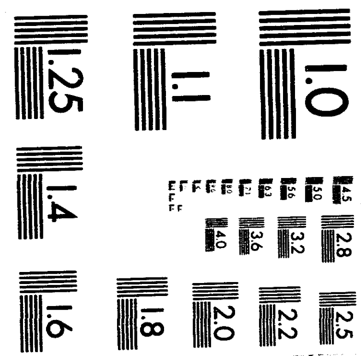

ADVANCED LIGHTING GUIDELINES: 1993

Final Report, 1993

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ABSTRACT

The *1993 Advanced Lighting Guidelines* document consists of twelve guidelines that provide an overview of specific lighting technologies and design application techniques utilizing energy-efficient lighting practice. *Lighting Design Practice* assesses energy-efficient lighting strategies, discusses lighting issues, and explains how to obtain quality lighting design and consulting services. *Luminaires and Lighting Systems* surveys luminaire equipment designed to take advantage of advanced technology lamp products and includes performance tables that allow for accurate estimation of luminaire light output and power input. The additional ten guidelines -- *Computer-Aided Lighting Design, Energy-Efficient Fluorescent Ballasts, Full-Size Fluorescent Lamps, Compact Fluorescent Lamps, Tungsten-Halogen Lamps, Metal Halide and HPS Lamps, Daylighting and Lumen Maintenance, Occupant Sensors, Time Scheduling Systems, and Retrofit Control Technologies* -- each provide a product technology overview, discuss current products on the lighting equipment market, and provide application techniques. This document is intended for use by electric utility personnel involved in lighting programs, lighting designers, electrical engineers, architects, lighting manufacturers' representatives, and other lighting professionals.

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Lighting Design Practice

Achieving Energy Savings

Up to half of all electricity used in modern commercial buildings is for lighting. A typical office building meeting the current California Nonresidential Energy Standards uses about four kWh/ft^2 per year for lighting, and 0.7 additional kWh/ft^2 per year for air conditioning to remove the heat produced by the lighting. Furthermore, much of this energy is used during the peak demand period, when utility rates are higher and peak demand charges are in effect.

Energy-effective lighting includes careful design and quality equipment, effectively employed to achieve energy efficiency while improving the appearance, visual comfort, and perceived quality of the visual environment.

Delamping, underlighting, and other similar cost cutting methods can result in lower energy consumption, but may be realized at the expense of worker productivity and human comfort (see "Lighting and Human Performance," National Electrical Manufacturers Association and Lighting Research Institute, 1989).

Efficient, quality lighting design will include the following:

- Practicing task-ambient lighting design
- Using the most efficient lighting technologies
- Using effective lighting controls

Efficient, effective lighting systems require efficient equipment and should be carefully designed by skilled professionals. Methods of selecting a lighting designer are discussed later in this guideline.

Demand-Side Management (DSM)

In order to accommodate economic and demographic growth, electric utilities have traditionally built more power plants (Supply-Side Management). Demand-Side Management (DSM), however, is an alternative used by utilities to manage growth at a lower cost and with fewer environmental problems than building new power plants. Electrical utility DSM programs encourage customers to reduce electricity use through more efficient equipment and conservation practices. Both Supply Side Management and DSM Programs require a capital investment from the utility, but with DSM, utilities invest in their customers' energy efficiency, rather than building new power plants.

Lighting is considered the "cream of the crop" in DSM programs. Lighting improvements usually offer the easiest efficiency gains, are the most cost effective, and are the most noticeable. For example, nearly 40% energy savings can be achieved in the average office building by refitting

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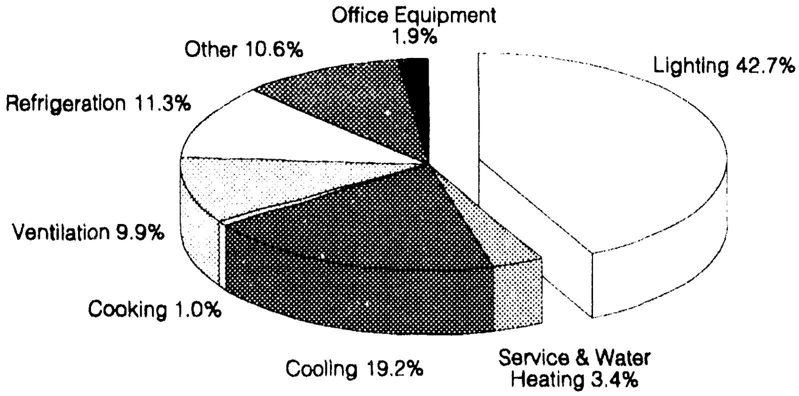


Figure 1-1

Lighting accounts for more than 40% of all commercial electric energy use in California (Source: California Energy Commission, October 1990 Energy Efficiency Report)

existing fixtures with more efficient ballasts, lamps, and reflectors. Even larger savings may be gained with comprehensive redesigns of lighting and control systems. The average payback period for lighting retrofits is about 4 to 5 years. If the utility pays for a portion of the improvements, the payback period for the customer is often less than 3 years, a measure of economic performance acceptable to most every building owner.

Lighting improvements are usually very noticeable, and if well done, appreciated by the persons affected. For example, the improved color rendering of T-8 lamps and the elimination of flicker by electronic ballasts can be seen as major contributors to an office building "makeover".

Lighting measures are the key elements in the Environmental Protection Agency's (EPA) "Green Lights" program, as well as the Department of Energy's Federal Energy Management program. By improving the work environment and saving energy, the nation's largest corporations are being galvanized in a proactive program in cooperation with the federal government. Funding for these programs through rebates and other incentives assures utilities a win-win situation.

Efficient Lighting Technologies

The California Energy Commission has identified a number of lighting technologies that can significantly reduce the amount of energy needed for lighting. These technologies include energy-efficient lamps, luminaires, ballasts, and lighting controls, as well as lighting design strategies that focus on lighting energy conservation and improved lighting quality. These goals can be achieved with little or no perceivable change in illuminance levels. These *Advanced Lighting Guidelines* address the following technologies or issues:

- *Lighting Design Practice* focuses on the design of high quality, energy-efficient lighting systems.
- *Computer-Aided Lighting Design* assists lighting designers in providing quality illumination at the task area without overlighting surrounding areas.
- *Luminaires and Lighting Systems* discusses advanced optical systems and efficient reflector materials and illustrates how different luminaire-lamp-ballast systems affect lighting power use and light output.
- *Energy-Efficient Fluorescent Ballasts* offer great potential for energy savings, have improved in quality in recent years, and have become cost effective.
- *Full-Size Fluorescent Lamps* that employ newer technologies are more efficient than standard lamps, especially when combined with electronic ballasts.
- *Compact Fluorescent Lamps* are versatile, have excellent color rendering capabilities, and, in many cases, are ideal replacements for inefficient incandescent lamps.
- *Tungsten-Halogen Lamps* have applications in retail stores and other building types where point sources of illumination and/or excellent color rendering is necessary.
- *Metal Halide and HPS Lamps* in many cases can be used in lieu of inefficient incandescent lamps, while having many other applications.
- *Daylighting and Lumen Maintenance Controls* can reduce electric lighting power consumption through lighting control technology and fenestration design.
- *Occupant Sensors* exploit passive infrared and ultrasonic "motion detector" technologies to automatically turn off lights in unoccupied areas.
- *Time Scheduling Systems*, from simple time switches to sophisticated energy management systems, can significantly reduce lighting operating hours.

- *Retrofit Control Technologies* are available to save energy in existing buildings.

These advanced technologies may be used in most types of buildings to reduce lighting energy consumption. Detailed information on these advanced lighting technologies can be found in other Advanced Lighting Technologies Application Guidelines.

Task-Ambient Lighting Design

Task-ambient lighting design is the practice of providing higher illuminance levels for the visual tasks, while keeping ambient lighting in the surrounding areas at lower levels. Areas surrounding visual tasks need less illuminance than the visual tasks themselves. Good design practice recommends that the "ambient" light in a space be no less than 33% of the task illuminance for comfort and ease of transient adaptation. For instance, if a visual task requires 750 lux (75 fc), the ambient lighting level should be at least 250 lux (25 fc).

Modern commercial lighting systems often require between 0.02 and 0.04 W/ft^2 per footcandle of illumination. In a typical office building, with 300 to 750 lux (30 to 75 fc) required for visual work, nearly half the space could be illuminated to 200 to 300 lux (20 to 30 fc) using a task-ambient design. This would theoretically save at least 0.6 W/ft^2 for nearly half the office work area.

There are two design methods that may be used to accurately employ task-ambient principles:

- Use point-by-point lighting analysis methods to assure appropriate task and ambient lighting levels (see *Computer-Aided Lighting Design* application guideline).
- Design the general or ambient lighting system using conventional design and analysis methods (lumen method or zonal cavity method). Then, provide task lights as needed that are known empirically to provide adequate illumination quantity and quality (see *Luminaires and Lighting Systems* application guideline).

Matching Electric Light Sources

Different electric light sources produce different colors of "white" (polychromatic) light. As part of quality lighting design, designers are responsible for specifying these subtle tints. Two metrics are used to specify lighting color and quality. *Correlated color temperature* (CCT) measures in degrees Kelvin (K) the chromaticity or color of a light source. CCT refers to the temperature of a black body radiator that would produce the same color light as the light source being rated. Incandescent lamps emit a yellowish light, having a low color temperature (2700-3100 K), while cool white fluorescent lamps are greener and bluer, with a higher CCT (4100 K). *Color Rendering Index* (CRI) is used to assess the degree of color shift that objects undergo when lighted by a light source as compared with the appearance of those same objects when lighted by a reference light source of the same color temperature. The same objects may exhibit entirely different color characteristics when viewed under light sources with different CRIs, even if the different sources have similar color temperatures.

The "Rare Earth 70" (RE-70) fluorescent lamp uses a thick coat of conventional halophosphor – such as that used for warm white or cool white lamps – plus a thin coat of expensive rare earth phosphors. The rare earth phosphors significantly improve color rendering for a reasonable increase in cost. These lamps can be used in almost every application and reduce concern

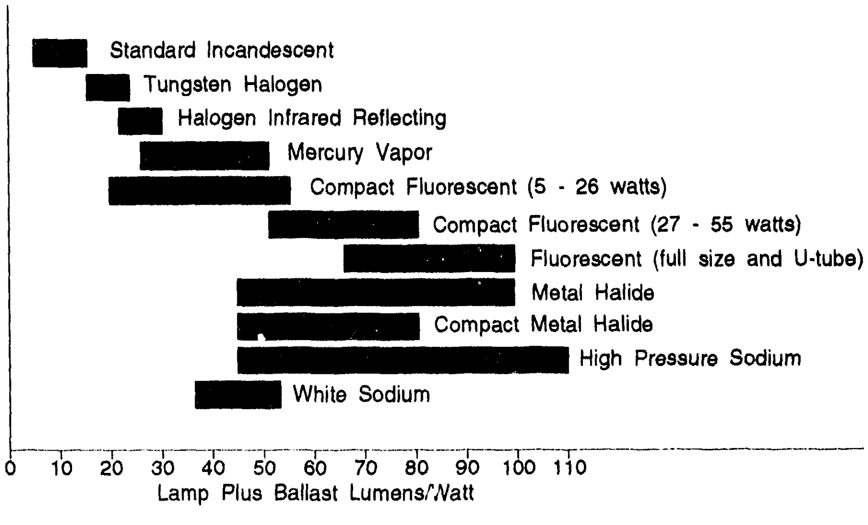


Figure 1-2
Efficacy of Various Light Sources

over the effects of fluorescent light sources on color.

An even higher color rendering fluorescent lamp is the "Rare Earth 80" (RE-80), previously referred to as the "thick coat triphosphor" lamp. The rare earth phosphor content in this lamp type is higher than it is in the thin coat RE-70 lamp. This increases the color rendering index significantly, but at a higher cost than that of the RE-70 lamp.

Several other lighting technologies offer good color rendering. Compact fluorescent lamps also employ rare earth phosphors. Improved color metal halide and high pressure sodium lamps are available, as well. Figure 1-3 shows the lamp color characteristics for a variety of electric light sources.

The wide variety of color temperatures and color rendering indices makes it possible to design interior spaces that flow easily from one light source to another. One approach is to match the CCT of all light sources in a space. However, very few exact matches are available; most are in the 3000 K range (tungsten-halogen).

A more common design strategy presents a smoothly flowing rendering of colors, where ambient light is warmer, and accent and task lighting is slightly whiter, clearer, and brighter. The effect is best when the difference between the sources is subtle; wide differences result in an unnatural appearance.

Lighting designers use three methods to match electric light sources as closely as possible:

- Matching the color temperature of all electric sources. The sources should either have approximately the same CCT within 300 K, or there should be a natural progression from lower ambient color temperatures to higher task color temperatures. However, overall differences in color temperatures should not be in excess of about 1000 K.
- Matching the CRI of sources. If color rendering and color temperature properties are reasonably similar, the coloration of room surfaces and objects will probably appear similar when seen under different light sources.
- Concealing small differences between adjacent light sources by using high-quality, well shielded luminaires, and by carefully preventing different sources from illuminating different parts of the same surface.

Choice of color temperature influences the mood of a space. The coloration of white light, combined with interior finishes can affect perception of thermal comfort. Warm lamps and earth tones can make the air temperature in a room seem one degree Centigrade (about 2° F) warmer than the same environment with cool lamps and cool colors.

The most common commercial environments are cool (4100 K), a direct result of the use of cool white fluorescent and cool-colored high intensity discharge (HID) lamps. Cool environments are recommended for active work task areas with lighting levels over 1000 lux (100 fc). Examples would include laboratories, assembly areas and some medical areas.

Warm color temperatures create the most desirable lighting environment for residences, restaurants, lounges and other "hospitality" spaces. These environments are created by incandescent-colored sources of about 3000 K and less.

Intermediate or neutral color temperatures (3500 K) combine some of the best qualities of both warm and cool lamps. The environments are warm and friendly, yet have a clarity and crispness not found in warmer environments. Energy efficiency can be achieved in intermediate colored environments. These environments are recommended for offices, schools, stores, hospitals and many other applications.

To take full advantage of the color possibilities, select light sources according to the type of application and the amount the client is willing to spend.

Assessing Lighting Equipment Performance Data

Energy and performance data on lighting components and systems must be critically reviewed. Information from manufacturers' catalogs, published research reports, or independent laboratory test reports is often based on different test conditions, preventing a direct comparison of results. Many times the test

Figure 1-3

Lamp Color Characteristics

Source	Color Temperature (CCT)	Color Rendering Index (CRI)
Incandescent and Tungsten Halogen		
Incandescent	2800 K	100
Light blue incandescent	4000 K	100
Daylight incandescent	5000 K	100
Tungsten-Halogen (T-H)	3100 K	100
T-H with light blue filter	4000 K	~100
T-H with blue filter	5000 K	~100
Fluorescent		
RE-830 Phosphor Coat	3000 K	80-89
RE-835 Phosphor Coat	3500 K	80-89
RE-841 Phosphor Coat	4100 K	80-89
RE-850 Phosphor Coat	5000 K	80-89
RE-730 Phosphor Coat	3000 K	70-79
RE-735 Phosphor Coat	3500 K	70-79
RE-741 Phosphor Coat	4100 K	70-79
RE-750 Phosphor Coat	5000 K	70-79
Incandescent	2700 K	92
Warm white deluxe	2800 K	77
Warm white	2900 K	53
White	3450 K	77
Natural	3450 K	55
Cool white deluxe	4100 K	87
Cool white	4100 K	62
Light white	4100 K	49
C/D 50	5000 K	91
Daylight	6500 K	56
High Intensity Discharge (HID)		
"Deluxe" high pressure sodium (70W)	2200 K	65
White high pressure sodium (95W)	2500 K	80
Standard metal halide (175W)	4200 K	65
Standard coated metal halide (175W)	3900 K	70
Standard clear metal halide (175W)	3100 K	65
Standard coated metal halide (175W)	3000 K	70
High CRI warm clear metal halide (150W)	3000 K	85
Standard high wattage MH (1000W)	3400 K	65
High CRI neutral clear metal halide (250W)	4100 K	85
High CRI daylight clear metal halide (250W)	5500 K	92
Compact metal halide (70W)	3000 K	81
Compact metal halide (250W)	5400 K	93
Coated mercury vapor "deluxe white" (250W)	4100 K	50

conditions can be selected that are favorable to a particular technology or system but are not representative of typical applications. This is prevalent with test data on fluorescent lamp systems whose performance is very sensitive to temperature. Often performance characteristics are provided only for the lamp and not for the luminaire-lamp-ballast system, although there are cases where a change in lamp, ballast, and/or luminaire type can alter the efficiency of the system by as much as 20% to 25%. Additionally, some claims of efficacy improvement by a device may simply be due to a change in the lamp bulb wall temperature that could be readily achieved by other means.

Good data will clearly specify the test conditions, the measuring equipment, and the test procedures, often by reference to a standard ANSI or IESNA test procedure. Test reports should provide all relevant information, not only the input power but the light output and other germane characteristics.

The National Lighting Product Information Program (NLPIP) was established in 1990 as a nonprofit, objective source of information on efficient lighting products. NLPIP, affiliated with the Lighting Research Center of Rensselaer Polytechnic Institute in Troy, NY, publishes lighting documents that enable lighting professionals to assess lighting equipment:

- *Guide to Performance Evaluation of Efficient Lighting Products* cross-references performance characteristics, testing methods, and standards for a variety of energy-efficient lighting equipment. The *Guide* also provides a glossary of lighting terms and a directory of lighting publications and organizations.
- *Specifier Reports* provide educational and performance-related information for specific lighting equipment. Each report addresses a separate lighting technology, such as electronic ballasts or compact fluorescent lamps.

For more information about the National Lighting Product Information Program, contact the Lighting Research Center at Rensselaer Polytechnic Institute, 115 Greene Building, Troy, NY 12180.

Physiological Aspects of Lighting

Lighting professionals must be aware of the relationships between lighting and human health, and they should be able to discuss these issues with end users. Effectively addressing the concerns – both legitimate and not – that people may express about lighting, is crucial to the lighting design process.

Video Display Terminals

Most computers use video display terminals (VDTs) for data display and interaction. A growing awareness of potential physiological problems associated with VDT computer work has called attention to lighting and possible vision-related problems.

Many problems experienced by people who work with computers are related to vision. Many people do not have their vision properly corrected for the VDT viewing distance. Regular eye examinations and the wearing of proper glasses or contact lenses are extremely important. No lighting or computer screen improvement can eliminate this problem.

Problems actually involving lighting and daylighting are primarily related to task visibility problems. The wrong lighting (or daylighting) can obscure the screen or cause various types of disability glare. For example, virtually all prismatic lens luminaires and many parabolic louvered luminaires reduce the visibility of the visual task in a large room VDT environment due to luminaire reflections in VDT screens. Reduced visibility can, in turn, contribute to physical and psychological stresses, fatigue, and reduced worker productivity.

The Illuminating Engineering Society of North America (IESNA) recently addressed the relationship between lighting design, lighting systems, and VDT work in its 1989 publication, *VDT Lighting: IES Recommended Practice for Offices Containing Computer Visual Display Terminals* (RP-24-1989). Some of the recommendations made by RP-24 are summarized as follows.

High Angle Light

Luminaires with high angle light cause objectionable reflections in VDT screens, especially in large, open offices, and should be avoided. For direct luminaires in large spaces (5 meters by 5 meters or larger), RP-24 recommends the following preferred luminance limits:

Viewing Angle (θ)	Preferred Maximum Luminance
≥55°	850 cd/m^2
≥65°	350 cd/m^2
≥75°	175 cd/m^2

Ceiling Luminance and Indirect Lighting

Some designers use indirect lighting luminaires in the VDT environment. However, indirect lighting does not necessarily guarantee the elimination of objectionable reflections in VDT screens. Ceiling luminance gains importance in the VDT environment when indirect lighting luminaires are employed. Luminance refers to the luminous intensity of a surface in a given direction per unit area (cd/m^2 or cd/ft^2) as viewed from that direction. When using indirect luminaires in large spaces with VDTs, RP-24 recommends the following in regard to ceiling luminance characteristics:

- Ceiling luminance ratio (ratio of brightest area to darkest) must be less than 10:1; the ideal luminance ratio will not exceed 4:1.
- Ceiling luminance should not exceed a level of 850 cd/m^2 at any angle (luminance to be averaged over a 0.6 by 0.6 meter area).

Illuminance Levels

RP-24 recommends that illuminance levels at the task should fall in the range of 200-500 lux (20-50 fc) in the VDT environment, corresponding to IES category D. Illuminance levels in many offices are much higher than this.

Other Lighting Design Issues

RP-24 offers other specific recommendations addressing lighting design in the VDT work place. Key points include:

- The advantages and disadvantages of direct, indirect, and direct-indirect lighting systems
- Using performance criteria to select luminaires
- The advantages of various task lighting systems
- How to control daylight in areas with VDT screens

RP-24 is highly recommended to anyone who applies lighting design to offices or other spaces with VDTs. The IESNA anticipates that as VDTs and work spaces change, RP-24 will be revised. Further research on the subject is currently being carried out by the Lighting Research Institute and Pennsylvania State University.

Radiation

Electromagnetic field (EMF) radiation has recently gained some attention as a possible cause of leukemia and other cancers. Lighting is one type of electromagnetic radiation, and some have suggested lighting may generate "dangerous" radiation.

Conventional 60 Hertz (Hz) fluorescent lighting lamps and ballasts can radiate EMF similar to that cited in the most publicized cases. The primary concern is the 60 Hz magnetic field, similar to that in most other electrical appliances. Because electric lighting is generally overhead and at a distance from people, it is significantly less of a concern than numerous other appliances, such as electric blankets and hair dryers, which are in close proximity to the user. Measurements at Lawrence Berkeley Laboratories (LBL) in 1985 showed that 60 Hz magnetic fields of electronic ballasts are significantly lower than those of magnetic ballasts.

Other forms of electromagnetic radiation (other than UV and X-rays) from electric lighting are generally low-level signals of ultrasound and radio frequency. The Federal Communications Commission limits certain emissions, particularly from electronic ballasts, and in general, electric lighting emits less radio frequency radiation than an ordinary personal computer.

Some compact fluorescent lamps contain a minute amount (~1 billionth of a Curie) of radioactive krypton or promethium. Even in the most improbable scenario, human exposure to this amount of radioactive material is harmless. To take an extreme example, if over an 8-hour period a person were to breathe the air in a small room in which all the radioactive krypton from a broken compact fluorescent was evenly distributed, he or she would be exposed to approximately 100 nrems of radiation. This amount of exposure is approximately a thousand times less than the background radiation to which we all are exposed each day. (Source: "State of the Art: Lighting," Competitek, 1988)

Photobiology

Photobiology is the field of science relating life and light. There is no doubt that light affects human life and health. The question remains, however, as to how and to what extent. Since 1965, American culture has encouraged the reexamination of many pre-existing assumptions about our environment. The ecological and environmental movements were directly related to this shifting of focus. Lighting, as well as many other facets of our lives, has been questioned. The current beliefs regarding lighting and health are summarized below.

Full Spectrum Light

Daylight provides a complete spectrum of visible and invisible light. The visible portion is white light, consisting of all of the colors of the rainbow. The invisible portions include infrared light (radiant heat) and ultraviolet (UV) light. "Full spectrum" type electric lamps, which simulate the daylight spectrum, are also available. These lamps are sometimes advertised as providing "natural" or "healthy" light.

Most electric lights produce whitish-colored light. For persons leading normal lives with daily exposure to natural daylight, the importance of daylight-matching electric lights is minimal. However, extreme living and/or working situations, such as inside submarines or deep mines, may suggest the use of daylight-simulating electric light.

Daylight also includes UV light. UV radiation is split into three categories according to wavelength. UV-A light (long wave UV between 320 and 380 nanometers), often referred to as "black light," is generally thought to have minimal effect on human health, but can be used to create interesting visual effects by causing certain materials to phosphoresce. UV-B (medium wavelength between 280 and 320 nanometers) causes sunburn and skin cancer (with chronic exposure), and can damage the interior of the eye. UV-B is largely filtered out by the earth's atmosphere. UV-C (short wave UV below 280 nanometers) is dangerous to people, but is useful in killing bacteria. It is almost entirely filtered out by the ozone in the upper atmosphere.

Research suggests that the human body uses a small amount of UV light to produce vitamin D. As such, full spectrum type lamps, which radiate UV in similar proportions to noon sunlight, can be used in applications where humans are totally deprived of natural light. However, except for these "clinical" applications, UV-radiating electric lamps are probably unnecessary. In some cases, they should be avoided, as UV radiation can cause eye damage.

Light, Cancer, and AIDS

Several research teams have tried to link electric lights with cancer, and to use full-spectrum light to treat cancer and AIDS. Nevertheless, at this time, none of this research has suggested any relationship between electric light and cancer, nor has it constructed a successful electric-light-based therapy for AIDS.

Seasonal Affective Disorder

Electric light has been used successfully to treat Seasonal Affective Disorder (SAD), also known as "winter depression." Winter depression is caused by the short daylight cycle of polar climates. By introducing bright light in the early morning hours, the body is stimulated into releasing enzymes and hormones that counteract the depression. Research shows that ordinary fluorescent lighting can be used in this therapy.

Flickering Light

Flickering light can cause physiological problems, as any person who has experienced a strobe light-induced headache can attest. Fluorescent and HID lamps on magnetic ballasts flicker at 120 Hz in the United States (100 Hz in Europe and southeast Asia). This rate is much faster than most strobe lights, and the flicker percentage of strobe lights is much greater. Nonetheless, flickering light sources can cause problems. In extreme cases, headaches and dizziness have been reported, primarily involving HID lamps on a single AC power phase and in the same room. Flicker in a workplace with moving machinery or other equipment may cause an unsafe situation. Less dramatic problems are office fatigue and headache from some types of fluorescent lamps and ballasts. Both of these situations can be prevented through proper design techniques (electronic ballasts in particular).

Plant Lights

Plants require light as a primary nutrient. In general, plants require daily periods of light; the amount varies from plant to plant. Natural daylight, fluorescent grow-lights, and metal halide lamps are the best sources for most common plant growth lighting.

Hazardous and Toxic Waste Disposal

Electric lighting is generally clean and safe. There are only a few special considerations for electric lighting in the environment. Most of these considerations center around the disposal of fluorescent lamps, HID lamps, and older ballasts containing PCBs. The need for disposal of these materials has increased as a result of upgrading lighting systems with new, more energy-efficient lamps and ballasts

Under California law, the disposal of certain ballasts and fluorescent lamps is regulated by the Department of Environmental Protection (formerly the Department of Health Services). On a national level, the Environmental Protection Agency's Green Lights program currently is formulating methods to assess the disposal of fluorescent lamps and ballasts. However, as of January 1992, the EPA had no specific regulations on the disposal of lamps or non-leaking ballasts.

Ballast Disposal

Polychlorinated Biphenyls (PCBs) were used in electric ballasts until 1979. The best way to identify those ballasts which contain PCBs is to call the manufacturer with the ballast make and model number. Older ballasts should be replaced as soon as possible to prevent burnout or other failure causing the release of PCBs into the environment. Any leaking ballast should be disposed of immediately in an environmentally responsible manner.

Regulations regarding the disposal of PCB ballasts vary on a regional, state, and local level. The best source for up to date information is the state Environmental Department or regional EPA office. The EPA also runs a hotline for information about ballast disposal: (202) 554-1404. In California, contact the Department of Environmental Protection, listed in the white pages of the phone book. PCB ballasts should be disposed of only by companies licensed to dispose of electric PCB equipment.

Fluorescent and HID Lamp Disposal

A small amount of mercury is used in the manufacture and operation of fluorescent and high intensity discharge (HID) lamps. Older fluorescent lamps may also contain cadmium. The presence of these potentially hazardous metals in many lamps has generated a lot of discussion in regard to lamp disposal. While the EPA currently has no restrictions regarding the disposal of these lamps, this is expected to change. In California, restrictions are placed on the quantity of lamps containing mercury that may be disposed of at one time. Currently, the limit is 25 lamps per day. Used lamps containing mercury or cadmium may be disposed of through a company licensed to dispose of fluorescent lamps or mercury products. Some companies now reclaim certain components in fluorescent lamps.

Sodium is commonly used in many HID lamps. Sodium is reactive with water, and the disposal of low pressure sodium lamps may create a hazard (the sodium in high pressure sodium lamps is in the form of a sodium/mercury compound and does not react with water). Sodium lamps should be disposed of through operators familiar with sodium product disposal.

For further information on California regulations regarding the use and disposal of products containing potentially hazardous materials, contact the Department of Environmental Protection; elsewhere, contact your regional EPA office, or the EPA Toxic Substances Control Act hotline at (202) 554-1404.

Obtaining Quality Lighting Design, Consulting Services, and Information

When a new building, addition, or improvement begins, the owner or developer often considers lighting to be a necessary but small portion of the project. Traditionally, architects and engineers have provided lighting design as a part of their normal work.

Major changes in the construction industry in the last two decades have introduced other principal sources of technical and design information and decision making. These include the design-build contractor, the energy service contractor, and the building maintenance contractor. Both provide design services for all types of projects, and many use energy conservation as a sales and marketing tool. Design-build contractors are popular because of reduced cost and turn-key services. Building maintenance contractors have grown due to the on-going need for intelligent lighting maintenance by persons trained to seek out energy-saving opportunities.

The best sources of quality lighting design, consulting, and information are those who are able to combine energy efficiency with lighting quality. This requires lighting practitioners to be knowledgeable about advanced lighting technologies and techniques.

Lighting Education and Certification

In 1986, the California Energy Commission reported to the State Legislature that advanced lighting technology and technique were available but were not being implemented. If fully employed, advanced lighting would dramatically improve the energy efficiency and effectiveness of lighting systems. In response, the Legislature directed the Commission to investigate and determine the barriers to advanced lighting application, and to take actions to remove those barriers.

Advanced Lighting Professional Advisory Committee

In 1987, the Commission formed the Advanced Lighting Professional Advisory Committee (ALPAC) to advise the Commission on means to achieve greater energy efficiency through the use of more efficient lighting. ALPAC members are selected volunteers from the community, and include architects, engineers, lighting designers, manufacturers, utility personnel, professional and technical societies, trade organizations, consumer and environmental advocates, and representatives of the public at large. ALPAC meetings are open to the public and occur quarterly at locations around the State of California.

ALPAC immediately identified the need for lighting education as the key to advancing lighting technology and technique. Recognizing a lack of concise, readily available *reference documents*, ALPAC recommended the development of the *Advanced Lighting Guidelines.* The first edition was developed through a consensus process and was published in 1990. The 1990 Guidelines have received several awards and are nationally recognized as important documents. These updated Guidelines were developed during 1991 and 1992 under funding from the California Energy Commission, the Electric Power Research Institute (EPRI) and the U.S. Department of Energy (DOE).

ALPAC's second major action was to recognize the need for *formal lighting education* in California. ALPAC submitted a position paper to the Legislature calling for a three-tier education program:

- Tier 1: Directed at non-technical decision makers, such as developers, building owners, and managers, as well as others who make economic decisions affecting lighting.
- Tier 2: Educational lighting programs for technical practitioners who frequently make decisions involving lighting design and application.
- Tier 3: Programs for innovators, educators, and researchers in the lighting field.

Educational lighting programs currently exist on an informal basis conducted by individual instructors and organizations. The position paper recommended to the Legislature that the state fund the development of more formal educational programs through the California State College and University systems. Formal programs are now being developed at California Polytechnic University, Pomona, California.

- Tier 1 programs are now being offered around the state, generally in association with professional organizations such as the Illuminating Engineering Society of North America (IESNA), Building Owners and Managers Association (BOMA), Association of Energy Engineers (AEE), and/or Association of Professional Energy Managers (APEM).
- Tier 2 programs are being developed throughout the state as part of the Community Colleges curriculum. Some courses are now being offered.
- Tier 3 curriculum is now in development, and is scheduled to be offered as a special program at California Polytechnic University, Pomona, California.

