mercury Vapor</td>
<td>300W Retrofit High-Pressure Sodium</td>
<td>80</td>
<td>=</td>
<td>=</td>
<td>$76.80</td>
</tr>
<tr>
<td>1000W Mercury Vapor</td>
<td>1100W Retrofit High-Pressure Sodium</td>
<td>160</td>
<td>=</td>
<td>=</td>
<td>$204.80</td>
</tr>
<tr>
<td>500W Mercury Vapor</td>
<td>500W Retrofit Metal Halide</td>
<td>30</td>
<td>=</td>
<td>=</td>
<td>$48.00</td>
</tr>
</tbody>
</table>

**Notes:**

1. This table does not indicate all possible lamp replacement options and, in some cases, replacing the ballast and lamp or relying on a new fixture, ballast, and lamp will provide better overall performance and energy efficiency than the replacement shown. All numbers reported in the table are approximations, and in certain cases, assumptions are made about the types of fixtures and other conditions involved. Consult manufacturers for accurate data relative to direct replacements possible for a given installation as well as any ballast operating temperature or other restrictions which may apply.
2. Wattage savings include ballast losses, where applicable, assuming use of a standard ballast. Actual ballast losses to be experienced depend on the specific type of ballast involved and operating conditions which affect its performance. In those cases where wattage savings exceed the difference in lamp wattage (if any), operation of the replacement lamp also has the effect of reducing ballast losses.
3. Symbols used indicate the following: += (substantially more) + (more) = (about the same) - (substantially less). Consult manufacturers for accurate information relative to conditions unique to the lamps and installations involved.
4. Other benefits typically provided by retrofit lamps include lower maintenance costs due to longer lamp life, improved productivity, safety/security, quality control, etc., due to higher light output, ability to reduce number of lamps installed statewide due to higher output of retrofit lamps, and improved color rendition.
5. When installed in a stack-lit fixture.
6. For high-voltages only.
lamps, the most efficient of all, render colors as shades of gray. When color rendition is not a concern, however, or when low-pressure sodium lamps can be mixed with others, substantial savings can result.

**Light Distribution**
Light distribution refers to the controllability of the light given off by a lamp. Generally speaking, the light from tubular lamps such as fluorescent and low-pressure sodium, sometimes referred to as "linear sources," is more difficult to control than that from more compact "bulb" lamps, also referred to as "point sources."

**Useful Life**
The useful life of lamps can sometimes be important because it affects the cost of replacement lamps and lamp replacement labor required over the life of a system. In some cases it is most useful to install long-life incandescent bulbs—the least efficient of all lamps—when used in remote areas of a building only on an occasional basis.

**Cost**
The cost of a lamp is best evaluated in terms of life-cycle cost. One must consider not only how much the lamp costs to buy, but also how much will be required over a period of time for replacement lamps and lamp replacement labor, the amount of light derived for the energy consumed, and so on. It often will be found that lamps which are the most expensive to purchase are the least expensive to own.

**Other**
Several other factors are important depending on the nature of the application and installation involved. These include the rate of lamp lumen depreciation (the rate at which a lamp's lumen output recedes with use), amount of time required to achieve full lumen output after the lamp is activated or reactivated (strike and restrike times), and disposability (some lamps require special precautions), among others.

**Improve Fixture Efficiency**
Manufacturers of lighting fixtures (luminaires) provide catalog information about the efficiency of their products.

**Case History**
Merrimack College was not happy with the lighting installed in its S. Peter Volpe Physical Education Center, used for all Merrimack's sports programs, and the college's primary facility for accommodating large audiences. The Center's major constituents are a 3,500-seat ice-skating arena and an 1,800-seat gymnasium. Analysis revealed the college was spending almost $31,000/yr to operate and maintain its illumination system. The LEMOs applied reduced that expense by more than 70%, to just under $9,000/yr. However, the new system also provided far better lighting. As a result, four schools came to Merrimack to rent ice time for their hockey teams. The rental income generated $18,000/yr. In addition, the number of off-season events the College hosted increased from 20 to 30, generating a small amount of additional income but a substantial amount of additional goodwill. Overall, the value of the benefits of lighting were worth $20,000/yr which, when combined with the $21,874/yr derived from O&M savings, resulted in a payback of less than 6 months.

