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Energy- Conservation Opportunities In Lighting

MASTER

April, 1981

Prepared for:
U.S. Department of Energy
Assistant Secretary for
Conservation and Renewable Energy
State Energy Conservation Programs

Under Contract No. FGO1-79CS60467

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Much of the material in this manual is drawn from "Saving Energy Dollars in Retail Stores" and other publications of the Massachusetts Office of Energy Resources and the U.S. Department of Energy. The technical and engineering analysis was performed by Pequod Associates, Inc. of Boston and their sub-contractor, Jay M. Silverston Associates, Inc. of Waltham, Massachusetts.

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Introduction

Lighting is a good place to begin conserving energy in your building; the savings are immediate, and many of the things you can do are low-cost or no cost actions.

Chances are good that your lighting system was designed when energy was cheap and efficiency was not an issue. This manual will discuss technologies and techniques which can be employed by your existing personnel—without the need for consultants—to reduce your lighting costs by as much as 70%.

As a building owner you can reduce energy costs and improve the effectiveness of your lighting system by following four basic steps:

- Get acquainted with some of the basic terminology and energy efficient lamps and fixtures which are on the market.
- Conduct a survey of your building to determine where you can reduce and how much energy—and money—you will be saving in the process.
- Implement the simple, low-cost or no-cost measures immediately.
- Calculate the payback period for capital investment modifications, and implement those which make economic sense.

In the following sections of this manual, each of these areas will be discussed with the emphasis on a "do it yourself approach". As an example of the kinds of savings which are possible, various case studies which were conducted under contract to the Massachusetts State Building Code Commission and the Massachusetts Executive Office of Energy Resources will be reported.

Government Lighting Power Program: An Opportunity to Conserve

Another factor encouraging the public to reduce energy waste in lighting is the diverse State lighting efficiency programs. Most establish lighting power budget requirements for buildings to meet to save energy.

One example is Massachusetts, where the State Building Code Commission has established requirements affecting lighting power limits for both new construction and existing buildings. A maximum limit is set on the total wattage used in buildings or structures larger than 10,000 square feet. Tenants who occupy space in a facility of that size are likewise subject to the code's requirements.

A designer or building owner determines the power limits for an individual building by auditing it with reference to six "use area categories". These categories are structured around the difficulty of tasks or the type of commerce that occurs in different parts of a building. Each use area category is assigned a power allowance, expressed in watts-per-square-foot. The designer or building owner simply multiplies the total area of his building in each category by the respective power allowances, and adds the sub-totals.

This means that only the *total wattage of the building is limited*; the designer or building owner is free to choose where that power is concentrated according to individual need.

The Massachusetts Lighting Power Code Project has been quite successful: more than 9,000 audits were reported, and most owners whose buildings exceeded the limits filed detailed plans to meet project requirements. Many owners expressed

satisfaction with the program, and indicated that the forced exercise of auditing their buildings induced them to make changes which were not even required. But they saved money in the process.

Effect of Lighting Modifications on Heating and Cooling

The electricity used for lighting produces a significant amount of heat. In some buildings, this heat is beneficial during the winter season, because it reduces the amount of energy needed to operate the heating system.

However, during the summer, the heat which is generated by the lighting system is a liability; it increases the cooling load and requires additional energy consumption for air conditioning. Even worse are those buildings where air conditioning must be operated year round to offset the heat generated by occupants' body temperatures or equipment such as computers and reproduction machines. In these buildings, the heat generated by lighting is never beneficial.

In short, lighting is not an efficient way to heat a building, and although heating costs may rise in some buildings, the combined utility costs (heating, cooling, and lighting) will almost always drop when lighting levels are reduced. This is true because lighting reductions reduce electrical costs directly and indirectly by reducing the cooling requirements.

Special Problems for Retail Stores

Retail stores present a different set of circumstances than other buildings because they employ lighting not just to illuminate work areas, but also to achieve a

merchandising effect. The central concept they must consider to achieve energy conservation in lighting is contrast—reducing general illumination to a minimum, so that highlighting or spotlighting of merchandise need not be exorbitant for it to stand out.

Conserving energy does not mean having a dark or dull store. Indeed, aesthetic appeal can actually be enhanced by the cost-saving modifications which will be suggested. Except for the few who use light excessively and irresponsibly, most stores can reduce their lighting power consumption without altering the appearance or merchandising effect of their displays—it may even improve them.

In 1977, the Massachusetts Executive Office of Energy Resources (MEOER) and the Retailers Association of Massachusetts (RAM) conducted a joint study of the affect of the lighting power code on the industry.

Actual lighting costs at that time ranged from \$.30 to \$3.00 per square foot, and the average was \$.99 per square foot. As much as 85% of utility costs in retail stores could be attributed to lighting, and it was not at all unusual for lighting costs to exceed net profits.

Light levels showed considerable variation, with store-wide averages ranging from 16 footcandles to 120 footcandles. The most inefficient systems were in small specialty shops in shopping malls and in large multi-state chain stores.

Rising lighting costs can hurt a store competitively. Consider the case of two competing retail stores in a shopping mall. Both stores have about 2,000 square feet of sales area, but Store B uses about 36% more lighting energy. As energy prices rise, the difference in the cost of lighting the two stores will grow. While Store B currently spends about \$1,300 more for lighting than Store A, in five or six years, if no

changes are made, Store B will spend \$2,600 more for lighting.

In a second phase of the MEOER/RAM study, six stores were selected and subjected to detailed engineering analysis to determine what modifications would be necessary to achieve the minimum level of lighting energy efficiency required by the State Building Code. In one case study, the store exceeded those limits by 350%.

The engineering consultant found that in most cases, simple and inexpensive changes in the lighting system were sufficient. But even where some investment was necessary, the energy cost savings paid for the modifications within 6 months to 2½ years. The owners and managers were not only convinced that it was a sound economic decision, but they were also satisfied that their merchandising requirements were not jeopardized. Some of the modifications and their cost benefits will be treated below.

Lighting Basics

Terminology

Your choice of lighting sources has everything to do with how much you will pay to operate the system, and how effective it will be in achieving your illumination needs. An understanding of a few basic terms will be helpful in making informed energy management decisions.

Lamp—The part of the fixture that actually produces light; incandescent bulbs and fluorescent tubes.

Luminaire—The complete lighting fixture, including the lamp(s), lamp holder(s), enclosure, and, in some cases, a lens or diffuser.

Watt—Electric power is measured in watts and kilowatts (kw.). (One kw = 1000 watts). Watts measure the amount of electricity used by the lamp, but they tell us nothing about the amount of light actually produced (lumens).

Lumen—A unit of measure for the amount of light that a particular lamp produces. A standard 60-watt incandescent lamp produces about 890 lumens; a 40-watt, 4-foot fluorescent tube produces about 3150 lumens. Note that the amount of energy you use (and pay for) does not necessarily correspond to the amount of light you get.

Lumens/watt—The amount of light you get (lumens) for the amount of energy you use (watts) is a measure of your lighting efficiency. The relative efficiencies of two or more light sources can be measured by comparing the lumens/watt of those light sources.

Lamp wattage—All lamps (or the shipping cartons containing the lamps) are marked according to the amount of electricity the lamp requires to operate. A designation such as 60W indicates a 60-watt lamp.

Watt-hour—Electric power consumption is measured in watt-hours or kilowatt-hours (kwh): One kwh = 1000 watt-hours. A 60-watt lamp will consume 60 watt-hours for each hour it burns. If left burning one hundred hours, it would consume 6000 watt-hours or 6kwh.

Footcandle—A measurement of light (lumens) which reaches a surface or object; it is a measurement of lumens per square foot. For example, 1,000 lumens of light falling within a 5 square foot area would achieve an average light level of 200 footcandles (fc). Footcandle levels can be measured with a simple and inexpensive device called a light meter.

Lighting Sources

Incandescent Sources

Incandescent sources produce light through heat. Although a popular and familiar choice, they are among the least efficient sources on the market. Despite this fact, they do offer certain advantages over fluorescent. Incandescent sources are compact, and their light output can more easily be concentrated and aimed at a specific target. They are often preferred when the color, form and texture requires special emphasis.

Incandescent lamps are available in a variety of shapes and sizes, and the basic distinctions are important in choosing among the most common lamp types.

General Service (A-type, PS-type) The familiar incandescent lamp is widely used. It is difficult to use this type of lamp efficiently because it does not produce a directed beam. In order to concentrate its light output in a desired direction, a general service lamp must be used with some type of external reflector. Unless these fixtures are well maintained, much of the light output will be absorbed and wasted. Thus, the general service lamp is usually a poor choice and should be replaced with one of the lamp types discussed below.