ALPAC's third major action was to recognize the need for *certification* of lighting professionals. Those who make lighting application decisions are called "lighting practitioners." The ALPAC realized that the public would be best protected if some means of certification and/or licensing were required for qualified lighting practitioners who are capable of applying the advanced technologies and techniques explained in these *Advanced Lighting Guidelines* and taught in the education programs listed above.

To stress the need for lighting certification, the ALPAC recommended that the State begin development of a certification and licensing program based on the Tier 2 curriculum. Because of concurrent national programs, the state is proceeding cautiously. However, ALPAC currently is assessing plans to put an examination-based, certification and/or licensing program in place within the next few years.

For more information on ALPAC or the state-sponsored education programs, contact the Buildings and Appliance Efficiency Office of the California Energy Commission.

Illuminating Engineering Society of North America

The Illuminating Engineering Society of North America (IESNA) is an independent technical society to which most lighting scientists, manufacturers, educators, and designers belong. The IESNA's charter requires it to be a resource for lighting information and education. It is accredited by the American National Standards Institute (ANSI) to develop national standards.

The IESNA develops and publishes illumination recommendations for the quantity and quality of both interior and exterior illumination design. These recommendations are created by a consensus of committees representing all parts of the lighting and construction industry. IESNA recommendations often become American National Standards when they are approved by ANSI.

In general, the single most complete source of IESNA recommendations is the *IES Lighting Handbook*. The Handbook is republished periodically as technologies and recommendations change, so be certain to use a recent version. *Recommended Practices* are shorter IESNA documents that provide recommendations specific to a type of building or project. Certain Recommended Practices, such as RP-3-88 – Educational Facilities Lighting – are also ANSI-approved.

The IESNA has local sections across the country. For further information, contact IESNA Headquarters, 345 East 47th Street, New York, NY 10017-2377; (212) 705-7926. These sections hold technical meetings and teach classes in lighting. The sections in California include:

- San Diego Section
- Orange Section (Orange County)
- Los Angeles Section (Southern California)
- Golden Gate Section (San Francisco)
- Mother Lode Section (Sacramento)
- Mission Section (Santa Barbara)
- Arrowhead Section (San Bernardino)

Lighting Specialists

With the rapid changes in design practice and equipment, the role of lighting design specialists and illuminating engineers is increasing. These specialists are highly skilled and knowledgeable about advanced lighting technologies and their applications. Some may be graduates of college programs in illuminating engineering, usually within a college of architecture or architectural engineering. Others are design professionals, such as architects, engineers, or interior designers, who choose to concentrate their practice in the field of illumination.

These lighting specialists operate in four principal roles:

- Lighting consultants in private practice
- Lighting specialists in manufacturing and sales
- Utility lighting consultants and engineers
- Lighting specialists in maintenance, operations, and Demand-Side Management (DSM)

Lighting Consultants in Private Practice

Lighting professionals who work in private practice generally advertise as "lighting consultants" or "lighting designers." Some belong to the International Association of Lighting Designers (IALD), a professional society based in New York City. IALD members must submit design work for critical review to join the organization and must adhere to a code of professional ethics. IALD members are prohibited from selling lighting products or from having any other conflict of interest. Although most IALD members work in lighting design consulting firms, some IALD members are employed by architectural or engineering consulting firms.

Lighting specialists may also be registered Professional Engineers (PE) or registered architects (American Institute of Architects [AIA] members are all registered architects). If engaged in private practice, engineers and architects are also required to provide ethical advice that is free of conflicts of interest.

Lighting specialists working in an energy-oriented capacity may also be members of energy-focused groups like the Association of Professional Energy Managers (APEM) and the Association of Energy Engineers (AEE). Neither of these groups limit member's conflicts of interest. The AEE offers a program of certification through examination. Qualified individuals are recognized as "Certified Lighting Efficiency Professionals."

Lighting Specialists in Manufacturing and Sales

Many lighting specialists are employed by lighting fixture manufacturers as manufacturers' representatives or as distributors and sales people. In these cases, a design or consulting fee is seldom charged. The cost of any design service is usually included in the cost of the product being sold.

Most lighting specialists in manufacturing and sales provide quality information regarding the products they sell or represent. These specialists often offer valuable technical support, which can be used by lighting designers, architects and engineers in making final, independent evaluations. This support can be particularly valuable in cases when lighting specialists are not directly involved in the project. However, few manufacturers' representatives will provide unbiased comparisons among design or equipment alternatives, so it may be wise to solicit information from more than one source.

There are no professional or technical certificates or memberships to help identify lighting specialists working in sales; however, many are professionally qualified.

Lighting Specialists in Utilities

Most utilities have lighting specialists on staff and/or can provide referrals to local lighting professionals who are qualified to make recommendations for improving the energy efficiency of lighting systems.

Lighting Specialists in Energy Management, Operations, and Demand-Side Management Companies

The importance of the energy conservation and retrofit industries is growing rapidly. In addition to the programs of the California Energy Commission and the California utilities, significant federal programs, such as the EPA's "Green Lights" program, and the Department of Energy's "Federal Energy Management Program (FEMP)," call for the refitting of millions of square feet of buildings in the next decade. A large portion of the conservation opportunity is in lighting.

Lighting specialists, particularly in the area of energy efficiency, are found among the engineers and contractors engaged in lighting management companies and energy service companies (ESCOs). These companies vary from sales-oriented organizations with vested interest in proprietary products, to independent contractors, capable of designing and/or supplying lighting products. Lighting management companies focus primarily on improving the efficiency of existing lighting systems, while ESCOs work on improving other building systems, such as HVAC, as well.

Lighting Management Contractors

In many commercial buildings, lighting management personnel are contracted to periodically clean, relamp, and otherwise maintain the building's lighting systems. Lighting management specialists are trained to recognize energy conservation opportunities in the course of their work, and to properly implement retrofits. Often, this is a cost-effective strategy for the customer, since the contractor is already on the site and familiar with the building, its lighting systems, and its operation.

Lighting management specialists often belong to the interNational Association of Lighting Management Contractors (NALMCO), and members who pass an examination on principles of lighting and energy efficiency are awarded Certified Lighting Management Consultant (CLMC) status by NALMCO.

Energy Service Companies

Some ESCOs have the ability to provide lighting design or retrofit services. Additionally, ESCOs can finance lighting retrofits (or in some cases, new lighting systems). Building owners without access to capital can obtain financing through an ESCO. ESCO financial personnel are well-equipped to assess the investment quality of energy-efficiency projects. They either have lending institutions prepared to capitalize efficiency projects, or shared savings arrangements. In the shared arrangement, a building owner pays an equivalent "electric bill" to the ESCO. For its part, the ESCO implements improvements to the building at its own cost while amortizing the investment through the energy savings.

When a Lighting Specialist is Required

The number of projects requiring the services of lighting specialists is increasing. Projects in which the following situations occur are likely to require this type of service:

- Visually demanding tasks or a wide variety of different tasks
- Significant daylighting potential
- Opportunities for extremely high efficiency and unusually low energy consumption in lighting
- High-quality new projects and restorations

- Projects that will be owned and maintained for a number of years

A lighting specialist should improve both the energy efficiency and the aesthetic and functional quality of building designs through knowledge and experience in the use of advanced lighting technologies. Even simple projects, such as tenant improvements or small retail stores, can benefit through the wise use of advanced technologies.

The primary decision is whether or not to obtain the services of an independent lighting designer or consultant, since fees paid to a professional consultant add to the cost burden of the design. It is probably best to retain an independent, professional lighting designer if any of the following apply to the project:

- A significant potential exists for energy savings (see figure 1-4)
- A variety of different lighting systems are required to meet a variety of different tasks or needs
- Comparative analyses are necessary to select among different lighting systems and/or different manufacturers
- The project has substantial aesthetic or creative goals, or inventive or complex lighting systems
- The project design requires using specific products not necessarily sold or represented by the same manufacturer or agent

Figure 1-4

Hiring a Lighting Professional Can Save You Money

The lighting system in an office space with 15,000 watts of connected lighting load will cost between $3000 and $6000 per year to operate. A lighting designer can significantly reduce energy costs through the implementation of efficient lighting strategies, often with little or no additional equipment cost. The extra cost of hiring a lighting professional, in this case, can be recouped in a very short period of time.

The more economical approach of obtaining advice from a manufacturer's sales representative can be effectively used in a number of situations. These include:

- Comparative analyses of luminaire-lamp-ballast systems, especially once a preferred lighting system has been selected
- Assistance in assessing specific advanced lighting technologies
- Providing computer analyses and other advanced design assistance
- Economic and life-cycle cost analyses of various systems and combinations

How to Choose a Lighting Specialist

The process of selecting a lighting specialist is similar to the selection of any professional. Once a list of candidates has been identified, the following factors should be considered:

- Energy efficiency of previous projects and experience in application of alternative technologies
- Familiarity with the California's Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)
- References from other clients or customers
- Previous work with similar lighting design projects
- In-house expertise and/or personnel appropriate for the size of the project
- Reputation in the lighting design field
- Aesthetic quality of previous lighting design projects

When possible, visits should be made to previous projects, since lighting quality can best be assessed by experiencing the space first hand. It is difficult to assess lighting quality through photographs or other printed material.

Sections of the IESNA often provide technical presentations on lighting design achievements in the local area. Participation in these activities affords an excellent opportunity to evaluate options and identify skilled designers. Independent lighting consultants can generally be found in the Yellow Pages under "Lighting Consultants."

A list of IALD members for your area can be obtained from the International Association of Lighting Designers (IALD), 18 East 16th Street, New York, NY, 10003-3193, (212) 206-1281.

The Consulting Engineers Association of California can provide a list of its members who practice lighting design. Contact them at Park Executive Building, 925 L Street, Suite 870, Sacramento, CA, 95814, (916) 442-2322.

The American Consulting Engineers Council can provide a list of members for other areas of the country: 1015 15th Street N.W., Suite 802, Washington, DC. 20005, (202) 347-7474.

Lighting sales personnel can be found in the Yellow Pages under "Lighting – Sales." A company making a product of interest can be contacted directly to obtain the name of a local representative.

Lighting management contractors can be reached through NALMCO: 14 Washington Rd. Building 5, Princeton Junction, NJ 08550, (609) 799-4900. Local companies are often listed in the Yellow Pages under "Lighting Maintenance."

Demand-Side Management companies, especially ESCOs, can be found through most of the foregoing means. In addition, the Demand-Side Management Society, at (703) 759-5060, can supply lists of members.

Computer-Aided Lighting Design

Introduction

One of the primary goals of a lighting system is to enable people to perform tasks. Some examples of visual tasks include:

- Reading text on a video display terminal screen
- Reading the fine print on a legal document
- Reading the calibration numbers on a lathe
- Observing the level of a liquid in a chemistry beaker

The object being observed is referred to as a "target." The amount of light needed for an individual to perform a visual task depends on a number of factors, including:

- The contrast, color, and reflectance characteristics of the target
- The size of the target
- The angle of viewing the target
- The orientation and light distribution of the lighting system with respect to the target
- The age of the viewer and the state of his/her visual system
- The importance of speed and accuracy in performing the visual task
- The location and luminances of the surrounding room surfaces and room furniture
- The adaptation level of the eye
- The polarization of the light
- The color spectrum of the light source
- Several other physiological and physical factors

Contents

Lighting Calculations

Calculations can be performed to assure that adequate illuminance is provided at the task. Calculations can also help predict light patterns in a room or help predict visual performance. Interior lighting calculations take into account not only the design of the lighting system, but also room geometry and finishes. Exterior lighting calculations are generally simpler, since there are no walls or ceilings to reflect light.

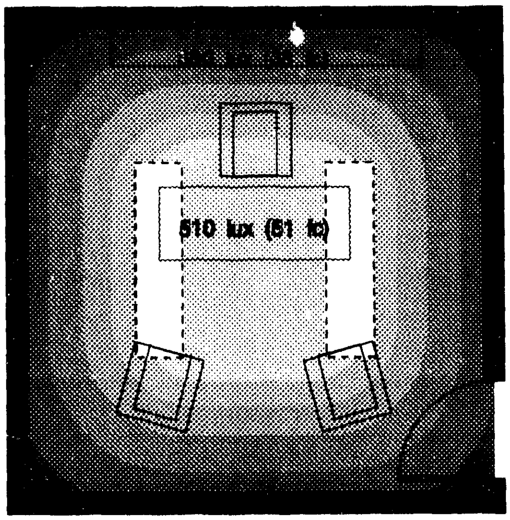
Lighting calculations may be performed at four levels of precision:

- *The Lumen Method*, also known as Zonal Cavity calculation, is a quick and simple technique for predicting the average illuminance level in a room. The major drawbacks of the lumen method are that it does not determine the range of light intensity in a room, nor where differences in light intensity levels occur, and it cannot provide information about lighting quality, visual performance, or lighting patterns in the room. This

Figure 2-1

Comparison of Lumen Method and Point Calculations

IESNA recommendations for a Type "D" visual task are 200-500 lux (20-50 footcandles), and for a Type "E" visual task, 500-1000 lux (50 to 100 footcandles). If both of these tasks are performed in the same space, a reasonable design illuminance is 500 lux (50 footcandles) at the work plane. The figure below represents a gray scale plot of a point-by-point calculation for a typical 10 x 10 office with two recessed fluorescent troffer luminaires. The room cavity ratio is 6.8, ceiling/wall/floor reflectances are 80/50/20 and the light loss factor (LLF) is 0.75 . The gray scale plot shown is for two T-8 lamps per luminaire with electronic ballasts. This design operates at about 1.15 W/ft^2, not including controls credits. Using a task-ambient design the point-by-point calculations show the desk surface has 45 to 52 footcandles and the credenza has 30 to 40 footcandles. This method provides adequate illumination for the office. Had the lumen method been used to achieve a 50 footcandle average, it would have required using two 2'x 4' fixtures with three T-8 lamps each. This would increase the lighting power density to 1.72 W/ft^2, or a 50% increase in energy use. Overall, more detailed calculation methods, such as point-by-point programs, allow illuminance targets to be met with less energy consumption.



method is inaccurate for non-uniform lighting systems.

- *Computer-Generated "Point" Calculations* determine light levels at specific locations in a space. They can predict the brightness of room surfaces and give the patterns of light on the ceiling, walls, and floor. Some programs, such as Relative Visual Performance (RVP) and Equivalent Sphere Illumination (ESI) can also calculate metrics of lighting quality and visual performance. Others can address glare issues through calculation of Visual Comfort Probability (VCP).
- *Graphically-Enhanced Point Calculations* go beyond the capabilities of standard "Point" calculation programs by providing graphic presentation of the results. These may include gray-scale plots and isolux (isofootcandle) plots for either interior or exterior lighting, and three dimensional synthetic photographs of an interior space with its lighting system.
- *Advanced "Ray-Tracing" Calculations* are capable of extreme accuracy and use "synthetic photography" for realistic depictions of interior and exterior lighting, including daylight.

See Figure 2-1 for a comparison of lumen method and point calculations.

Approaches to Lighting Design

Lighting design strategy will often determine the appropriate type of lighting calculation. Two approaches are discussed here: general lighting approaches and task-ambient lighting approaches.

General Lighting

The general lighting design approach is a common strategy used to provide a fairly uniform amount of light throughout a room. If the task location in a room is likely to vary widely, or if the space is likely to be frequently reconfigured to accommodate changes in work groups (such as a company that will be adding staff and moving work stations around a couple of times per year), then it may be advisable to design for task levels of illuminance everywhere in the room.

The general lighting system is usually a regular pattern of light fixtures that produces very even light levels, slightly higher than the average value in the center of the room, and slightly lower in the outer corners of the room. Lumen method calculations, such as the example shown in Figure 2-2 are appropriate for the design of general lighting systems.

Task-Ambient Lighting Design

Task-ambient lighting refers to designs in which a general uniform lighting system is supplemented with local task luminaires. Task-ambient design approaches save energy when compared with most general lighting strategies, because higher light levels are provided for the task areas only. For example, in a task-ambient design, lighting fixtures might be concentrated primarily over work areas, while an indirect lighting system provides relatively low levels of general (ambient) illuminance. Thus, when compared to a more traditional design, which might rely on a uniform layout of direct lighting luminaires, the average light level for the room may be lower, and the number of required light fixtures may be reduced. This design strategy usually requires point calculations to insure that luminaires are correctly located to produce the lighting level and quality necessary for performing visual tasks at the needed locations.

General lighting is still the most widely practiced lighting design approach, due to the perception that task-ambient lighting equipment is more expensive, the assumption that point calculations are expensive and difficult to perform, and the belief that task-ambient strategies create an inflexible interior space. However, task-ambient systems are becoming more attractive with the development of new lighting equipment and easy-to-use point calculation computer programs, and with rising electrical energy costs.

The skilled application of computerized point lighting calculations can optimize lighting levels in both the task and ambient domains in order to minimize energy consumption. The lighting professional should consider the use of point lighting calculations, both to design more energy-efficient spaces, and to create spaces with more drama and visual interest.

Lighting Calculations

Interior Lighting Calculations

A wide variety of computer programs are available to perform interior lighting calculations. Some programs are very simple, while others are extremely sophisticated products that can interface with computer-aided design (CAD) programs.

Lumen Method Programs

Lumen method calculation programs have simple input requirements:

- Physical characteristics of the room, including length, width, and height
- Ceiling, wall, and floor reflectances (% of light reflected by the room surfaces)
- Work plane height (i.e. desk height or height above the floor at which the visual work is to be performed)
- Distance from the work plane to the luminaires
- Coefficient of utilization (CU) for the luminaire: the percentage of initial lamp lumens that are delivered to the work plane. This value depends on the design of the luminaire and the characteristics of the space where the luminaire is located (see above bullets).
- Number of lamps per luminaire and initial lumen output of each lamp
- Light Loss Factors (LLFs): multipliers that account for the degradation of rated initial lamp lumens. Light loss factors may be either recoverable due to maintenance of the lighting system and room, or nonrecoverable and constant. Light loss factors include dirt accumulation on luminaires and room surfaces, lamp depreciation, ballast factors, and thermal application effects. The overall LLF ranges from 0.65 to 0.85 for ballasted lighting systems, and from 0.75 to 0.95 for most incandescent systems.

The lumen method can be used to calculate the average illuminance incident on the work plane once the lighting system has been designed. Alternatively, the method may be used to calculate the number of luminaires required to produce a desired light level (see Figure 2-2 for an example of lumen method calculations). While the method is most commonly used with direct lighting systems, it can also be used with indirect and direct-indirect lighting systems.

While the method easily lends itself to hand calculations, lumen method computer programs are available that vary widely in capabilities and cost. Some will incorporate manufacturers' data so that it is not necessary to look up the CU for each case. Some programs combine the lumen method calculation with an Economic Analysis program. Other programs work in

Figure 2-2

Using the Lumen Method

The lumen method is easy to use without a computer. A simple equation gives the average illuminance in a room based on the number of luminaires, the total lamp lumens for each luminaire, the coefficient of utilization (CU,) and the light loss factor (LLF):

$$\text{Average Illuminance} = \frac{\text{Number of Luminaires x Lumens per Luminaires x CU x LLF}}{\text{Area}}$$

If the illuminance and luminaire types are known, the equation may be used to calculate the quantity of luminaires required to achieve the specified lighting level. This form of the equation is shown below.

$$\text{Number of Luminaires} = \frac{\text{Illuminance x Area}}{\text{Lumens per Luminaire x CU x LLF}}$$

The number of luminaires, the design illuminance, and the room area are all design factors. The lumens per luminaire is calculated by multiplying the rated lumens per lamp times the number of lamps per luminaires. For instance, if a design uses three lamp troffers and F32T8 lamps, each with initial lamp lumens of 2900, the lumens per luminaire is 3 x 2900 or 8700 lumens.

The coefficient of utilization (CU) is the fraction of light produced by the lamps that makes it to the work plane. CU tables are provided by luminaire manufacturers; CU tables for standard luminaires are also provided in several IES documents. The CU for a luminaire in a particular application depends on the room cavity ratio (RCR). The RCR is a metric that deals with room size and shape. Small cramped rooms have high RCRs and the associated CUs are lower, while large open spaces have low RCRs and higher CUs. The RCR of rectangular rooms can be calculated using the following equation where "W" is the room width, "L" is the room length and "h" is the room cavity height (the distance from the work plane to the luminaires).

$$RCR = 5 \times h \times \frac{W + L}{W \times L}$$

The CU for the luminaire under consideration is then determined by applying the RCR along with the assumed reflectance of the ceiling cavity (ρ_{CC}) and the reflectance of the walls (ρ_W). to the luminaire manufacturer's CU chart. (The reflectance of the floor is usually assumed to be 20%.) A sample of a CU table is shown above.

The RCR for a 15 x 20 room with a 9.5 foot ceiling height (h = 7) is
5 x 7 x(15+20)/(15x20) = 4.1. If the ceiling reflectance is 80 % and the wall reflectance is 50%, then the CU selected from the above table is 0.51.

The light loss factor accounts for the ballast factor, thermal factors, dirt depreciation, lamp aging, and other factors that will reduce lamp output. The LLF is multiplied times the value for initial lamp lumens to adjust for these factors . The following values are typical LLFs: 0.80 for open down lights or louvered troffers, 0.75 for lensed down lights, and 0.70 for enclosed, lensed troffers.

If the space in this example has four luminaires with three lamps each (8700 initial lumens), a CU of 0.51 (see above), and a LLF of 0.70, then the average illuminance level (in footcandles) can be calculated as shown below:

$$\text{Average Illuminance} = \frac{4 \times 8700 \times 0.51 \times 0.70}{15 \times 20} = 41.4 \text{ footcandles}$$

	ρcc = 0.80			ρcc = 0.70		
RCR	ρW = 50	ρW = 30	ρW = 10	ρW = 50	ρW = 30	ρW = 10
0	0.78	0.78	0.78	0.76	0.76	0.76
1	0.71	0.68	0.66	0.69	0.67	0.65
2	0.63	0.60	0.57	0.62	0.59	0.56
3	0.57	0.52	0.49	0.56	0.52	0.48
4	0.51	0.46	0.43	0.50	0.46	0.42
5	0.46	0.41	0.37	0.46	0.41	0.37
6	0.42	0.37	0.33	0.41	0.37	0.33
7	0.38	0.33	0.29	0.38	0.33	0.29
8	0.35	0.30	0.26	0.36	0.30	0.26

conjunction with CAD programs, allowing the graphical input of room data or the importing of previously generated building plans. Many of the CAD-integrated programs also enable luminaire layout, as well as the generation of fixture schedules. Still others can keep track of lighting and control loads, luminaire costs, and utility rebates.

Lumen method software can operate on very basic computers, including hand-held calculators. The most common programs operate on MS-DOS computers with a minimum of two-floppy disk drives. Lumen method calculations and Life-Cycle Cost calculations can also be implemented with popular spreadsheet programs. Programs range in cost between $30 and $800, depending on features and capabilities.

Standard Point Calculation Programs

Point calculation computer programs are far more precise in their calculation abilities, and thus require more detailed input, including:

- Room dimensions, work plane height, and luminaire suspension length (for pendant mounted luminaires)
- Room surface reflectances, including "inserts" -- portions of room surfaces that may have different reflectances
- Detailed luminaire photometric data in IES format, or hand-entry of candlepower distribution values
- Precise location and orientation of luminaires using x, y, z coordinates, or using an interface with CAD programs
- Light loss factors and any other multiplying factors to adjust the lamp and ballast output from the assumptions used in the luminaire photometry

Point calculation programs calculate the lighting effects caused by specific luminaires in specific rooms. They cannot choose an appropriate lighting system given the designer's requirements. Most programs can only analyze an empty, rectangular space lighted with electric lights and will provide the following output:

- Illuminance (lux or footcandles) on a horizontal work plane at selected points in the room, as well as summary statistics such as average, maximum, minimum, and standard deviation of illuminance values
- Room surface luminances (candelas per unit surface area) or exitances (lumens per unit surface area). These results are based on the assumption that room surfaces have a matte, not shiny, finish.
- Lighting power density (watts/m^2 or watts/ft^2)

Point calculation programs may also have some or all of the following capabilities:

- Daylighting analysis. Calculated illuminance values and light patterns include daylight contributions through windows and skylights as well as contributions from the electric lighting system. Consideration of daylighting generally requires that outdoor illumination conditions be specified along with details about the orientation and transmission characteristics of the building's fenestration.
- Partition analysis. The effect of interior partitions or other light-blocking objects in the room is considered.
- Task visibility metrics. These may include ESI and/or RVP. These calculations are made for exact locations and viewing directions in the room, which must be specified. The characteristics of the visual task must also be accurately defined. In some cases, statistical comparisons of ESI or RVP (assuming common tasks and viewing angles) throughout a room for competing lighting systems may be used to select a system based in part on visual performance criteria.
- Visual comfort metrics. VCP is the principal comfort metric. This is calculated for a specific location in the room and for a specific viewing direction. It represents the probability (expressed as a percent) that a lighting system will not cause visual discomfort.

Output from these programs is usually a chart of calculated values, an isolux (isofootcandle) plot, or a shaded plan with gray scales representing a range of light levels. All programs print results, and some will display the results directly on the screen. A few advanced programs offer three-dimensional, black-and-white or color shaded perspective views of the room showing light patterns produced on the room surfaces by the lighting system.

Point calculation software requires greater computing power than lumen method software; exact requirements vary with the capabilities and design of a specific program. The run time for point calculations can range between several seconds to several hours. Many programs will run in batch mode, so that several sets of input data can be stacked up and run without the operator in attendance (perhaps overnight). The calculation time for point calculation programs depends on the software and hardware used, the size of the room being analyzed, the number of fixtures in the room, and the number of points at which illuminance and lighting quality metrics are evaluated.

Programs for general use will range in cost between $400 and $1500, depending on features and capabilities. Some manufacturers offer software for a nominal price (less than $100), but these programs are generally limited to the evaluation of a single manufacturer's product line.

Interior Lighting Renderings

Rendering interior spaces with perspective drawings is a common task performed by architects and interior designers. The most difficult aspect of interior rendering is the accurate representation of lighting effects on room surfaces. Most hand-drawn renderings are unable to depict the manner in which lighting and daylighting affects a room.

With the enhanced graphics images created by modern point lighting programs, perspective renderings of interior spaces can depict accurate light patterns and effects that would be created by electric lights, windows, and skylights. Commercially-available point lighting programs can draw a moderate-resolution light pattern rendering on a VGA monitor or on paper (using a laser printer).

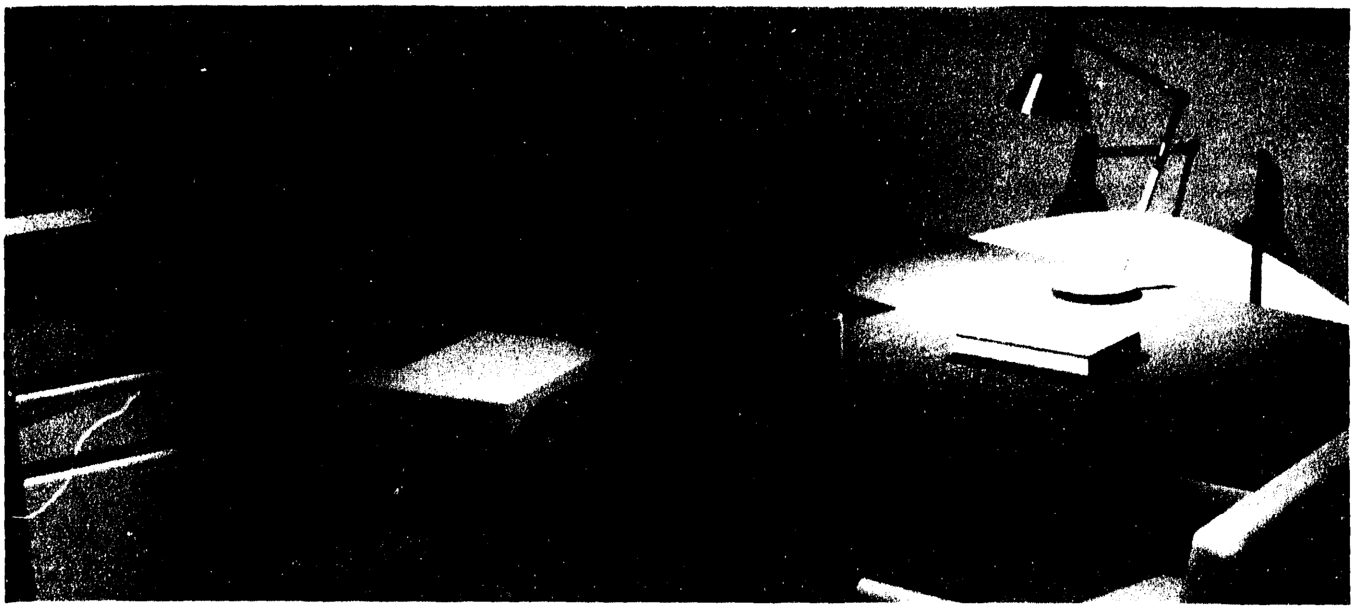
Synthetic Photography

Ray-tracing programs are the most accurate means of computing lighting effects. By tracing each "ray" of light, extremely complex visual scenes, including furniture, artwork, and windows, can be analyzed exactly. The best programs of this type can produce lifelike video images and drawings, but require a tremendous amount of computing power and input time. Hardware requirements, at a minimum, include a minicomputer with powerful graphics capabilities or an engineering work station. These specialized programs can display lighted rooms in full color, with accurate light patterns on room surfaces and partitions, and realistic shadows from realistic furniture. Use of these programs requires much more training than ordinary point lighting programs, and considerably more input. (A rendering by one of these programs is shown in Figure 2-3.)

Exterior Lighting Calculations

Exterior lighting programs are used for parking lots, roadways, pedestrian paths, and special situations such as airport aprons, car sales lots, and sports fields.

Figure 2-3
Rendering Produced by Ray Tracing



Exterior lighting calculations are very similar to interior calculations, except that they are simpler, since no light reflectances from room surfaces are calculated. Exterior programs generally allow the user to aim the fixture (interior programs usually assume the fixture will be parallel to the floor). Input data typically include the following:

- Plan dimensions of the site to be studied, usually entered in x, y coordinates or through a CAD interface
- Points on the site where illuminance is to be calculated. Some programs permit blocking out the printing of light levels on areas of the site where light levels are not critical, or where buildings or trees would block the light.
- Luminaire photometry
- Mounting heights, site locations, orientations, and tilt of luminaires
- Lumen output of the specified lamp
- Light loss factors due to lamp aging, ballast factor, and luminaire dirt accumulation

As with interior programs, photometric data files for exterior lighting fixtures are generally supplied by manufacturers on data disks in IES format. Or, if a data disk is not available, the candlepower data may be keyed in by hand from the manufacturer's photometric report.

The most common form of exterior lighting analysis is the calculation of illuminance on horizontal and vertical planes. Horizontal planes usually are used for roadways, pathways, and parking lots, while vertical planes are typically used for sports fields and automobile display areas. Exterior lighting programs are also very useful in calculating light trespass onto adjacent properties, the lighting of adjacent building facades, and evaluating a lighting system for the use of exterior closed circuit television cameras.

Because the results of roadway and parking lot calculations lend themselves well to graphic presentation, output from most of these programs is provided as a grid of illuminance levels, scaled gray tones, and/or isolux (isofootcandle) plots. Most programs will limit analysis to areas of the site where illumination is important, such as between the curb lines in roadway analysis. No analysis is performed (or at least not printed) for areas of the site where light levels are not critical. Many programs can take into account the shadowing from buildings. All exterior lighting programs are designed to run on MS-DOS computers.