### Example
A factory has 200 luminaires installed, each containing two 75W eight-foot lamps, kept on 7,500 hours per year. The plant customarily group relamps all fixtures at the end of 13,000 hours of use (the lamps have an average rated life of 18,000 hours at 12 hours per start). Its annual lighting energy cost (at $0.08/kWh) is:

\[
200 \text{ fixt.} \times 2 \text{ lamps/fixt.} \times 82.5 \text{W/lamp (including ballast factor)} \times 7,500 \text{ hrs/yr} \times 0.08 \text{ kWh} = 19,800 \text{ yr}
\]

The plant relamped its existing fixtures with reduced-wattage high-efficiency lamps that consume 60W each. Although they produce slightly less light, the light of illumination lost is very small, keeping total output within acceptable limits. The plant's annual lighting energy bill drops to:

\[
200 \text{ fixt.} \times 2 \text{ lamps/fixt.} \times 66W/lamp (including ballast factor) \times 7,500 \text{ hrs/yr} \times 0.08 \text{ kWh} = 15,840 \text{ yr}
\]

For a savings of:

\[
19,800 \text{ yr} - 15,840 \text{ yr} = 3,960 \text{ yr}
\]

Since the existing lamps had to be replaced anyway, the cost of the modification is limited solely to the premium paid for the new lamps. Assuming the premium is $0.25 each, purchased in quantity (actual prices will vary), the cost of the modification is:

\[
400 \text{ lamps} \times 0.25 \text{$/lamp} = 100
\]

The payback period is:

\[
900 \div 3,960 \text{ yr} = 0.225 \text{ yr} = (0.225 \text{ yr} \times 365 \text{ days/yr}) = 82 \text{ days}
\]
in terms of coefficient of utilization, or CU. A coefficient of utilization rating indicates the percentage of light emitted by the lamps alone which reaches the work plane. For example, consider two fluorescent luminaires. Both house two 60W reduced-wattage high-efficiency fluorescent lamps with an efficiency rating of 88 lumens per watt (l/w). Fixture A has a CU of 0.70 (meaning 70% of the light emitted by the lamps is delivered to the work plane); fixture B has a CU of 0.50. As a result, the efficiency of fixture/lamp combination A could be said to be 62 l/w (88 l/w × 0.70CU), while the other’s is 44 l/w.

It is important to note that the CU of any given fixture varies depending on factors unique to an installation, such as room size and shape, fixture height from the floor, and wall and ceiling finishes, among others. When luminaires are laid out in a uniform pattern, CU data provided in manufacturers’ catalogs usually can be used to determine which fixture has the best CU for the application involved. When luminaires are laid out in a nonuniform pattern, CU must be determined through other means, generally with the assistance of a computer. Many fixture manufacturers have computer programs for this purpose, and make them available on request.

Other factors also should be considered when selecting fixtures. One of these is called VCP, which stands for visual comfort probability. VCP is a measure of direct glare which a lighting system produces. A VCP of 70 indicates that at least 70% of the people seated in the worst location in a space will not be bothered by glare from the fixtures. A VCP of 70 is considered good.

Another major fixture rating factor is LDD, which stands for luminaire dirt depreciation. This is a representation of the amount of initial light output which is lost due to dirt build-up on the fixture’s reflective surfaces, lens or louver deterioration, etc. All of these factors reduce light output over time and require the designer to install more fixtures than would be required if the initial light output of a luminaire stayed constant. This has important implications for maintenance procedures and energy savings which are discussed below.

A luminaire should not be selected on the basis of efficiency (CU) alone. If glare-free lighting is important, high VCP ratings may be more vital than high CU ratings. (Fixtures with relatively high VCP and CU ratings are available.) In industrial areas, LDD may be the most im-
portant factor, especially if there is a considerable amount of pollutants in the air.