Reflector Lamps (R-type, ER-type) These lamps are constructed with a built-in reflector, which concentrates the light output into a directed beam. Reflector lamps are classified as both flood lamps and spot lamps. The terms spot and flood are often confused or are used interchangeably. However, there are important differences which should be understood. A flood lamp has a wide beam, while the spot light concentrates its light output in a more narrow beam (see Fig. 1). For most applications, spot lamps are preferred over flood lamps. Most flood lamp fixtures block a large portion of the light beam. A spot lamp gets more light out of the fixture and concentrates it where you need it—on the merchandise. In many cases you can replace a flood lamp with a spot using half the wattage and get the same light where you need it. The ER-type lamp (ellipsoidal reflector) is a relatively new type of spot lamp. This lamp was designed to be effective in getting light out of the baffled or recessed fixtures.

Parabolic Aluminized Reflector Lamps (PAR-type) These lamps operate on the same principle as the standard R and ER-type reflector lamps. PAR lamps are more expensive than R lamps, but they produce a more concentrated and better controlled beam. PAR lamps are also available in various spots and flood beam patterns for specialized applications.

Here's why reflector lamps deliver more light than standard Incandescent in directional fixtures. . .

Fluorescent Sources

Fluorescent lamps offer you much more light per watt than do incandescent sources, resulting in lower lighting costs. They have a longer lamp life, which means fewer replacements and lower labor costs. Fluorescent lamps need not produce excessive brightness, glare, or unflattering color rendition. Many of the undesirable qualities associated with earlier fluorescent lamps have been corrected by improved lamps and fixtures. Fluorescent lamps are not appropriate for all applications in all buildings; they have no distinct beam and are difficult to control and direct. However, there are a great many cases where they can be used to save energy dollars and produce an aesthetically appealing atmosphere. Many effective systems combine low levels of fluorescent general lighting with incandescent accent lighting to provide sufficient overall lighting while effectively highlighting merchandise in the case of retail stores.

Fluorescent lamps produce light in a completely different way than do incandescent lamps. In a fluorescent lamp, an electric arc passes through mercury vapor in the tube and produces radiation. This radiation causes the fluorescent material which coats the tube wall to emit light. The choice of fluorescent material (phosphor) determines the color of the emitted light.

Color Fluorescent lamps are available in various "colors" which are actually shades of white. The appearance of the lamp does not indicate how your merchandise will look when lighted by it. The lamp may appear white but render color poorly, so you should be familiar with the color effects of fluorescent lamps. The table below describes the color "rendering" qualities of standard fluorescent lamps and their relative efficiencies. Because there is a tradeoff between quality of color rendition and efficiency, the more efficient lamps should be used except in areas where color rendition is an overriding concern.

Notice that even the least efficient fluorescent source is more than twice as efficient as a typical incandescent source.

Fluorescent Ballasts Fluorescent fixtures require a ballast, a device which limits the flow of current to the lamp. Without a ballast, the fluorescent lamp would draw so much current that it would destroy itself. Fluorescent fixtures usually employ one ballast for two lamps. The ballast consumes some power over and above that consumed by the lamps. The ballast wattage must be added to the lamp wattage to determine the power requirements of the fixture and its overall efficiency. Ballast wattage is generally 13% to 24% of the fixture wattage. Ballasts have recently been developed which use less power than conventional ballasts. In some cases they reduce the light output and power usage of the fluorescent lamps as well. Low energy ballasts should be used for new installations and for replacement of burned-out ballasts. It would not be cost-effective to remove good ballasts and replace them with low energy ballasts. One low energy ballast consumes only 6 watts per two 40-watt lamp fixture compared with 12 watts for the conventional ballast.

Types of Fluorescent Lamps Of the numerous types and sizes of fluorescent lamps available, four-foot and eight-foot instant-start or rapid-start lamps are the most commonly used in retail stores. The most common four-foot lamp is the rapid-start type. The standard four-foot lamp consumes 40 watts, although new reduced-wattage replacement lamps are available. Rapid-start lamps are available in a variety of colors. With a standard ballast which consumes 16 watts, the typical four-foot, two-lamp fixture consumes 96 watts. When lamps are removed from a rapid-start fixture to conserve energy, the ballast will continue to draw 7-10 watts so it should be disconnected.

Many stores rely on eight-foot fluorescent lamps. The instant-start lamp, also called the "slimline" lamp, is the most common type in use. Most instant-start lamps are recognizable by the single pin on each end. A few instant-start lamps use a bipin base, and can be mistaken for rapid-start lamps. Since the two types are not interchangeable, instant-start lamps with the bipin base are marked "instant-start" or "IS". The standard eight-foot lamp consumes 75 watts. In a two-lamp fixture, the standard ballast

7 Lighting Sources

consumes 22 watts and the fixture consumes a total of 172 watts. In most instant-start fixtures, the circuit is designed to disconnect the ballast automatically whenever a lamp is removed. Ballasts need not be disconnected manually.

Other Fluorescent Types In addition to the standard four- and eight-foot lamps, there is a variety of other fluorescent lamp types available for special applications:

- For two-foot by two-foot fixtures, a 40-watt U-shaped tube is available. Although this tube is less efficient than the straight 40-watt lamp, it is much more efficient than two 20-watt, two-foot tubes.
- Circular rapid-start fluorescent lamps are also available in several sizes.
- At least one manufacturer has developed a fluorescent fixture that directly substitutes for an incandescent lamp.

Fluorescent Lamp Selection Guide

	Effect on "Atmosphere"	Colors Strengthened	Colors Weakened or Grayed	Remarks	Lumens/ Watt
Cool white	neutral to fairly cool	orange, yellow, blue	red	blends with natural daylight	67
Deluxe cool white	neutral to fairly cool	all nearly equal	none appreciable	simulates natural daylight	46
Warm white	warm	orange, yellow	red, blue, green	blends with incandescent light	68
Deluxe warm white	warm	red, orange, yellow, green	blue	simulates incandescent light	46

High Intensity Discharge Lamps

High intensity discharge (HID) lamps produce light by passing electrical current through one of a variety of chemical mediums. A physical/chemical reaction occurs, and its response is the production of light. The low level of charge which is needed to produce the reaction, the high level of energy which is released and the absence of heat as a by-product all

combine to make this an extremely efficient source of light. Low-pressure and high-pressure sodium and metal halide are the most important varieties.

Traditionally, these have been used for security and outdoor uses such as parking lots. Recent developments have made high-pressure sodium and metal halide useful for inside building uses. You may want to consult your manufacturer to determine if these lamps would be appropriate in your building.

Efficiency of Various Light Sources

Matching Lighting Systems

Lighting systems can be classified as either general or local. General lighting refers to the fixtures (often in a patterned layout) which light the room as a whole. Local lighting systems are used to highlight specific areas. Both systems can be incandescent or fluorescent. Local and general lighting systems can be effectively combined, as can incandescent and fluorescent, to provide energy-efficient lighting which does the job effectively. Which system you choose, and whether you combine systems, will depend on your particular needs, and a full understanding of the variety of combinations possible will help you choose wisely.

Several other variables need to be considered in designing or modifying your lighting use. These include the types of fixtures you select. Different fixtures can have a substantial effect on the amount of light which reaches the surface. The amount of light lost within the fixture depends on the design of the fixture, the configuration of the lamp, and the location of the lamp within the fixture.

Another important consideration is the positioning and spacing of the fixtures. Many lighting systems are designed on a geometric grid, with light falling equally everywhere. A more efficient design would direct the light on the work surface where it is needed and minimize the light in between without creating black spots.

It has been mentioned above that in retail stores, the contrast between general and local lighting is critical to achieving energy conservation. The principal concern of retailers is to maximize the visibility and attractiveness of their merchandise, and because the customer's eye is drawn to the sources of greatest brightness, the illumination of the ceiling, walls and floors should be at lower levels. Even distribution of high light levels is not advantageous; indeed, in some stores, the wider the variety of light sources, the better.

How does this issue of contrast provide an opportunity for energy conservation? Merchandise which is spotlighted to 50 fc against a 10 fc background will appear highly visible; whereas, if the general background was lighted to 100 fc, then the merchandise would require 500 fc for an equivalent effect to be achieved.

The survey of retail stores conducted by the Massachusetts Energy Office and the Retailers Association of Massachusetts indicated that 20-30 fc of general illumination was sufficient, but that a more dramatic—and far less costly—merchandising effect could be attained by reducing the general illumination levels even further.

Typical General Lighting Systems

The chart on the following page (see Fig. 2) is a comparison of four commonly used general lighting systems. The prices are based upon 1977 Massachusetts conditions (4.1¢ per kwh) for systems which would be designed to achieve 30-40 fc. A description of each system's major characteristics follows.

1. **Fluorescent Strip System:** The fluorescent strip system provides the greatest efficiency and lowest operating costs of those considered, but poses problems of high ceiling brightness and an appearance that is associated with large discount stores and supermarkets. Imaginative design can overcome this association in some cases.
2. **Recessed Fluorescent with Prismatic Diffuser System:** This system has moderate fixture brightness and looks better than fluorescent strips, but is about 8 percent less efficient. Nevertheless, it is an efficient lighting system. In areas with high ceilings, the fixtures are sometimes grouped in pairs to provide fewer,

more localized light sources. A more expensive parabolic louver diffuser is available which provides extremely good control of light distribution with low fixture brightness and an efficiency roughly equal to that of the standard recessed fixtures with prismatic diffusers. Because of the very good appearance of this diffuser, it may be suitable for certain buildings in which conventional recessed fixtures are not acceptable.