Many exterior lighting programs are designed to work with CAD programs. CAD interface capabilities allow rapid data input and layout using a mouse or digitizer. This type of drawing and computing relationship accelerates and improves the accuracy of site and roadway lighting design. Locations of luminaires can be determined from CAD data, and output information such as isolux/isofootcandle plots can be entered directly onto the base civil engineering or site plan. Enhanced screen and printer images include three-dimensional representations, such as perspective-isolux drawings.

Exterior programs for general use cost $200 to $1500. Several outdoor luminaire manufacturers will supply software to specifiers for a nominal fee ($0-$100), but these programs may only analyze that particular manufacturer's luminaires.

Computer Requirements

Computer hardware requirements for lighting calculation software varies considerably. Lumen method calculations can be performed on a hand-held calculator or even manually, while sophisticated synthetic photography software will slow down even the fastest personal computer. Generally, the minimum equipment required for optimum performance of the standard point lighting calculations discussed in this Guideline include:

- 386 or 486 MS-DOS computer with math co-processor
- 2 MB RAM
- 40 MB (minimum) hard disk
- VGA graphics card and monitor (color for most applications)
- Graphics printer
- Floppy Drive (5.25" 1.2 MB and/or 3.5" 1.44 MB

Application Guidelines

Point calculations are an exceptionally accurate way to compare general lighting systems. While the easier lumen method allows the comparison of average illuminance, point calculations permit the comparison of uniformity of light on the work plane, the patterns of light produced on ceilings and walls, and task contrast rendering. More specifically, point calculations allow consideration of the effects listed below.

- *Effects on Room Surfaces.* By evaluating the patterns of light on a wall caused by a

Figure 2-4

Lighting System Comparison -- Troffers

This example compares the illuminance levels and distribution uniformity of parabolic troffers to imaging reflector-equipped lens troffers. Even though (according to the manufacturer) the silver film reflector-equipped lens troffers are more "efficient," in this comparison, the parabolic troffer design has a higher average illuminance and a more uniform illumination of the task plane. This illustrates that the parabolic troffer actually has a higher coefficient of utilization than does the reflector-equipped luminaire, and that the parabolic luminaire distributes lamp lumens more effectively.

This example is based on a 35' x 36' room with 16 2-lamp luminaires. The ceiling height is eight feet, and the ceiling/wall/floor reflectances are 80/50/20. The parabolic troffer is 12-cell, 3-inch specular.

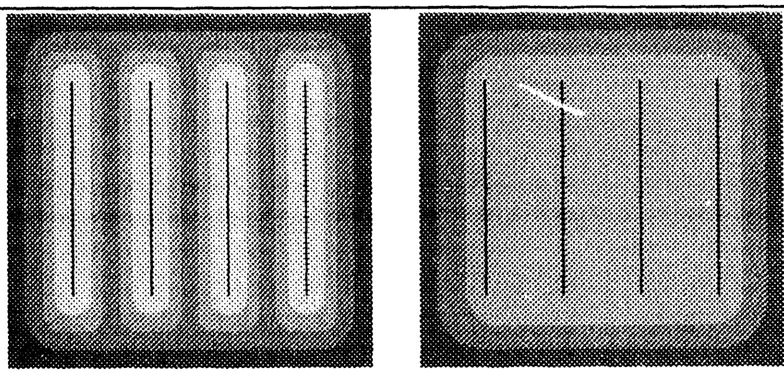
	Parabolic Troffers	**Lensed Silver Reflector**
Average FC	53	51
Maximum FC	73	75
Minimum FC	18	14
Mean Deviation	15	15
Watts/Ft.^{2}	1.06	1.06

row of compact fluorescent down lights, an aesthetic evaluation can be made. Artwork locations may be selected or lighting may be designed to highlight artwork. It may also be possible to determine whether the pattern created on a wall will produce luminance extremes that will cause glare or reflections in VDT screens.

- *Indirect Lighting Effects on Ceiling.* When they are too close to the ceiling, indirect lighting systems may create definite stripes or pools of light on the ceiling that are distracting and that may image in VDT screens. Careful ceiling luminance calculations can help identify the problem, and allow comparison of lighting products with various optical distributions and suspension lengths to reduce the effect. Gray-scale printouts or shaded VDT screen output of luminances make visual assessments possible.

- *Interior Task-Ambient Lighting.* Point calculations should be used for any type of lighting design where the task locations and types are well known and are unlikely to move without a lighting redesign. They may also be used for lighting designs where tasks that move end up in predefined locations.

Cautions for Point Calculations. In the case where a task light is used, or where an indirect fixture is mounted within 12" of the ceiling, point calculations are not always appropriate. In general, if the luminaire is close to the surface where lighting patterns are to be evaluated, a *near field* situation exists. A shortcoming of the mathematics used in point calculations is that these near field calculations are



Illuminance plot with silver film strip lights has a higher average illuminance, but lighting is very non-uniform.

Illuminance plot with standard strip lights has a lower average illuminance, but lighting is more uniform.

Figure 2-5

Lighting System Comparison -- Open Strip Lights

Figure 2-6

Common Lighting Performance Terms

Luminous Flux, measured in lumens, refers to the gross amount of light generated by a source, irrespective of the intensity of the light in a given direction.

Candlepower is the measure of the intensity of a light source in a given direction, measured in candelas (cd). Candlepower distribution curves describe the direction and intensity of light radiation by a luminaire or a light source.

Illuminance describes the amount of light falling on a surface. If the surface is horizontal, light striking it is known as horizontal illuminance; if the surface is vertical, it is called vertical illuminance. The average illuminance on a surface may be calculated by dividing the number of lumens falling on the surface by the area of the surface. Or, the illuminance incident at a point may be calculated as the candlepower of the light ray from the light source to the point, divided by the square of the linear distance between them, times the cosine of the angle between the light ray and the surface. Both methods result in "footcandles" if the area or distance is measured in square feet, or in "lux" if the area or distance is measured in square meters (1 fc =10.27 lx). Illuminance can be measured with an inexpensive meter. This value is still used as a measure of lighting quantity and as a standards value.

Equivalent Sphere Illuminance (ESI) is a measure of how visible a specific target under a proposed lighting system is, as compared to the same target illuminated by a uniformly bright hemisphere, expressed as the illuminance created by the hemisphere. ESI can be a powerful design tool in evaluating performance of competing lighting systems. In simple terms, ESI indicates how much illuminance on the task is actually aids visibility, as opposed to causing veiling glare. This metric is very difficult to measure in the field or calculate by hand; however, available computer programs are able to compute it easily and can be an aid to understanding basic principles of lighting quality.

Relative Visual Performance (RVP) - Based on experimental measurements made at the National Research Council of Canada, this is a metric describing the potential of performing a visual task accurately under a very specific set of conditions. RVP is an important tool for comparing lighting systems. It is expressed as a percentage that predicts the probability of successfully performing a task where speed and accuracy are important by measuring how well the lighting system renders the target's contrast. User age, precise reflectance characteristics of the task, distribution of the light approaching the task, viewing location, and orientation with respect to the task and lighting system must be known to compute RVP at a point. This does not diminish its utility when comparing lighting systems. RVP for an existing task, user, and lighting system may be determined using an instrument designed for this purpose. RVP is considered an important tool for comparing lighting systems, but it has been slow to gain widespread acceptance, because it is generally limited to those who comprehend how it is calculated and understand its limitations and narrow application.

Visual Comfort Probability (VCP) - A calculation taking into account the relative brightness of a lighting system from a given viewing angle, resulting in the likelihood (as a percent) that a lighting system will be visually comfortable. VCP data were confirmed experimentally using uniform layouts of lensed fluorescent luminaires. While it is accepted practice to extrapolate the VCP concept to apply it to various size louvers and luminous ceilings, it should be noted that VCP data have not been experimentally confirmed using these systems. As such, one should be cautious in using VCP to evaluate the potential visual comfort of lighting systems using other than lensed luminaires.

Exitance, Luminance, and Brightness - Properties describing how light is reflected from or transmitted through a real (or imaginary) surface. Exitance is the total quantity of light emitted by, reflected from, and transmitted through a surface into a complete hemisphere. It is expressed in units of lumens per unit surface area. Luminance is a very important concept in lighting, since luminance is what we actually see. Rigorously, luminance is defined to be the ratio of the intensity of light produced by a surface in a given direction to the projected area of the emitting surface. In SI units, luminance is generally expressed as candelas/meter^2. In English units, luminance should generally be expressed in candelas/ft^2. The footlambert unit for luminance that has been used in the past has been deprecated and should be avoided. Brightness is used to describe the strength of the physical sensation caused by viewing surfaces (or volumes). Brightness is related to luminance, but takes account of the fact that a surface with a luminance of, for instance, 100 cd/m^2 will not appear twice as bright as a surface of 50 cd/m^2.

Spacing to Mounting Height Ratios and Spacing Criteria (S/MH and SC) refer to the maximum recommended spacing between luminaires to achieve uniform general lighting. S/MH is often expressed as "parallel" or "perpendicular," and refers to the ratio of the center to center distance between luminaires to their mounting height above the work plane in the direction either parallel or perpendicular to the length of the lamps. Current luminaire photometry uses the term "Spacing Criteria" (SC) instead. While these metrics are useful for lumen method general lighting calculations, neither S/MH nor SC is applicable in spaces with work station partitions or where task-ambient design is appropriate.

comparatively inaccurate unless near field photometric data is available from the luminaire manufacturer, or the computer program is capable of adjusting the characteristics of the luminaires to improve the accuracy of the results. Otherwise, it may be more accurate to evaluate the light patterns from the task light or indirect fixture empirically.

Lighting Quality Computations

The emphasis of most lighting calculations is to predict illuminance levels in lux or footcandles. In addition, it is possible to calculate more specific lighting quality measures, which take many other factors into consideration. Relative Visual Performance (RVP) and Equivalent Sphere Illumination (ESI) are measures of visibility and visual performance that measure a person's ability to perform visual tasks under specific lighting conditions. Visual Comfort Probability (VCP), on the other hand, addresses visual comfort and the presence or absence of discomfort glare. These visual quality measures have certain lighting design applications (as well as limits) and are features of many lighting analysis programs.

Inputs for Lighting Quality Computations

ESI, RVP and VCP values are all influenced by factors other than lighting system illuminance. Factors may include task type, age of the observer, angle of viewing the task, and lighting system characteristics. In order to use lighting quality metrics effectively, the designer must know all the factors listed below with absolute certainty. This will allow the designer to calculate these values accurately for specific types of tasks and task locations.

Task Type

Different ESI and RVP values will result in the same room and lighting system for different tasks. Values will not only be higher or lower, but a wider range will be evident with veiling reflection-sensitive tasks. The size of the task must be known (such as the solid angle of the letter "e" on this page).

Reflectance of Task and Room Surfaces

Significant differences in luminance between the task and surrounding room surfaces may have a profound effect on task visibility and/or visual performance. This is particularly relevant for work spaces containing VDT terminals.

Task Orientation

Exact viewing direction and angle of the task must be known within a few degrees. The same task may have widely different ESI and RVP values depending on the angle from which it is viewed in the room.

Luminaire Photometry and Room Geometry

The room under study must be described exactly and the photometric data of a specific luminaire must be used in the study. This can be a limitation if, for instance, the computer program is unable to include the effects of partitions or task lights.

User Age

Human visual systems deteriorate with age, and older eyes allow less light to reach the retina than do younger eyes. Therefore, in order to predict how visible a task will be, it is necessary to account for this reduction. RVP requires a user age input and applies an average light reduction for that age group.

Visual performance computations, when performed properly, are much more accurate indicators of the visibility of visual tasks than are simple illuminance measures. The IES has announced that in the future, visual performance will replace illuminance level computation as the standard for lighting design. Computation of visual performance metrics is fairly easy to perform, given the right computer program. However the application of ESI and RVP metrics is relatively limited unless the designer or engineer is experienced with the technology and its limitations, and is cautious with its application. Formal training is available and highly recommended for those desiring to employ visibility metric analysis.

Comparing Different Lighting Systems

ESI, RVP, and VCP are useful at comparing competing lighting systems and designs on a statistical basis when specific tasks and locations are unknown. As long as reasonable assumptions are made in regard to possible tasks, viewing directions, viewing angles, and task locations, the probability that one system will provide superior performance over another may be ascertained, assuming the analyst respects the statistical significance of the results.

Equivalent Sphere Illuminance (ESI)

ESI is the illuminance in lux (footcandles) created by a uniformly bright enclosing hemisphere that results in the *same visibility* as that produced by the lighting system under consideration. The quality and effect of the hemisphere light upon a target is considered a good reference standard for comparing task visibility.

ESI addresses task visibility by taking into account the lighting system characteristics, the reflectivity and contrast of the visual target, and the exact geometry of the lighting in relation to the task and the viewer. The real value of the ESI system lies in its ability to evaluate a lighting system in terms of veiling reflections. This factor makes it an effective design tool for system comparisons. ESI recommendations are expressed in lux (footcandles) of ESI.

In the early 1970's, the IES' recommended illuminance levels were expressed in ESI for tasks with sensitivity to veiling reflections, such as hard pencil on paper. Recommended illuminance levels for tasks less sensitive to veiling reflections were expressed in traditional footcandles. However, the IESNA no longer uses ESI for recommended illuminance. Instead, it reminds the designer of task sensitivity to veiling reflections. The designer is responsible for selecting an appropriate ESI criterion if ESI methods are to be used as a design tool or as a technique for comparing lighting systems.

Calculating ESI is relatively easy with most interior point calculation computer programs. However, field measurement of ESI is extremely difficult. One must use the measured field contrast of a known reference target in order to determine the ESI value of a lighting system. This requires measuring task and background luminances of a standardized target, and computing the ESI in a complex formula using the two values. Highly specialized field measurement equipment is required.

Relative Visual Performance (RVP)

Relative Visual Performance (RVP) is emerging as a popular alternative to ESI as a measure of visual task visibility. RVP, like ESI, assesses task visibility under exact viewer and lighting conditions. However, unlike ESI, RVP expresses results in terms of visual performance, rather than equivalent illuminance. RVP is a feature of most sophisticated point calculation programs. The practitioner is reminded that RVP analyses, like ESI, must be carefully performed.

RVP is the percentage likelihood of seeing a visual target accurately. RVP values are affected by the age of the viewer, as well as the lighting system and nature of the visual task. RVP is a precise measurement or calculation for evaluating the contrast-rendering ability of a lighting system. For normal, relatively critical visual tasks, RVP ranges between 95% and 100%, and is significant only in 1% increments. That is, it is correct to say that a reading task in a lighted room in which a 30-year-old individual will have a 99% RVP, is *more visible* than that same reading task in a room where that individual will have a 98% RVP.

The major advantage of RVP, when compared to ESI analysis, is that RVP yields a percentage, which is more intuitively grasped by the user. However, unlike ESI, RVP is unable to compare two lighting systems on a scale related to the illuminance required for equal performance.

RVP may be measured using a specialized instrument that combines a calibrated video camera, illuminance meter, computer, and RVP software. Thus, it is possible to evaluate the RVP in an existing installation. It is more often computed, however, so that it may be used as a design tool. For example, RVP is useful in the comparison of various lighting systems to determine which one is best suited for a particular application.

Visual Comfort Probability (VCP)

Visual Comfort Probability (VCP) is the fraction of the observer population that will find a lighting system and its associated space visually comfortable or free from glare. The presence or absence of discomfort glare is the consideration in calculating VCP. Discomfort glare occurs when luminance ratios are high within the visual field. It is usually the result of inadequately shielded luminaires or reflections from bright or specular surfaces. While discomfort glare can result from windows or any surface in the field of view, it is generally limited to direct light from luminaires. Discomfort glare does not necessarily interfere with visual performance.

VCP can be calculated separately for each observer location and line of sight. However, a computation based on the average worst case location in the area, and used in a similar manner as ESI or RVP measures, can be computed for designs when the locations and orientations of observers are unpredictable.

The main limitation to VCP calculations is that the metric was designed to measure visual comfort in areas with uniform layouts of lensed fluorescent luminaires. The IES has issued a statement to the fact that VCP not to be used as a measure of discomfort glare when applied to parabolic or pendant indirect luminaires.

Resources

Each year, the Illuminating Engineering Society publishes a lighting software survey in its monthly *Lighting Design + Application*. Products are surveyed in many areas, including hardware requirements, analysis features, applications, types of output, user features, and price. At the time of the printing of the *1993 Advanced Lighting Guidelines*, the IES survey was the most up to date and complete source of information on lighting software on the market. The following list attempts to list some of the more advanced software available at the time of this printing. For additional information, consult the June 1992 edition of *Lighting Design + Application.*

Interior Lighting Programs

- CALA
  Holophane Company, Inc.,
  Newark, OH
- Genesys
  The Genlyte Group
  Secaucus, NJ
- LightCAD
  Electric Power Research Institute (EPRI)
  Palo Alto, CA
- LUMEN-MICRO
  Lighting Technologies, Inc.
  Boulder, CO
- Micro Eye Light
  Lighting Sciences, Inc.
  Scottsdale, AZ

Synthetic Photography Ray-Tracing Programs

- LUMEN MICRO
  Lighting Technologies, Inc.
  Boulder, CO
- RADIANCE
  Lawrence Berkeley Laboratories
  University of California
  Berkeley, CA

Exterior Lighting Programs

- AUTOLUX
  Independent Testing Laboratories, Inc.
  Boulder, CO
- AUTO-SITE-LITE
  Lighting Sciences, Inc.
  Scottsdale, AZ
- CALA
  Holophane Company Inc.,
  Newark, OH
- Genesys
  The Genlyte Group
  Secaucus, NJ
- ICON II
  Cooper Lighting, Inc.
  Elk Grove, IL
- LUMEN-POINT
  Lighting Technologies, Inc.
  Boulder, CO
- SPAULD
  Spaulding Lighting, Inc.
  Cincinnati, OH

(Inclusion in these lists does not imply applicability or endorsement. Additional programs may also be available. Daylighting software programs are listed in the *Daylighting and Lumen Maintenance* guideline.)

Luminaires and Lighting Systems

1993 Advanced Lighting Guidelines

General Considerations

There are more luminaires on the market than any other type of lighting equipment. Thousands of different luminaires are made by hundreds of manufacturers. Choosing luminaires that efficiently provide appropriate luminance patterns for the application is an important part of energy efficient lighting design.

The function of the luminaire is to efficiently direct light to appropriate locations, without causing glare or discomfort. Ideally, a luminaire directs lamp output to where it is needed while shielding the lamp from the eyes at normal angles of view. Often, modern lamp technologies require special luminaire features in order to be used correctly. For example, T-8 lamps are 33% smaller in diameter than equivalent T-12 lamps, even while producing nearly as many lumens. Because T-8 lamps are brighter per unit length than T-12 lamps, proper luminaire shielding is more critical than for T-12 lamps.

Different luminaires may significantly affect the operating temperatures of lamps. This can have significant effects on the total performance of the luminaire-lamp/ballast system. For example, luminaires that cause fluorescent lamps to operate above their optimum operating temperatures will also cause reduced light output in those lamps.

Similarly, electronic ballasts have high frequency outputs that are subject to greater power losses in applications requiring extended wiring runs between the lamps and ballasts. It is also important to have a matched lamp-ballast combination that is not simply a combination that lights the lamps, but that is truly energy efficient, as well. In addition, luminaire photometry should be performed using the specific lamp-ballast system under consideration. Furthermore, conventional photometric calculations should be supplemented with correction factors that account for the application conditions.

Luminaire Components

Luminaires generally consist of some or all of the following parts:

- lamps and their respective lamp holders or sockets
- ballasts, in many instances, to start and operate the lamps
- reflectors to direct the light in the desired direction
- shielding/diffusion components (lens, diffuser, louver, or the like) to reduce visual discomfort and disability glare and to distribute the light evenly
- housings to contain these and electrical components, such as wiring connections

Contents

An efficient luminaire optimizes the system performance of each of its components. Careful evaluation of photometric data often reveals the overall quality of a particular luminaire design.

In evaluating a luminaire, its efficiency (the ratio of lumens emitted by the luminaire to lumens emitted by that luminaire's lamps) and its distribution characteristics are of considerable importance. When assessing luminaire distribution, one should consider how the luminaire controls glare, as well as the proportion of lamp lumens that reach the work plane, as measured by the coefficient of utilization (CU). The CU also takes into consideration the effects of room configuration and surface reflectances.

Light Sources

Efficient luminaires use the most efficient sources appropriate for luminaire type. Luminaires should be selected specifically to take advantage of the unique features --particularly with respect to source size and thermal performance -- of each respective light source.

Internal Reflecting Materials

Advances in materials science have resulted in several key new materials capable of improving luminaire efficiency. These reflector materials have a mirror-like or specular finish that permits precise redirection of incident light rays. These differ from standard painted reflectors that produce diffuse, scattered, or wide-spread distribution of the incident light. New reflector materials include the following:

- Anodized, specular aluminum, having a total reflectivity of 85-90%
- Anodized, specular aluminum, enhanced with a multiple thin film dielectric coating, having a total reflectivity of 88-94%
- Vacuum-deposited, specular silver, applied on the front or rear surface of a clear polyester film and adhered to a metal substrate, having a total reflectivity of 91-95%

Some efficient luminaires use the specular materials listed above in carefully-contoured reflectors for maximum control and efficiency. Another use of these materials is in specular "imaging" reflectors, designed as retrofit components to be inserted into existing. For example, in theory, an existing three or four lamp fluorescent troffer can have one or two lamps removed, and some of the lost light output can be recovered through the use of a "one-bounce" or specular reflector. The specular reflector replaces the troffer's original white-painted reflecting surface. By removing a lamp from a 4-lamp troffer and inserting an optically superior specular reflector, it is possible to recover efficiency losses due to degradation of the original white paint and reduce trapped light and heat in the luminaire. This typically results in approximately the same light output from three lamps as from four without the reflector. When reflector replacement is combined with relamping of a luminaire's aging lamps, along with a cleaning of the luminaire surfaces, light output may actually be greater than it was prior to the retrofit. In addition, by further improving lamp-ballast combinations, more dramatic delampings can be performed. However, use of reflectors with delamping will almost always change the original candlepower distribution pattern of the luminaire, which may or may not be desirable, depending on the application.

Often spaces are over-lighted to the extent that lamps can be removed without adding a reflector and adequate illumination can be maintained. In these cases, reflectors may still be considered because, with a reflector, the luminaire lens is more uniformly bright, and the luminaire does not appear as if some of the lamps are missing.

Specular reflectors are also included in a number of new products. However, the efficiency improvements are not as dramatic, when compared to the retrofitting of white-painted reflectors, because some of the advertised effectiveness of these reflector products is due to improvements over poorly-shaped and/or deteriorated, painted reflector surfaces in *old* luminaires.

Advanced Luminaire Technologies

The most widely used luminaires are those designed for general illumination of large areas. In commercial lighting, these luminaires are usually fluorescent lighting systems designed to be mounted onto or recessed into a ceiling. These lighting systems consist of a luminaire layout pattern or "grid" that provides uniform lighting throughout the space. General lighting systems constitute the majority of lighting installations and the majority of the energy consumed for lighting.

General Lighting Luminaire Types

Among the thousands of lighting products on the market, there are a few that represent opportunities for energy conservation in lighting systems design. These are discussed below for general types of lighting systems.

Open Direct Luminaires

Open direct systems do not employ shielding at all. These systems include surface and pendant-mounted strip fluorescent fixtures and suspended open industrial and commercial luminaires. Unless equipped with reflectors, these systems radiate light in all directions (see Figure 3-1). Open direct lighting systems are often very efficient, with high CU values, but they may cause visual discomfort and disability glare.

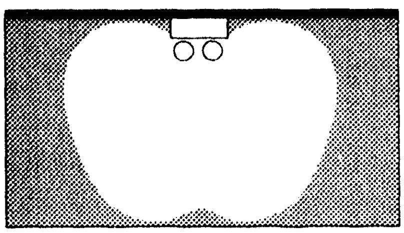


Figure 3-1
Open Direct Luminaire

Imaging Specular Reflector Open Luminaires

The basic, open luminaire can be equipped with an imaging specular reflector. The imaging reflector may not improve luminaire efficiency, but the luminaire's CU can be increased as more light is redirected toward the work plane.

Shielded Direct Lighting Systems

Shielded systems use some form of lens, louver, or baffle to prevent direct viewing of the lamps at normal angles of view (see Figure 3-2). Surface and suspended luminaire types include "industrial" HID downlights, baffled industrial fluorescent luminaires, fluorescent wraparound lens luminaires, and commercial fluorescent lens luminaires. Recessed systems include HID downlights and a wide range of fluorescent "troffers" using lenses, louvers or baffles to control glare.

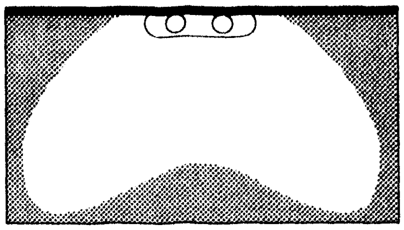


Figure 3-2
Shielded Direct Luminaire

Shielded Industrial and Commercial Luminaires with Specular Imaging Reflectors

These luminaires are similar to open industrial and commercial luminaires. However, they are equipped with louver shielding. Specular imaging reflectors can increase luminaire efficiencies and CUs.

Parabolic Louvered Recessed Troffers

An increasingly popular commercial general lighting fixture is the recessed parabolic troffer. There are large-cell and small-cell parabolic luminaires. Large cell luminaires are generally more efficient, with relatively high CU values, while smaller cells usually offer better glare control. The large-celled parabolic louvered troffer is a luminaire that can combine sharp cut-off glare control with an efficient reflector/louver design. Many different standard sizes are readily available, including 2'x 4', 2'x 2', 1'x 4' and others.

Three variations of large-cell parabolic luminaires are available:

- Standard parabolic troffers generally have louvers about 3" deep. Standard parabolics are efficient, they have good glare control and reasonably low brightness.
- Deep cell parabolic troffers have louvers that are a minimum of 4" deep. Deep cell parabolics have moderate efficiency and CU values, very good glare control, and very low brightness.
- Compound parabolic troffers have specially designed parabolic louver assemblies to create extremely low brightness for Video Display Terminal (VDT) work environments. These fixtures have excellent glare control, and will not produce reflected images in VDT screens if they comply with the luminance limits specified in the Illuminating Engineering Society's VDT Lighting: *IES Recommended Practice for Lighting Offices containing Computer Visual Display Terminals* (RP-24-1989).

Specular and Semi-Specular Louvered Luminaires. These luminaires are high end parabolic fixtures containing shielding components made of anodized high reflectivity aluminum. Semi-specular finishes, similar to stainless steel in appearance, are the most common type, as they tend to give the luminaire just enough brightness to appear "on". This brightness, however, may still be enough to be reflected in VDT screens, causing a loss in visual task visibility. Mirror-like specular finishes tend to decrease luminaire brightness. Compound parabolic troffers generally use specular louvers, and they are intended for use in VDT environments.

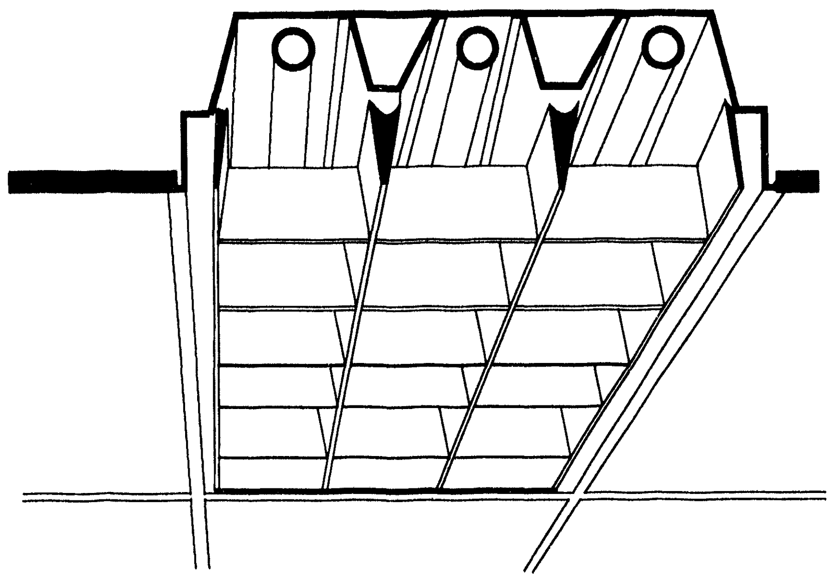


Figure 3-3
Typical 3-Lamp Parabolic Troffer

Compound Parabolic Luminaires. Work areas having VDT screens generally require very low brightness luminaires and ceilings to avoid veiling or reflected glare. Specially designed compound parabolic luminaires serve this requirement much more efficiently than do the small parabolic cube cell louvers often used for this application, because less light is blocked by a smaller number of larger cells.

Standard Lensed Troffers Equipped with Specular Imaging Reflectors

The traditional lensed troffer can be equipped with a specular imaging reflector. The efficiency of a 2-lamp, 2' x 4', reflector-equipped luminaire, consisting of a pattern-12 (standard) prismatic lens, and properly aligned lamps, rises from about 70% to about 80% with the addition of a specular imaging reflector. CU values increase, as well. The increase in efficiency and CU is greatest when the reflector is designed exactly for the luminaire and the desired light distribution. Most common lens types, such as prismatic, batwing, linear batwing, and polarized, can be used, though not all types will exhibit increased efficiency when used with a reflector. Final photometric performance -- especially uniformity of illumination -- may be significantly altered, when compared to traditional painted troffers.

Indirect Lighting Systems

Lighting systems that radiate light up to a reflecting ceiling are called indirect lighting systems (see Figure 3-4). Indirect lighting systems generally employ luminaires suspended from the ceiling, though cove lights and lights mounted to walls and furniture can also be used. Indirect lighting systems using well designed and properly spaced luminaires can provide excellent illumination, uniformity, and freedom from glare. Their success depends on maintaining a high ceiling reflectance in combination with nearly uniform brightness. In this way, a maximum amount of light is reflected down to the work plane, yet light patterns are less likely to create reflected glare in VDT screens. IES RP-24 specifies the maximum to minimum ceiling luminance (brightness) ratio if reflections in VDT screens are to be avoided. Additionally, when using indirect lighting systems, it may also be necessary to install energy-efficient task lighting, as CU values may be low.

Recent designs in fluorescent indirect lighting systems use lenses or imaging reflectors to achieve high luminaire efficiency, by producing a broad batwing light distribution, while allowing for close-to-ceiling mounting. These designs can increase an indirect system's CU to nearly that of traditional lensed troffer systems.

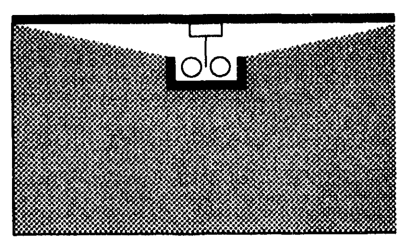


Figure 3-4
Indirect Lighting Luminaire

Cove Lighting Systems

New designs in indirect lighting luminaires, especially for cove and coffer installations, increase the effectiveness of traditional strip lights and eliminate socket shadows. Figure 3-5 shows a typical distribution pattern.

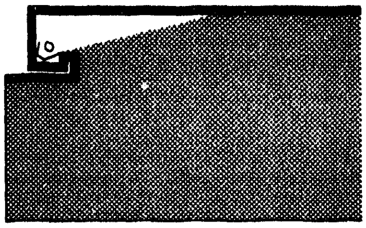


Figure 3-5
Cove Lighting System

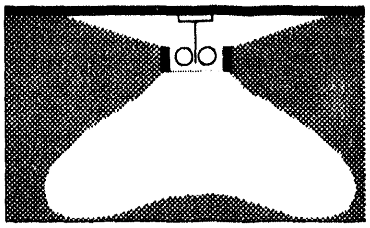


Figure 3-6
Direct/Indirect Luminaire

Compact HID Indirect Lighting Systems

Compact HID lamps allow for smaller uplight luminaires that are easily installed in furniture-mounted luminaires and wall sconces. (HID luminaires may not be suitable for applications when periodic switching is anticipated.)