If there is no opportunity to replace a fixture, several other techniques could be investigated. The simplest of these may be fixture relocation. This is a particularly worthwhile LEMO if the existing locations of luminaires, as they relate to workstations, are in the “offending zone,” that is, directly above and in front of the viewer (Figure 4). In such situations, light from the fixture tends to bounce off the task surface (a printed page such as this, for example) and into the viewer’s eyes. This reduces contrast rendition, that is, the contrast between the details of the task (black print in this case) and the task background (the white paper on which the letters and numerals are printed). When contrast rendition is reduced, task details become obscured, as indicated in Figure 5. Since an insufficient quantity of light also makes it more difficult to distinguish task details, low quality can have the same effect as low quantity. Conversely, high-quality lighting which eliminates veiling reflections helps minimize lighting quantity needs, thus helping to minimize energy consumption. Likewise, high-quality lighting—by improving contrast rendition—can help people work faster, and with fewer errors, saving even more money. Properly locating fixtures can thus be an extremely effective LEMO. And note that much the same benefit may be obtainable by moving workstations rather than fixtures.

The incidence of veiling reflections also can be reduced by relying on new shielding and diffusing media, that is, lenses and louvers which shield the lamps from view to prevent direct glare, and diffuse their light to control its distribution. Lenses which distribute light in a “batwing” pattern (Figure 6) or which polarize it are among several types of shielding and diffusing media designed to reduce veiling reflections.

If fixture lenses have yellowed due to age or dirt build-up, they should be replaced. If it is decided to convert from plastic to glass lenses, the impact of the additional weight of the glass lens should be evaluated before the change is made. If fixtures in the past have had their lenses removed to increase their light output, new lenses in most cases should be installed, principally to correct the glare problems usually created by unlensed fixtures.

**Case History**

Pennsylvania Power & Light Company (PP&L) performed a comprehensive lighting system audit of its N3 drafting room in Allentown, PA. The analysis indicated that veiling reflections were seriously eroding the productivity of the drafters working in the space. As a result, a new lighting system was designed principally to provide better quality lighting. The new system was tested in a portion of the space. Based on results of the test, PP&L determined that it could reduce annual lighting O&M costs by 76%, to just $3,106/yr, and increase productivity by 7.5%. The 76% lighting O&M cost savings were worth almost $10,000/yr: As impressive as this may have been, the dollars involved almost become minor when it is realized that the value of the productivity increase exceeded $235,000/yr.

**Figure 5: The Impact of Veiling Reflections on Contrast Rendition**

The top photograph indicates the impact of veiling reflections on penciled stenographic notes. A small, bright light source in the offending zone is the source of the problem. When light is directed from a more favorable angle, far better legibility is obtained, as indicated by the bottom photo.

**Figure 6: Typical Batwing Distribution**
Example

A five-story office building is being remodeled. Each floor is identical and contains 200 fixtures, each holding four 40W lamps. Existing fixtures have a CU of 0.50. An average of 70 fc is provided on each floor, which is required for the tasks involved. Lighting is activated an average of 4,000 hours each year, at $0.08/kWh. Annual lighting cost is:

\[ \text{Annual lighting cost} = (200 \text{ fixtures/floor} \times 4 \text{ lamps/fixture} \times 40 \text{W/lamp} \times 1.1 \text{ ballast factor} \times 4,000 \text{ hrs/yr} \times 0.08 \text{$/kWh} \times 5 \text{ floors} = \$56,320/yr} \]

In reviewing the new lighting system to be installed, it is decided to use a fixture similar to that installed before, except it has a CU of 0.70 instead of 0.50. As a result, only 150 luminaires are needed on each floor. That change alone would result in savings of \$19,080 per year, all other factors being equal. In addition, however, the new fixtures are specified with energy-saving ballasts and lamps. As a result, annual lighting energy costs will be:

\[ \text{Annual lighting energy cost savings are:} \]
\[ \$56,320/yr - \$33,600/yr = \$22,720/yr} \]

originally designed for shielding.

Another fixture LEMO worth considering is lowering the luminaire, so more of its light falls directly on the task. Fixture removal or deactivation is another possibility, but only in unused areas or in other areas following completion of a comprehensive professional analysis which indicates this LEMO is warranted. Fixture removal or deactivation frequently results in undesirable light distribution which can erode productivity and overall space appearance, as well as safety and security. (Generally speaking, the most effective way to reduce lighting levels is to relamp a fixture with lower-wattage lamps having the same or better lumens/watt output, or to rely on control strategies such as installation of dimmers or use of split-ballasting.)

Ballast replacement comprises another fixture LEMO insofar as fluorescent lighting is concerned. This strategy is so significant, however, it is discussed separately in the following section.