3. **Incandescent Downlights with Baffles:** This is an inefficient fixture at best. As in most downlight fixtures, much of the light is lost within the fixture. The amount lost depends on the design of the fixture, the beam configuration of the lamp, and

the location of the lamp within the fixtures (adjustable by the use of extenders). Heavily baffled fixtures frequently block more than half of the light leaving reflector flood lamps. Using a spot lamp or an ellipsoidal reflector lamp placed close to the aperture of the fixture can reduce light loss tremendously, but even this arrangement is still inefficient overall because of the incandescent source.

4. **Incandescent Lamps in Large Diffusing Spheres:** This type of system is more efficient than the downlight system and can be aesthetically pleasing in some applications. As the table indicates, it will exceed the wattage limit in the 35-40 fc range.

Fig. 2. Systems Comparison

System	Annual Cost per 1000 sq. ft.	Efficiency
<p>A Fluorescent Strip</p>	energy; \$222 lamps: 9 labor: 3 total: \$234 Cost/Million lumen hours: \$1.46	MAINTAINED LIGHT: 40fc WATTS/SQ. FT: 1.03 LUMENS/WATT: 38.8
<p>B Recessed Fluorescent</p>	energy; \$315 lamps: 6 labor: 4 total: \$325 Cost/Million lumen hours: \$1.99	MAINTAINED LIGHT: 41fc WATTS/SQ. FT: 1.47 LUMENS/WATT: 27.6
<p>C Incandescent Downlights</p>	energy; \$935 lamps: 254 labor: 174 total: \$1,363 Cost/Million lumen hours: \$9.27	MAINTAINED LIGHT: 37fc WATTS/SQ. FT: 4.35 LUMENS/WATT: 8.45
<p>D Incandescent Diffusing Spheres</p>	energy; \$963 lamps: 82 labor: 240 total: \$1,285 Cost/Million lumen hours: \$8.48	MAINTAINED LIGHT: 38fc WATTS/SQ. FT: 4.50 LUMENS/WATT: 8.42

11 Matching Lighting Systems

As fixtures are added or removed from the store, the watts per square foot and the average illumination will be altered. The table below (Fig. 3) indicates the relationship between average footcandles and watts per square foot for the four systems described above. It illustrates the limitations of using an incandescent general lighting system.

Fig. 3

Average footcandles vs. watts/square foot for typical general lighting systems.

Conclusion

For general lighting, fluorescent systems offer obvious advantages:

- Based on the average 1977 Massachusetts price of 4.1¢ per kwh, the total operating costs for a fluorescent system are 70% less than for an incandescent: \$.33/sq. ft. versus \$1.30/sq. ft. respectively.
- An acceptable general light level (30-40 fc) can be maintained by a fluorescent system with a connected power load of less than 1.5 watts/sq. ft. An incandescent system would require more than 4.3 watts/sq. ft. to produce equivalent light levels.

Conservation Opportunities

General Lighting

There are many opportunities to reduce the energy costs of general lighting, often at very little cost. You can probably use some of the following ideas in your building's lighting system. More complete information on the energy and cost savings potential of these ideas is included later in this chapter.

Switch Off Unnecessary Lights: The least expensive way to reduce lighting cost is to switch off unnecessary lights. Before opening the building and immediately after closing, light levels should be reduced to a bare minimum.

This measure is practical only if adequate and convenient light switching is available, and responsibility for implementing the switching policy is assigned by management to a specific person or persons.

Lights in storage and toilet areas should be switched off, perhaps by a timer switch, whenever those areas are unoccupied. At current energy prices, it pays to shut off fluorescent lights if they are likely to remain off for at least 10 minutes. (It used to be economically sound to leave them on because lamp life decreases with more frequent switching.) It always pays to shut off incandescent lamps. As a rule of thumb, it costs about 1¢/hr. for the energy required to run a single four-lamp, four-foot fluorescent fixture, or a 200-watt incandescent lamp. Significant savings will require a continuing and systematic management effort, but they are possible, as many stores have shown.

Remove Unnecessary Lamps: This low-cost measure is simple and effective. Both fluorescent and incandescent lamps can be removed safely by existing maintenance personnel.

Fluorescent lamps are usually connected in pairs and wired in series. If one lamp of the pair is removed, the other usually will not start, depending on the ballast and capacitor wiring. In any case, both lamps should be removed to avoid damaging the ballast and capacitor wiring. The ballast should also be disconnected, since it continues to draw 7-10 watts of power, except in slimline fixtures.

Incandescent fixtures have no ballast and consume no power when lamps are removed. Removing lamps may be unnecessary if adequate switching is available. To improve the appearance of a delamped fluorescent fixture, you can alter the wiring so that the two inner lamps remain in use. The energy cost savings will be directly proportional to the total wattage removed. Assuming 4,000 annual operating hours, each pair of 40-watt fluorescent lamps removed, with ballast disconnected, would save about \$20.00 per year.

Replace Existing Fluorescent Lamps with Reduced Wattage, More Efficient Lamps: Since the recognition of the energy crisis, several lamp manufacturers have developed reduced-wattage, slightly more efficient fluorescent lamps which can be directly substituted for existing lamps. When applied throughout an existing fluorescent system, these lamps substantially reduce energy costs with only a minor reduction in general light level. The reduced wattage lamps, sold under labels such as Econ-o-watt, Watt-miser, Energy-miser, Supersaver, Econo-miser, or the like, depending upon the manufacturer, are available in four-foot and eight-foot lengths. Before installing reduced wattage lamps, consult the ballast manufacturer to verify that the lamps will not damage the ballast. In a typical building with a fluorescent general lighting system, installing reduced energy lamps reduces annual operating costs by 14% with only a 10% reduction in light level.

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One manufacturer has devised a unique lamp substitute called Thrift/Mate for use in standard four-foot fixtures. The Thrift/Mate is designed as a replacement for every other lamp in two- or four-lamp fixtures. It reduces energy consumption and light output of the fixtures by one-third or one-half depending upon which of two available sizes is selected.

Install Non-Lighting Tubes in Fluorescent

Fixtures: Another unique substitute lamp is called a Phantom Tube. A Phantom Tube is a plain glass tube which looks like and replaces a fluorescent tube but does not light. By replacing a fluorescent lamp with a Phantom Tube, the two-lamp circuit is complete and the remaining lamp continues to operate. Normally, if one tube is removed from a two-lamp circuit, the other lamp will not burn. Phantom Tubes provide a more uniform light level around a room than simple lamp removal. They are useful in areas lit by two-lamp fixtures where substantial reductions in light level are desired, but where substitution of single-lamp fixtures would be too costly.

At current energy prices, replacing one lamp of a two-tube fixture with a Phantom Tube would reduce the annual operating cost of that fixture by approximately \$13.00 or 67%. Note that the light output of the fixture is also reduced by two-thirds.

Brighten Building Interiors: The choice of color for walls and ceilings has a surprising effect on the efficiency of the lighting system. Light colors reflect more light than they absorb. Dark colors absorb more. A given lighting system may be as much as twice as efficient in a light-colored room as it is in a predominately dark one.

Repainting walls and ceilings should be considered in conjunction with other measures (lamp removal, reduced wattage lamps, or Phantom Tubes) for improving lighting efficiency. In some cases the owner may be able to maintain existing light levels (if so desired) by brightening his color scheme while removing lamps or using lower wattage lamps. The color selected does not necessarily have to be white, but may be any lighter (more brilliant) hue.

Replace Incandescent General Lighting System with a Fluorescent System: Although this action will require some capital investment, the energy savings which are achieved are so dramatic, and the pay back periods are so short, that it is ordinarily one of the best energy management decisions you can make.

By carefully selecting from the wide variety of fixture sizes, diffuser types and mounting arrangements, a building owner or store manager can reduce electrical costs, and maintain a distinctive, aesthetically pleasing and effective general lighting system in which more wattage can be devoted to spotlighting.

Fixture size: The most commonly used modules are the 2' by 4' four-lamp and the 1' x 4' two-lamp fixtures. A less commonly used module is the 2' x 2' two-U-lamp fixture.

Diffuser type: The prismatic diffuser is used most commonly. A more expensive alternative is the parabolic louver diffuser. These fixtures provide extremely good control of light distribution with low fixture brightness, at efficiencies roughly equivalent to the standard prismatic diffusers.

Because of their very good appearance, they may be more suitable for buildings seeking to create a more unconventional ambience.