Direct/Indirect Lighting Systems

These systems combine the efficiency and high CU of direct illumination with the uniformity and glare control of indirect lighting (see Figure 3-6). Some industrial lighting systems are designed for a limited percentage of indirect uplight; some office and school lighting systems are designed for an equal balance between direct downlight and indirect uplight. Additionally, there are high efficiency versions of direct/indirect lighting systems for commercial and institutional lighting, including some especially designed for VDT work environments. When used in VDT environments, these systems should meet the performance criteria of IES RP-24 with respect to both direct and indirect lighting.

Architectural Luminaires

Architectural lighting systems are generally used in building spaces such as lobbies, corridors and the like. Typical lighting types include recessed downlights, wall washers, track lights and some wall sconces. Since these luminaires are used mainly for highlighting high quality spaces, aesthetics is a principal consideration in their design and selection. Nevertheless, there are many opportunities to utilize efficient lighting in these applications.

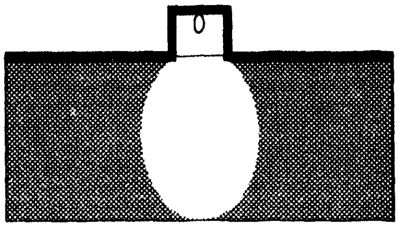


Figure 3-7
Recessed Architectural Downlight

Recessed Low Wattage HID Downlights

HID downlights suitable for lower ceilings and high quality spaces have been made viable with high-CRI compact metal halide and white high pressure sodium lamps. This allows for replacement of traditional incandescent downlights, making significant energy savings possible.

Recessed Compact Fluorescent Downlights

The popular compact fluorescent downlight is now available in a variety of configurations, including dimmable lamps designed for use with electronic ballasts. In general, compact fluorescent lamps replace incandescent downlights on a 1 watt for 3 watt basis. A relatively recent development, the 1'x 1' parabolic downlight for compact fluorescent lamps, is extremely efficient, allowing replacement of incandescent lamps on a 1 watt for every 4 watts basis.

Track-Mounted HID and Compact Fluorescent Floodlights

Several interesting designs in track luminaires using compact fluorescent and low wattage HID lamps have been introduced. These products offer significant energy savings over standard incandescent luminaires of this type. Figure 3-8 illustrates an example of a compact fluorescent track light.

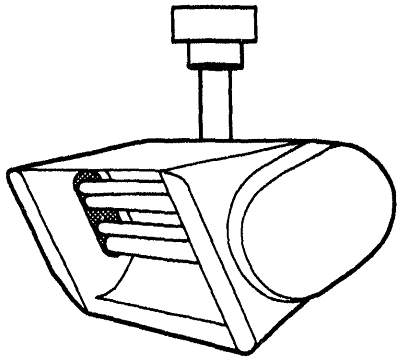


Figure 3-8
Compact Fluorescent Track Light

Compact Fluorescent Adapters with Screw In Power Connections

Techniques are available for retrofitting incandescent downlights to compact fluorescent technology. Except for the means of connecting power, these designs have elements used in conventional luminaires: a lamp holder with replaceable lamp and a housing for the ballast and other components. Some designs make use of the incandescent lamp holder's medium-base screw-shell for mounting and power connection. Some designs are also equipped with reflectors and/or lenses to improve light distribution and provide shielding. See Figure 3-9. The reflector and lens assembly is designed to correctly match the lamp for optimum performance. Also, the lamp can be replaced without replacing the rest of the assembly, reducing the chance that an incandescent lamp will be substituted at a later time.

Figure 3-9
Screw-In Compact Fluorescent Luminaire

Care should be taken in the specification process for these types of luminaires. Since they are considered by UL as "lamp holder accessories," the thermal testing procedure common to luminaires does not apply. It is particularly important that the specifications call for the lamp to perform within the manufacturers limits when the unit is operated in its intended application. Key items in the specification should include the lamp operating current, lamp compartment temperature, and the lamp base temperature. In general, these types of luminaires cannot be used with dimmers.

Permanent Compact Fluorescent Conversions

Realizing the inadequacies and impermanence of screw-in compact fluorescent adapter kits, manufacturers have introduced permanent remodel compact fluorescent kits. These kits include efficient reflectors, properly positioned and shielded lamps and, in some cases, electronic ballasts. Many major companies who make standard incandescent downlights are now producing compact fluorescent conversion kits specially designed to upgrade their existing products. These kits offer the advantage of extremely rapid conversion. Non-OEM companies, on the other hand, make kits to convert many existing 5"-7" aperture incandescent luminaires. These products are supplied with universal conversion kits. Once again, the specifiers should be aware that some types of conversion kits may not be UL listed and/or may void listing of the assembly once installed, and care should be taken in the specification process.

Task Lights

Task-ambient lighting designs generally utilize two separate lighting systems to improve lighting while saving energy. First, an ambient lighting design provides a medium to low level of uniform illumination in a room. Most general lighting systems can be used for ambient lighting. Second, task lighting is provided at and for specific visual tasks. Compact fluorescent lamp technology has special relevance for task lighting applications. In VDT applications where high levels of ambient light often interfere with visibility, task lighting may be especially important for non-VDT tasks, particularly when those visual tasks are difficult to perform because of low contrast, high speed, and/or worker age.

Decorative Luminaires

A renaissance in decorative lighting fixtures in the form of pendants, wall sconces, chandeliers, exterior lanterns, and landscaping lights occurred in the 1980s. In most instances, decorative lighting luminaires are used to provide general or ambient lighting in areas where a more customized appearance is desired. Although decorative lighting is still most often used in restaurants and hotels, an increasing number of applications exist in offices, retail stores, apartment buildings, and other commercial spaces. Energy-conserving decorative luminaires utilizing advanced lighting technologies have increased options for lighting efficiency.

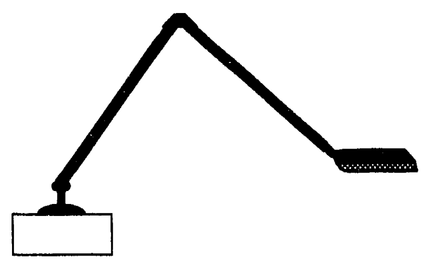


Figure 3-11
Typical Compact Fluorescent Task Light

Figure 3-10

Advanced Technology Design Considerations

Option	Replaces	Why More Efficient?
	Shielded Direct Lighting Systems	
Parabolic large cell louvered recessed and surface troffers	Lensed painted troffers	Increase in luminaire efficiency and effectiveness; improved glare control
Low brightness "CRT" type parabolic luminaires	Small cell parabolic cube louvered luminaires	Increase in luminaire efficiency and effectiveness; no loss of glare control; no apparent ceiling darkness
Standard lensed troffers equipped with imaging reflectors	Standard lensed troffers	Increase in luminaire efficiency, generally with an increase in coefficient of utilization
Shielded industrial-commercial fixtures with imaging reflectors	Painted reflector luminaires	Imaging reflectors can increase luminaire efficiency by concentrating light downwards and can increase overall lighting effectiveness
Indirect Lighting Systems		
High efficiency and low-ceiling fluorescent indirect systems	Conventional up lights	Increased luminaire efficiency; wider spread in luminaires designed to be used in computer CRT spaces
Cove lighting systems	Staggered fluorescent strips	Increase in cove efficiency combined with improved installation due to luminaire butt-joint without socket shadow; better spread across ceiling due to asymmetry
Compact HID lighting systems	Incandescent and halogen luminaires	Allows use of high-efficacy HID lamps in up lights, previously available only for low-efficacy incandescent and halogen luminaires
	Direct/Indirect Lighting Systems	
High efficiency direct/indirect lighting system	Conventional direct/indirect luminaires	Improved cutoff for use in computer work is combined with efficient optical systems to provide greater efficiency and acceptability in modern office applications
Open Direct Lighting Systems		
Imaging specular reflector open luminaires	Painted open luminaires	Imaging reflectors can concentrate light downwards, increasing overall lighting system effectiveness
	Architectural Luminaires	
Recessed compact fluorescent downlights	Incandescent downlights	Direct replacement in many situations with approximate wattage reduction of 67% at same illumination level and aesthetic effect. Especially useful in low-to-medium height ceilings.
Recessed low wattage HID downlights	Incandescent downlights	Direct replacement in many situations with approximate wattage reduction of 50-67% at same illumination level and aesthetic effect. Useful at most ceiling heights.
Track-mounted HID and compact fluorescent floodlights	Incandescent and halogen wall washers	Direct replacement in many situations with approximate wattage reduction of 50-67% at same illumination level and aesthetic effect. Useful at most ceiling heights.
Compact fluorescent task lights	Incandescent and halogen task lights	Significant wattage reduction
Low wattage HID and compact fluorescent wall lights	Incandescent and halogen wall lights	Significant wattage reduction
Compact fluorescent pendants & chandeliers	Incandescent and halogen luminaires	Significant wattage reduction

Low Wattage HID and Compact Fluorescent Wall-Mounted Luminaires

Many traditional applications for incandescent wall-mounted sconces and brackets can be replaced with similar-appearing luminaires designed specifically for compact fluorescent or HID lamps. See Figure 3-12 for an example.

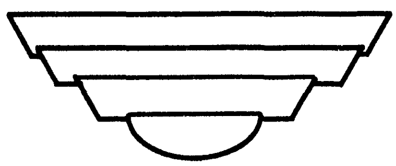


Figure 3-12
Compact Fluorescent Wall Sconce

Compact Fluorescent Pendants and Chandeliers

Luminaire designs continue to evolve for compact fluorescent decorative chandeliers and pendants used in applications once limited to traditional incandescent fixtures. See Figure 3-13 for an example.

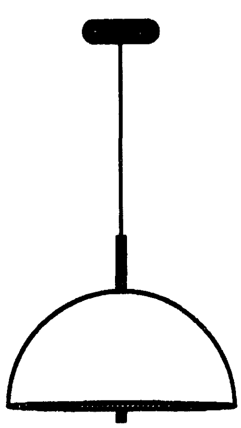


Figure 3-13
Decorative Pendant Luminaire

Compact Fluorescent Exterior Luminaires

Compact fluorescent lamps can be used in enclosed luminaires for exterior lighting throughout most of the U.S. In colder climates, electronically-ballasted compact fluorescent lamps may be required to insure proper operation at extremely low temperatures. A number of compact fluorescent lamps can be operated at temperatures down to -18 °C (0 °F). Compact fluorescent outdoor luminaires are especially well suited to landscape lighting applications which previously used low-wattage incandescent lamps.

Low-Wattage HID Exterior Luminaires

While larger HID lamps are commonly used as exterior light sources, low wattage (100 watts or less) HID lamps offer the opportunity to use these energy efficient sources in a variety of applications calling for more compact luminaires. In many cases, low-wattage HID luminaires can be used where incandescent lamps are typically chosen.

Low-wattage HID lamps can be used in every climate region because of their wide temperature range for starting and operating. The small lamp size makes them suitable for many outdoor luminaires.

Photometric Data

"Photo" means light; "metrics" means measurement. Photometrics involves the measurement of the light radiated by luminaires. Photometric charts, diagrams, and other data are used in all types of lighting calculations and design.

The introduction of new technologies makes it difficult for the lighting industry to provide consistent photometric data because of the number of different combinations of luminaire components; Each combination has a different effect on luminaire-lamp-ballast system performance. Additionally, products designed to be operated in conjunction with older technologies, such as standard F40T12 fluorescent lamps and electromagnetic ballasts, will behave differently and will require different measurements, when operated in conjunction with a newer technology, such as T-8 lamps and electronic ballasts. Thus, the designer must consider the entire luminaire-lamp-ballast *system* when selecting the correct photometric data.

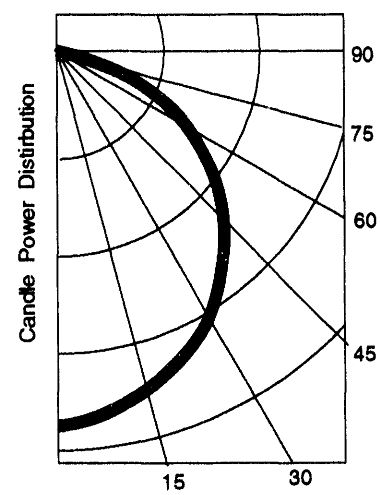


Figure 3-14
Typical Photometric Chart for Prismatic Lensed Troffer

Figure 3-15
Terms for Photometric Evaluations

Coefficient of Utilization **(CU):** A table of scalar values which describes the percentage of light generated by the lamps in a luminaire that reaches the work plane in the room. The CU chart describes the luminaire's performance under a variety of room surface reflectance conditions and RCRs. In spaces with very light surfaces, a CU in excess of 100% is actually possible, as the room will use a single ray of light more than once before it reaches the work plane.

Luminaire Efficiency: The absolute percentage of lamp lumen output that exits a luminaire.

Relative Photometry: Photometry (light measurement) is conducted under laboratory conditions. The results are adjusted or normalized to take into account the many variables of real products in a real world and are based on lamps with an actual output at the manufacturer's rating.

Room Cavity Ratio **(RCR):** A scalar value describing the relative geometry of a room. An RCR of 3.5 or less is associated with most normal larger rooms having a proportionately low ceiling. An RCR of 3.5 to 7.0 is generally associated with either a larger room with an unusually high ceiling, or with more proportionate, smaller rooms, such as offices. An RCR of 7.0 or greater is associated with a much smaller room and/or a disproportionately tall ceiling.

Most standard data provided by manufacturers and test laboratories are of fairly high quality. In particular, coefficient of utilization (CU) data and candlepower curves (or charts) are generally derived in a consistent manner based on Illuminating Engineering Society of North America (IESNA) test procedures.

Nevertheless, in today's era of evolving technologies, the designer must account for a variety of light loss factors (LLFs) that must be used in conjunction with photometric data provided by manufacturers and testing laboratories. It is important to consider all factors that affect lighting system performance and to account for the influence of these individual factors as accurately as conditions permit. If these factors are not carefully considered, the designer may be tempted to use a very large LLF as a safety margin. This leads to inefficient designs that are wasteful, consuming more power than designs with well-conceived light loss factors.

There are two types of LLFs: non-recoverable and recoverable.

Non-Recoverable Light Loss Factors

Non-recoverable light losses are losses that are not recoverable by standard lighting system maintenance (cleaning and relamping). There are many of these factors to consider when formulating a total light loss factor, but most of these factors are well-treated in standard references, such as the *IES Lighting Handbook*. Two non-recoverable light loss factors that are important for evaluating new lighting technologies and that are not adequately treated in the current literature are the ballast factor and the thermal factor.

Ballast Factor

Most fluorescent lamps generate less light when operated on a commercial ballast than they do on the laboratory reference ballast used to establish the lamp lumen ratings listed in lamp manufacturers' catalogs. Therefore, the rated lumen output of the lamp must be adjusted to account for the lamp-ballast interaction. This adjustment is known as the ballast factor, and it must be known in order to determine actual lamp output. Actual lamp output is equivalent to the rated initial lamp lumens multiplied by the ballast factor.

On a given ballast, energy saving lamps generally have different ballast factors than full wattage F40 lamps. For example, the ballast factor for an energy efficient ballast operating a standard F40 lamp is generally higher than it is for operating an energy saving lamp.

With electronic ballasts, a wide range of ballast factors have been measured. Some ballast factors are quite low, while others demonstrate that electronic ballasts can actually increase light output above the rated lamp lumen levels (ballast factor greater than 1.00). Please note that ballast factors do not directly relate to energy efficiency; a low ballast factor with a proportionately low input power to the ballast is still an energy-efficient system, such a system is useful in spaces that would otherwise be over-lighted.

Ballast factors are known for most of the common fluorescent lamp-ballast combinations. For further information on ballast factors refer to the *Energy-Efficient Fluorescent Ballasts* guideline.

Application Thermal Factor

Fluorescent lamp lumen output is quite sensitive to the lamp's bulb wall temperature. Lamp lumen ratings are determined under ANSI operating conditions: in free (open), unmoving air at 25 °C (77 °F). The temperature inside a closed luminaire can vary considerably from ANSI conditions, which will affect lamp lumen output.

Luminaire design can significantly affect the thermal conditions that influence light output. The thermal effect on lamp lumens is partly accounted for in published photometric data provided for each luminaire. This data, called relative luminaire photometry, automatically compensates for the actual lamp temperature, since the luminaire is operated under ANSI conditions during the photometric test. However, since many luminaires are mounted in a ceiling where the temperature in the plenum may be greater than 25 °C, it is important to include an application thermal factor to account for variations in equipment or operating conditions.

Recoverable Light Loss Factors

Accurate lighting calculations must account for recoverable light loss factors as well as non-recoverable factors. Lamp lumen depreciation (LLD) from aging, and dirt accumulation on lamps, reflectors, lenses, and room surfaces are the principal recoverable light loss factors. Since lumen output depreciates with aging, most lighting designs base calculations on "maintained," as opposed to "initial," lamp lumens. Many fluorescent lamp phosphors, such as halophosphor "cool white," depreciate significantly over lamp life. On the other hand, newer technology rare earth phosphor lamps depreciate significantly less over the same period of time, as compared to conventional halophosphor lamps. This results in different LLD values.

Overall Light Loss Factor

The combination of ballast factor, thermal factor, dirt depreciation factors, and lamp lumen depreciation can be significant. Accurate design calculations must consider these and other variables. As an example, if photometric data is given for standard F40T12 cool white lamps and electromagnetic ballasts, but the luminaire is to be equipped with F32T8/RE70 lamps and an electronic ballast, the following adjustments should be considered:

- Change in initial lamp lumens, from 3050 to 2900, due to the different lamp type
- Change in ballast factor, due to the electronic ballast
- Increase in application thermal factor, due to the electronic ballast
- Probable increase in the LLD multiplier, because of the rare earth phosphor coatings in the T-8 lamp (Note: an increase in LLD actually means that lamp lumen depreciation is less)
- Possible increase in luminaire efficiency, due to the smaller diameter of the T-8 lamp

The end result of using the T-8 lamps and electronic ballasts as described above would be a reduction of energy use of more than 20% with no significant change in lighting level. This would more than offset the higher cost of this lamp-ballast combination. When LLFs are considered, electronic ballasts produce even more dramatic energy savings and should be considered in almost every possible lighting application.

Luminaire System Performance

The luminaire system consists of the luminaire itself along with its reflectors, lenses and housings, as well as the lamps and ballasts. System performance depends on how well all these components work together. With the introduction of many new products -- especially electronic ballasts -- designers must pay special attention to the interactions between lamps, ballasts, and luminaires. Thermal effects, in particular, vary widely and affect luminaire-lamp-ballast system performance. With fluorescent lamp-ballast systems, light output (lumens), input watts, and efficacy are all sensitive to changes in the ambient temperature. When the ambient temperature around the lamps is]significantly above or below 25 °C (77 °F), the performance of the lamp ballast system can change significantly. Figure 3-16 shows the relationship between two common lamp-ballast systems: the F40T12 lamp with a magnetic ballast and the F32T8 lamp with an electronic ballast.

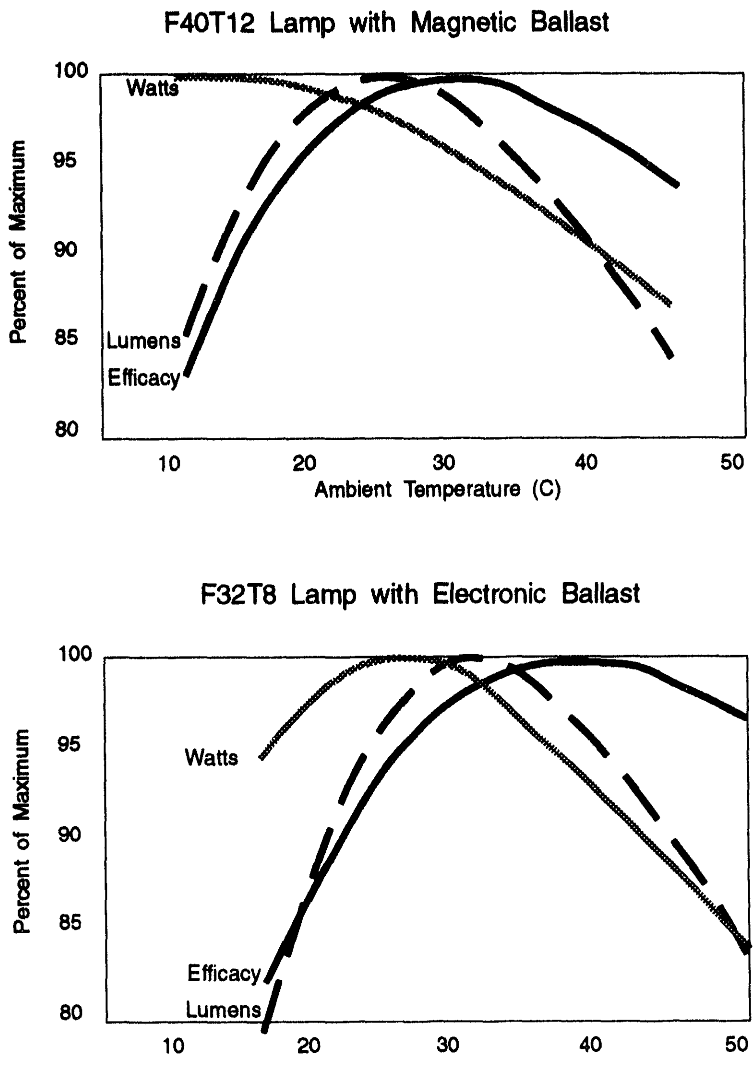


Figure 3-16

Sensitivity of Lamp-Ballast Performance to Ambient Temperature

Figure 3-16 shows that the optimum operating temperature for the F32T8 lamp-ballast system is higher than the F40T12 system. This means that for installations when the lamp ambient temperature is greater than 25 °C (77 °F), the performance of the F32T8 system is actually higher than performance under the rated ANSI conditions. Performance of lamps with even smaller diameters, such as T-5 twin tube lamps, peaks at even higher ambient temperatures. For example, the FT40T5 lamp peaks in lumen output when the ambient temperature approaches 32 °C (90 °F).

Performance Tables

While the information in Figure 3-16 is interesting, it does not provide much information to the designer faced with the responsibility of designing an energy-efficient lighting system that provides specified design illuminance levels. Data like that shown in Figure 3-16 is combined with test condition performance data for common lamp ballast combinations to produce the table in Figure 3-17 for full size fluorescent lamps and Figure 3-18 for compact fluorescent lamps. These tables give information that will enable the designer to assess the total luminaire system performance.

The columns of the tables are typical luminaire installations, labeled A through I for full size fluorescent lamps and J through S for compact fluorescent lamps. The rows of the tables are grouped by lamp/ballast combinations.

For each lamp/ballast combination and luminaire installation, the table presents the *Application Correction Factor*, which is the product of the thermal factor and the ballast factor. This factor represents the most significant portion of total non-recoverable light loss for a given luminaire. For instance, the first lamp-ballast combination in Figure 3-17 is the standard F40T12 lamp with a standard energy-efficient (manufactured after 1990) magnetic ballast with a ballast factor of 0.94 for the test conditions. The application correction factor is given for this lamp/ballast combination for the nine different luminaire installations (labeled A through I). The table also gives the input watts for common lamp installations, in this case, four lamps, three lamps or two lamps. The table also gives input watts separately for one-, two- or three-lamp ballasts when this is appropriate. Descriptions of the luminaire installations and other assumptions about the luminaires are provided in the following sections.

The Application Correction Factor may be used to adjust the CU for a particular luminaire to account for non-recoverable light loss factors. Recoverable light loss factors due to lamp lumen depreciation or dirt accumulation must be accounted for separately using standard procedures. These adjustments are made for either lumen method calculations or point calculations (see *Computer-Aided Lighting Design* guideline).

Assumptions

In order to generate the tables, certain assumptions were made about the features of the space where the lighting system is located. These assumptions are common to both Figures 3-17 and 3-18 and are listed below.

- All luminaires are static (not heat extraction type) unless otherwise indicated.
- Where indicated, "acoustic tile ceiling" assumes a lower floor of a multi-story building, with ducted supply and return plenum.
- Where indicated, "gypsum wallboard ceiling" assumes lower floor of a multi-story building if not insulated; otherwise assumes residential style construction in a single story building.
- Air movement and temperature maintained by the HVAC systems is typical of a variable air volume system in an office occupancy. Room temperature is maintained at 25 °C (77 °F).
- Plenum temperature is assumed to be 30 °C (86 °F).
- For Figure 3-17, the relationship for the various luminaire-lamp-ballast systems between lamp lumen output and ambient temperature, and between system input power and ambient temperature are taken from [Bleeker, N., and W. Veenstra, "The Performance of Four-Foot Fluorescent Lamps as a Function of Ambient Temperature on 60 Hz and High Frequency Ballasts," *Proceedings of the 1990 Annual IES Conference,* Baltimore, MD, August 1990]. Since thermal performance data of lamp-ballast systems using the T-5 lamp was not available, the thermal performance of the T-5 systems is assumed to be the same as for the T-8 systems. This table will be amended at a later date when more data becomes available.
- The thermal performance data for Figure 3-18 is from unpublished Lawrence Berkeley Laboratories data.
- The estimated lamp ambient temperatures for all nine luminaire categories are listed at the end of Figure 3-17 for the magnetic pre-1990 ANSI/CBM ballasts driving F40 and F40ES lamps. The temperatures listed for the F40 system are used for all the F40 lamp systems. All other systems use the temperature values for the F40ES lamp systems.
- The estimated change in lamp ambient temperature that results in going from the application condition to the luminaire photometric condition (see row labeled "ΔT LM-41$\rightarrow$app") are listed for the F40 and F40ES lamps operated on magnetic pre-1990 ANSI/CBM ballasts. The temperature changes for the F40 lamp system is used for all F40 lamp systems. The temperature changes for all other systems use the ΔT values for the F40ES lamp system. Note that, except for the heat extract luminaire, these ΔTs are positive (or 0); i.e., the lamp ambient temperature is generally higher under the application condition than under the photometric test condition.
- For heat extract luminaires (luminaires in which return air is drawn through the lamp compartment), the reduction in ambient temperature around the lamps, relative to the lamp ambient temperature obtained in the photometric test condition, is assumed to be 9 °C (16 °F) for full wattage F40 lamps and 7 °C (13 °F) for F40ES lamps.

Description of Luminaire Installations

A. Generic large cell "parabolic" troffer recessed into acoustic tile grid ceiling with little or no air movement around the luminaire.

B. Generic closed troffer with flat prismatic lens recessed into an acoustic tile ceiling.

C. Same as "A," except luminaire is of the heat extract type where the HVAC system draws return air through the luminaire. This data may also be used for luminaire installation "B" if it is of the heat extract type.

D. Surface mount commercial luminaire with "wraparound" lens, mounted to uninsulated gypsum board ceiling (for U-lamps, a commercial flat lens luminaire is assumed).

E. Same as "D," except the ceiling is insulated.

F. Open mounted strip light surface mounted to uninsulated gypsum board ceiling.

G. Same as "F," except ceiling is insulated.

H. Tubular fluorescent suspended luminaire, lensed indirect, enclosed top, suspended 2' below the ceiling.

I. Square section fluorescent luminaire with open top uplight in free air at 25 °C (77 °F). This situation most closely resembles ANSI standard test conditions for full size fluorescent lamps, so the lamp lumen output and ballast factor most closely correspond to the catalog values.

J. Recessed unvented downlight with vertical base-up lamps and nominal 7" aperture recessed in acoustic tile ceiling.

K. Same as "J", except the luminaire is vented to improve thermal performance.

L. Recessed unvented downlight with horizontal lamps and nominal 7" aperture recessed in acoustic tile ceiling.

M. Same as "L", except the luminaire is vented.

N. Surface mounted "vandal resistant" luminaire (enclosed) on uninsulated gypsum wallboard ceiling.

O. Same as "N", but insulated ceiling.

P. Open top wall sconce, surface mounted to uninsulated wall.

Q. Enclosed and gasketed wall bracket, industrial "jelly jar" type luminaire.

R. Free air table lamp, essentially ANSI/catalog values.

Using the Tables

Figures 3-17 and 3-18 are intended to enable designers to more accurately estimate the actual power consumed and the lumen output produced by a particular luminaire in the application condition. The ballast factors assumed for each combination are clearly noted in the tables. Generally, these ballast factors are estimates of 1992 "industry-average" ballast factors for each respective lamp-ballast system. If the ballast factor for an intended lamp-ballast factor is substantially different from the listed value, the input power values can be determined simply by applying the following equation:

$$\text{Corrected Input Power} = \text{Listed Input Power} \times \frac{\text{Intended Ballast Factor}}{\text{Listed Ballast Factor}}$$

The application correction factor should be used to correct an *appropriate* photometric report for the application condition. If a photometric report exists for a specific luminaire equipped with one of the lamp-ballast combinations listed in the tables, then the CU (and fixture efficiency value) listed for that luminaire in the report may simply be multiplied by the appropriate application correction factor listed in Figure 3-17 or 3-18 to estimate the effects of ballast factor and thermal factor on lighting system performance.