Improve Ballast Efficiency

All types of lamps except incandescent require a ballast to function. The ballast transforms line voltage and controls lamp current to make them compatible with a lamp’s requirements.

Fluorescent ballast manufacturers have made some substantial innovations in design and fabrication of their products. One of the most significant is the energy-saving ballast which can reduce the energy consumption of fluorescent fixtures by as much as 10%, and which may last two to three times as long as its standard counterpart. When matched with the appropriate type of high-efficiency, reduced-wattage fluorescent lamps, the energy savings in some instances can be as much as 27%, with only a 15% (or less) light loss. Even more significant savings can be derived from use of new electronic fluorescent ballasts, but these tend to be somewhat more expensive than energy-saving ballasts, and they may not last as long.

When new fixtures are being ordered, most manufacturers will install whatever ballast is specified, imposing a premium when the nonstandard ballast is more costly. In the case of existing fixtures, it generally is best to reballast when existing ballasts are due for replacement. In this way the cost of upgrading is limited solely to the premium paid for the energy-saving ballasts, since labor costs would be involved in any event. If lamps are used for a considerable period of time each time, and/or if particularly high utility costs are involved, it may be cost-effective to install energy-saving ballasts even before the useful life of the existing ones is at an end.

Improve Maintenance

It is an unfortunate fact that lighting systems are seldom maintained well. In smaller buildings they sometimes are not maintained at all, except for replacing lamps when they burn out.

Lack of proper maintenance wastes money and energy and in many instances denies users the benefits which good lighting can bring.

Figure 7 indicates a typical lamp lumen depreciation survey, illustrating the rate at which light output from lamps declines with use. Lamps which are left in place too long provide continually decreasing light but continue to consume the same amount of energy at the same cost. (Low-pressure sodium lamps and—to a far lesser extent—high-pressure sodium lamps tend to provide the same amount of light, but their energy consumption increases.) Stated another way, the per-footcandle cost of lighting continues to rise.

Although some think it wasteful to discard lamps which are still operable, the facts indicate otherwise. The
Example

An office has 100 fluorescent fixtures installed, each containing four 40W lamps. The lighting is operated 3,500 hours per year at a cost of $0.08/kWh. The annual cost of lighting energy consumption is:

\[ 100 \text{ fixtures} \times 4 \text{ lamps/fixture} \times 44\text{W/lamp (including ballast factor)} \times 3,500 \text{ hrs/yr} \times \$0.08/\text{kWh} = \$4,928/\text{yr} \]

The existing ballasts are ready for replacement, and it is decided to install energy-saving units. In this ballast replacement labor and materials would have been required in any event; the cost of the LEMO is limited to the premium paid for energy-saving ballasts, estimated at $1,500 (actual prices will vary). The new ballasts will reduce energy consumption by approximately 9%, resulting in annual savings of:

\[ \$4,928/\text{yr} \times 0.09 = \$444/\text{yr} \]

But more than energy savings are involved. Assuming fixtures will be kept in place for 30 more years, standard ballasts would over that period be replaced at least once, at an estimated cost of $7,000 (not allowing for inflation). By avoiding that expenditure, the new ballasts avoid an annualized ballast replacement expense of:

\[ \$7,000 \div 30 \text{ yrs} = \$233/\text{yr} \]

Accordingly, the simple payback of the LEMO is:

\[ \$444/\text{yr} + \$233/\text{yr} = \$677/\text{yr} \]

\[ \$1,500 \div \$677/\text{yr} = 2.2 \text{ yrs} \]

When converting to energy-saving fluorescent ballasts, it is advantageous to convert to reduced-wattage, high-efficiency fluorescent lamps at the same time. In this case the premium paid for reduced-wattage, high-efficiency lamps is estimated at $0.25 each (actual prices will vary), for a total cost of $1,600 ($100 for the lamps and $1,500 for the ballasts). It is assumed the new lamp/ballast combination will reduce lighting energy consumption by 20%, in addition to providing the annualized rebalancing cost avoidance worth about $233/yr. Accordingly, the LEMO will save:

\[ (\$4,928/\text{yr} \times 0.20) + \$233/\text{yr} = \$1,219/\text{yr} \]

Simple payback is:

\[ \$1,600 + \$1,219/\text{yr} = 1.3 \text{ yrs} \text{ or } (1.3 \text{ yrs} \times 12 \text{ mos/yr}) = 15.6 \text{ mos} \]

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Figure 7: Lamp Lumen Depreciation of Standard Lamps

![Figure 7: Lamp Lumen Depreciation of Standard Lamps](image-url)
cost of using lamps whose light output has depreciated severely is substantial, especially when one considers that insufficient lighting may cause low productivity, reduced retail sales, problems with safety and security, etc.