Mounting arrangement: In any particular area, the general lighting fixtures should be distributed fairly evenly. For example, a typical building using standard 2' x 4' four-lamp fixtures to provide 30-40 fc would need one fixture for each 60-65 square feet of floor space. Thus, the spacing between fixtures could be 6' x 10' 8', x 8', etc., depending on merchandise arrangement, structural constraints in the ceiling design, etc.

Cost of a complete system conversion will vary from building to building, depending on difficulty of installation and cost of labor. A cost of approximately \$1.00/sq.ft., with a payback period of about 1-1.4 years, would be a conservative estimate. Installing a fluorescent system will yield the greatest savings if the same light level is maintained. Often fluorescent replacement systems are designed to produce an

unnecessarily high light level, reducing expected savings. A typical conversion maintaining the same lighting level (30-40 fc) would save about \$0.96/sq.ft. annually at current energy prices of 4.1¢ per kwh.

Local Lighting

Up to this point, what has been said about energy conservation of general lighting has been applicable to all buildings, but it has been obvious that the mix of general and local lighting is especially important to retail store owners. In this section we will refer specifically to that sector, but it should be remembered that these concepts could apply elsewhere where decoration, highlighting or spotlighting effects are important.

The primary function of local lighting—in those stores that have local lighting systems—is to attract the customers' attention to specific displays, either in show windows or on the sales floor. To be effective, local lighting must make the display appear at least as bright or brighter than other objects within the customer's field of vision.

Although desirable as a merchandising tool, local lighting is expensive. Many retailers use local lighting very inefficiently and excessively. A typical show window may use up to 50 watts per square foot of lighting at an annual operating cost of over \$12.00 per square foot. In order to balance the merchandising advantages of local lighting with the high costs of operating these systems, the Massachusetts retailer must first recognize how much local lighting is actually needed and then improve the efficiency of the lighting system.

One reason local lighting systems are expensive is that they generally use incandescent lamps. While fluorescent sources are recommended for general lighting systems, incandescent sources are usually preferred for most local lighting displays, because they are compact and their light output can be concentrated and directed.

Unfortunately, many retailers misuse incandescent spot lighting, either by using much more of it than is actually needed, or by using spotlights in applications for which other sources would be better suited.

For example, there are three cases in which fluorescent local lighting should be used rather than incandescent spot lights:

1. In stores with a large portion of the sales and display area devoted to locally lit displays;
2. In show windows where uniform brightness is more important than the texture and contrast of display merchandise; and
3. In linear displays (e.g., clothing racks along walls), especially extensive ones, where a fluorescent valance is preferred.

Because incandescent sources are inefficient, they should be used with moderation and only where the color, form or texture of merchandise must be emphasized. In sales areas where the general light level is 20-30 fc, the following local lighting levels are recommended.

Incandescent Spotlighting in Sales Areas: In an area with 30 fc of general lighting, an additional 30 fc of incandescent spotlighting* will provide ample highlighting for color rendition, definition of shadows and textures, and the provision of sparkle in shiny surfaces. Forty to sixty additional footcandles of incandescent light is bright enough to attract the customer's attention from across the store.

Fluorescent Valance Lighting in Sales Areas: Valance lighting systems generally use fluorescent sources to serve the same purpose as incandescent spotlighting. Valance fixtures are usually located along store walls and often used to brighten walls and ceilings, thus contributing to the general light level of the store. Thirty additional footcandles of valance lighting is enough to highlight vertical displays in an area with thirty footcandles of general lighting. Forty to sixty footcandles will provide sufficient brightness to attract visual attention from other areas of the store.

Show Window Lighting: In downtown stores, 200 fc is the maximum level needed for show windows

*Note: Lighting levels from multiple sources are additive. For example, if a point was lit to 30 fc by the general lighting system and an additional local fixture was switched on which alone would produce 30 fc at the same point, the overall effect of both systems would be 60 fc at that point.

15 Conservation Opportunities

during peak traffic periods. At night and during low traffic periods, 100 fc is adequate. These recommendations apply to stores maintaining a uniformly bright window. Other stores may choose to use fewer lamps to produce a high contrast display, with high levels on specific items and reduced levels elsewhere.

Principles of Efficient Local Lighting

In order to get the most from your local lighting system at the least cost, you should apply the following principles:

- **Select the Proper Type of Lamp for the Job:** Lamps—especially incandescents—are available in a vast array of sizes and types. Choose those which most closely match your requirements at the lowest cost, generally lamps with the lowest wattage.
- **Select an Efficient Fixture:** Select fixtures which maximize the amount of light reaching its target. Fixtures with baffles, louvers, and deeply recessed lamps are inefficient and should be modified or replaced. With efficient fixtures, you can use a lower wattage lamp with substantial cost savings.
- **Position Light Fixtures Properly:** The placement of a light fixture in relation to the target has a lot to do with both lighting efficiency and effectiveness. Proper placement of spotlighting and valance lighting fixtures is especially important. The application of each of these principles is illustrated in the following section.

Energy Conservation Opportunities in Local Lighting Systems

The misuse of local lighting sources is so widespread in current practice that many opportunities exist for reducing lighting costs without sacrificing lighting quality. With a common sense

approach, you can maintain an adequate and flexible local lighting system. In fact, you can probably cut your local lighting costs by as much as 50% by applying some of the following ideas in your store.

Relamp Existing Fixtures with More Efficient, Lower Wattage Lamps

The first type of modification you should consider in your local lighting system is relamping existing fixtures with more efficient, lower wattage lamps. For most local lighting fixtures, modification is almost always cost-effective because few, if any, changes are required in the fixtures or the wiring of the system. In other cases, minor fixture modification may be required. The application of relamping to save energy in typical retail lighting systems is illustrated in the following examples.

Spotlighting: In spotlighting, lighting efficiency is not just a matter of the lumens per watt produced by the lamp. Selecting an efficient lamp for spotlighting requires that the size of the target and its orientation to the lamp be considered as well. A lamp that fails to concentrate most of its light output on the target is inefficient. In order to spotlight efficiently, you must choose a lamp which will illuminate only the target.

Many stores rely on 150-watt and 300-watt R-flood lamps for spotlighting. As explained in the section on incandescent lighting sources, flood lamps are inefficient and inappropriate in this application, because very little of the light in their wide beams actually reaches the target. Often these flood lamps can be replaced with spot lamps of half the wattage, without reducing the illumination of the target. At current prices each substitution of a 75-watt spot lamp for a 150-watt flood will save about \$15 annually in energy costs.

Two of the most common spotlighting targets are a five-foot high vertical display such as a clothing rack or bookshelf (Fig. 4) and a horizontal target such as a table or counter top (Fig. 5). Recommended lamps for each of these targets are described below.

Fig. 4
Typical vertical display

Fig. 5
Typical horizontal display

Vertical Targets: Fig. 6 lists efficient spot lamps for a five-foot high by two-foot wide vertical display. Lamp recommendations are suggested for alternative mounting positions and for various gradations of average illumination (up to 60 footcandles above the general light level). Note: These recommendations are based upon manufacturers' information and assume that an efficient fixture is to be used.

Fig. 6
Lamp Recommendations for effective
spotlighting of vertical targets

Position	Average Light Level				
	20 fc	30 fc	40 fc	50 fc	60 fc
A.	75 ER-30	75 PAR/SP	150 R-40/SP	150 PAR/SP	
B.	75 R-30/SP	75 ER-30	75 PAR/SP	150 R-40/SP	150 R-40/SP
C.	75 R-30/SP	75 R-30/SP	75 ER-30	75 PAR/SP	150 R-40/SP
D.	75 R-30/SP	75 PAR/SP	75 PAR/SP	150 R-40/SP	150 R-40/SP
E.	75 R-30/SP	75 R-30/SP	75 ER-30	75 PAR/SP	150 R-40/SP
F.	75 R-30/SP	75 R-30/SP	75 R-30/SP	75 R-30	75 ER-30

RECOMMENDED LAMPS

Vertical display

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Horizontal Targets: Efficient lamps are recommended in Fig. 7 for lighting a 4' x 4' table or counter top from various mounting heights. Again, these recommendations are based upon manufacturers' data and assume the use of an efficient fixture.

Fig. 7
Lamp recommendations for effective spotlighting of horizontal targets

Height	Average Light Level				
	20 fc	30 fc	40 fc	50 fc	60 fc
12'	75R30/SP	75ER30	75PAR/SP	150R/SP	150R/SP
10'	75R30/SP	75ER30	75PAR/SP	150R/SP	150R/SP
8'	75R30/SP	75R30/SP	75ER30	75PAR/SP	150R/SP
6'	75R30/SP	75R30/SP	75R30/SP	75ER30	150R/SP

RECOMMENDED LAMPS

Horizontal display

Fig. 8
Spotlights with extenders

Show Window Lighting: In many show windows, particularly in stores over ten years old, general service incandescent lamps are used with reflectorized fixtures. These fixtures are inefficient because they reflect much of the light from the lamp outside the show windows. The efficiency of these fixtures is further reduced by dirt accumulation, unless the fixtures are cleaned regularly.