Figure 3-17

Luminaire System Performance -- Full-Size Fluorescent Lamps
(Base Case Lamp-Ballast Systems)

Luminaire Type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Luminaire Description	**Recess Static Open**	**Recess Static Closed**	**Recess Heat Extract**	**Surface Closed Uninsul.**	**Surface Closed Insulated**	**Surface Open Uninsul.**	**Surface Open Insulated**	**Suspend. Closed**	**Suspend. Open ANSI**
F40T12 Lamps, Magnetic Pre-1990 ANSI/CBM Ballast, Ballast Factor: 0.94									
Application Correction Factor	0.90	0.89	1.07	0.94	0.87	0.94	0.91	0.94	0.94
Input Watts:									
4 lamps (2) ballasts	176	174	190	174	164	188	182	176	192
3 lamps (2) ballasts	136	134	146	134	126	145	140	136	148
3 lamps (T) ballasts	132	131	143	131	123	141	137	132	144
2 lamps (1) ballast	88	87	95	87	82	94	91	88	96
Ambient Temperature (°C)	41	43	41	43	50	29	35	41	25
ΔT LM-41→app (*)	+4	+4	-9	0	+5	0	+4	0	0
34-Watt F40T12/ES Lamps, Magnetic Pre-1990 ANSI/CBM Ballast, Ballast Factor: 0.87									
Application Correction Factor	0.85	0.83	0.95	0.87	0.83	0.87	0.87	0.87	0.87
Input Watts:									
4 lamps (2) ballasts	160	156	164	160	154	164	162	160	164
3 lamps (2) ballasts	131	127	134	131	126	134	132	131	134
3 lamps (T) ballasts	119	116	122	119	115	122	121	119	122
2 lamps (1) ballast	80	78	82	80	77	82	81	80	82
Ambient Temperature (°C)	38	43	38	40	46	28	33	38	25
ΔT LM-41→app (*)	+3	+4	-7	0	4	0	3	0	0
FB40T12 Lamps, Magnetic Pre-1990 ANSI/CBM, Ballast factor:: 0.94									
Application Correction Factor	0.90	0.89	1.07	0.94	0.87	0.94	0.91	0.94	0.94
Input Watts									
3 lamps (2) ballasts	140	139	151	139	131	150	145	140	153
3 lamps (T) ballasts	132	131	143	131	123	141	137	132	144
2 lamps (1) ballast	88	87	95	87	82	94	91	88	96

Notes:

(*) = Estimated change in lamp ambient temperature between photometric test condition and application condition
(1) = 1 ballast per luminaire
(2) = 2 ballasts per luminaire
(T) = Tandem wiring for 3-lamp luminaires
3-lamp luminaires with magnetic ballasts have 1 single-lamp ballast and 1 double-lamp ballast

Figure 3-17 (continued)

Luminaire System Performance -- Full-Size Fluorescent Lamps
(Magnetic Energy-Efficient Ballasts)

Luminaire Type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Luminaire Description	**Recess Static Open**	**Recess Static Closed**	**Recess Heat Extract**	**Surface Closed Uninsul.**	**Surface Closed Insulated**	**Surface Open Uninsul.**	**Surface Open Insulated**	**Suspend. Closed**	**Suspend. Open ANSI**
F40T12, Magnetic Energy-Efficient Ballast, Ballast Factor: 0.94									
Application Correction Factor	0.90	0.90	1.04	0.94	0.89	0.94	0.91	0.94	0.94
Input Watts									
4 lamps (2) ballasts	161	160	174	160	150	172	167	161	176
3 lamps (2) ballasts	123	121	133	121	114	131	127	123	134
3 lamps (T) ballasts	121	120	131	120	113	129	125	121	132
2 lamps (1) ballast	81	80	87	80	75	86	83	81	88
34-Watt F40T12/ES Lamps, Magnetic Energy--Efficient Ballast, Ballast Factor: 0.87									
Application Correction Factor	0.85	0.83	0.95	0.87	0.83	0.87	0.87	0.87	0.87
Input Watts									
4 lamps (2) ballasts	140	137	144	140	135	144	142	140	144
3 lamps (2) ballasts	109	107	112	108	105	112	112	109	112
3 lamps (T) ballasts	105	103	108	105	101	108	108	105	108
2 lamps (1) ballast	70	68	72	70	68	72	72	70	72
F32T8 Lamps, Magnetic Energy-Efficient Ballast, Ballast Factor: 0.94									
Application Correction Factor	0.92	0.90	1.01	0.94	0.90	0.94	0.93	0.94	0.94
Input Watts:									
4 lamps (2) ballasts	133	129	137	132	127	139	136	133	140
3 lamps (2) ballasts	101	98	104	100	96	105	103	101	106
3 lamps (T) ballasts	100	97	103	99	95	104	102	100	105
2 lamps (1) ballast	66	65	69	66	63	69	68	66	70
FB40T12 Lamps, Magnetic Energy-Efficient Ballast, Ballast Factor 0.94									
Application Correction Factor	0.90	0.90	1.04	0.94	0.89	0.94	0.91	0.94	0.94
Input Watts:									
3 lamps (2) ballasts	123	121	133	121	114	131	127	123	134
3 lamps (T) ballasts	118	117	128	117	110	126	122	118	129
2 lamps (1) ballast	79	78	85	78	73	84	82	79	86
FB31T8 Lamps, Magnetic Energy-Efficient Ballast, Ballast factor: 0.94									
Application Correction Factor	0.92	0.90	1.01	0.94	0.90	0.94	0.93	0.94	0.94
Input Watts:									
3 lamps (2) ballasts	100	97	103	99	95	104	102	100	105
3 lamps (T) ballasts	99	96	102	98	94	103	101	99	104
2 lamps (1) ballast	66	64	68	65	63	68	67	66	69
FT40W/2G11 Twin-Tube T-5 Lamps, Magnetic Energy-Efficient Ballast, Ballast Factor: 0.93									
Application Correction Factor	0.90	0.89	1.00	0.93	0.88	0.93	0.91	0.93	0.93
Input Watts									
3 lamps (2) ballasts	123	120	128	122	118	129	127	123	130
2 lamps (1) ballast	82	79	84	81	78	85	84	82	86

Notes:
(T) = Tandem wiring for 3-lamp luminaires
3-lamp luminaires with 2 magnetic ballasts have 1 single-lamp ballast and 1 double-lamp ballast

Figure 3-17 (continued)

Luminaire System Performance -- Full-Size Fluorescent Lamps
(Magnetic Heater Cutout Lamp-Ballast Systems)

Luminaire Type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Luminaire Description	**Recess Static Open**	**Recess Static Closed**	**Recess Heat Extract**	**Surface Closed Uninsul.**	**Surface Closed Insulated**	**Surface Open Uninsul.**	**Surface Open Insulated**	**Suspend. Closed**	**Suspend. Open ANSI**
F40T12 Lamps, Reduced Output Heater Cutout Ballast, Ballast Factor: 0.83									
Application Correction Factor	0.79	0.79	0.92	0.83	0.79	0.83	0.80	0.83	0.83
Input Watts									
4 lamps (2) ballasts	127	125	137	125	118	135	131	127	138
3 lamps (T) ballasts	95	94	103	94	89	102	99	95	104
2 lamps (1) ballast	63	63	68	633	59	68	65	63	69
F40T12 Lamps, Full Light Output Heater Cutout Ballast , Ballast Factor: 0.95									
Application Correction Factor	0.91	0.91	1.05	0.95	0.90	0.95	0.92	0.95	0.95
Input Watts									
4 lamps (2) ballasts	147	145	158	145	137	157	152	147	160
3 lamps (T) ballasts	110	109	119	109	103	118	114	110	120
2 lamps (1) ballast	73	73	79	73	68	78	76	73	80
34-Watt F40T12/ES Lamps, Reduced Output Heater Cutout Ballast, Ballast Factor: 0.81									
Application Correction Factor	0.79	0.77	0.88	0.81	0.77	0.81	0.81	0.81	0.81
Input Watts									
4 lamps (2) ballasts	113	110	116	113	109	116	116	113	116
3 lamps (T) ballasts	85	83	87	85	82	87	87	85	87
2 lamps (1) ballast	57	55	58	57	54	58	58	57	58
34-Watt F40T12/ES Lamps, Full Light Output Heater Cutout Ballast, Ballast Factor: 0.88									
Application Correction Factor	0.86	0.84	0.96	0.88	0.84	0.88	0.88	0.88	0.88
Input Watts									
4 lamps (2) ballasts	129	126	132	129	124	132	132	129	132
3 lamps (T) ballasts	97	94	99	97	93	99	99	97	99
2 lamps (1) ballast	64	63	66	64	62	66	66	64	66

Notes:
(T) = Tandem wiring for 3-lamp luminaires
3-lamp luminaires have 1 single lamp ballast and 1 double-lamp ballast

Figure 3-17 (continued)

Luminaire System Performance -- Full-Size Fluorescent Lamps
(Electronic Rapid Start Ballasts)

Luminaire Type	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Luminaire Description	**Recess Static Open**	**Recess Static Closed**	**Recess Heat Extract**	**Surface Closed Uninsul.**	**Surface Closed Insulated**	**Surface Open Uninsul.**	**Surface Open Insulated**	**Suspend. Closed**	**Suspend. Open ANSI**
F40T12 Lamps, Electronic "Standard" Rapid Start Ballast, Ballast Factor: 0.88									
Application Correction Factor	0.85	0.85	0.96	0.88	0.84	0.88	0.87	0.88	0.88
Input Watts:									
4 lamps (2) ballasts	136	133	142	133	125	143	140	136	144
3 lamps (1) ballast	101	99	106	99	93	106	104	101	107
2 lamps (1) ballast	68	67	71	67	63	72	70	68	72
34-Watt F40T12/ES Lamps, Electronic "Standard" Rapid Start Ballast, Ballast Factor: 0.85									
Application Correction Factor	0.87	0.85	0.94	0.88	0.84	0.88	0.88	0.88	0.88
Input Watts:									
4 lamps (2) ballasts	124	120	126	122	118	125	126	124	124
3 lamps (1) ballast	90	87	91	89	86	91	91	90	90
2 lamps (1) ballast	62	60	63	61	59	63	63	62	62
F32T8 Lamps, Electronic "Standard" Rapid Start Ballast, Ballast Factor; 0.88[TT16]									
Application Correction Factor	0.86	0.84	0.95	0.88	0.84	0.88	0.88	0.88	0.88
Input Watts									
4 lamps (1) ballast	116	111	122	114	108	123	121	116	124
3 lamps (1) ballast	87	83	92	86	81	93	91	87	93
2 lamps (1) ballast	58	55	61	57	54	62	60	58	62
FB40T12 Lamps, Electronic "Standard" Rapid Start Ballast, Ballast Factor 0.84									
Application Correction Factor	0.81	0.81	0.91	0.84	0.80	0.84	0.83	0.84	0.84
Input Watts									
3 lamps (1) ballast	94	93	99	93	87	99	98	94	100
2 lamps (1) ballast	63	62	66	62	58	67	65	63	67
FT40W/2G11 Twin-Tube T-5 Lamps, Electronic Rapid Start Ballast, Ballast Factor 0.83									
Application Correction Factor	0.81	0.79	0.90	0.83	0.79	0.83	0.83	0.83	0.83
Input Watts									
4 lamps (2) ballasts	133	127	140	131	123	141	138	133	142
2 lamps (1) ballast	67	64	70	65	62	71	69	67	71
FT50W/2G11 Twin-Tube T-5 Lamps, Electronic Rapid Start Ballast, Ballast Factor: 0.97									
Application Correction Factor	0.95	0.93	1.05	0.97	0.92	0.97	0.97	0.97	0.97
4 lamps (2) ballasts	199	190	209	195	184	211	206	199	212
2 lamps (1) ballast	99	95	104	98	92	105	103	99	106

Figure 3-17 (continued)

Luminaire System Performance -- Full-Size Fluorescent Lamps
(Electronic Instant Start & Electronic Reduced Output Lamps)

Luminaire Type	A	B	C	D	E	F	G	H	I
Luminaire Description	Recess Static Open	Recess Static Closed	Recess Heat Extract	Surface Closed Uninsul.	Surface Closed Insulated	Surface Open Uninsul.	Surface Open Insulated	Suspend. Closed	Suspend. Open ANSI
F32T8 Lamps, Electronic Instant Start Ballast, Ballast Factor: 0.95									
Application Correction Factor	0.93	0.91	1.03	0.95	0.90	0.95	0.95	0.95	0.95
Input Watts:									
4 lamps (1) ballast	116	111	122	114	108	123	121	116	124
3 lamps (1) ballast	90	86	94	88	83	96	93	90	96
2 lamps (1) ballast	59	56	62	58	55	63	61	59	63
FB31T8 Lamps, Electronic Instant Start Ballast, Ballast Factor: 0.95/0,92									
Application Correction Factor	0.93	0.91	1.03	0.95	0.90	0.95	0.95	0.95	0.95
Input Watts:									
3 lamps (1) ballast	83	79	87	81	76	88	86	83	88
Application Correction Factor	0.90	0.88	0.99	0.92	0.87	0.92	0.92	0.92	0.92
Input Watts:									
2 lamps (1) ballast	57	55	60	56	53	61	59	57	61
F40T12 Lamps, Electronic Reduced Output Rapid Start Ballast, Ballast Factor: 0.71/0.73									
Application Correction Factor	0.69	0.69	0.77	0.71	0.68	0.71	0.70	0.71	0.71
Input Watts:									
3 lamps (1) ballast	85	83	89	83	78	90	88	85	90
Application Correction Factors	0.71	0.71	0.79	0.73	0.70	0.73	0.72	0.73	0.73
Input Watts:									
2 lamps (1) ballast	57	57	60	57	53	61	59	57	61
F32T8 Lamps, Electronic Reduced Output Rapid Start Ballast, Ballast Factor: 0.71/0.73									
Application Correction Factor	0.71	0.70	0.79	0.73	0.69	0.73	0.73	0.73	0.73
Input Watts:									
3 lamps (1) ballast	71	68	75	70	66	76	74	71	76
Application Correction Factor	0.70	0.68	0.77	0.71	0.67	0.71	0.71	0.71	0.71
Input Watts									
2 lamps (1) ballast	48	46	50	47	44	51	50	48	51

Figure 3-18

Luminaire System Performance -- Compact Fluorescent Lamps

Luminaire Type / Luminaire Description	J Recess Unvent Base Up	K Recess Vented Base Up	L Recess Unvent Horiz.	M Recess Vented Horiz.	N Surface Closed Uninsul.	O Surface Closed Insul.	P Wall Open Uninsul.	Q Wall Closed Jar	R Free Air ANSI Table
9 Watt Twin-Tube Lamps, 120 Volt Standard Reactor Ballast, Ballast Factor: 0.85									
Application Correction Factor	0.82	0.84	0.81	0.84	0.83	0.80	0.83	0.83	0.85
Input Watts									
1 lamp (1) ballast	13	13	13	13	13	13	13	13	13
2 lamps (2) ballasts	26	26	25	26	25	25	26	26	26
13 Watt Twin-Tube Lamps, 120 Volt Standard Reactor Ballast, NPF, Ballast Factor: 0.90									
Application Correction Factor	0.87	0.89	0.85	0.89	0.88	0.84	0.88	0.88	0.90
Input Watts									
1 lamp (1) ballast	16	16	16	16	16	16	16	16	16.5
2 lamps (2) ballasts	32	33	32	33	32	32	33	32	33
13 Watt Quad-Tube Lamps, 120 Volt Standard Reactor Ballast, NPF, Ballast Factor: 0.90									
Application Correction Factor	0.87	0.89	0.85	0.89	0.88	0.84	0.88	0.88	0.90
Input Watts									
1 lamp (1) ballast	16	16	16	16	16	16	16	16	16.5
2 lamps (2) ballasts	32	3	32	33	32	32	33	32	33
26 Watt Quad-Tube Lamps, 277 Volt Standard Reactor Ballast, HPF, Ballast Factor: 0.90									
Application Correction Factor	0.87	0.89	0.85	0.89	0.88	0.84	0.88	0.88	0.90
Input Watts									
1 lamp (1) ballast	32	33	32	33	32	32	33	32	33
2 lamps (2) ballasts	65	65	64	65	64	64	65	65	66
26 Watt Quad-Tube Lamps, 277 Volt Electronic Ballast, Ballast Factor 0.90									
Application Correction Factor	0.88	0.89	0.86	0.89	0.88	0.85	0.88	0.88	0.90
Input Watts									
1 lamp (1) ballast	24	25	24	25	24	24	25	24	27
2 lamp (2) ballasts	49	51	48	50	48	47	51	49	54

Notes:
(1) = 1 ballast per luminaire
(2) = 2 ballasts per luminaire

Guideline Specifications

Lighting specifications for luminaires should be carefully written to avoid the substitution of inferior products that might sacrifice in energy savings. A good specification can insure the quality and energy efficiency of the lighting design.

Proprietary and "Three-Name" Specifications

There are two methods of specifying luminaires. The easiest way is to give the make and model number of the luminaire in the lighting fixture schedule. This type of specification is often called a proprietary specification because the basis of the specification is a certain manufacturer's product.

Most governmental agencies and corporations require that more than one product be listed. Often, at least three "equal" products must be listed. Since many "advanced" products are not generic, most agencies allow the specifier to list only the one product -- the one which served as the basis of design -- provided that the specifier can demonstrate that the product is unique, and that the specifier has no vested interest.

Performance Specifications

Instead of specifying a product by name, it is possible to specify a product by thoroughly describing its performance characteristics. Key identifying characteristics are the photometric curves of the luminaire. Like fingerprints, photometric data are virtually unique to each luminaire. Characteristics may include coefficient of utilization, efficiency, distribution patterns, and candlepower at specific angles. It is especially important to use a performance specification in cases where visual performance may be impaired by poor luminaire characteristics as in, for example, VDT areas.

It is also advisable to include construction parameters when writing a performance specification. Material gauge, construction method, tolerances, and other quality factors should be included to prevent substitution by photometrically correct but otherwise inferior products.

The performance specification should require certified test data from an independent laboratory using IES or ANSI recommended testing methods. In the highly competitive business of luminaire manufacturing, very few designs are successfully patented, and inferior "knock-off" products are frequently substituted for a well-engineered luminaire. A cheap copy may be acceptable as long as it performs as well as the original, although construction quality may be reduced causing higher maintenance costs.

Resources

The Illuminating Engineering Society of North America (IESNA) regularly lists luminaire product offerings complete with lists of features and vendors. Write to IESNA at 345 East 47th Street, New York, NY 10017, or refer to the IESNA publication *Lighting Design + Application* (LD + A), a periodical having an annual directory of lighting equipment, including luminaires. Other notable lighting publications with product offerings include *Architectural Lighting*, *Record Lighting* and *Lighting Dimensions.*

Figure 3-19
Sample Specification for Project XYZ

Tag	Description	Lamps	Ballast	Input Watts	Volts	Product
F1	Recessed parabolic troffer 2' X 4', 3" deep 18 cell specular clear louver, black floating door, slotted grid NEMA NFSG mechanical unknown	(3)F32T8/ RE735	ES. magnetic 265 MA or as approved	70	277	ABC-123-3F32-ES-GT-277 DEF-345-3F32-ES-GT-277 GHI-678-ES-GT-S-332-277
F2	F2 Suspended uplight continuous aluminum extruded housing in painted finish to match architect's sample. Sample 18" stem with earthquake ball side lens layout and lengths per plans	(2)F32T8/ RE735 per each 4' length	Instant start electronic 2-lamp or 4-lamp as required TTT 440 series	56	277	JKL-F32-LENGTHS

Note: This example shows a type "F1" for which at least three possible products exist which are known to meet the designer's specifications. The type "F2" is a unique product.

Energy-Efficient Fluorescent Ballasts

1993 Advanced Lighting Guidelines

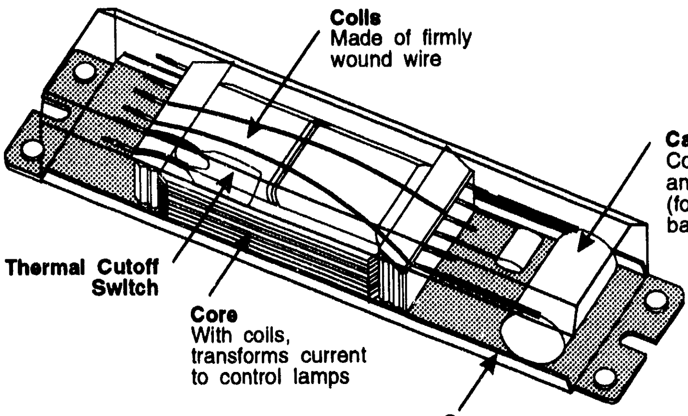


Figure 4-1
Typical Electromagnetic Fluorescent Ballast

Contents

Introduction

Recent advances in fluorescent lamp ballast technology have created opportunities for improved lamp performance and increased energy efficiency. Relatively new products, such as electronic high-frequency and heater cutout ballasts, are now widely available and accepted in the marketplace. The recent trend toward more competitive pricing of these products should continue, due to an expansion of manufacturing facilities and more competition between manufacturers. Energy-efficient ballasts are an excellent energy-saving strategy that should not be overlooked by anyone who is interested in saving money through the use of efficient lighting products.

The most prevalent fluorescent lamps for general commercial lighting today continue to be the rapid start 4-foot lamp (F40T12) and the instant start, 8-foot, "slimline" (F96T12). However, the more efficacious, smaller diameter F32T8 lamp is gaining in popularity in general lighting applications and as an energy-efficient replacement for standard lamps. This guideline mainly addresses electronic ballasts that operate full-size fluorescent lamps at high frequencies, but it also covers energy-efficient magnetic ballasts with heater-cutout circuits that switch off a lamp's electrode heaters after startup.

Technology Description

All gas discharge lamps, including fluorescent lamps, require a ballast to operate. The ballast provides a high initial voltage to initiate the discharge, then rapidly limits the lamp current to safely sustain the discharge. Lamp manufacturers specify lamp electrical input characteristics (lamp current, starting voltage, current crest factor, etc.) required to achieve rated lamp life and lumen output specifications. Similarly, the American National Standards Institute (ANSI) publishes recommended lamp input specifications for all ANSI type lamps. Ballasts are designed to optimally operate a unique lamp type; however, some ballasts will adequately operate more than one type of lamp. In these cases, optimum lamp performance is generally not achieved under all conditions. Less than optimum conditions may affect the lamp's starting characteristics, light output, and operating life.

Circuit Type and Operating Mode

Fluorescent ballasts are manufactured for three primary types of fluorescent lamps: preheat, rapid start, and instant start.

- *Preheat Operation* Lamp electrodes are heated prior to initiating the discharge. A 'starter switch' closes, permitting a current to flow through each electrode. The starter switch rapidly cools down, opening the switch, and triggering the supply voltage across the arc tube, initiating the discharge. No auxiliary power is applied across the electrodes during operation.
- *Rapid Start Operation* Lamp electrodes are heated prior to and during operation. The ballast transformers has two special secondary windings to provide the proper low voltage to the electrodes.
- *Instant Start Operation* Lamp electrodes are not heated prior to operation. Ballasts for instant start lamps are designed to provide a relatively high starting voltage (with respect to preheat and rapid start lamps) to initiate the discharge across the unheated electrodes.

Rapid start is the most popular mode of operation for 4-foot 40 watt lamps and high output 8-foot lamps. The advantages of rapid start operation include smooth starting, long life, and dimming capabilities. Lamps of less than 30 watts are generally operated in the preheat mode. Lamps operated in this mode are more efficient than the rapid start mode as separate power is not required to continuously heat the electrodes. However, these lamps tend to flicker during starting and have a shorter lamp life. Eight-foot 'slimline' lamps are operated in instant start mode. Instant start operation is more efficient than rapid start, but as in preheat operation, lamp life is shorter. The 4-foot 32 watt F32T8 lamp is a rapid start lamp commonly operated in instant start mode with electronic high-frequency ballasts. In this mode of operation lamp efficacy is improved with some penalty in lamp life.

Energy Efficiency

Fluorescent lamps are reasonably efficient at converting input power to light. Nevertheless, much of the power supplied into a fluorescent lamp-ballast system produces waste heat energy.

There are three primary means of to improving the efficiency of a fluorescent lamp-ballast system:

- Reduce the ballast losses.
- Operate the lamp(s) at a high frequency.
- Reduce losses attributable to the lamp electrodes.

Newer, more energy-efficient ballasts, both magnetic and electronic, exploit one or more of these techniques to improve lamp-ballast system *efficacy*, measured in lumens per watt. The losses in magnetic ballasts have been reduced by substituting copper conductors for aluminum and by using higher grade magnetic components. Ballast losses may also be reduced by using a single ballast to drive three or four lamps, instead of only one or two. Careful circuit design increases efficiency of electronic ballasts. In addition, electronic ballasts, which convert the 60 Hz supply frequency to high frequency, operate fluorescent lamps more efficiently than is possible at 60 Hz. Finally, in rapid start circuits, some magnetic ballasts improve efficacy by removing power to the lamp electrodes after starting.

Figure 4-2
Ballast Terminology

***Ballast Efficacy Factor (BEF)*:** An efficiency factor defined in ballast regulations (state and federal) that is used to establish minimum efficiency levels for compliance. It equals the percent rated light output (ballast factor times 100%) of a particular lamp-ballast combination under ANSI test conditions divided by the measured input power in watts, (%/ watts). Ballast efficacy factors are significant only for comparing different ballasts operating the same quantity and type of lamp. Current federal and state regulations specify BEF limits for ballasts that operate standard F40T12 and F96T12 lamps.

Ballast Factor: The ratio of a lamp's light output on a ballast, compared to the lamp's rated light output, as measured on a reference ballast. Most ballast factors are less than one; some new ballast designs have ballast factors greater than one.

***Input Voltage*:** The design operating voltage of the ballast. In the US, most ballasts are designed to operate at either 120 or 277 volts.

***Lamp-Ballast System Efficacy*:** The ratio of lamp light output to ballast input watts, in units of lumens/watt.

Lamp Current Crest Factor (LCCF): The ratio of the peak current to the root mean square (RMS) lamp current. The LCCF for lamps operated at high frequency is equal to the peak current of the modulated wave (60 Hz) divided by the RMS lamp current. High current crest factors reduce lamp life. The rated lamp life of 20,000 hours for rapid start F40T12 lamps is based on a LCCF of 1.7 or less.

***Line Current Amps*:** The current drawn by the ballast when operating at rated voltage.

***Power Factor*:** The ratio of power (watts) to RMS volt-amps of the ballast. The power factor ratio may be used to determine how efficiently total input power is being used. A High Power Factor (HPF) rating signifies a ballast power factor equal to or greater than 0.90. This HPF rating is most desirable. A Low or Normal Power Factor (NPF) ballast rating signifies a power factor less than .90 -- usually between .40 and .70. Utilities may penalize customers whose electric load has a low power factor.

***Regulation* (of line voltage):** The ability of the system light output to adjust for input voltage variations. Generally expressed as a percentage variation in light output of a lamp for a percentage variation in input voltage.

Volt-Amps: The apparent power of a system. It is equal to RMS of voltage times RMS of current.

Ballast Factor

One of the most important ballast parameters for the lighting designer/engineer is the ballast factor. The ballast factor is needed to determine the light output for a particular lamp-ballast system. Ballast factor is a measure of the actual lumen output for a specific lamp-ballast system relative to the rated lumen output measured with a reference ballast under ANSI test conditions (open air at 25 °C [77 °F]). An ANSI ballast for standard 40-watt F40T12 lamps requires a ballast factor of 0.95; the same ballast has a ballast factor of 0.87 for 34-watt energy saving F40T12 lamps. However, many ballasts are available with either high (conforming to the ANSI specifications) or low ballast factors (70 to 75%). It is important to note that the ballast factor value is not simply a characteristic of the ballast, but of the lamp-ballast system. Ballasts that can operate more than one type of lamp (e.g., the 40-watt F40 ballast can operate either 40-watt F40T12, 34-watt F40T12, or 40-watt F40T10 lamps) will generally have a different ballast factor for each combination (e.g., 95%, <95%, and >95%, respectively).

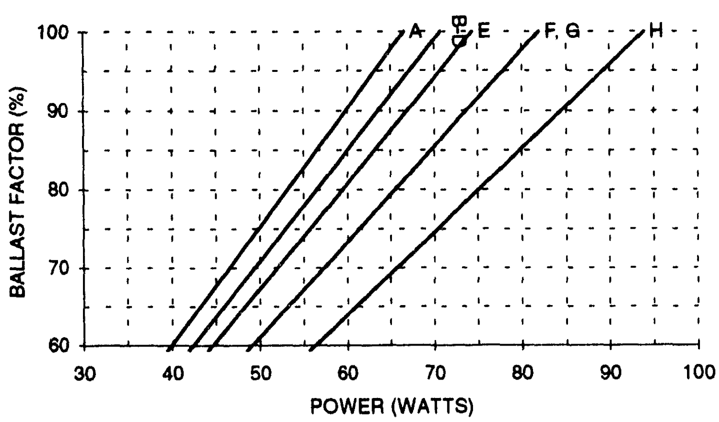
Ballast factor is not a measure of energy efficiency. Although a lower ballast factor reduces lamp lumen output, it also consumes proportionally less input power. As such, careful selection of a lamp-ballast system with a specific ballast factor allows designers to

Figure 4-3

*Power vs. Ballast Factor Curves for 2-lamp 4-Foot Fluorescent Lamp-Ballast Systems**

To use the graph, locate the curve (a-h) for the lamp-ballast system of interest. Draw a vertical line from the cited input power to that curve. Draw a horizontal line from that point to the vertical axis to find the ballast factor for that lamp-ballast system. It is essential that the input power cited by the manufacturer be measured under standard ANSI test conditions.

*Note: This graph is applicable only for 2-lamp 4-foot systems; other lamp-ballast systems will differ.



A 32W F32T8 IS electronic ballast
B 32W F32T8 RS elect. ballast
C 34W F40T12 RS elect. ballast
D 40W F40T12 RS htr. cut. ballast
E 32W F32T8 RS magnetic ballast
F 40W F40T12 RS elect. ballast
G 34W F40T12 RS mag. ballast
H 40W F40T12 RS mag. ballast

better minimize energy use by "tuning" the lighting levels in the space. For example, in new construction, high ballast factors are generally best, since fewer luminaires will be required to meet the light level requirements. In retrofit applications or in areas with less critical visual tasks, such as aisles and hallways, lower ballast factor ballasts may be more appropriate.

To avoid a drastic reduction in lamp life low ballast factor ballasts (<70%) should operate lamps in rapid start mode only. This is particularly relevant for 32-watt F32T8 lamps operated at high frequency.

Finding the ballast factor for lamp-ballast combinations may not be easy, as few ballast manufacturers provide this information in their catalogs. However, if the input power for a particular lamp-ballast system is known (usually found in catalogs) an estimate of the ballast factor is possible. Figure 4-3 provides a set of curves for determining the ballast factor for several two-lamp four-foot lamp-ballast systems. It is based upon the average system efficacy measured for ballasts at standard ANSI conditions.

Lamp-Ballast System Efficacy

The efficiency of a fluorescent lamp ballast changes depending on the type of lamp operated. Similarly, lamp efficacy is affected by ballast technology: the same lamp will perform differently when operated by a heater cutout ballast than it will when operated at high frequency. As a consequence, the only meaningful comparison between lamps or ballasts is the lamp-ballast system efficacy. The system efficacy can be calculated as follows:

System Efficacy (lumens / watt)

$$= \frac{\text{Rated Lamp Lumens}}{\text{Input Power (Watts)}} \times \text{Number of Lamps} \times \text{Ballast Factor}$$

The above equation calculates initial system efficacy as measured under ANSI test conditions. More comprehensive estimates of overall lighting system efficacy can be performed by using data from Figure 3-17 in the *Luminaires and Lighting Systems* guideline, which takes into account luminaire effects on light output and input wattage.

Figure 4-4 shows how lamp-ballast system performance changes with a simple substitution of ballast. This table is based on two common lamp types: a 34-watt energy saving F40T12/ES and a 32-watt F32T8. Both are RE-70 lamps in which rare earth phosphors are used to produce a color rendering index of between 70 and 79 (See the *Full-Size*

Figure 4-4

Comparative Fluorescent Lamp-Ballast Systems

Ballast Type	Typical Input Power (W)	Typical Ballast Factor	System Efficacy (Lumens/Watt)
Two 34 Watt F40T12/RS ES Lamps, 2800 Initial Rated Lumens, RE-70			
Magnetic Energy Efficient	72	0.87	68
Magnetic Heater Cutout	58	0.81	78
Magnetic Heater Cutout--Full Light Output[1]	66	0.88	75
Electronic Ballast A	60	0.85	79
Electronic Ballast B	63	0.82	73
Two 32 Watt F32T8/RS Lamps, 2900 Initial Rated Lumens, RE-70			
Magnetic Energy Efficient	70	0.94	78
Magnetic Heater Cutout	61	0.86	82
Magnetic Heater Cutout--Full Light Output[2]	n.a.	n.a.	n.a.
Electronic Ballast Rapid Start	62	0.88	82
Electronic Ballast Instant Start	63	0.95	87

Notes:
(1) New product at the time of this printing.
(2) New product for which values were unavailable at the time of printing.
All values are as measured under ANSI testing conditions

Fluorescent Lamps guideline for a discussion of lamp phosphors). With electronic ballasts, the input watts are significantly lower. In some cases, the ballast factor is also higher. Figure 4-8 has more detail on these systems, and includes other systems as well.

Ballast Efficacy Regulations

Beginning in 1982, the State of California began regulating the performance of ballasts operating the most common types of fluorescent lamps. Several other states followed suit, and subsequently, the Federal Appliance Standard prohibited the issue of inefficient ballasts, beginning April 1, 1992. In order to assess ballasts that operated lamps at different light levels the regulations were based upon the Ballast Efficacy Factor (BEF), defined as ballast factor/input power. The regulations set minimum BEF limits for the following type ballasts:

- Two-lamp ballasts for 75-watt F96T12 slimline lamps
- Two-lamp ballasts for 110-watt F96T12 high output lamps
- One-lamp ballasts for F40T12 rapid start lamps
- Two-lamp ballasts operating F40T12 rapid start lamps

BEF criteria are not required for either low temperature or dimming ballasts.