There are several ways to determine when lamps should be replaced. One is to consult with a manufacturer’s representative or a qualified professional electrical contractor or engineer. Another is to obtain readings with a lightmeter and compare them with illumination levels suggested by the IES/NA.

Generally speaking, the most economical method of lamp replacement is group relamping, that is, replacing all lamps in a building or large space at the same time. This greatly reduces the lamp replacement labor costs involved. It typically takes three minutes per lamp to change all lamps at the same time, because all the labor, materials and equipment are assembled for the purpose, typically “after hours.” By contrast, it often takes 30 minutes or more to replace a lamp on a one-at-a-time “spot relamping” basis, as already discussed.

Although there still will be occasional burn-outs with group relamping, requiring a spot relamping procedure, the overall savings can be very significant. Group relamping also helps maintain even light, minimizes storage requirements, and can result in volume discounts on the price of lamps. It also makes reliance on contract lighting maintenance far more practical.

Note that group relamping also is essential for application of timely lamp replacement, one of the most cost-effective of all LEMOs. To understand its benefits, recognize that most lighting designers include “compensatory lighting” in their designs. Compensatory lighting usually is needed to help assure that the average amount of illumination provided by a system over time is sufficient to meet design conditions, despite poor maintenance. If lamps are replaced on a group basis, before their light output is too seriously diminished (Figure 8), their average light output over time would be higher than otherwise. As such, through timely lamp replacement, it is possible to derive more average light from the existing system, or the same amount of light output from fewer lamps and fixtures. In fact, conversion to group relamping and timely lamp replacement may permit elimination of 10% or more of the existing lamps. In existing facilities, this can mean a 10% or more energy cost savings. In new buildings, it means lower life-cycle cost.
Example

A library has 50 luminaires installed, each with four 40W lamps. Lighting is used 4,000 hours per year. On average, each lamp lasts seven years. At burn-out, it is replaced on a spot-replacing basis, taking approximately 30 minutes (0.5 hr). Maintenance workers are paid $7.50 per hour, inclusive. The cost of labor for replacing, not allowing for inflation is:

\[ \text{200 lamps/7 yrs} \times 0.5 \text{ hrs/amp} \times 7.50/\text{hr} = \$107/\text{yr} \]

It is decided to use group-replacing, replacing all lamps on a group basis every five years.

Because group-replacing increases the average maintained lighting levels over the life of the lamps, the number of lamps installed can be reduced by 10%, without affecting the amount of lighting provided. Accordingly, the cost of group-replacing every five years becomes:

\[ \text{110 lamps/5 yrs} \times 0.05 \text{ hrs/amp} \times 7.50/\text{hr} = \$14/\text{yr} \]

The 10% reduction in lamps also results in an annual energy savings of $280, for a total annual savings of about $375. The additional cost of lamps due to more frequent replacement is approximately $20 per year.

energy costs, as well as lower capital requirements.

Keeping lamps, lenses and other fixture components clean also is an important part of lighting maintenance, indoors and outside. Dirt build-up absorbs light and, therefore, the energy and dollars associated with that light. The frequency of maintenance that’s best depends upon the rate at which dirt builds up. Figure 9 provides guidance in this regard.