This type of fixture can easily be modified to reduce energy cost by replacing the existing general service lamp with R-type or PAR-type lamps. These lamps are more efficient because their reflectors are built into the lamp. The use of adjustable extenders with reflectorized lamps allows you to create a highly flexible window lighting system. Extender sockets are available in various lengths for less than \$5.00. Although the reflectorized lamps are more expensive initially, they have a longer rated life and offer substantial energy savings. (See Fig. 8)

In a typical display window equipped with sixteen 300-watt general service lamps, the substitution of sixteen 150-watt R-40 spot lamps would cost about \$28 initially. If extenders were used, the additional cost would be about \$65. The annual energy savings would be about \$480 and the savings in lamp cost would be about \$20. In other words, an investment of less than \$100 would provide not only a more flexible lighting system, but also an annual savings of \$500.

Fig. 9
Inefficient fixtures

Modify or Reposition Existing Fixtures

In many stores, inefficient local lighting fixtures are a source of energy waste. An inefficient fixture can trap more than half of the light output of a lamp so that a higher than necessary wattage lamp is required. Fig. 9 illustrates a number of inefficient incandescent fixtures. Inefficient fixtures can sometimes be modified to allow for the use of lower wattage lamps.

In other situations a fixture may be inefficient because it is too close or too far from the target. In these cases, it is necessary to reposition the existing fixture in order to use a lower wattage lamp. While this measure will require an investment, the energy cost savings can be very substantial.

Fig. 10 **Socket extender**

Spotlighting: If you are now using spotlighting fixtures like those shown in Fig. 9, you should consider modifying or replacing them. In some cases, you can simply remove impediments such as louvers, grills, and baffles from the fixtures and then install a lower wattage lamp. You may also install an extender socket to move the lamp forward in the fixture thereby increasing the light output (see Fig. 10).

If you are using ceiling-mounted spot lamps for local lighting, you could probably save a great deal by suspending your fixtures closer to the target (see Fig. 11). Suspending a four-foot track light fixture on pendants costs about \$10-\$15, but will allow you to cut your lamp wattage by half.

Fig. 11 **Suspended track lighting**

Valance Lighting: As a local source of illumination for a linear display, fluorescent valance lighting can be very effective, although placement of the fixtures in relation to the merchandise is critical. Many existing systems are not effective because the lamps are mounted too close to the vertical edge of the merchandise (see Fig. 12). This situation actually reduces merchandise visibility, because the eye is drawn away from the dimly lit merchandise to the extremely bright wall surfaces above and behind the display. As the lamp is moved out from the display, its lighting of the display becomes much more

effective. The valance fixture is a very inefficient contributor to the general lighting level. A variety of fluorescent lamps and lamp combinations is used in valance lighting systems. Single-tube fixtures, if properly designed and located, can provide more than adequate illumination of a five-foot high vertical display. Dual-tube fixtures should be modified for a single-tube operation. If a higher light level is desired, the typical valance fixture should be replaced by a polished parabolic through-reflector (see Fig. 13).

Fig. 12

Inefficiently mounted valance

Fig. 13

**Single tube valance
with parabolic reflector**

Do-It-Yourself Lighting Power Survey

Once you are familiar with the terminology and lighting basics presented thus far, you are well-equipped to conduct a thorough survey of your building's lighting system yourself. Before we consider the step-by-step lighting survey procedures, let's look at some of the advantages which this self-audit approach to energy conservation offers:

It's Cheaper To Do It Yourself: As we've said before, some of the most immediate and cost-effective changes you can make are low-cost or no-cost actions such as delamping or buying and replacing with more efficient lamps. These changes are obvious—but only after you take the time and effort to look at your system. By making these decisions yourself, you reduce the pay back period for investments, because expensive consulting service need not be included in your calculations. Even if it appears that one or more areas present special problems, when you do consult with someone, you can direct them to the specific problem areas and save time and money in the process.

Your Employees Become Part of Your Corporate Conservation Effort: If top management takes the lead in this audit project, assigning staff to execute it and reviewing their results and recommended changes, your concern and determination to conserve energy and save money are conveyed quite directly—certainly more so than by simply circulating a consultant's report. This lesson is quite likely to carry over into other operational habits which affect energy consumption and costs.

No One Knows Your Building and Its Needs Better Than You Do: Explaining these things to some expert takes time and money which might be better spent educating yourself—about lighting systems and about your building's current use of them.

Six Easy Steps For Auditing Your Lighting System

Step 1. Divide Your Building Into Categories

These categories should be defined by the level of illumination which is necessary to conduct business or commerce in those areas. Classrooms, offices or merchandising areas might comprise "Category A"; auditoriums, waiting areas or inventory storage might comprise "Category B"; corridors, lobbies, and inactive storage might comprise "Category C" (see Fig. 14).

Fig. 14
Suggested Category Areas

TYPE OF USE

Interior

Category A: Classrooms, office areas, automotive merchandising areas, museums, conference rooms, drafting rooms, clerical areas, laboratories, merchandising areas, kitchens, examining rooms, book stacks, athletic facilities.

Category B: Auditoriums, waiting areas, spectator areas, restrooms, dining areas, transportation terminals, working corridors in prisons and hospitals, book storage areas, active inventory storage, hospital bedrooms, hotel and motel bedrooms, enclosed shopping mall concourse areas, stairways.

Category C: Corridors, lobbies, elevators, inactive storage areas.

Category D: Indoor parking.

Exterior

Category E: Building perimeter: wall-wash, facade, canopy.

Category F: Outdoor parking.

Step 2. Determine the Total Square Footage for Each Category

One key tool for completing this step quickly and accurately is your floor plan. The actual blue prints are the best source for room size, but you might also draw a schematic plan like the one shown here, so that you can color code it by category (see Fig. 15).

Fig. 15
Building Floor Plan

Category A ☐
Category B ☐
Category C ☐

Step 3. Assign a Power Allowance For Each Category

These allowances should be expressed in watts-per-square foot. Some states already assign specific allowances for pre-defined categories, and you may want to check with your state energy office. But for your own auditing purposes, you may want to *assign allowances which are even more stringent*. For example, some states currently allow 3 watts per square foot in offices, but experience has shown that 2 watts per square foot is more than adequate for achieving a healthy and productive office work environment.

Step 4. Multiply the Total Square Footage for Each Category by the Respective Power Allowances

This will establish the maximum level of lighting power which should be necessary in each category. If your state has adopted a standard which requires you to meet minimum lighting power efficiencies for each category, this step will provide you with the respective budgets you must meet.

Step 5. Add the Budget Sub-Totals for Each Category to Determine Your Total Building Budget.

Some states allow you "trade-off" lighting power between and among categories within a building. Using retail as an example, this would mean that you could exceed the power allowance for merchandising areas so long as you reduced by an equivalent amount in inventory or storage areas. Compliance with standards in states which allow this option is achieved by meeting the total budget for the total building, as determined by this step. The Summary Sheet provides a useful format for calculating these individual category and total building budgets (see Fig. 16).

Step 6. Walk Through Your Building Room-by-Room, and Calculate Your Connected Lighting Load Fixture-by-Fixture

Up to now, it is conceivable that you may have completed Steps 1-5 without ever having left your office. But the only way to adequately assess if you have met the individual category or total building budgets is by a thorough accounting of the system. The Detail Sheet is your key tool, and a separate one should be completed for each category. It should include the following: room name or number, size of each room in square feet, a separate line for each fixture or lamp type within each room.

SUMMARY SHEET**

LIGHTING POWER AUDIT

GENERAL INFORMATION:

Building Name: _____ Tenant ☐ Landlord ☐

Address: _____

City/Town: _____

Building Owner: _____

Building Supt./Engineer: _____

Telephone #: _____

Building Use Type: _____

TOTALS BY CATEGORY:

Category	Total Area/ Category	Allowance/ Sq. Ft.	Total Watts Allowance	Total Connected Load
A				
B				
C				
D				
Interior Total				
E				
F				
Exterior Total				

**This Summary Sheet is similar to the one which was employed by the Massachusetts State Building Code Commission in their Lighting Power Project: hence, the identification of six use categories and the respective power allowances. Your state may have more or fewer categories or more or less stringent allowances. If your state has no standard, you might want to adjust the categories and their respective allowances yourself. In any event, contact your State Energy Office for the best information.

Fig. 16

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If you use fluorescent or high intensity discharge lamps, the total fixture wattage—including ballast—should be noted (see Fig. 17).

On the bottom of the Detail Sheet, you should identify the totals for both square feet and connected load for the given category as reported on that page. The final totals for each category should be transferred to the Summary Sheet, where the respective budgets should already be identified from Steps 4 and 5.

You simply compare. If you exceed either the individual category or the total building budgets, you

can then use the Detail Sheets to plan the necessary modifications (see Fig. 18).