BEF was selected as a measure to allow meaningful comparisons between different ballasts by eliminating lamp variations as a factor. The BEF metric is used solely to show compliance with the state and federal ballast efficacy regulations. *It should not be used as a ballast specification criterion.* The BEF is not a true measure of ballast efficiency as its value depends on the following factors:

- Quantity of lamps operated
- Type of gas fill in the lamp (i.e. argon vs. argon/krypton fill)
- Lamp tube diameter (T-8, T-10, T-12)
- Lamp operating frequency

Some ballast manufacturers provide BEF data in their catalogs, but it is only of value when comparing ballasts operating the same type and number of lamps. In general, BEF values are not particularly useful to the specifier; the best method of comparing lamp-ballast systems is by their system efficacy.

Flicker

Electromagnetic ballasts are designed to condition the 60 Hz input voltage to the electrical requirements of the lamps. A magnetic ballast alters the voltage, but not the frequency. Thus, the lamp voltage crosses zero 120 times each second, resulting in 120 Hz light output oscillations. This results in about 30% flicker for standard halophosphor lamps, operated at 60 Hz. The flicker is generally not noticeable but there is evidence that flicker of this magnitude can cause adverse effects, such as eyestrain and headache.

Most electronic ballasts, on the other hand, use high-frequency operation, which reduces lamp flicker to an essentially imperceptible level. The flicker percentage of a particular ballast is usually specified by the manufacturer. For a given ballast, the percent flicker will be a function of lamp type and phosphor composition.

Audible Noise

One characteristic of iron-cored electromagnetic ballasts operating at 60 Hz, is the generation of audible noise. Noise can be increased by high temperatures, and it is amplified by certain luminaire designs. The best ballasts use high quality materials and workmanship to reduce noise. Noise is rated A, B, C, or D in decreasing order of preference. An "A" rated ballast will hum softly; a "D" rated ballast will make a loud buzz. The number of ballasts, their sound rating, and the nature of ambient noise in the room determine whether or not a system will create an audible disturbance.

Virtually all energy-efficient magnetic ballasts for F40T12 and F32T8 lamps are "A" rated, with a few exceptions, such as low temperature ballasts. Still, the hum of magnetic ballasts may be perceptible in a particularly quiet environment such as a library. Well-designed electronic high-frequency ballasts, on the other hand, should emit no perceptible hum. All electronic ballasts are "A" rated for sound.

Dimming

Unlike incandescent lamps, fluorescent lamps cannot be properly dimmed with a simple wallbox device such as those used for incandescent lamps. For a fluorescent lamp to be dimmed over a full range without a reduction in lamp life, its electrode heater voltages must be maintained while the lamp arc current is reduced. As such, lamps operated in rapid start mode are the only fluorescent lamps suitable for wide-range dimming applications. The power required to keep electrode voltage constant over all dimming conditions means that dimming ballasts will be less efficient when operating lamps at dimmed levels.

Dimming ballasts are available in both magnetic and electronic versions, but there are distinct advantages to using electronic dimming ballasts. To dim lamps, magnetic dimming ballasts require control gear containing expensive high power switching devices that condition the input power delivered to the ballasts. This is economically viable only when controlling large numbers of ballasts on the same branch circuit. In addition, luminaires must be controlled in large zones that are determined by the layout of the electrical distribution system. Since the distribution system is fixed early in the design process, control systems using magnetic dimming ballasts are inflexible and are unable to accommodate changes in usage patterns.

Dimming of electronically-ballasted lamps, on the other hand, is accomplished within the ballast itself. Electronic ballasts alter the output power to the lamps by a low-voltage signal into the output circuit. High power switching devices to condition the input power is not required. This allows control of one or more ballasts independent of the electrical distribution system. With dimming electronic ballast systems, a low voltage control network can be used to group ballasts together into arbitrarily-sized control zones. This control network may be added during a building renovation or even, in some circumstances, during a lighting retrofit. Low voltage wiring does not have to be run in conduit, which helps keep installation costs down. In addition, it is less costly to modify the size and extent of lighting zones by reconfiguring low voltage wiring when usage patterns change. Low voltage wiring is also compatible with photocells, occupant sensors, and energy management system (EMS) inputs.

Dimming range differs greatly among ballasts. With most electronic dimming ballasts, light levels can vary between full output and a minimum of about 10% of full output. However, electronic, full-range dimming ballasts are also available that operate lamps down to 1% of full lumen output. Magnetic dimming ballasts also offer many dimming options, including full-range dimming.

Harmonics

When a current or voltage wave shape deviates from the ideal (sinusoidal), current or voltage harmonics are produced. Harmonics are sinusoidal voltages or currents that are higher multiples of the fundamental frequency. For example the harmonics of 60 Hz are 60 Hz, 120 Hz, 180 Hz, etc., representing the first (fundamental), second, third, etc. multiples. Fluorescent ballasts affect the current, as opposed to the input voltage; in the process, current harmonics are generated. The amplitude of these harmonics are expressed as a percentage of fundamental.

Recently electrical utilities have been concerned with the growing use of electrical equipment that generates harmonics. Such equipment may include variable speed drives, uninterruptable power supplies, personal computers, and electronic ballasts. Any circuit that is nonlinear (e.g. a gas discharge lamp), uses rectifying circuits, or uses high speed switching systems will generate harmonics. If any one or combination of the above systems makes up a significant portion of a building's electrical load, the following undesirable effects may result:

- Overloading of transformers

- Adding of current to the neutral in three phase electrical distribution systems
- Current/voltage surges and/or spikes due to circuit resonances with one or more of the harmonic frequencies
- Interference with electrical equipment or communications on the same circuit
- Distortion of the electrical service entrance voltage with accompanying adverse effects on the performance of other electrical equipment in the building

Harmonic Distortion and Electronic Ballasts

When electronic high-frequency ballasts were first introduced in the early 1980s, some models generated relatively high line harmonics. Nevertheless, at that time, harmonic currents produced by lighting equipment and other electronic systems were not, as yet, a utility issue. However, by the mid-1980's, utilities and power engineers were becoming increasingly more concerned about power equipment that generated line harmonics.

The harmonics issue first surfaced as a concern to the professional lighting community when a major utility announced that electronic ballasts were required to have total harmonic distortion (THD) of less than 20% of the fundamental in order to qualify for their rebate program. Electronic ballast manufacturers responded to the utility's requirement by employing passive filtering that met the 20% limit at a slightly higher cost to the end user.

To help understand the issue, it is of interest to examine and compare the harmonics generated by *magnetic* ballasts. The harmonics for some magnetic ballasts exceed the 20% limit, and have been measured at levels over 37%. This suggests that there are presently many magnetic ballasts in use that exceed the 20% THD limit. These ballasts have not been known to cause any problems with the electrical distribution where they are installed, further suggesting that the choice of a 20% limit on THD may be arbitrarily conservative. In any case, most electronic ballast manufacturers now make electronic ballasts that are well under the 20% limit.

ANSI Harmonic Standards for Electronic Ballasts

The Fluorescent Lamp and Ballast Committees of ANSI are proposing updated harmonics standards for electronic ballasts. These will be consensus standards that consider the harmonic levels found for all ballasts in the field. These figures are summarized in Figure 4-5. The proposed standards are intended to provide guidance for ballast developers and manufacturers, and they are based on the absence of reported problems associated with existing magnetically-ballasted products. The proposed ANSI standards are slightly more restrictive than existing European harmonic standards (IEC 555).

Third Harmonics of Current Electronic Ballasts

Figure 4-6 lists test results for the third harmonics (potentially disruptive 180 Hz currents that add upon the three phase neutral) of several electronic ballasts now on the market. There are electronic ballasts that have third harmonic levels below 20% and 10%. Harmonic levels of 20% are achieved by passive filtering devices, such as chokes, resistors and capacitors. Active filters, such as integrated circuits and other semi-conductive devices can reduce harmonics down to well under 10%.

While both electronic and magnetic fluorescent lamp ballast generate harmonics one should understand that it is a systems problem. The potential for adverse effects in a given building primarily depends upon the size of the load imposed by harmonics-generating devices as a proportion of the total building load. The current harmonics (triplens) for fluorescent ballasts in three phase distribution systems (e.g., branch circuits) are 120° out of phase and will add on the neutral wire.

Figure 4-5

ANSI Proposed Harmonic Standards for Electronic Ballasts

Fundamental	100%
Second Harmonic (maximum)	5%
Third Harmonic (maximum)	30%
Individual Harmonics >Eleventh	7%
Sum of Odd Triplens[1]	30%
Distortion Factor[2]	32%

(1) Square root of sum of squares of 3rd, 9th, 15th, 21st, etc. harmonics.
(2) Square Root of sum of square of all harmonics (not including the fundamental.

Figure 4-6

Measured Third Harmonics from 1991 Electronic Ballasts

Ballast	Lamp Type 40W F40T12	32W F32T8	75W F96T12
A	6%	3%	15%
B	29%	23%	34%
C	17%	27%	30%
D	5%	33%	22%

Data collected from unpublished measurements made at the Lighting Research Laboratory at Lawrence Berkeley Laboratories.

Other Harmonics Research

At the present time, data is being collected by the Electric Power Research Institute (EPRI) to measure the voltage distortion at the service entrance of buildings that are lighted with electronically-ballasted fluorescent lamps. While the proposed ANSI standards appear to be adequate at the present time, the data currently being collected should determine whether or not future lighting equipment should require more stringent harmonic limits. The new limits would take into consideration the relative contribution of lighting to the total electrical load in relation to the expanded use of other equipment (personal computers, variable speed drives, microwave equipment, etc.) that also generates line harmonics.

K-Factor and Harmonic Distortion

K-Factor is a metric used for electrical transformer design that accounts for non-sinusoidal currents (i.e. currents that cause harmonics). These line currents generate higher eddy currents than a pure 60 Hz sinusoidal fundamental. Eddy currents cause transformers to operate at higher temperatures, increasing losses. To reduce the effect of eddy currents, transformer manufacturers use secondary windings consisting of well-insulated, multiple wire strands. This increases the resistance of those windings, helping to limit the flow of eddy currents.

Until recently, engineers rarely specified K-factors for transformers. However, it is recommended that electrical engineers designing lighting distribution systems calculate the K-Factor from the known harmonic distortion generated by the lamp-ballast system under consideration. This figure should be available from the ballast manufacturer. ANSI/IEEE 57.110-1986 is the recommended practice for establishing transformer capability for non-sinusoidal line currents, and it contains the equations for calculating K-Factor. Transformers with K-Factors of 1, 4, 9, 13 and 20 are standard products. Transformers with K-Factors of 4 or less are usually sufficient for lighting systems.

Harmonic Distortion and Power Factor

As was noted in Figure 4-2, utilities are concerned with low power factors because end users draw higher currents for the power that they are using.. Ideally, lighting equipment should have a power factor greater than 0.9 and as close to 1.0 as possible. Power factors of less than 1.0 occur when the voltage and current are out of phase and/or when the sinusoidal wave shape is distorted. Harmonic currents generated by electronic ballasts reduce power factor due to a distorted current wave shape. (Harmonic currents produced by other types of electronic equipment can also lower the power factor by producing a phase shift between the voltage and current.)

Electronic ballast manufacturers now make a habit of publishing the percentage of total harmonic distortion (THD) produced by their products. This allows a lighting professional to quantify how the installation of electronic ballasts in a building will affect power factor. Electrical distribution wiring may be sized accordingly. The relationship between power factor and total harmonic distortion with no voltage-current phase shift may be determined as follows:

$$\text{Power Factor} = \sqrt{\frac{1}{1+\text{THD}^2}}$$

As long as there is no voltage-current phase shift contribution to the power factor, THD may be as high as 48% and maintain a power factor of over 0.90.

Reliability of Electronic Ballasts

The reliability of electronic ballasts has been questioned since their introduction in 1981. Some manufacturers' initial products failed prematurely. Those manufacturers who were unable to improve their products are no longer producing electronic ballasts. Other manufacturers have been in production over ten years with documented ballast failure rates of less than 1% after five years of operation. At this time, it is apparent that long term usage has demonstrated the reliability of electronic ballasts.

A main reason for the questioning of the reliability of electronic ballasts has been the lack of large scale, controlled, on-site data. However, in 1988, the University of California-Berkeley energy management group presented their findings on failures of electronic ballasts installed in a variety of campus buildings over a period of three and one-half years. Over 32,000 electronic ballasts were installed, supplied by three different manufacturers. (Source: R.S. Abesamis, et.al., "Field Experience with High-Frequency Ballasts", Trans. IEEE-IAS, 26, #5, 810, Sept./Oct. 1990.) Two of the manufacturers' ballasts had failure rates of less than 1% -- well within acceptable limits. The third manufacturer's ballasts had a 6% failure rate, and the company has since ceased manufacturing electronic ballasts. For comparison purposes, the general failure rate for 60 Hz magnetic ballasts is about 0.5%.

The results of the University of California case study clearly demonstrate that electronic ballast technology has advanced enough so that efficient, reliable electronic ballasts can be successfully designed and manufactured in large volume. Based on these findings, the University's ballast retrofit program was expanded, and a total of over 75,000 electronic ballasts have been installed at the campus, leading to considerable energy savings.

The above case study suggests that reliable electronic high-frequency ballasts can be produced with the quality control necessary to reach or exceed the ten to twelve year life span common with magnetic ballasts. Most ballast failures, when they do occur, will happen within the first six months of installation. Early ballast failures are usually due to either poor quality control in the manufacturing process or to incorrect installation procedures. Failures occurring after a normal "wear-out" period of ten to twelve years are usually due to the eventual degradation of the electrolytic capacitor.

Electronic ballast problems can be kept to a minimum if specifiers are diligent in their selection of ballast manufacturers. They should research the track records of manufacturers and obtain verification for the reliability of any new or unfamiliar products.

Current Products

There are two methods of improving the efficacy of fluorescent lamp-ballast systems. One involves a simple modification to the magnetic energy-efficient ballast; the other utilizes electronics to operate fluorescent lamps at a high frequency.

Heater Cutout (Hybrid) Ballasts

Heater or electrode cutout energy-efficient magnetic ballasts are equipped with an electronic circuit that removes the voltage to the electrode heaters in rapid start fluorescent lamps once the lamps are ignited and operating. (These are sometimes called "hybrid" ballasts, due to the electronic cutout circuit. They should not be confused with electronic ballasts that operate lamps at high frequency.) Most heater cutout ballasts consume about 16 fewer watts of input power (2-lamp 40-watt F40 system) than standard magnetic energy-efficient ballasts, but lumen output is reduced by around 12%. However, one manufacturer now offers a product that produces the same lumen output as does a magnetic energy-efficient ballast, while operating at 6 fewer watts in a 2-lamp F40 system.

Heater cutout ballasts are cost effective and energy efficient and will operate most straight tube rapid start F40 lamps. In addition a full light output heater cutout ballast for F32T8 lamps is now available. Heater cutout ballasts should only be used with rapid start lamps, and they should not be used in dimming applications. Some lamp manufacturers derate lamp life by 25% for heater cutout operation.

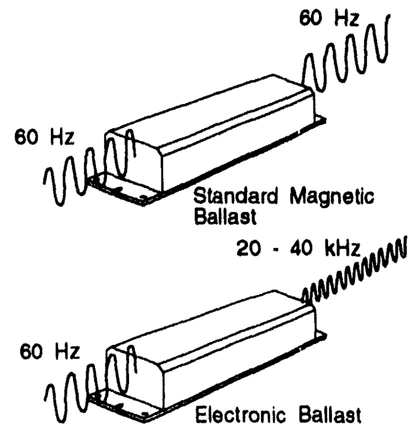


Figure 4-7
Magnetic & Electronic Ballasts

Electronic Ballasts

Electronic high-frequency ballasts increase lamp-ballast efficacy, leading to increased energy efficiency and lower operating costs. Electronic ballasts operate lamps using electronic switching power supply circuits. Electronic ballasts take incoming 60 Hz power (120 or 277 volts) and convert it to high-frequency AC (usually 20 to 40 kHz). Electronic ballasts are more efficient than magnetic ballasts in converting input power to the proper lamp power, and their operating of fluorescent lamps at higher frequencies reduces end losses, resulting in an overall lamp-ballast system efficacy increase of 15% to 20%.

Electronic ballasts have a number of other advantages over magnetic ballasts. Electronic ballasts are readily available that operate three or four lamps, allowing the use of a single ballast in 3-lamp and 4-lamp luminaires. This reduces both installation and field wiring labor costs, and may negate the necessity of tandem luminaire wiring as required by the 1992 *Energy Efficiency Standards for Residential and Nonresidential*

Buildings (Title 24). Electronic ballasts are designed to operate lamps in either series or parallel mode. The advantage of the parallel mode of operation is that a single lamp failure will not affect the operation of the remaining lamps controlled by the same ballast. However, ballast losses will increase slightly in the parallel mode. Other advantages of the electronic ballast include reduced weight, quieter operation, and reduced lamp flicker. Electronic ballasts are directly interchangeable with magnetic ballasts, and they are available to operate most full-size and compact fluorescent lamps. Electronic ballasts currently available include the following principal types. In most cases more than one manufacturer offers a product, and all types listed here are available at this time.

Rapid Start Electronic Ballasts

Rapid start electronic ballasts heat lamp electrodes continually during starting and operation. Ballasts are available for 1, 2, 3, and 4-lamp operation. Some ballasts will operate either T-8, T-10, or T-12 lamps. However, the ballast factor will not be constant for all lamp types, and lamp operation may not be in accordance with the lamp manufacturer's recommendations.

Instant Start Electronic Ballasts

Instant start electronic ballasts are available for the popular 75-watt F96T12 slimline lamps commonly used in many commercial applications. Ballasts are available for either one or two lamps. Instant start ballasts that operate rapid start T-8 lamps at full light output are also available. Although these lamps are rapid start, the lamp electrodes are never heated. This increases system efficacy. Lamp life is reduced by approximately 25% (for 20,000 hour lamps at three hours per start), but this is compensated for by increased energy efficiency. In most commercial applications, where lamps are operated at ten hours per start or longer, lamp life is only slightly reduced in comparison to rapid start operation.

Using occupant sensors with instant start lamp-ballast systems may cause an accelerated loss of lamp life for rapid cycle times. Rapid start lamp operation is usually a better choice in such applications.

Two-Level Electronic Ballasts

Two-level electronic ballasts increase the flexibility of standard electronic ballasts by allowing the light level to be switched between 50% and 100% of full light output. These ballasts may be used to meet the bi-level switching requirements in Title 24. Standard switches, occupant sensors, photocells, or other building energy management control devices may be used to switch the ballast. A two-level ballast is supplied with an additional input lead to allow the switching between 50% and 100% operation.

Adjustable Output (Dimming) Electronic Ballasts

Dimming electronic ballasts permit the light output of the lamp to be continuously controlled over a range of approximately 10% to 100% of full light output. A low voltage signal (usually between 0 and 10 volts) to the ballast output circuit modifies the current to the lamp. Dimming electronic ballasts are equipped with feedback circuits that maintain electrode voltage when the lamp current is reduced. This allows the lamp to be dimmed over a wide range without reducing lamp life. This dimming technique contrasts with that of magnetic ballasts in which input power to the ballast is modified to alter the lamp current, which also reduces electrode voltage. This limits the practical dimming range of lamp to about 50% of full light output.

Full Range Dimming Ballasts

A full dimming range of from 1% to 100% of full light output may be achieved through the use of premium-priced electronic ballasts designed for this purpose. At present, these ballasts are part of proprietary control systems.

Performance of Advanced Products

Typical performance characteristics of several energy-efficient lamp-ballast systems are illustrated in Figure 4-8. Of particular interest is the variation in the performance of ballasts operating the same types of lamps. This demonstrates the wide range of ballast choices available to lighting practitioners, allowing them to attain their lighting objectives more efficiently.

Figure 4-8

Typical Performance Values for Lamp-Ballast Systems (2-Lamp Systems)

Ballast Types	Lamp Watts (ea.)	Input Watts	Initial Lamp Lumens	Ballast Factor	System Efficacy
Pre-1990 ANSI/CBM Magnetic					
2-F40T12/RE70	40	96	3200	0.94	62
2-F40T12/ES/RE70	4	82	2800	0.87	59
Standard Energy-Efficient Magnetic					
2-F40T12/RE70	40	88	3200	0.94	68
2-F40T12/ES/RE70	34	72	2800	0.87	68
2-F40T10/RE80	42	92	3700	0.95	76
2-F32T8/RE70	32	70	2900	0.94	78
2-FT40W/2G11 (RE80)	40	86	3150	0.93	68
2-F96T12 Slimline/RE70	75	158	6425	0.94	76
2-F96T12HO/RE70	110	237	9200	0.94	73
Magnetic Heater Cutout					
2-F40T12/RE70	40	69	3200	0.83	77
2-F40T12/ES/RE70	34	58	2800	0.81	78
2-F40T10/RE80	42	74	3700	0.85	85
2-F32T8/RE70	32	61	2900	0.86	82
Full Light Output Magnetic Heater Cutout (New Product)					
2-F4012/RE70	40	80	3200	0.95	76
2-F40T12/ES/RE70	34	66	2800	0.88	75
Electronic Rapid Start					
2-F40T12/RE70	40	72	3200	0.88	78
2-F40T12/ES/RE70	34	62	2800	0.88	79
2-F40T10/RE80	42	74	3700	0.85	85
2-F32T8/RE70	32	62	2900	0.88	82
2-FT40W/2G11 (RE80)	40	71	3150	0.83	74
2-F96 HO/RE70	110	190	9200	0.81	78
Electronic 75% Reduced Output Rapid Start					
2-F40T12/RE70	40	61	3200	0.73	77
2-F40T12/ES/RE80	34	52	2800	0.73	79
2-F40T10/RE80	42	63	3700	0.73	86
2-F32T8/RE70	32	51	2900	0.71	81
2-FT40W/2G11 (RE80)	40	60	3150	0.70	74
Electronic Instant Start					
2-F32T8/RE70	32	63	2900	0.95	87
2-F96T12 Slimline/RE70	75	130	6425	0.84	83
Electronic Two-Level Rapid Start (50% and 100% of Full Light Output)					
2-F40T12/RE70	40	37/69	3200	0.40/0.86	69/80
2-F40T10/RE80	42	40/72	3700	0.40/0.86	74/88
2-F32T8/RE70	32	38/65	2900	0.50/0.94	76/84

Application Guidelines

Advanced technology ballasts improve the efficacy of fluorescent lamp systems and are appropriate for both new construction and retrofit applications.

Electronic Ballasts

Electronic ballasts for fluorescent lamps can save energy and dollars in nearly every application. There is a cost premium for electronic ballasts, which may be reduced by utility rebate programs, but prices are becoming more competitive as the market expands. Users like the University of California have demonstrated that electronic ballasts are an excellent institutional investment. Electronic ballasts may be substituted for magnetic ballasts without any need for concern about lighting system performance. In fact, electronic ballasts can enhance lighting quality through the added benefit of a quiet, flicker-free lighting environment. This makes electronic ballasts an ideal choice for modern offices and in other applications with important visual tasks.

Use the following criteria when making ballast selections:

- Always consider electronic ballasts for general purpose applications in new construction. The higher cost of electronic ballasts makes economic sense in terms of energy savings and improved lighting performance.
- Always consider electronic ballasts for routine maintenance replacements and renovations. (It may not be cost-effective to retrofit large groups of existing energy-efficient magnetic

Figure 4-8 (continued)

Typical Performance Values for Lamp-Ballast Systems (2-Lamp Systems)

Ballast Types	Lamp Watts (ea.)	Input Watts	Initial Lamp Lumens	Ballast Factor	System Efficacy
Electronic Adjustable Output (to 15%)					
2-F40T12/RE70	40	73	3200	0.89	78
2-F40T12/ES/RE70	34	60	2800	0.86	80
2-F40T10/RE80	42	73	3700	0.87	88
2-F32T8/RE70	32	73	2900	1.04	83
Electronic Dimming (to 1%)					
2-F40T12/RE70	40	83	3200	0.93	72
2-F40T10/RE80	42	85	3700	0.93	81
2-F32T8/RE70	32	75	2900	1.00	77
2-FT40W/2G11 (RE80)	40	80	3150	1.00	79

*Notes:
All values as measured under ANSI test conditions (25 °C [77 °F] open air).
75% reduced output refers to percentage of rated lamp lumen output that this lamp is deliberately designed to produce (also referred to in text as a "low ballast factor" ballast)
All lamps except F40T10s and FT40 twin tubes are RE-70 phosphor coatings; T-10s and FT40s are RE-80 phosphor coatings.
All values for input watts and ballast factors are for specific ballasts available on the market. Other ballasts may differ substantially from these values.

ballasts in working order that would not otherwise be replaced.)

- Consider operating F32T8 lamps at full output with instant start ballasts to obtain maximum energy efficiency for dedicated (non-dimming) applications.
- Exercise caution to avoid using instant start lamp-ballast systems with occupant sensors or other applications with rapid switching cycles.
- Consider stepped multi-level electronic ballasts as an excellent alternative to switching adjacent lamps in luminaires (tandem wiring) to meet Title 24 requirements. An additional benefit will be a quiet, flicker-free, space.
- Consider the use of low ballast factor (<75%) rapid start electronic ballasts in aisles or other circulation areas where partial light output will suffice. Installation of low ballast factor ballasts is also a cost-effective solution for retrofitting spaces that are over-illuminated. Low ballast factor electronic ballasts should be operated in rapid start mode only to maintain lamp life at reduced lamp currents.
- Consider full range (1-100%) dimming electronic ballasts for functional dimming requirements in applications such as board rooms, conference rooms, and residences.

Continuously adjustable dimming electronic ballasts are especially appropriate for all of the following lighting control strategies (see the appropriate guidelines for application details):

- *Tuning*: the adjustment of illuminance levels according to user needs
- *Daylighting*: the control of electric lighting levels in spaces where natural light is present
- *Lumen maintenance*: the reduction of lighting power lost in conventional systems that are designed to produce excess light when new to compensate for future light depreciation
- *Peak demand limiting* (load shedding): the reduction of lighting power during the time of day when utility charges are at their highest levels
- *Adaptation compensation*: adjusting interior lighting levels to more closely correspond with exterior illumination

In most instances, electronic ballasts are manufactured in standard ballast housings. This allows for quick and easy replacement in existing luminaires and permits their use in already tooled new luminaires. To facilitate replacement, the wires on typical non-dimming electronic ballasts use the same color coding as magnetic ballasts. Installation of electronic ballasts is actually easier than installing magnetic ballasts, because they weigh less. Most adjustable output and dimming ballasts have separate, low-voltage leads that permit a low voltage, Class I signal to control lamp output. These ballasts are often designed to use some form of optical isolator mounted in the luminaire so that Class II low voltage wiring can be used within the building. Other dimming ballasts require no additional control wiring.

System Compatibility of Electronic Ballasts

Like virtually all lighting products, there are some applications in which high-frequency electronic ballasts may be incompatible with existing technologies. One of these instances that has been identified occurs in libraries equipped with magnetic detectors used to prevent theft. However, as long as electronic ballasts are at least 10 to 15 feet away from the detector units, problems with the detectors are unlikely to occur.

A second potential system compatibility problem with electronic ballasts may occur in conjunction with high frequency power line carrier (PLC) control systems. The carrier frequency for PLCs usually ranges from 50 kHz to 200 kHz. These frequencies may be affected by one of the harmonic currents generated by electronic ballasts. The extent of this potential problem has not as yet been fully researched. However, in simple PLC systems for residential applications when lighting and other appliances share the same distribution network, electronic ballasts may not be compatible. This may be resolved by the selection of a more appropriate frequency for the PLC system. In commercial systems where the PLC is isolated from the lighting circuits, problems may be minimal. If, however, the PLC is used to control the lighting system, the probability of problems occurring will increase.

It is important to realize that the possible compatibility problems posed by the use of electronic ballasts arise only on rare occasions. The above incompatibilities can be resolved or avoided, and they should not be used to disqualify the use of electronic ballasts in other applications.

Heater Cutout Ballasts

Heater cutout ballasts are less expensive than electronic ballasts and are a viable energy-efficient option to consider when a project budget does not permit electronic ballasts. Heater cutout ballasts can be used in any non-dimming situation involving straight 40-watt F40T12 and F40T10 lamps, and a heater cutout ballast for F32T8 lamps is now available. Typical applications include offices, schools, retail and wholesale stores, health care facilities, and general industrial and commercial lighting. Because of their lower initial cost they are especially appropriate for use as replacement ballasts in retrofit applications. Some heater cutout ballasts may have a problem starting very high voltage F40T10 lamps when the line voltage is below the rated center voltage (120/277V). In addition, some lamp manufacturers derate lamp life when lamps are operated by heater cutout ballasts.

Guideline Specifications

The following ballast specifications may be used as a guideline for full-size fluorescent lamp ballasts. In general, for important applications, detailed specifications should be included for ballasts. The specification may include acceptable manufacturers and model numbers, especially when using electronic ballasts.

Electronic Ballasts

1. UL Listed Class P.
2. Sound Rated A.
3. Total harmonic distortion ≤ 32% (<20% for rebates) with input current third harmonic not to exceed ANSI recommendation.
4. Ballast shall conform to ANSI specification C. 82,11-19XX
5. Power factor ≥ 0.90.
6. Enclosure size and wiring in same color as magnetic ballast (for retrofit applications).
7. Ballast factor of _____ (see chart or manufacturer's literature, or as required).
8. Light regulation ±10% with ±10% input voltage variation.
9. Lamp current crest factor ≤ 1.7.
10. Flicker 10% or less with any lamp suitable for the ballast.
11. Lamps shall be operated in (instant start) (rapid start) (rapid start, stepped output) (rapid start, continuously adjustable output) mode.
12. Shall be designed to withstand line transients, per IEEE 587, category A.
13. Shall meet FCC Rules and Regulations, Part 18C.
14. Circuit diagrams and lamp-ballast connections shall be displayed on all ballast packages.
15. Three year warranty including $10 labor allowance.

Heater Cutout Ballasts

1. UL listed class P.
2. Sound rated A.
3. Energy-efficient ballast with heater cutout circuit shall not require restrike period.
4. Standard ballast enclosure size and wiring.
5. Light regulation ±10% with ±10% input voltage variation.
7. Power factor ≥ 0.90.
8. Lamp current crest factor ≤1.7.

9. Shall be designed to withstand line transients, per IEEE 587, category A

Special Note

Specifiers should investigate the marketplace and compare the product offerings with the information contained in this guideline. New product developments may make some portions of this report incomplete or obsolete.