Case History

Ski Acres is a major ski area in the state of Washington. Only 45 miles east of Seattle, its night skiing facilities are particularly popular. A lighting system audit revealed that the owner of Ski Acres was spending some $33,000/yr on his ski lighting system. He relied upon a consulting illuminating engineer to design a new system for him, and the one developed reduced lighting O&M costs by almost 75%, to just $8,609/yr. However, the quality of lighting was substantially improved, covering a far greater area. The owner was so impressed with the results, that he had the same designer provide new illumination system design for another neighboring ski area he owned, Snoqualmie Summit. Altogether, lighting O&M costs for both ski areas were reduced by 71%, from $47,904/yr. to $13,905/yr. However, the better lighting also encouraged more skiing, and the revenue is estimated at $150,000/yr. As a result, the new lighting systems at both ski areas paid for themselves in 7.5 months.
DEVELOPING YOUR LIGHTING ENERGY MANAGEMENT PLAN

The LEMO’s discussed in the preceding pages only "scratch the surface" in terms of all the many specific types of modifications which can be made. To achieve maximum savings without detracting from the benefits of good lighting, or while actually improving upon the benefits you may be receiving right now, rely upon other sources. Many trade magazines run articles on lighting and how to improve it while reducing energy expenses. There are many different manuals and guidebooks available, including those from trade and professional associations, manufacturers, and federal and state government agencies.

You may also wish to consider retaining someone to perform a lighting system audit and/or to develop a lighting energy management plan for you, such as a qualified electrical contractor or a consulting engineer who specializes in lighting system design.

If you do perform the work on your own you will discover there may be several different approaches available for any given situation. In such cases it is best to perform cost evaluations, as have been demonstrated in the examples given in this booklet.

Remember, however, that not all factors can have a price tag easily assigned to them, given the interrelationships between lighting and other concerns. These are indicated in Figure 10.

Productivity: Productivity is a primary concern wherever lighting is needed for performance of work. Numerous studies, tests and case histories show without question that maximum productivity cannot be achieved unless the amount of lighting is proper for the tasks and workers involved. The cost of labor on a per-square-foot-per-year basis can be as much as 250 times the cost of lighting on the same basis. If a modification which reduces lighting levels and costs by 25% reduces productivity by 5%, every energy dollar saved may result in as much as $50 of labor being wasted.

Retail Sales: Some people consider it wasteful to illuminate outdoor signs or to not reduce lighting in retail sales areas. The nation’s economy is dependent upon a healthy retail sector, however, and it is known that retail sales are affected by lighting. Using lighting in support of
retail sales is a wise use of energy, providing the lighting is as efficient as it can be for the application involved.

**Consumer Discretion:** Good lighting is needed in retail areas to permit consumer discretion. Consumers can compare colors and textures or read the fine print of labels only when they have the lighting they need. This is particularly true for older consumers.

**Quality Control:** In manufacturing areas, good lighting is needed to help assure a high level of quality control. Not only does good lighting help assure fewer errors, rejects and rework, it also helps assure those errors which do occur are caught later on, before they cause problems.

**Beautification:** Lighting is often used for beautification. In fact, it is the way in which lighting is used which determines what a nighttime environment will look like. Using lighting to help people enjoy America after dark is not a waste. Nonetheless, many of the systems now employed to do the job are wasteful. Turning off the lights is not the answer. Using more efficient lighting is.

**Safety and Security:** It is considered a civic responsibility to help assure the safety of persons who use a building or its grounds after dark. Be familiar with all codes and ordinances which apply. Use good judgement, too. “Meeting code” is no excuse for not providing the lighting needed to prevent problems which the wise use of lighting could help prevent. Remember, too, that safety and security lighting can also be applied to enhance the environment.

**Heating:** Lighting gives off heat. When lighting is removed, the heat which is lost must be made up by a central heating system which may be oil- or gas-fired. In some cases, the cost of this make-up heat may be more than the value of the energy saved by removing the lighting.

In warmer parts of the nation cooling is used far more than heating. And in some cases, no matter where the location, cooling is needed year-round in certain parts of a building. For example, in the core or central areas of large office buildings, the heat given off by lighting, people, office equipment and other sources makes it necessary to provide cooling during all occupied hours, no matter what the outdoor temperature may be. In such cases you may wish to consider different types of lighting systems which are integrated with ventilation systems. They can remove major portions of lighting system heat before it enters core areas, thereby reducing the need for cooling. The heat which is removed often can be utilized for other purposes in a building, saving even more energy and money.

**Other:** Many other factors must be considered, some of which will be unique to your own situation. Remember that there are numerous different economical methods available to reduce the energy consumed for lighting. But remember, too, that lighting is there for a purpose. To take the easiest or least expensive way out can cause you the most difficulty and the most expense later on. Plan wisely.