It should be noted that some states have allowed an exemption for "task lighting" from inclusion in the Total Connected Load. Task Lighting is defined as that which illuminates a specific work site and is individually switched at that site. (Examples: desk lights, machine lights, examining lights). Here too, you should check with your State Energy Office to see if this exemption applies.

Fig. 17 Typical Lighting Fixture Wattage

I. Fluorescent

Lamp Description	Lamps per/ Fixture	Lamp Type	Fixture Wattage*
4 Ft. 40 Watt Rapid Start	1-F40T12		50
	2-F40T12		92
	3-F40T12		142
	4-F40T12		184
8 Ft. Slimline Instant Start	1-F96T12		100
	2-F96T12		170
	3-F96T12		270
	4-F96T12		340
8 Ft. High Output	1-F96T12/HO		140
	2-F96T12/HO		252
	3-F96T12/HO		392
	4-F96T12/HO		504
8 Ft. 1500 ma Power Groove, SHO or VHO	1-F96PG17		
	1-F96T12/SHO or VHO		230
	2-F96PG17		
	2-F96T12SHO or VHO		450
	3-F96PG17		
	3-F96T12/SHO or VHO		680
	4-F96PG17		
	4-F96T12/SHO or VHO		900

POWER TO ENERGIZE BALLASTS WITHOUT LAMPS

Ballast	Watts Loss
Rapid Start 2 Lamp 40 Watt	6.5 Watts
Rapid Start 1 Lamp 40 Watt	8 Watts
High Output Rapid Start (800 ma)	12.5 Watts
Power Groove, SHO or VHO Rapid Start (1500 ma)	13.5 Watts
Instant Start—Slimline—All	Zero**

**These fixtures disconnect ballast automatically when lamp removed.

II. High Intensity Discharge

Lamp Type	Lamp Designation	Watts	Fixture Wattage*
Mercury	MV 100	100	118
	MV 175	175	200
	MV 250	250	285
	MV 400	400	450
	MV 1000	1000	1075
Metal Halide	MH 175	175	210
	MH 250	250	292
	MH 400	400	455
	MH 1000	1000	1070
High Pressure Sodium	HPS 70	70	88
	HPS 100	100	130
	HPS 150	150	188
	HPS 250	250	300
	HPS 400	400	465
	HPS 1000	1000	1090

*Includes Lamp and Ballast Wattage

DETAIL SHEET

LIGHTING POWER AUDIT

Sheet ____ of ____

GENERAL INFORMATION:

Building Name:_____

Address: _____

City/Town: _____

Building Owner:_____

Superintendent: _____

Phone: _____

CATEGORY OF USE: _____

[illegible]

Fig. 18

Some Case Study Examples

A year and a half after the Massachusetts lighting power project's requirements took effect, the State Building Code Commission contracted with a management consultant and an engineering firm to conduct an in-depth evaluation of the project.

Eight specific case study buildings, whose owners had reported connected lighting power in excess of the project allowance, were selected. Sufficient data was gathered at each site to allow a comparison of the Massachusetts requirements to three alternative standards which have been adopted by other states. This comparison contrasted three variables which would result from complying with each of the four standards: the energy saved by each, the illumination levels resulting from each and the financial costs and benefits of each standard's requirements.

For the purpose of illustrating the financial benefits which can be realized by conducting a self-audit and by making the cost-effective changes, four of the case studies, as they were affected by the Massachusetts requirements, are treated below.

Before considering them, let's look at some of the conceptual tools which were used in the case study analyses:

Auditing Cost: is an estimate of the cost in man-hours to certify and document compliance with the lighting standard requirements.

Compliance Cost: is the total cost of achieving the limits prescribed by a lighting standard, and it is comprised of two elements:

Design Cost: is that portion of the compliance cost which would include the cost of in-house labor or,

alternately, the cost of professional services of architects, engineers, or energy auditors to design and supervise a plan for meeting the lighting requirements.

Physical Cost: is that portion of the compliance cost which would include all labor and materials necessary to meet the requirements.

Discounted Energy Savings: is the ten year stream of dollar savings "discounted" to present dollar value so as to correct for inflation. The figure is calculated by subtracting the cost of compliance (auditing, design and physical costs) from the present discounted value of dollar savings realized from reduced electrical costs.

Illumination Cost Penalty: Ordinarily, a building owner or manager would choose the *least* expensive set of changes to a lighting system in order to meet a lighting efficiency requirement. However, there are certain instances—particularly in retail stores—when illumination requirements might dictate a more elaborate or expensive set of changes to achieve the same energy budget. The illumination cost penalty is the difference between the compliance plan chosen and the least expensive option available to meet the same lighting power budget established by the program requirements.

Economic Assumptions: In order to conduct the financial analysis of the case studies, the consultants used Massachusetts electrical utility costs in 1979, and they assumed the following (generally conservative) inflation rates:

	<u>Years 1-5</u>	<u>Years 6-10</u>
General Inflation	8.0%	6.0%
Electricity Rates	5.0%	

First Year Cash Flow: Is the dollar figure of energy savings which would be realized during the first year after completion of the recommended energy conservation changes.

Payback Period: Is the length of time measured in years which it would take for a building owner to recover the costs of his energy conservation investment by the realized energy savings. Cost of investment includes auditing, labor, design, capital expenditure and finance costs of borrowing capital.

Internal Rate of Return. To give a better feel for the advantages of their recommended changes, the management consultants also calculated the internal rate of return (IRR). A technical definition of IRR is, "that discount rate which would equate the present dollar value of energy savings over time, with the dollar value of the capital outlay." In layman's terms, it can be said that a capital outlay project is sound if the IRR is greater than the cost of borrowing money or greater than the return which could be realized by investing the money elsewhere. Hence, an internal rate of return of 200%, such as that calculated for some of the case studies, is a very sound move because it far exceeds the cost of borrowing money or the interest or return which could be gained by virtually any other investment.

Office Building

Facility Profile

This 31,000 square foot office building is the corporate headquarters and general offices for a natural gas pipeline company serving the northeastern United States. The building was built more than 30 years ago; it has undergone two major remodelings—one 17 years ago and the other 11 years ago. The building undergoes annual space changes, and at the time of the case study, 2,000 square feet were undergoing such changes. Individual office areas range from a 1,500 square foot general accounting area to 70 square foot partitioned cubicles. Offices comprise approximately 75% of the building area; lobbies, storage, rest rooms, corridors and mechanical rooms comprise 25%.

Lighting System Profile

The office lighting system as originally installed 17 years ago used standard 2' x 4' fixture with lens, using four standard F 40 fluorescent lamps. These fixtures are attached to the concrete ceiling in a grid pattern. During space alterations, white partition walls were used. These walls, in two foot or four foot sections, are adapted to the existing light fixtures instead of moving the light fixtures for ideal space illumination.

Lighting levels were designed to be in excess of 100 footcandles (fc). However, over the past several years, the fixtures have been reduced to two lamps with the corresponding ballasts disconnected. Lighting levels in the offices now range from 45 fc to 90 fc. The levels vary within cubicles due to the positioning of the partition walls.

The dining, and field training areas are lit by 27 incandescent floodlights of 200 watts each. The lights are in cans which are hung below the suspended ceiling. They are evenly placed over the 74 foot by 20 foot space. Light levels range from 40 footcandles under lights to 25 fc between lights.

Lavatories are lit by a mixture of 30" and circular fluorescent lamps. Light levels range from 25 fc to 115 fc.

Corridors are lit by 2' x 2' fixtures with four, 2' fluorescent lamps of 20 watts each. Fixtures are spaced evenly every ten feet with light levels between 40 fc and 60 fc. The company does not use two-thirds of the lamps during the working day, so that light levels then average between 12 fc and 40 fc.

The lobby is lit by 25 incandescent spotlights in a mixture of 75 watt and 150 watt bulbs. Light levels range from 10 fc to 30 fc. All lights except four in the reading area of the lobby and four used for wall wash are off during the day.

Compliance Assessment

In-house personnel were able to complete the audit requirement of the Massachusetts program at a labor cost of \$140.

27 Some Case Study Examples

The audit showed that the building had a total connected load of 76,675 watts, while the program allowance was only 70,953. This 8% difference was caused by excessive lighting power in corridors, the lobby, storage areas and lavatories. In some of these areas, the connected load was more than twice as high as allowed.

Compliance Strategy

The compliance strategy to meet the Massachusetts requirement consisted of two actions: 1) Forty of the 100 watt fluorescent fixtures in the corridors were delamped; and, 2) the 25 incandescent fixtures in the lobby were changed from 150 watt flood lamps to 75 watt floods. This brought a total reduction of 5,875 watts.

Area	Before	After
Corridors	160 F-20T12 CW	120F-20T12CW
Lobby	25 150 R/FL	25 75 R30/FL

Illumination Cost Penalty

The recommended changes would not result in illumination levels below those recommended in the Illuminating Engineering Society Handbook. For this reason, no illumination cost penalty is assigned.