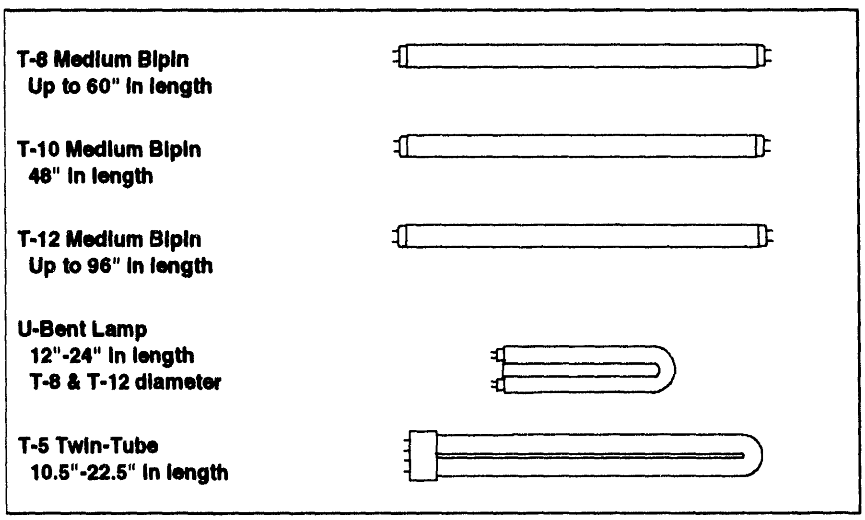
Manufacturer/Product References

Electronic Ballasts	Dimming Electronic Ballasts	Heater Cutout Ballasts
Advance Transformer Co.	Advance Transformer Co.	Advance Transformer Co.
MagneTek Triad	Electronic Ballast Technology, Inc.	MagneTek Universal
ELBA (Light Energy Corp.)	ETTA Industries, Inc.	Valmont Electric
Electronic Ballast Technology	Lutron Electronics	
ETTA Industries, Inc.		
Motorola Lighting, Inc.		
OSRAM Corporation.		
Smallwood P C/Sci.		
Toshiba Electronics		
Valmont Electric		

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Full-Size Fluorescent Lamps

Figure 5-1
Full-Size Fluorescent Lamps



Contents

Technology Description

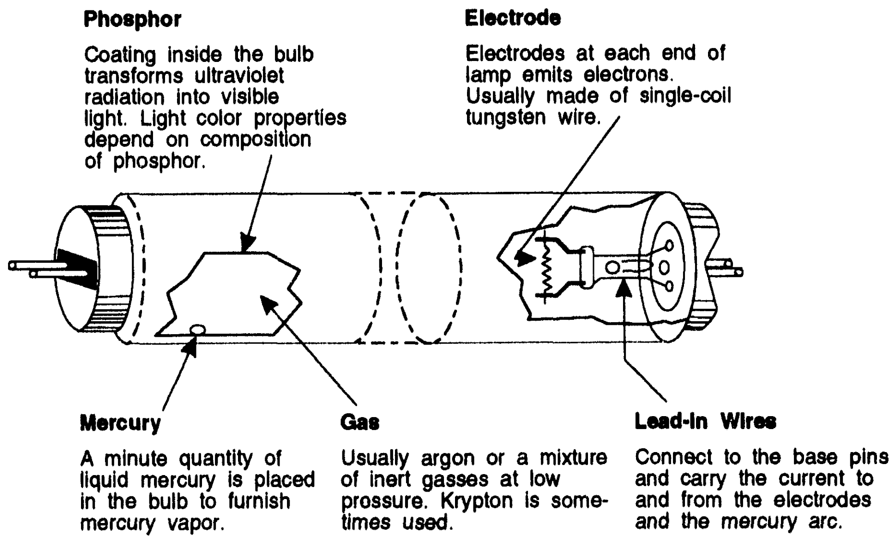
Fluorescent lamp technology has made tremendous advances over the past few years. The trend has been away from high energy consumption lamps to more energy-efficient products, improved color rendition, and a greater selection of color temperatures. These improvements are due in large part to the use of rare earth phosphors in place of the traditional halophosphors used in standard "cool white" lamps. To a lesser degree, efficiency improvements are due to the more widespread use of smaller diameter lamps. The smaller diameter lamps can also increase luminaire efficiency and improve light distribution patterns.

Fluorescent Lamp Operation

A fluorescent lamp is a glass tube with the inside surface coated with phosphor. The tube is filled with argon gas, or sometimes with a mixture of argon and krypton. A small amount of mercury is also inside which is vaporized during lamp operation. Electrodes (also referred to as cathodes) are located at each end of the sealed tube. When a suitable high

Figure 5-2

Detail of Rapid Start Fluorescent Lamp



voltage is applied across the electrodes, an electric arc discharge is initiated and the resulting current ionizes the vaporized mercury in the tube. The ionized mercury emits ultraviolet (UV) radiation that strikes and excites the phosphor coating on the inside surface of the tube, causing it to glow or *fluoresce* and produce visible light. The exact makeup of the phosphors coating the tube is what determines the color temperature of the light produced by the lamp.

Fluorescent lamps require a ballast to regulate the electric current through the lamp. For optimum performance, a particular ballast must match a specific lamp's current requirements. There are three basic types of fluorescent lamp circuits (see also the guideline on *Energy-Efficient Fluorescent Ballasts*):

- *Preheat Lamps* use an external starter that heats the lamp electrodes before the electric arc is struck. Preheat lamps are relatively uncommon, except in shorter, lower wattage lamps (usually 20 watts or less).
- *Rapid Start Lamps* have ballasts that heat the electrodes prior to lamp starting, as well as during normal operation. This feature helps produce long life in addition to smooth starting. Rapid start lamps start quickly, exhibiting only a brief flicker prior to reaching full light output. These lamps are the only fluorescent lamps suitable for dimming applications.
- *Instant Start ("Slimline") Lamps* have ballasts that do not heat the lamp's electrodes prior to starting or during normal operation. The arc is struck by high voltage discharge only. Instant start lamps are popular for their immediate starting characteristics. Some electronic ballasts operate rapid start lamps in instant start mode, with a reduction in lamp life. Lamp life ratings for instant start lamps generally are lower than for rapid start lamps.

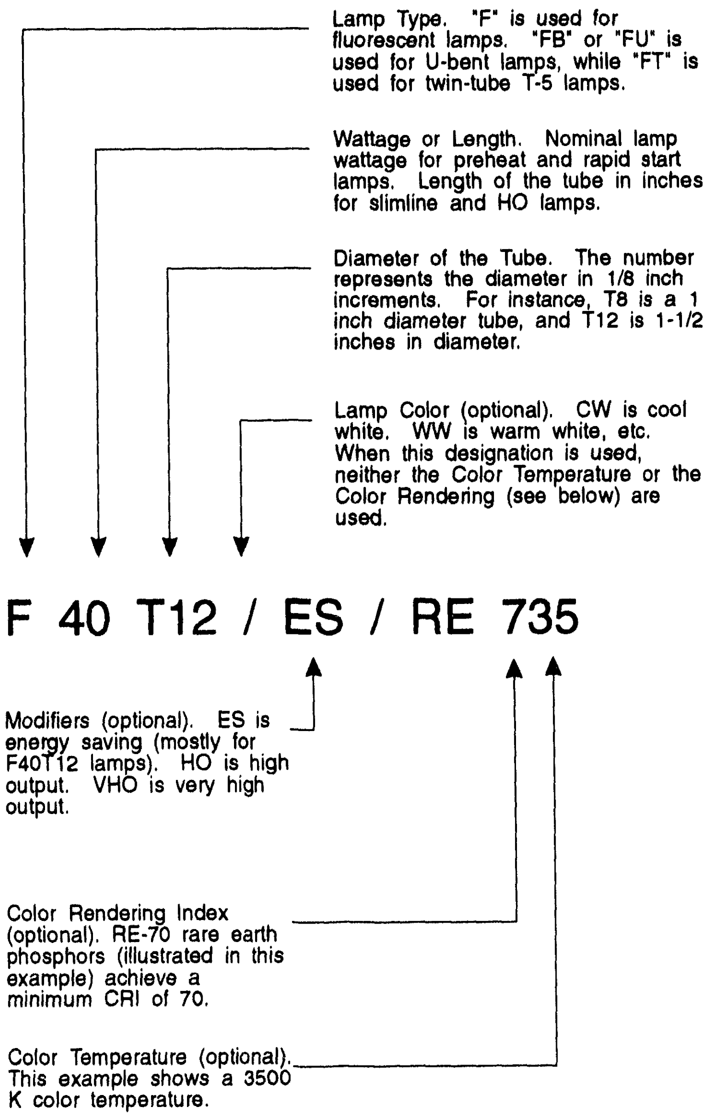
Manufacturers can vary the gas fill, phosphor type and content, as well as the lamp's tube length and diameter, in order to achieve different lamp characteristics. As a result, there is a wide range of lamps being designed and sold. The smallest standard fluorescent lamp is the 6-inch, 4-watt preheat lamp; the largest and most powerful lamps are the eight-foot, 1500 mA, very high output (VHO), rapid start lamps.

Standard Fluorescent Lamps

The standard 40-watt (F40T12) lamp is filled with argon gas. The most commonly used phosphor is halophosphor "cool white". Standard cool white lamps are rated at 3050 initial lumens. The previous standard lumen rating for cool white lamps, 3150 lumens, was recently reduced by about 3% due to phosphor changes necessitated by federal regulations.

Figure 5-3 illustrates the nomenclature used to specify fluorescent lamps. The standard 4-foot F40 rapid start fluorescent lamp is the most common light source in commercial facilities. The most common diameter is 1.5 inches (designated a T-12, where the number following the "T" represents the diameter of the tube in 1/8 of an inch increments). There are about ten times more rapid start F40T12 lamps in use than all other types combined. Obviously, any improvement in efficacy for this type of lamp can have profound energy savings implications.

Figure 5-3
Fluorescent Lamp Nomenclature



High demand for the F40T12 lamp over the years has resulted in mass production and low cost. The most popular fluorescent lamp configuration from the 1950s through the 1970s was 2-F40T12 lamps, producing 3150 lumens each on a single ballast. The system consumed approximately 96 watts, including ballast losses, and usually generated at least 95% of the rated lamp lumens in open air at a temperature of 25 °C (77 °F). This resulted in a light output of approximately 5985 lumens at a "cost" of about 96 watts for an efficacy of approximately 62 lumens per watt.

When connected with conventional ballasts, most lamps deliver less than 100% of their rated lumens. The percentage of actual lumens generated is known as the *ballast factor*, an important figure to consider when making lighting calculations. The ballast factor is the ratio of the light produced by a particular lamp ballast system to the rated light output of the same lamp(s) on an ANSI reference ballast operated in free air at 25 °C (77 °F). The term "ballast factor" implies that it is a property of the ballast, but it is really a property of the lamp-ballast system. The ballast factor for a given ballast will be different, for instance, depending on whether it is operating a F40T12 lamp or a F40T12/ES lamp. See the *Energy-Efficient Fluorescent Ballasts* guideline for more information on the ballast factor.

Standard Fluorescent Lamps and Lighting Legislation

The U.S. Energy Policy Act of 1992 (Public Law 102-486), signed into law on October 24, 1992, contains energy efficiency standards and other regulations that will preclude certain lamps from being manufactured or imported into the U.S. after a transition period. With respect to fluorescent lamps, full-wattage 4-foot T-12 lamps with calcium halophosphors (e.g. cool white and warm white halophosphor lamps) will not longer be permitted. However, reduced-wattage lamps (34-watt F40T12/ES) with the same phosphors will continue to be allowed. Full-wattage 4-foot T-12 lamps with high CRI rare earth phosphors will be permitted. Similar restrictions will apply to 8-foot T-12 lamps. This legislation does not affect T-8 lamps. The transition lasts until April of 1994 for 8-foot lamps and October of 1995 for 4-foot lamps. The Act exempts several categories of lamps.

Energy Saving (ES) Lamps

In response to the energy crises of the 1970s, lamp companies introduced "energy saving" lamps with krypton added to the gas fill. These lamps have the designation "F40T12/ES" in this guideline. These lamps draw less power than standard F40T12 lamps (usually about 34-35 watts). F40T12/ES lamps can be operated by standard F40T12 ballasts, so they may be readily substituted in existing lighting systems. Both wattage and light output are reduced proportionately. However, the slight reduction in light output is generally acceptable to most users, given the energy savings and system efficacy.

ES lamps have a lower ballast factor than standard F40T12 lamps (about 0.87 with a standard energy-efficient ballast, as opposed to about 0.95 for standard F40T12 lamps). The lower ballast factor further reduces light output. The lower lumen output of ES lamps means that their most appropriate application is for lamp retrofit or replacements in overlighted spaces. Substituting F40T12/ES lamps for standard F40T12 lamps reduces input wattage by about 12% to 15%. Lumen output is reduced by 18% to 20% for a 2-lamp system.

Energy saving lamps are more sensitive to low temperatures than standard lamps. Minimum starting temperature is about 16 °C [60 °F], as opposed to 10 °C [50 °F]) for standard 40-watt F40 lamps, and they are not recommended for dimming applications. ES lamps are manufactured for many different types of fluorescent lamps, including rare earth phosphor lamps, slimlines, and high output (HO) lamps.

Rare Earth (RE) Phosphor Lamps

Rare Earth (RE) phosphor technology improves the performance of fluorescent lamps. RE phosphor compounds are selected for their ability to produce visible light at the most sensitive wavelengths of the eye's red, blue and green sensors. When compared with conventional halophosphors, such as cool white (with a CRI of 60-62), RE phosphors produce better color rendering and higher efficacy, while improving lumen maintenance characteristics. For reasons of lumen maintenance, rare earth materials are required in small diameter lamps, such as compact fluorescents.

RE phosphors raise lumen output up to 8% over conventional halophosphors. RE phosphor lamps are available for most fluorescent lamp configurations and are available in a wide range of color temperatures. Two generic types of RE phosphor lamps are offered: RE-70 and RE-80.

RE-70 Lamps

The expression "RE-70" refers to a fluorescent lamp containing phosphor mixes that create a CRI of 70 to 79. These lamps, formerly called "thin coat triphosphor" lamps, contain less of the rare earth phosphors than do the coatings of more expensive, high-CRI RE-80 lamps. They increase lumen output of 4-foot lamps by 5% to 6%.

RE-80 Lamps

RE-80 fluorescent lamps, sometimes referred to as "thick-coat triphosphor" or "high CRI" lamps, increase lumen output up to 8% over halophosphor cool white, and increase CRI to 80-89. The additional rare earth phosphor content in the coating of these lamps improves color rendering but also increases lamp cost.

Figure 5-4 lists the availability of RE phosphor lamps in terms of color temperatures and CRIs. In addition, see Figure 5-8 for some performance characteristics of RE lamp types as compared to halophosphor cool white lamps.

Heater Cutout Lamps

In a rapid start lamp, it is possible to disconnect the lamp electrode heater after the lamp has started. This is accomplished with a thermal switch in the lamp. This reduces lamp power by about 2.0 to 2.5 watts per lamp with no reduction of light output. These lamps are known as "cathode cutout," "heater cutout," or "ES+" lamps. They are suitable for retrofit applications, but are not recommended for use with electronic ballasts or in dimming applications.

Disconnection of a lamp's electrode heaters can also be achieved with heater cutout ballasts, used with conventional rapid start lamps. These ballasts are not recommended for use in conjunction with heater cutout lamps. For more information, see the discussion on heater cutout ballasts in the *Energy-Efficient Fluorescent Ballasts* guideline.

A drawback of ES+ lamps is that there is a restrike time of one to two minutes if the lamp is extinguished and then immediately restarted. Because of this, use of ES+ lamps is not recommended with occupant sensors or other frequent switching applications. Some manufacturers, but not all,

Figure 5-4

Availability of RE Lamp Products

CCT (K)	CRI Range	Generic Designation	Various Manufacturer Designations*	Color Temperature Matches
3000	70-79	RE-730	D30 SP30 Spec30 TC730	Incandescent Tungsten Halogen
	80-89	RE-830	D830 30K SPX30 30U AX30 TC830	3000 K Metal Halide White Sodium
3100	70-79	RE-731	31K	Same As Above
3500	70-79	RE-735	D35 35K SP35 Spec35 TC735	Tungsten-Halogen
	80-89	RE-835	D835 35K SPX35 35U AX35 TC835	3300-3700 K Metal Halide White Sodium
4100	70-79	RE-741	D41 41K SP41 Spec 41 TC741	
	80-89	RE-841	D841 41K SPX41 41U AX41 TC841	Standard Metal Halide
5000	80-89	RE-850	F0U AX50	Daylight

***Note:** These are some designations of selected major manufacturers. To be assured of the proper color temperature and CRI, check each manufacturer's data to determine the exact color designation.

have derated the lamp life by 25% for heater cutout lamps. In most applications, however, reduced lamp life will be more than offset by potential energy savings.

Extended Output (EO) Lamps

EO lamps are premium versions of standard 40-watt F40T12 lamps which, due to gas fill, redesigned electrodes, thicker or more efficient phosphors, and/or tube diameter, generate more light than standard cool white F40T12 lamps. In some cases, this is accomplished with a slight increase in lamp wattage. Compared to standard F40T12 lamps, they offer higher efficacy, increase both lumen output (up to 21%), and lamp life (20%), and improve lumen maintenance, and color rendering. The "EO" nomenclature is not used by any manufacturer; current products use manufacturer-specific trade names or designations.

EO lamps were originally intended to replace F40T12 lamps in applications requiring increased light, or in situations where retrofits or delamping reduced light levels too much. EO lamps can be used in the same luminaires as standard 40-watt F40T12 lamps, without a change of sockets or ballasts. This makes EO lamps especially useful in retrofit applications requiring an increase in light output, as no replacement of luminaire hardware is required. More currently, EO lamps are receiving increased consideration in new construction applications.

EO lamps may be operated with either electronic or magnetic ballasts. EO lamps are only available for 40-watt F40 lamps, in both T-12 and T-10 diameters, as described below.

T-12 EO Lamps

F40T12/EO lamps typically deliver about 11% to 15% more light output in some designs than standard halophosphor lamps. Light output is rated at 3400 lumens for the RE-70 lamp and 3500 lumens for the RE-80 version. Color temperatures of 3000 K, 3500 K, and 4100 K are available. Rated lamp life is 24,000 hours at 3 hours per start.

T-10 EO Lamps

F40T10/EO lamps can produce significantly more light output than standard F40T12 halophosphor lamps. Rated initial lamp lumen output for premium T-10 lamps is 3700 lumens, made possible by increased power and RE-80 phosphor coatings. The only available T-10 lamp size at this time is the 4-foot replacement for the standard F40T12. It actually consumes about 42 watts, but due to its higher voltage, it draws slightly less current (about 400 mA), and ballast losses are lower. A typical energy-efficient magnetic ballast for two F40T10 lamps will draw about 92 watts, with a ballast factor of 0.95, and a system efficacy of about 76 lumens/watt. Some T-10 lamps are sensitive to variations in voltage input and may not start properly with the 40-watt T-12 ballast over the entire voltage input range. One manufacturer makes a ballast to match the T-10 lamp. T-10 lamps also have a rated lamp life of 24,000 hours. At present, T-10 lamps are premium-priced products.

U-Tube Lamps

Another popular version of the standard 40-watt F40T12 fluorescent lamp is a U-shaped configuration, usually referred to as a "U tube" or "U-bent lamp". These lamps are designated "FB" by some manufacturers, while others use a "/U designation. They are available with both 6-inch and 3-5/8-inch leg spacing, and have an overall length of about 22 inches. Some products are manufactured with rare earth phosphors. U-tubes are also available in 34-watt ES versions and with RE phosphors.

U-lamps are used mostly with square luminaires, such as 2' x 2' troffers or surface mounted luminaires. The halophosphor cool white version of the lamp produces about 2800 lumens; RE-80 phosphors raise the lumen rating to approximately 3000. U-lamps are rated for an effective life of up to 18,000 hours at 3 hours per start.

Slimline Lamps

Slimline fluorescent lamps are recognizable by their single pin bases. While slimlines are available in T-6, T-8 and T-12 diameters, and in lengths ranging from 24 to 96 inches, the focus of this document is on the 425-mA F96T12 configuration, popular in many commercial applications.

Slimline lamps use a lamp designation code different from most other fluorescent lamps: the number following the "F" designates the lamp length in inches, *not* the wattage. For example "F96T12" refers to a slimline lamp, 96 inches long and 1.5 inches in diameter. Lamp wattage must be determined from lamp catalogs. The F96T12 lamp, for instance, is actually 75 watts.

Slimline lamps are popular in many commercial applications using open luminaires. Eight-foot slimline lamps are more efficacious than standard F40T12 rapid start lamps, due to instant start operation. In addition, the greater length of the F96T12 creates a higher lumen package, due to reduced lamp end losses as a percentage of the total lamp wattage (end losses are constant, so increasing the length of the tube reduces their impact).

Slimline lamps are available in standard, 60-watt ES, and RE versions. Instant start operation means that the rated lamp life of slimline lamps is significantly shorter than in rapid start lamps. The F96T12 slimline lamp, for instance, is rated at 12,000 hours, at 3 hours per start. It is also worth noting that magnetic ballasts for slimline lamps have a lower (i.e. noisier) sound rating than standard magnetic ballasts.

High Output (HO) Lamps

Rapid start fluorescent lamps that operate at 800 mA are known as high output (HO) lamps. They have a recessed double contact base and require a special ballast. HO lamps use the same designation terminology as slimline lamps. Thus, an 8-foot HO lamp uses the designation "F96T12/HO". HO lamps are available in lengths ranging from 18 inches to 96 inches. The 110-watt F96T12 and 85-watt F72T12 are the most popular configurations and are commonly used in many commercial and industrial applications. HO lamps are available with rare earth phosphors and in reduced wattage, ES versions.

A standard 8-foot HO lamp has a rated lamp output of 8900 lumens and a lamp life rating of 12,000 hours (3 hrs/start operation). RE-70 and RE-80 phosphor coatings raise the light output to 9200 and

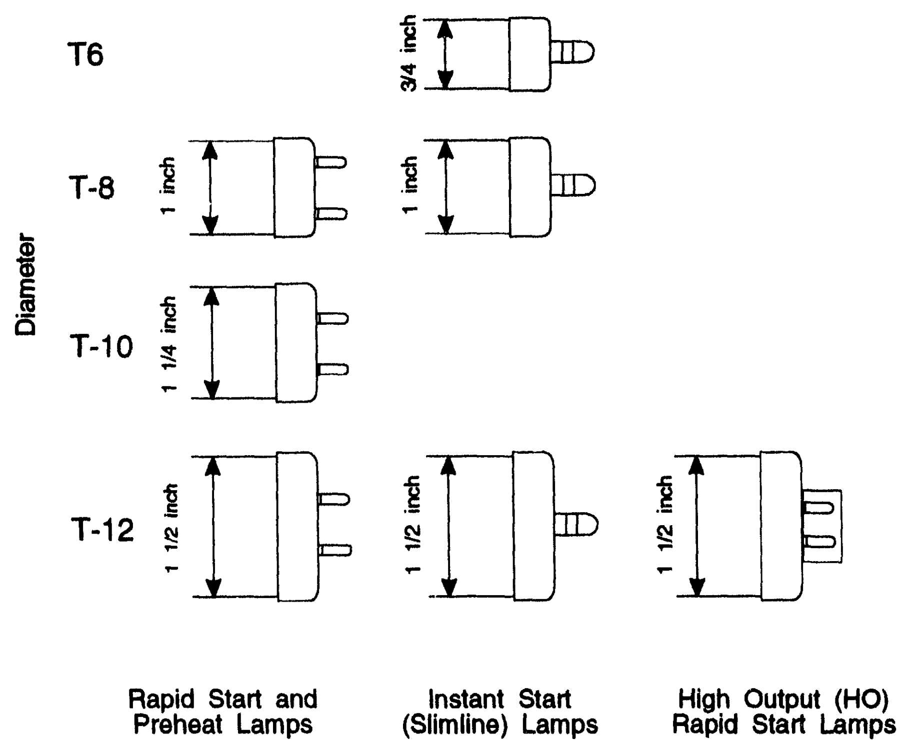
9350 lumens, respectively. HO lamps increase lumen output significantly by drawing considerably more power than standard fluorescent lamps. For example, a cool white 4-foot HO lamp (F48T12/HO) produces about 4300 lumens and draws about 60 watts, not including ballast losses. A standard F40T12CW lamp, by comparison, produces 3050 lumens and uses 40 watts.

Very High Output (VHO) Lamps

The most powerful fluorescent lamp is a 1500 mA lamp, known as a very high output (VHO) lamp. An F96T12/VHO lamp uses conventional halophosphors and produces 13,500-15,700 initial lumens, while consuming 215 watts, not including ballast losses. Some reduced wattage, ES versions of VHO lamps are available.

Generally, HO and VHO lamps are not a practical retrofit situation for standard fluorescent lamps due to their different base configurations (recessed double contact). However, there are many cases in new construction where the installation of F96T12/HO lamps over standard F40 lamps should be considered. For example, including ballast factors, a single F96T12/HO lamp produces about 47% more lumens than two standard F40 lamps, while using approximately 33% more power. This translates to a 10% to 11% increase in efficacy. In general, HO lamps should be considered in applications where light output is of paramount importance, and where a shorter lamp life (12,000 hours) and increased ballast noise is acceptable.

Figure 5-5
Standard Fluorescent Lamp Bases



Advanced Products

In addition to the EO family of lamps, two other fluorescent lamp types have significantly improved efficacy when compared with the standard F40T12 lamp-ballast system. These are the T-8 and T-5 lamp families. T-8 lamps use the common medium bipin base, while T-5 twin-tube lamps are configured with a four-pin 2G11-type base. Smaller lamp diameters and the exclusive use of rare earth phosphors increase the efficacy of these lamps over standard F40T12 lamps. In addition, specially designed ballasts may be used for even greater increases in lamp-ballast system efficacy. Data regarding these lamp types is summarized in Figure 5-6.

T-8 Lamps

The 265 mA T-8 fluorescent lamp-ballast system is a relatively recent energy-efficient lighting product. Introduced to the American market in 1982, these lamps are now made by all major U.S. lamp manufacturers. The straight T-8 lamps have the same medium bipin bases as T-12 lamps, allowing them to fit the same sockets (this is not true for the U-bent T-8 lamps, which have different leg spacings than their T-12 counterparts). However, T-8 lamps have different electrical characteristics, so they may not use a standard F40T12 type lamp ballast designed for 430 milliampere operation. The standard T-8 lamp family is

Figure 5-6
Advanced Fluorescent Lamp Technologies Data

Lamp Style	Watts	Initial Lamp Lumens	Normal Length
Straight T8 Bipin Lamps			
F17T8	17	1350	2'
F25T8	25	2150	3'
F32T8	32	2900	4'
F40T8	40	3650	5'
U-Shaped T8 Bipin Lamps			
FB16T8	16	1250	1'
FB24T8	24	2050	1.5'
FB31T8	31	2800	2'
Straight F40/EO Bipin Lamps			
F40T12/EO/RE70	40	3400	4'
F40T12/EO/RE80	40	3500	4'
F40T10/RE80	42	3700	4'
T-5 Twin-Tube Lamps			
FT18W/2G11	18	1250	10.5"
FT27W/2G11	27	1800	12.85"
FT39W/2G11	39	2850	16.5"
FT40W/2G11	40	3150	22.5"
FT50W/2G11	50	4000	22.5"
FT55W/2G11	55	4800	21.0"

designed for 265 mA operation, but T-8 lamps are also being designed to operate with special ballasts at substantially higher power levels. There is only a minor cost difference between a standard T-8 lamp-ballast system and a standard F40T12 lamp-ballast configuration.

T-8 lamps are available in several straight tube and U-bent configurations. Generally, they are available in color temperatures of 3000 K, 3500 K and 4100 K. Depending on the manufacturer they have either RE-70 or RE-80 phosphor coatings. Rated power ranges from 16 to 40 watts.

Like standard F40T12 lamps, T-8 lamps are rated at 20,000 hours for 60 Hz rapid start operation. However, for highest efficacy, they are often matched with an electronic ballast that operates the lamps in an instant start mode and at 25 KHz (electronic ballasts for rapid start operation are also available). Instant start operation of T-8 lamps reduces rated lamp life by 25% (based on 3 hours per start operation), but lamp efficacy is increased by more than 10% when compared with magnetically-ballasted operation. In most commercial applications, where lamps are on for a period of ten hours between starts, lamp life is only slightly less than that of rapid start operation. Like T-12 lamps, T-8 lamps may be dimmed, but they require specialized dimmers and ballasts to work properly.

T-8 lamps offer several advantages over standard (non-RE phosphor) T-12 lamps:

- The 2-lamp F32T8 system with an energy-efficient magnetic ballast has an efficacy of 78 lumens/watt, as compared to 68 lumens/watt for a standard 2-lamp F40 T12/RE70 lamp system.
- The 2-lamp F32T8 system with an instant start electronic ballast can achieve an efficacy of up to 90 lumens per watt. Given optimum electronic ballast designs, a representative efficacy for an electronically ballasted 2-lamp F40T12/RE70 system is about 78 lumens/watt.
- All T-8 lamps contain rare earth phosphors. RE phosphor coatings give T-8 lamps improved color rendering and lamp lumen maintenance over T-12 halophosphor lamps.
- T-8 lamps purchased in large quantities are not much more expensive than halophosphor T-12 lamps, and are actually less expensive than either 34-watt or 40-watt T-12 lamps with RE phosphors. Additionally the cost of T-8 lamp system installations is often subsidized by utilities in the form of rebates or incentives. Overall, on a life-cycle cost basis, a T-8 lamp-ballast system is usually a better investment than any 4-foot T-12 system.

All manufacturers now make T-8 lamps. As Figure 5-6 shows, T-8 lamps are currently offered in standard 2, 3, 4, and 5-foot straight lamps, as well as in 1, 1.5, and 2-foot- U-shaped lamps. In addition, an 8-foot T-8 lamp has been announced in a single-pin slimline-type configuration.

T-5 Twin-Tube Fluorescent Lamps

T-5 twin-tube fluorescent lamps range in length from 10.5 inches to 22.5 inches. As such they are particularly effective in applications calling for smaller, more compact luminaires. Lamps of up to 55 watts are available, allowing for nearly any general/ambient lighting application. T-5 twin tube lamps now bear a designation code prefixed by the letters "FT."

Despite their small sizes, T-5 lamps have high lumen output, excellent color rendering, and good efficacy, due to the use of RE phosphor coatings. T-5 lamps use RE-80 high color rendition phosphors and are available in color temperatures of 3000, 3500 and 4100 K. T-5 twin-tube lamps operate at currents ranging from 250 to 550 mA and are configured with four-pin 2G11-type bases. In general, they require dedicated ballasts; however, the 270 mA FT40T5 twin-tube lamp may be used with a standard T-8 rapid start ballast.

T-5 twin-tube lamp configurations discussed here are available in 18, 27, 39, 40, 50, and 55 watts. The manufacturer of the 55-watt version claims that the lamp produces 4800 lumens and has a life of 20,000 hours when operated on an electronic ballast. The performance characteristics of these products vary greatly from lamp to lamp, as shown in Figure 5-7.

Performance data for full-size fluorescent lamp-ballast systems (2-lamp systems) may be found in Figure 5-8.

Application Guidelines

Advanced technologies in full-size fluorescent lamps are used to make rapid start straight and U-shaped lamps with unit lumen output comparable to the standard 40-watt F40T12 lamp. The technologies may be considered in all applications where F40T12 lamps are suitable.

T-12 Lamps

Retrofits: Consider the use of heater cutout lamps in applications where a 1-2 minute restrike time can be accepted. Any of the advanced technology T-12 lamps can be used as energy-efficient retrofits for standard F40T12 lamps.

New Construction: Consider the use of rare earth phosphor (RE) and high output (HO) lamps when their extra lumen output allows for design with fewer luminaires or fewer lamps per luminaire.

Extended Output T-10 and T-12 Lamps

Retrofits: Good applications for EO lamps are existing situations where delamping (alone, or combined with other retrofits, such as specular imaging reflectors) may produce unacceptably low lighting levels. EO lamps are designed specifically for these situations.

New Construction: Although EO lamps were initially introduced as retrofits for standard T-12 lamps, they can be considered for new construction applications where higher lighting levels are required. For example, occasional lighting problems may result from using standard luminaires and T-12 lamps. Without changing the lighting design, a 13% increase in lighting level, with only a 5% increase in power, can be obtained by using T-10 lamps and appropriate luminaires. In addition, there may be applications when fewer luminaires are required to achieve a design illuminance level, if T-10 lamps are used instead of T-12s.