**Develop the Plan**

Once you have considered the options, develop a plan which identifies the lighting energy management options that will be pursued, when they will be implemented, and by whom. Try to implement those which will save the most first. Coordinate the LEMOs with one another and with other modifications planned to prevent wasted time and expense. If a furnace is to be replaced, for example, its capacity should be kept as small as reasonably possible to promote more efficient operation. In performing calculations, therefore, heat gains from lighting (and other sources) should be considered. If a space is to be refurbished, consider using lighter colors on the ceiling, walls and floor to reduce the amount of light they otherwise may absorb. Also, consider selecting the colors of the finishes and furnishings under the same color and type of lighting you have or will have installed.

If substantial remodeling or rehabilitation is planned, consider replacing the lighting system altogether and relying on the most advanced applicable components. These may include lighting systems which transfer most lighting system heat out of the space before it has a chance to enter or application of flexible branch wiring which permits easy relocation of fixtures and which may entitle you to rapid depreciation and tax credits.

If you plan to install a computerized building control system, integrate lighting system control into it. If an improved security system is sought, consider having lighting activated by motion detectors, so unauthorized entries result in all lighting being switched on instantly.

The larger the building involved, the more comprehensive the plan should be. This may mean implementation of the plan over several years. In such cases the plan should be reviewed every six months or so and updated as appropriate. Be sure to consider modifying the plan, especially when new products will be more effective than those available at the time the plan was devised initially. From all appearances, the lighting industry will continue its remarkable record of progress, helping the nation enhance the quality of its lighting and the benefits good lighting can provide.
FOR ASSISTANCE

Many different sources of assistance are available. These include trade magazines which are involved with buildings and the enterprises conducted inside them (retail sales, data processing, industry, etc.) as well as journals of associations involved with these enterprises. The National Lighting Bureau publishes a number of guidebooks in addition to this one, as well as other types of literature. Each is written in lay language and is extensively illustrated to help assure ready comprehension by nontechnical readers. Such individuals can gain a great deal by reading appropriate NLB publications, because it permits them to communicate more effectively with those upon whom they rely for lighting guidance. A complete, illustrated directory of NLB publications is available without charge by writing to the National Lighting Bureau, 2101 L Street, N.W., Suite 300, Washington, DC 20037; or by calling the Bureau at 202/457-8437.

The U.S. Department of Energy, some state energy offices, and independent publishers produce periodicals and books which discuss the subject of energy conservation in general, and lighting energy conservation or lighting energy management in particular. Some relatively nontechnical publications also are available from the Illuminating Engineering Society of North America (IES/NA), 345 East 47th Street, New York, NY 10017.

Recognize that the “stakes” involved when larger buildings are concerned are somewhat high. Even comprehensive reading cannot substitute for the expertise and experience of a professional who is in a better position to identify what should and should not be done, the interrelationships involved, etc.

Typical sources of assistance include:

**Illuminating Engineers**

Many consulting electrical engineering firms have lighting design divisions. Some specialize exclusively in lighting design. Contact a local chapter (section) of the IES/NA or of the American Consulting Engineers Council (ACEC) or ACEC itself at 1015 15th St., N.W., Suite 802, Washington, DC 20005.

**Electrical Contractors**

Many electrical contracting firms have extensive lighting divisions and lighting system designers. For more information, contact the closest chapter of the National Electrical Contractors Association (NECA).

**Electrical Distributors**

Electrical distributors provide guidance on the different products available and can put you in touch with manufacturers’ representatives. Many have developed their own expertise in lighting, through programs and materials developed by the National Association of Electrical Distributors (NAED), 600 Summer Street, Stamford, CT 06901.

**Electrical Utilities**

The electrical utility which serves your building is likely to have an energy management or energy services department. Contact the utility to determine the assistance it can provide to you.

**Manufacturers and Their Representatives**

Manufacturers and manufacturers’ representatives often can be of assistance and will be familiar with many different approaches, materials and products, not just what they produce. Some also can provide assistance in terms of computer-generated plans which identify the savings associated with each of several alternatives.

**State Energy Offices**

Some state energy offices will be able to provide literature and/or references to other sources of assistance, government programs which may be applicable, etc.