Cost-Benefit Analysis and Investment Summary

Auditing Cost	\$ 140
Compliance Cost	
Design	35
Physical Changes	330
Discounted Energy Savings (10 years)	6,931
Illumination Cost Penalty	0
Pre-Tax Benefit	\$6,426
First Year Cash Flow	\$693
Payback Period	5 Years
Internal Rate of Return	222.5%

Retail Specialty Store

Facility Profile

This 7,016 square foot facility is located within a suburban shopping mall. It is one of a chain of stores

specializing in quality glass, crystal, fabric, dishes and other similar items. The merchandising area is comprised of three separate rooms: 2500 square feet with a 14 foot ceiling; 1000 square feet with a 9 foot ceiling; and, 1000 square feet with a 14 foot ceiling. One-third of the facility is devoted to stock and storage which is on two levels, each with 7 foot ceilings. In addition, there is an office, a restroom and a kitchenette.

Lighting System Profile

The three merchandising areas are lit with incandescent trade lighting using 150 watt narrow spot lamps. These fixtures are used only to spotlight merchandise and there is no general ambient lighting. The fixtures are moved and redirected whenever displays are changed. Light levels range from 40 footcandles to 180 footcandles (fc) on the merchandise itself and fall to only 20 fc in some circulation areas. The cash register stations are illuminated at 20 fc to 60 fc.

The back merchandising area is also lit with 18 industrial type, incandescent fixtures with 100 watt lamps. These fixtures are predominantly aesthetic; most of the display lighting is still accomplished with track lights. The stockrooms are lit with a combination of F40, F72, and F96 fluorescent lamps on both two-lamp and four-lamp fixtures. In one stockroom, light levels range from 70 fc to 250 fc, the latter occurring directly beneath a fixture. This area has a seven foot ceiling and four-lamp, F40 fixtures, thus the uneven distribution. The other three stockrooms are lit with two lamp fixtures. As a result, illumination is more uniform although light levels are still in the 80 fc to 120 fc range.

Two-lamp, F40 fixtures light all of the remaining rooms. Light levels range between 70 to 100 fc.

Compliance Assessment

In-house personnel were able to complete the audit requirement of the Massachusetts code at a labor cost of approximately \$25.

The audit showed that the connected load was 41,974 watts, while the code allowance was only 16,056. This significant difference occurs in two places.

In the merchandising areas, there is a heavy dependence on high-wattage incandescent lamps, while the code prescribes 3.0 watts/ft² in these areas, the actual connected load averages 7.65 watts/ft². In the stockrooms, there is an excessive use of fluorescent lighting; while the code prescribes 1.0 watts/ft², the actual connected load here averages 3.3 watts/ft².

Compliance Strategy

Area	Before	After
Offices, Restroom and Kitchenette	7, two-lamp F40 fluorescent fixtures	Replace all lamps with high efficiency fluorescents.
Back Stockroom Main Levels	8, two-lamp F96 fluorescent fixtures; 8, 2-lamp F40 fluorescent fixtures. 6, 2-lamp F72 fluorescent fixtures.	Install 1 matching Phantom Tube in each fixture.
Back Stockroom Upper Level	14, 4-lamp F40 fluorescent fixtures	Remove 2 lamps from every fixture. Replace remaining lamps with high efficiency fluorescents.
Side Stockroom Main Level	4, 2-lamp F40 fluorescent fixtures. 9, two-lamp F72 fluorescent fixtures.	Disable 3 of 4 F40 fixtures; replace remaining F40 lamps with high efficiency fluorescents. Install 1 matching Phantom Tube in all remaining fixtures.
Side Stockroom Upper Level	7, two-lamp F96 fluorescent fixtures	Install 1 matching Phantom Tube in fixture
Back Merchandising	18, 100w incandescents	Replace with 50w incandescent.
All Merchandising Areas	209, 150w narrow spot incandescents	Remove 54 fixtures; replace remaining lamps with 75ER30.

Illumination Cost Penalty

The compliance strategy outlined above illustrates the least expensive options available to reduce the connected lighting power load by 26,000 watts as dictated by the Massachusetts code.

But because this kind of retail store is highly dependent upon lighting for its merchandising effort, the consultants selected another, more expensive, option which would combine general lighting, provide by 115 high quality, 3,000° K fluorescent fixtures, along with spotlighting provided by 50 and 75 watt incandescent spotlights.

The difference between this more expensive option which provides the desired merchandising effect and the least expensive option is approximately \$11,000. This figure represents the "illumination cost penalty."

Cost Benefit Analysis and Investment Summary

Auditing Cost	\$ 25
Compliance cost	
Design	100
Physical Changes	1,615
Discounted Energy Savings (10 years)	44,309
Illumination Cost Penalty	11,000
Pre-Tax Benefit	\$31,569
First Year Cash Flow	\$4,430
Payback Period	.4 Years
Internal Rate of Return	287.3%

Jewelry Store

Facility Profile

This is one of two specialized jewelry stores, of an old Boston firm, featuring a limited variety of expensive merchandise: jewelry, china, silver, crystal, porcelain and clocks. This store is in a suburban shopping mall and the total facility is 6,170 square feet, of which 4,300 square feet is devoted to merchandising.

Lighting System Profile

The main merchandising area of the store is a single room, 130 feet long by 32 feet wide. It is illuminated by thirty-seven, 250 watt mercury vapor lamps situated in recessed reflectors, in a suspended ceiling 14' above the floor. Additional area lighting is provided by forty-three, 150 watt spotlights situated over display areas in cans recessed in the ceiling. Display cabinets are lit by 4' and 6' fluorescent tubes in a parabolic diffuser immediately above the display, and a translucent, milky white lens immediately below the display. The general floor lighting is between 60-75 footcandles (fc) while lighting in the jewelry cases is 200 fc and the level on the case is 80 fc. Lighting in display cases varies from 125 fc on the lowest of four shelves to 600 fc on the top shelf closest to the light source.

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Storage consists of two different facilities, a 12' by 12' vault for the jewelry, and a 1,500 square foot area for active storage of china, glass, porcelain and silver. Both areas are lit by 4' fluorescent tubes in single and double fixtures. The lighting levels are 30-50 fc in these areas.

In addition, there are eight display cases in the front of the store facing the main concourse of the Mall. These hold displays of jewelry and are lit by varying combinations of 150 watt spotlights, 30 watt spotlights, and 150 watt quartz crystal spotlights. Lighting in these 3' x 3' x 3.5' areas is 500 fc.

Compliance Assessment

In-house personnel were able to complete the audit requirement of the Massachusetts lighting program at a labor cost of approximately \$25.

The audit showed that the connected load was 36,009 watts, while the Massachusetts program allows 15,308 watts. This significant difference is accounted for by overages in all three program categories. The merchandising area is by far the most serious with an average of 7.3 watts/ft² as opposed to the 3.0 watts/ft² suggested by the program.

The changes which are recommended below to achieve compliance would require in-house and contract labor at an estimated cost of \$3,825.

Compliance Strategy:

Area	Before	After
General ceiling	37, H37 KC250/DX Mercury Vapor lamps	Remove all lamps, replace 17 with metal Halide MU175/BU lamps and fixtures.
Jewelry Display and Sales	26, PAR150 spots 16, 1-F40T12 fixtures	Remove lamps and ballasts from all 1-F40T12 fixtures. Replace with 75ER30 lamps.
Clock Sales	5, PAR150 spots	Disable all fixtures.
Front Offices (2)	1, 4-F40T12-RS	Remove 1, F40T12 and replace with matching Phantom Tube.
Customer Relations	2, 2-F40U3, 1, 4-F40T12-RS	Remove lamps and ballasts from 1, 2-F40U3 fixture. Remove 2 lamps and associated ballast from 4-F40 fixture.

Area	Before	After
Diamond Display and Sales	6, PAR150 spotlights 4, 75w incandescent lamps in fixtures, 3 1-F64T6-RS fixtures	Replace PAR lamps with 75ER30 lamps. Replace 75w lamps with 50R20 lamps.
Porcelain Display	6, PAR150 lamps	Replace with 75ER30 lamps.
Mail Display Cases (8)	8, PAR 150 spotlights, 16, PAR 46/150 spots, 4, 150 Q/CL lamps	Replace with 23, 75ER30 lamps.
Chandelier	12, 40w lamps	Replace with 25w lamps.
Wall Display Cases	20, 4-F72T120RS fixtures above, 7, 2-F72T12-RS fixtures below	Remove lamps and ballasts from 2 fixtures above; remove 1 lamp and replace with Phantom Tube in fixtures below.
Wall Display Cases	16, 4-F40T12-RS above, 6, 4-F40T13-RS 8, 2-F40T12-RS fixtures below	Remove 2 lamps and replace with Phantom Tubes in all 4-F40 fixtures. Remove 1 lamp and replace with Phantom Tube in 2 F-40 fixtures.
Mezzanine Storage	10, 2-F40T12-RS 4, 1-F36T12-RS	Remove lamps and ballast from 1, 2-F40 fixture.
Bathrooms (2)	1, 160w incandescent 1, 2-F40T12-RS fixture	Replace 1 F40 lamp with Phantom Tube.
Watch Repair	2, 4-F40T12-RS	Remove 2 lamps and replace with Phantom Tubes in 1 fixture.
Mezzanine Storage	10, 2-F40T12-RS 4, 1-F36T12-RS	Remove lamps and ballasts from 6 2F40 fixtures.
General Storage	12, 1-F40T12 fixtures	Remove lamps and ballasts from 6 fixtures.
Vault	2, 2-F40T12-RX fixtures.	Remove lamps and ballasts from 1 fixture.
Bathrooms (2)	1, 60w incandescent 1, 2-F40T12-RS fixture	Remove 60w incandescent.
Back Corridor	2, 2-F40U3 fixtures	Remove lamps and ballasts from 1 fixture.

Illumination Cost Penalty: The compliance strategy outlined above illustrates the least expensive option to reduce the connected lighting power load by 20,700 watts, as required by the Massachusetts program.

Jewelry stores are also highly dependent upon lighting for their merchandising effect, and for this reason the consultants selected a more expensive option to provide the necessary illumination without exceeding the code's allotted budget of 15,308 watts. The system selected would replace four 75 ER 30 lamps with four 50 ER 20 lamps in tensor fixtures at

the jewelry counters. In addition, the 36 wall display cases would be redesigned to accommodate more efficient lighting.

The difference between this more expensive option which provides the desired merchandising effect and the least expensive option is approximately \$21,830. This figure represents the "illumination cost penalty."

Cost-Benefit Analysis and Investment Summary

Auditing Cost	\$25
Compliance Cost	
Design	250
Physical Changes	3,825
Discounted Energy Savings	
(10 years)	32,496
Illumination Cost Penalty	21,830
Pre-Tax Benefit	\$6,566
First Year Cash Flow	\$3,249
Payback Period	1.2 Years
Internal Rate of Return	97.5%

Hotel

Facility Profile

This 84,845 square foot hotel is a prototype of a well-known national chain. Identical guest rooms account for 54,912 square feet. Four thousand square feet are function/conference rooms, and 3,500 square feet are devoted to a dining room and lounge. Small conference rooms, corridors, rest rooms, cooking facilities, general offices and auxiliary support services account for the remainder of the area.

Lighting System Profile

Lighting in the guest rooms is provided by incandescent fixtures: two 100 watt bulb table lamps, two 60 watt bulb reading lamps at bedside, one 160 watt fixture (4X40 watt) for the bathroom mirror, and a 60 watt bulb ceiling fixture at the entrance to the room. In addition to the above, there is a 250 watt heat lamp ceiling-mounted in the bathroom.

The rest of the motel is also predominately lit by incandescent fixtures; only the kitchen, general offices, laundry area, four small conference rooms, workshop and telephone room are lit by fluorescent fixtures.

Light levels in the building range from 1-5 fc in the lounge to 120 fc in the laundry folding room. The office illumination levels range from 35-90 fc, the lower ranges occur in those offices equipped with 4 foot lamps, and the higher ranges occur in those equipped with 8 foot lamps. Corridors are lit at 1-4 fc provided by wall-mounted fixtures which act as a wall wash on dark blue wall paper. The guest rooms' illumination levels are: bathroom, 20 fc; bed, 18 fc; reading area, 40 fc; and entry, 10 fc.

Exterior lighting consists of twenty-five, 150 watt flood lamps and twenty-seven, 75 watt flood lamps used for wall wash. There are twenty 4' x 4' fluorescent fixtures using four, 40 watt lamps which light the entrance canopy ceiling, and are ceiling-mounted. Eight, 400 watt mercury vapor lamps are used for parking lot illumination.

Compliance Assessment

In-house personnel were able to complete the audit requirement of the Massachusetts lighting program at a labor cost of approximately \$75.

The audit showed that the total connected load was 176,064 watts, while the allowance was only 106,206 watts. This large difference is primarily due to the guest rooms which alone have an excess of 84,128 watts beyond what their assigned category allowance would suggest. By making the changes suggested below in the 178 rooms, a total saving of 70,400 watts in the connected load can be achieved. The major costs incurred are for in-house labor and the purchase of new, downsized lamps.

Compliance Strategy

Area	Before	After
Bed lamps	Two, 60 watt bulbs	Replace with two, 40 watt bulbs.
Table lamps	Two, 100 watt bulbs	Replace with two, 75 watt bulbs.
Entry	One, 60 watt bulb	Replace with one, 40 watt bulb.
Bathroom	Four, 40 watt bulbs	Reduce to three, 40 watt bulbs.
Bathroom	One, 250 watt heat lamp	Remove

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Illumination Cost Penalty:

None of the recommended changes will result in illumination levels which fall below those that are recommended in the Illuminating Engineering Society Handbook. For this reason, no more expensive options for compliance were considered and no illumination cost penalty was determined.

Cost-Benefit Analysis and Investment Summary

Auditing Cost	\$ 75
Compliance Cost	
Design	20
Physical Changes	1,000
Discounted Energy Savings (10 years)	19,024
Illumination Cost Penalty	<u>0</u>
Pre-Tax Benefit	\$17,929
First Year Cash Flow	\$1,902
Payback Period	.5 Years
Internal Rate of Return	202.8%

Conclusion

These case studies demonstrate that substantial savings can be realized by taking a hard look at your building's lighting system and by making cost-effective changes. Most importantly, if you tailor the changes to your lighting needs, the reduced wattage need not imply unacceptable illumination levels.

The case studies also demonstrate that each building is unique and that there are no easy, well-established rules or formulas to follow in deciding which changes to make. But because energy and dollar savings are common to all, the last chapter includes some easy-to-use formulas for calculating these savings.

Calculating Your Energy and Dollar Savings

Once you have made reductions in your lighting power system you can calculate the *direct* energy and dollar savings by applying the four formulas below. (Remember, the lighting reductions will often bring additional *indirect* energy and dollar savings by reducing the air conditioning load during the summer months.)

1. The Energy Formula

To determine how much energy you have saved, simply calculate the total wattage you have reduced, and estimate your total hours of operation on a yearly basis. By running the numbers through the Energy Formula, you will have expressed your savings in kilowatt hours (KWH), which is the unit of measure used for utility billing purposes.

$$\boxed{\text{watts}} \times \boxed{\text{hours}} \div 1,000 \text{ watts/kilowatt} = \boxed{\text{kilowatt-hours (KWH)}}$$

2. Cost per KWH Formula

Calculating your dollar savings will require you to first calculate your cost per kilowatt hour. This is not always so easy, because your electric bill is determined by more than one rate or unit cost charge.

In most cases, it is quite difficult to determine precisely the dollar cost of the kilowatt-hour you've saved. As a rule of thumb, if you do not pay demand charges, compute your *marginal* price of electricity by adding the fuel adjustment charge to the rate that applies to the last kilowatt hour consumed. If you do pay demand charges, the rule of thumb is to use your *average* price as determined in the following exercise.

For the purposes of estimating your dollar savings from lighting power reductions, you can estimate your cost per kilowatt hour by completing the following equations using information from your most recent utility bill.

A. If you do pay demand charges, calculate your average cost as follows:

\$ 	÷		=	\$ per KWH
Total amount on your bill, including demand and any fuel surcharges.		Total kilowatt-hours shown on your bill.		Your <i>average</i> cost per kilowatt-hour

For Example:

$$\$282.00 \div 5321 \text{ KWH} = \$0.053 \text{ per KWH}$$

(or 5.3¢ per KWH)

B. If you do not pay demand charges, calculate your marginal cost as follows:

\$0. 	+	\$0. 	=	\$0. per KWH
Fuel adj. per KWH		Rate applied to last KWH		Your <i>marginal</i> rate

In summary, the cost per KWH figure you should use in the dollar formula depends on whether or not you pay demand charges. Select the appropriate formula in the box above, complete your calculation, and use that number in your dollar savings calculations.

Enter your cost per KWH here: \$ _____

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3. The Dollar Formula

Once you have both the number of kilowatt hours of energy you will save by reducing your lighting power and your cost per KWH, the dollars to be saved can be simply calculated:

$$\boxed{\text{Kilowatt-hours}} \times \boxed{\$ \text{ per KWH}} = \boxed{\$}$$

4. The Payback Formula

If the hours of operation which were calculated in the Energy Formula were based on annual building use, the payback period can be calculated thus:

$$\boxed{} \times \boxed{} = \boxed{}$$

Total Capital, Labor and inventory costs incurred while reducing connected lighting load.	×	Total anticipated savings per year (Dollar Formula) plus costs avoided— such as lamp replacement and labor if applicable.	=	Payback period in years.*
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