Figure 5-7

T-5 Twin-Tube Rapid Start/Preheat Lamps w/2G11 Bases

Lamp Type	Ballast Type	Input Watts	Typical Ballast Factor	Lumen Output	System Efficacy (L/W)
FT18W/2G11 1250 Lumens	370mA Magnetic PH	22	.90	1125	51
FT18W/2G11 1250 Lumens	270mA Magnetic RS 265mA Electronic IS	23 17	.90 .95	1125 1199-	49 70
FT24W/2G11 1800 Lumens	340mA Magnetic RS 265mA Electronic IS	32 21	.925 .810	1665 1458	52 69
FT39W/2G11 2900 Lumens	430mA RS 265mA Electronic IS	51 26	.925 .690	2682 2001	53 77
FT40W/2G11 3150 Lumens	265mA Magnetic RS 265mA Electronic RS	43 36	.930 .830	2930 2615	68 73
FT50W/2G11 4000 Lumens	430mA Electronic IS	54	.97	3880	72
FT55W/2G11 4800 Lumens	550mA Electronic IS	62	0.97	4656	75

Notes:
Lamp life will vary, depending on lamp current and ballast starting mode.

Figure 5-8

Lamp-Ballast System Comparison: 2-Lamp Open Air Systems

		Lamp-Ballast System					Comparison	
Lamps	**Ballasts**	**Test Ballast Factor**	**Lumen Output**	**Input Watts**	**Efficacy L/W**	**Input Watts**	**Lumen Output**	**System Efficacy**
40W F40T12 4100K CW 3050 Lumens	Magnetic EE	.94	5734	88	65	Base 100%	Base 100%	Base 100%
40W F40T12 4100K RE-70 3200 Lumens	Magnetic EE Heater Cutout Electronic RS	.94 .85/.95 .88	6016 5312/6080 5632	88 69/80 72	68 77/76 78	100% 78%/91% 82%	105% 93%/106% 98%/	105% 118%/117% 120%
40W F40T12 4100K RE-80 3300 Lumens	Magnetic EE Heater Cutout Electronic RS	.94 .83/.95 .88	6204 5478/6270 5808	88 69/80 72	71 79/78 81	100% 78%/91% 82%	108% 96%/109% 101%	109% 122%/120% 125%
34W F40T12/ES 4100K RE-70 2800 Lumens	Magnetic EE Heater Cutout Electronic RS	.87 .81/.88 .88	4872 4536/4928 4928	72 58/66 62	68 78/75 79	82% 66%/75% 70%	85% 79%/86% 86%	105% 120%/115% 122%
34W F40T12/ES 4100K RE-80 2850 Lumens	Magnetic EE Heater Cutout Electronic RS	.87 .81/.88 .88	4959 4617/5016 5016	72 58/66 62	69 80/76 81	82% 66%/75% 70%	86% 81%/87% 87%	106% 123%/117% 125%
32W F40T12/ES+ 4100K RE-70 2650 Lumens	Magnetic EE	.87	4611	67	69	76%	80%	106%
42W F40T10 4100K RE-80 3700 Lumens	Magnetic EE Heater Cutout Electronic	.95 .85/.95 .85	7030 6290/7030 6290	92 74/84 74	76 85/84 85	105% 84%/95% 85%	123% 110%/123% 110%	117% 131%/129% 131%
32W F32T8 4100K RE-70 2900 Lumens	Magnetic EE Electronic RS Electronic IS	.94 .88 .95	5452 5104 5510	70 62 63	78 82 87	82% 70% 72%	95% 89% 96%	120% 127% 135%
32W F32T8 4100K RE-80 3050 Lumens	Magnetic EE Electronic RS Electronic IS	.94 .88 .95	5734 5368 5795	70 62 63	82 87 92	82% 70% 72%	100% 94% 101%	126% 133% 142%
FT40W/2G11T5 4100K RE-80 3150 Lumens	Magnetic Electronic RS	.93 .83	5859 5229	86 71	61 74	109% 81%	102% 91%	94% 114%
FT50W/2G11 T5 4100K RE80 4000 Lumens	Electronic RS	.97	7760	106	73	120%	135%	112%
FT55W/2G11 T5 4100K RE80 4800 Lumens	Electronic IS	.93	8928	110	81	125%	156%`	125%
75W F96T12/IS 4100K Slimline Halophosphor 6150 Lumens	Magnetic EE Electronic IS	.94 .86	11,560 10,580	158 130	73 81	90% 74%*	101% 922%	112% 125%
110W F96T12/HO 4100K Halophosphor 8900 Lumens	Magnetic EE Electronic RS	.94 .81	6,732 14,418	237 290	71 76	135% 108%	146% 134%	109% 126%

Notes:

Open air bare lamp tests as per ANSI C82.2.
Ballasts cited are specific commercial ballasts available on the current market; use of other ballasts will produce different results.
Figures given for heater cutoff ballasts represent values for both reduced and full light output models.

T-8 Lamps

Retrofits: In retrofit situations involving F40T12 lamps, where the existing ballast must be changed, T-8 lamp-ballast system retrofits are often very cost effective, especially when utility rebates are factored in. However, if the existing ballast is an energy-efficient F40T12 type, in good condition, then an energy-efficient T-12 or T-10 system retrofit is usually more cost-beneficial in the short term.

New Construction: T-8 lamps are excellent for all new installations including:

- Offices
- Retail stores
- Commercial and industrial lighting
- Special applications, such as task lights, under cabinet lights, cove lights, and surface and decorative lights

Based on efficacy alone, T-8 lamps are generally superior to any T-12 technology. Considering the fact that T-8 lamps make many popular luminaires more efficient, a T-8 system with magnetic ballasts will typically provide 8% to 9% more light at 4% to 9% fewer watts than a system using F40T12/ES lamps with equivalent color rendering capabilities. Efficacy is further increased with the use of electronic ballasts. The lamp cost for larger commercial projects in major metropolitan areas is about the same as for T-12 lamps.

T-5 Lamps

Applications for T-5 twin-tube lamps are generally limited to new construction, as they require special sockets and ballasts. At present several luminaire designs are being developed to take advantage of this relatively new lamp technology.

T-5 lamps are ideal for applications requiring relatively high lighting levels from compact luminaires. 1' X 1' recessed parabolic troffers utilizing T-5 lamps provide good light levels while fitting in ¼ the ceiling space of a conventional 2' X 2' troffer. The use of 1'x 1' troffers in lieu of other types of downlights allows for the use of effective, efficacious sources and electronic ballasts in compact recessed luminaires. Similarly, 2' x 2' and other types of general lighting luminaires are appropriate in a variety of applications with energy saving results. For example, 40-watt U-lamps, the traditional lamps for 2' x 2' troffers, can be replaced by a smaller (22.5 inch) and more efficient (3200 lumens to 2800 lumens) FT40T5 compact fluorescent alternative, with no major drawbacks. Similarly, the high-powered FT50 and FT55 configurations perform well in well-shielded 2' X 2' troffers, as well as in specially designed chandeliers, pendants, wall washers, and indirect systems.

Overall, the applications for T-5 twin-tube lamps should increase as luminaire manufacturers begin to take advantage of this technology to build luminaires that are functional, energy-efficient and attractive. For example, for maximum lighting level applications, the new 55-watt T-5 lamp promises to provide the most light output of any of the newer technology lamp products. This may allow for designs with fewer luminaires and/or fewer lamps per luminaire, reducing overall costs with little loss of light levels. However, with a light output of 4800 lumens per lamp, luminaires with good shielding characteristics will be required to prevent glare.

Examples

New General Lighting Systems

A typical general lighting system

Figure 5-9

Lamp-Ballast Characteristics in 2' X 4' Troffers

Lamp Type	Ballast Type	Initial Footcandles: Small Room (RCR =5)	Initial Footcandles: Large Room (RCR=1)	Power Density (Watts/ Ft2)	Comparative Power Density
F40T12	Magnetic	50	68	1.23	100%
F40T12	Electronic RS	47	64	1.10	89%
F40T12/ES	Magnetic	41	56	1.09	89%
F40T12/ES	Electronic RS	41	55	0.90	73%
F40T12/ES+	Magnetic	38	52	0.87	71%
F40T10	Magnetic	57	78	1.29	105%
F40T10	Electronic RS	54	74	1.19	97%
F32T8	Magnetic	46	63	1.01	82%
F32T8	Electronic IS	47	63	0.90	73%

Notes:
1. Footcandle figures calculated using Lumen Method. *See Computer Aided Lighting Design* guideline for discussion of the benefits of Point-by-Point calculations.
2. All calculations are for initial footcandles and include ballast and thermal factors as found in or extrapolated from Figure 3-17 in *Luminaires and Lighting Systems* guideline.
3. All lamps, except T-10s are RE-70 phosphor coated; T-10s are RE-80.
Consult IES recommended lighting levels for specific activities.

using standard 3-inch deep cell, semi-specular, recessed parabolics utilizes recessed 3-lamp troffers on 8' by 10' centers. Figure 5-9 illustrates some typical results that can be obtained by different lamp-ballast combinations in non-air handling, high efficiency parabolic troffers in a room with white tile ceiling, light colored walls and normal carpet color. All footcandle levels are initial.

A Retrofit Situation

A traditional lens troffer design from the early 1970's utilizes 4-lamp troffers on 8' by 8' centers. The resulting system generates about 88 maintained footcandles (RCR=1) at 2.7 watts/ft^2 using F40T12 lamps, and about 84 footcandles at 2.4 watts/ft^2 using F40T12/ES lamps.

A survey of many office spaces in particular would reveal that lighting levels are excessive for some situations. Average illuminance levels between 20 and 50 footcandles (IES illuminance category "D") are usually appropriate for most visual tasks of medium contrast or small size. Higher task illuminance levels are needed only for the most demanding of visual tasks. As such, excellent energy-saving opportunities exist. In these cases, the lighting professional should examine several options:

- Check the ballast. If it is not an "energy-efficient" type, it almost always pays to replace with a newer ballast. Options include T-12 energy-efficient magnetic, T-12 electronic, T-8 magnetic, or T-8 electronic.
- Luminaire efficiency may be increased by 10% to 15% through the use of a specular imaging reflector retrofit. However, it should be noted that luminaire uniformity of distribution may be adversely affected.
- Delamp, leaving two lamps in each luminaire. (Caution: disconnect unused ballast from line). If delamping results in too low a lighting level, the lamps may be changed to F40T10 or F40T12/EO lamps, or specular imaging reflectors may be added to the luminaires.

Figure 5-10 shows examples of how footcandles can still be kept at a workable level by using delamping and reflector strategies. If delamping results in too low a light level, the situation may be remedied with the use of T-10 or T-12/EO replacement lamps.

Guideline Specifications

Specification of energy-saving fluorescent lamps and ballasts is not difficult. Most of the products are now generally offered through major electrical distributors across the U.S. In the case of T-8 lamps, many luminaire manufacturers consider T-8 technology to be a standard option.

Lighting Fixture Schedules

Most lighting designs list fixtures by type or "tag" in a schedule. This schedule often contains all information needed for lamps and ballasts. To properly specify fluorescent lamps, however, it is recommended that a few special notes be included to clarify the designer's intent. Please refer to the suggested "Lighting Fixture Schedule" (Figure 5-11).

Figure 5-10

Results of Delamping 2' x 4' Troffers

Action	Lamp-Ballast System	Footcandles (RCR=5)	Footcandles (RCR=1)
None (Base Case)	4-F40T12-Magnetic	65	88
Delamp	2-F40T12-Magnetic	36	48
Delamp	2-F40T12-Electronic	33	45
Delamp/Reflect.	2-F40T12/ES-Magnetic	38	52
Delamp/Reflect.	2-F40T12/ES-Electronic	37	50
Delamp	F40T10-Magnetic	43	59
Delamp/Reflect.	F40T10-Magnetic	50	68
Delamp/Reflect.	F40T12-EO-Magnetic	46	62
Delamp	F32T8-Magnetic	34	46
Delamp	F32T8-Electronic	34	46
Delamp/Reflect.	F32T8-Magnetic	39	53

Notes:
1. Delamping alone produces 10% improvement in relative light output due to improved thermal application factor and lower lumen absorption by lamps.
2. Delamping combined with reflector produces 15% improvement in relative light output.
3. Improvements greater than 15% achieved by use of more efficient lamp-ballast technologies.

Using lighting fixture schedules is an excellent method to properly specify lamps. There are several reasons:

- Lighting fixture schedules are used to quickly identify luminaires.
- Lighting fixture schedules contain most of the necessary information for complete specification of lighting on most projects.
- Contractors and distributors are more likely to read a lighting fixture schedule, whereas written specifications are seldom read or referred to, except by the contractor's office personnel.
- Highly detailed lighting fixture schedules reduce the possibilities of substitution of inferior goods.

Standard Specifications

Most commercial projects use variations of standardized specifications from the Construction Specifications Institute (CSI) recommended format. This shorter specification format is better for smaller, less complex projects. It contains all the basic information to assure proper provision of the required lamps.

Specifiers should be diligent, as minor cost differences and "value engineering" may be used to substitute standard T-12 lamps for more energy-efficient advanced products.

A Recommended Basic Specification

The following specification is intended for a typical job calling for T-8 lamps with electronic ballasts. See the *Energy-Efficient Fluorescent Ballasts* guideline for a sample specification for electronic ballasts.

Fluorescent Lamps

1. Meet applicable sections of ANSI C82 and C78.
2. In general, lamps shall be 265 mA "T-8" rapid start type as follows:
   a. 2' lamps shall be 17-watt F17T8
   b. 3' lamps shall be 25-watt F25T8
   c. 4' lamps shall be 32-watt F32T8
   d. 5' lamps shall be 40-watt F40T8
   e. 1' MOL U-lamps shall be 16-watt FB16T8
   f. 1.5' MOL U-lamps shall be 24-watt FB24T8
   g. 2' MOL U-lamps shall be 31-watt FB31T8
3. Color: lamps shall be (3000)(3500)(4100) Kelvin correlated color temperature.
4. Color rendering index: lamps shall have a minimum CRI of (70)(80) through the use of (RE-70)(RE-80) rare earth phosphor coatings.
5. Lumen output, lamp life, and lumen depreciation, as a function of mean lumens, shall be determined in accordance with IESNA testing procedures and according to the ratings

Figure 5-11
Sample Lighting Fixture Schedule

Tag	Description	Lamps	Ballast Description	Voltage	Input Watts	Product
F1	2' X 4' Parabolic Troffer, 18 cell floating door semi- specular 3-inch deep louver heat extract air handling NEMA G tandem ballasted pairs per Title 24	(3)F32T8/RE735	Magnetic Energy-efficient (1) 2-lamp in "slave" and (2) 2-lamp in "master"	277	100	LLL 123/ES PAIR
F1A	Same as F1	Same as F1	Magnetic energy saving (1) 2-lamp and (1) 1-lamp	277	103	LLL123
F2	2'X 2' Parabolic troffer 16 cell floating door specular 4-inch deep louver static NEMA F	(2)FB31T8/RE735	Electronic instant start type ABC 123 (2) lamp ballast	277	90	LLL234

General Requirements:
1. Lamps and ballasts shall meet applicable standards of the American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), and Underwriters Laboratories (UL). Luminaires shall be UL listed, or listed by other recognized testing agency. Ballasts and other materials shall be UL listed or recognized as appropriate and shall meet California energy standards.
2. Electronic ballasts shall be manufactured by _________ (list approved manufacturers) and shall be warranted for 3 years, including material cost and labor allowance.
3. Lamps shall be made by __________ (list approved manufacturers). Do not mix manufacturers of same type lamps.
4. (Insert any special project requirements here.)

published in (Manufacturer's Name) Catalog.

6. Replace defective lamps occurring within 90 days of beneficial occupancy.
7. Approved manufacturers (list).
8. No substitutions shall be made without prior approval.
9. Any other project-specific data.

Extensive Specifications

CSI recommends that more extensive technical specifications be written for complex projects or projects being built overseas. Although significantly longer and more work for the specification writer, these specifications protect against substitution with inferior "knock-off" products made by manufacturers over whom the designer has no influence. At present, world-wide specifications are reasonably standard. However, the cost or unusual nature of advanced technology lamps may be a cause for substitution with the less efficient T-12 lamps. Well-written specifications can reduce the likelihood of this occurring.

Manufacturer/Product References

Manufacturer	Products
General Electric	Lamps, most types
Mitsubishi	Lamps, some typ
OSRAM Corporation	Lamps, most t
Panasonic	Lamps, most t
Philips	Lamps, most typ
Sylvania	Lamps, most types

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Compact Fluorescent Lamps

Introduction

The continuing rise in the popularity of compact fluorescent lamp technology is good evidence of its value as an energy-efficient, long lasting substitute for the incandescent lamp. The average compact fluorescent lamp consumes only one-quarter to one-third as much energy as its incandescent counterpart and will last up to ten times longer. For example, a 10,000 hour, 13-watt compact fluorescent lamp (about 17 watts with the ballast) will provide about the same illumination as a 60-watt incandescent lamp that has a life of approximately 1000 hours.

Compact fluorescent lamps are available in a wide range of color temperatures, from 2700 K to 5000 K. They have very good color rendering properties, and they are available in a variety of sizes, shapes, and wattages. The increasing availability of luminaires designed for compact fluorescent lamps -- in both new and remodel applications -- means that compact fluorescent lamps can meet most any design application requirement.

Compact fluorescent lamps were developed in the late 1970s and introduced to the U.S. market in the early 1980s. Early model lamp production concentrated primarily on the retrofit market. Integral lamp-ballast combinations with screw-in Edison bases provided a convenient and inexpensive alternative to traditional incandescent lamps for hotels, apartment complexes, and other high volume users. Modular systems with replaceable lamps were popular, as well. By the late 1980's, the popularity of compact fluorescent lamps had risen substantially. Relatively recent large-scale production of dedicated compact fluorescent luminaires has extended the range of applications for this technology.

Contents

Technology Description

Compact fluorescent lamps are actually lighting systems consisting of a lamp (often with a starter integrated into the base), a lamp holder, and a ballast. Sometimes, a screw-in socket adapter is incorporated into the package. Generally, there are three different types of compact fluorescent lamp-ballast systems (see Figure 6-1):

- *Integral systems* are self-ballasted packages and are made up of a one-piece, disposable socket adapter, ballast, and lamp combination.
- *Modular systems* are also self-ballasted packages, consisting of a screw-based incandescent socket adapter,

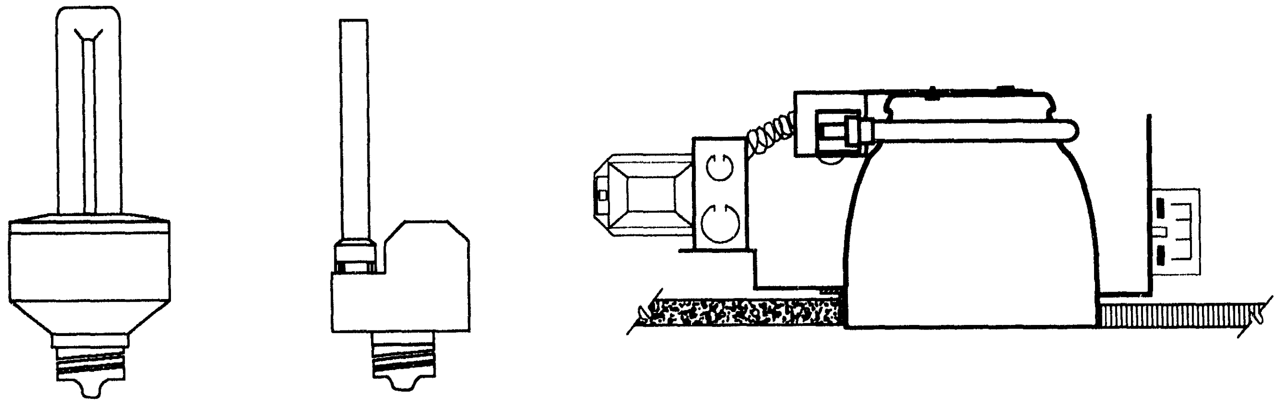


Figure 6-1
Compact Fluorescent Lamp-Ballast Systems

ballast, lamp holder, and replaceable lamp.

- *Dedicated systems* exist when a ballast and fluorescent lamp socket have been directly wired in as a part of the luminaire. While integral and modular systems are designed to screw into existing incandescent medium base sockets, dedicated systems generally are OEM (Original Equipment Manufacturer) components, supplied with luminaires.

Lamps are easily replaceable in both modular and dedicated compact fluorescent systems. On the other hand, relamping in an integral system requires the replacement of the entire integral unit.

Modular and integral compact fluorescent systems have particular relevance in remodel and retrofit applications. Dedicated systems are designed primarily for new construction purposes, although dedicated hardwire retrofit kits for downlights have been introduced recently by several companies. Simple permanent conversion kits for exit signs and table lamps are also available.

Lamp Types

The following lamp types are commonly available from a number of manufacturers.

- T-4 diameter twin-tube 2-pin lamps have a starter built into the lamp plug base. They operate on inexpensive reactor ballasts, come in wattages from 5 to 13 watts and are available for both modular and dedicated systems.
- T-4 and T-5 diameter quad-tube 2-pin lamps also have plug bases and built-in starters. These lamps produce more light than simple twin-tubes and are available up to 27 watts. These lamps are available for all compact fluorescent systems.
- Both T-4 and T-5 diameter twin-tube and quad-tube lamps are now available in 4-pin versions that do not contain a starter in the base of the lamp. These lamps are designed primarily for use with electronic ballasts. Larger T-5 lamps with 2G11 bases are discussed in the *Full Size Fluorescent Lamps* guideline.

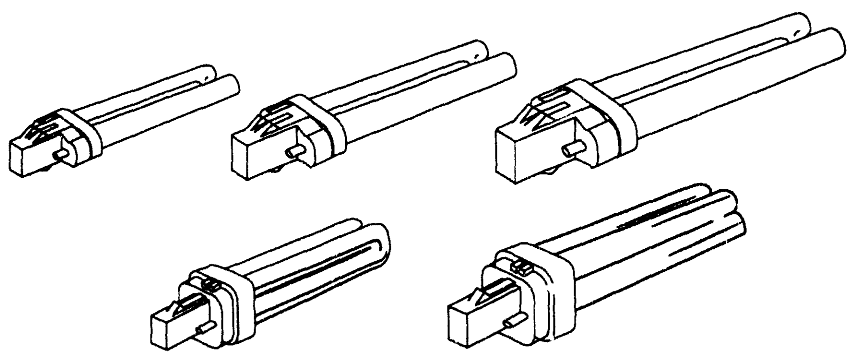


Figure 6-2
Common Compact Fluorescent Lamp Types

Compact fluorescent lamps for self-contained integral systems are generally a twin or quad-tube integrated with a ballast and screw-in socket base. In some cases a reflector or surrounding diffuser may be included in the package.

Ballasts

Compact fluorescent lamps are discharge lamps requiring ballasts to start and operate properly. A ballast provides the necessary voltage to start the lamp and, once started, keeps the lamp in operation. Ballasts also consume energy that must be accounted for when determining the efficacy of a particular lighting system.

Integral and modular compact fluorescent systems combine an Edison screw base with a ballast for direct retrofitting of incandescent luminaires. All other compact fluorescent lamps are designed to have an external ballast that must be specified for each individual lamp type and wattage. Ballast options for compact fluorescent lamps are listed below.

Normal Power Factor (NPF) Reactor Ballasts

NPF ballasts are common for the smaller two-pin lamp sizes. The 120 volt version is generally the least expensive and most compact type. These ballasts exhibit very low power factors (.45 for 120 volt, 0.25 for 277 volt), so it is important for engineers to calculate circuit loading carefully when designing the electrical distribution system.

High Power Factor (HPF) Reactor Ballasts

Also for the smaller preheat lamps, these ballasts contain capacitors to raise the power factor to 0.90 . They are more expensive and larger than the NPF type, but they allow for conventional branch circuit design and lower installation costs.

Conventional Electromagnetic Energy Saving Ballasts

The higher wattage lamps designed for 2G11-based four-pin operation generally operate on single or multiple lamp ballasts similar to those used for standard fluorescent lamps. Most ballasts are the "energy-efficient" type, consistent with California and national ballast standards.

Dimming Ballasts:

The starterless four-pin lamps can be used with either a magnetic dimming ballast with appropriate wall box dimmer, or a special electronic dimmer and electronic dimming ballast. Check with the manufacturer.

Electronic Ballasts

Several integral products are now available that combine a twin or quad-tube lamp with an electronic ballast. These products eliminate the objectionable starting flicker that has been associated with compact fluorescent lamps with integral starter bases.

In addition to electronically-ballasted integral products, several manufacturers now offer compact fluorescent luminaires with electronic ballasts instead of standard magnetic ballasts.

Electronic ballasts for compact fluorescent lamps offer several advantages over standard electromagnetic ballasts:

- The system efficacy (lumens per watt, including ballast losses) is generally about 20% higher with an electronic ballast. Under test conditions of 25 °C (77 °F), the efficacy of an electronically-ballasted compact fluorescent lamp ranges from 50-70 lumens/watt, compared to 40-55 lumens/watt for a magnetically-ballasted compact fluorescent lamp.
- The starting time of electronically-ballasted lamps is generally less than one second, while magnetically-ballasted lamps typically require one to four seconds to start.
- Electronic ballasts reduce lamp flicker.
- Electronic ballasts generally operate much more quietly than magnetic ballasts.
- Electronic ballasts can be manufactured in much smaller sizes and are lighter than conventional magnetic ballasts.

A disadvantage of electronic ballasts for compact fluorescent lamps is their higher price. This is compounded by the fact that there are few electronically-ballasted modular type compact fluorescent systems where the lamp can be replaced separately from the electronic ballast. Integral electronic designs require that the ballast be disposed of with the lamp. In addition, many of the current products exhibit a high percentage of total harmonic distortion (THD). The effects of THD produced by compact fluorescent lamp ballasts is still being evaluated by utilities, but it appears that the actual harmonic current is insufficient to cause major concern.

Power Quality Issues

Low power factor is one indicator of the effect that compact fluorescent lamps can have on the power quality of a utility distribution system. Compact fluorescent systems generally have power factors much lower than the 90% level achieved for high quality ballasts in typical full-size fluorescent lighting systems. Power factor is a performance measure that determines how effectively input current is converted into actual usable power delivered to the lamp. Optimum power utilization would result in a power factor of 1.0, meaning that the product of voltage and the current (volt-amperes or VA) is equal to the power used. Most compact fluorescent lamp systems, regardless of whether they are magnetically or electronically ballasted, are supplied with NPF ballasts, rated between 0.50 and 0.70 at 120 volts, and as low as 0.21 at 277 volts. Thus, a 13-watt lamp drawing a total load with ballast of 17 watts at a power factor of 0.50 actually draws 34 VA at 120 volts-- twice as much current as it would with a power factor of 1.0. Branch circuit current and overcurrent protection are based on VA. This makes it important to consult with a utility representative or professional engineer when using large numbers of NPF ballasted compact fluorescent luminaires.

High power factor ballasts for compact fluorescent lamps are available, but in most cases, luminaire manufacturers offer them only as optional add-on features. Utility-sponsored energy efficiency programs encourage the use of HPF ballasts, so they should become increasingly available in the near future. Whether using HPF or NPF ballasts, building engineers should follow the input current instructions of each ballast when designing the circuit loading.

Harmonic distortion is another indicator of the effect of compact fluorescent lamps on power quality. Any non-linear load, such as a personal computer, variable speed motor, television, or compact fluorescent lamp, causes harmonic distortion in power distribution systems. Most magnetically-ballasted CF lamps have a THD between 15% and 25%. The THD from most available electronically ballasted compact fluorescent lamps may be significantly higher, due to severe distortion of the current wave form. Distortion of the sinusoidal wave form may also be associated with a reduced power factor. A second potential concern is the presence of third (180 Hz) harmonics. In principle, these harmonics may cause overheating on the neutral line of three phase systems in older commercial buildings. This generally is not a practical problem for compact fluorescent lamps, because of the relatively small size of the load imposed by these lamps.

There are products currently available that reduce both the THD and the odd harmonics from electronically-ballasted lamps to levels approaching those of magnetic ballasts. Electronically-ballasted integral lamp-ballast packages with high power factors and low THD are currently available. However, increased size requirements, increased radio frequency interference (RFI), and cost factors have slowed the development of similar products. Utility energy efficiency programs are expected to encourage the mitigation of harmonic distortion problems, and low harmonic distortion ballasts for compact fluorescent lamps should become increasingly available in the near future.

For further information on ballasts, harmonic distortion, and other power quality issues, see the *Energy-Efficient Fluorescent Ballasts* Guideline.

Dimming

In general, compact fluorescent lamps cannot be dimmed using conventional dimming equipment. For example, according to at least one lamp manufacturer, using conventional incandescent dimmers in an attempt to dim integral units -- especially those using electronic ballasts -- can cause a fire. However, there are two specific products that enable dimming of compact fluorescent lamps:

- Dimming adapters permit an incandescent dimmer to dim a 4-pin quad-tube lamp. The adapter must be used with a specific ballast that is factory-installed on the luminaire.
- Solid state dimming ballasts permit the dimming of 4-pin twin-tube and quad-tube lamps with a remote potentiometer or low voltage signal.

Switching

The longevity of any fluorescent lamp, including compact fluorescents, is affected by the number of times the lamp is switched on and off during its life. Fluorescent lamp life ratings listed in lamp manufacturers' catalogs are based on a specific switching cycle of 3 hours on per start. Fluorescent lamp life may be less than the rated value if the lamp is switched more frequently than this. However, with electronic ballasting technology, manufacturers can include circuitry that optimizes the starting sequence (so-called "soft-starting"), thus preserving manufacturers' rated lamp life even if the lamp is switched more frequently than every 3 hours. The manufacturer should be contacted for more information if the application calls for frequent switching.

Of special concern are modern electronic control products. Devices such as wallbox touch switches, wallbox time switches, and wallbox occupant sensors may not be compatible with most compact fluorescent lamps. Incompatibilities are usually caused by the use of solid-state switches (triacs) instead of air gap switches or relays. A small continuous current (insufficient to illuminate an incandescent lamp) passes through the load even when it is "off." In magnetically-ballasted compact fluorescent applications, this idling current can cause continuous electrode heater and starter operation, resulting in reduced lamp life. In electronically-ballasted applications, the ballast may prevent idle current, in turn rendering the control device inoperable.

Environmental Conditions and Efficacy

It is important to realize that laboratory environmental conditions under which lumen output ratings are made are often quite different from actual installation conditions. The two environmental conditions that most significantly affect the performance of compact fluorescent lamps are ambient air temperature and the orientation or burning position of the lamp.

Figure 6-3 gives typical performance curves showing how ambient temperature affects lumen output of compact fluorescent lamps in both base up and base down burning positions. Note that while the compact fluorescent lamp produces rated lumens at 25 °C (77 °F) with the lamp base up, its lumen output drops to 80% of its rated lumens at 50 °C (122 °F). In applications where compact fluorescent lamps are mounted in small volume fixtures with a lack of air circulation (such as in lensed downlights), the user should expect that the ambient temperature would be between 40 °C and 50 °C (104 °F-122 °F), and should lower the lamp lumen rating accordingly. Some compact fluorescent luminaire manufacturers provide luminaires designed to improve ventilation in order to lower ambient air temperature and increase lumen output.

Figure 6-3 also shows how lamp orientation (burning position) can have a major influence on lumen output of a typical compact fluorescent lamp. Under identical ambient temperatures (25 °C [77 °F]), a compact fluorescent lamp in a horizontal or base up orientation will produce about 20% more lumens than a lamp in a base down position. As such, in any application where a compact fluorescent is used in a base down position (such as in a retrofit of an incandescent table lamp), the expected lumen output should be lowered by at least 10%. At higher ambient temperatures, a lowering of 15% is appropriate for base down operation. Manufacturers data should be consulted for specific values for individual lamp types, as performance differences are related to lamp shape and wattage.

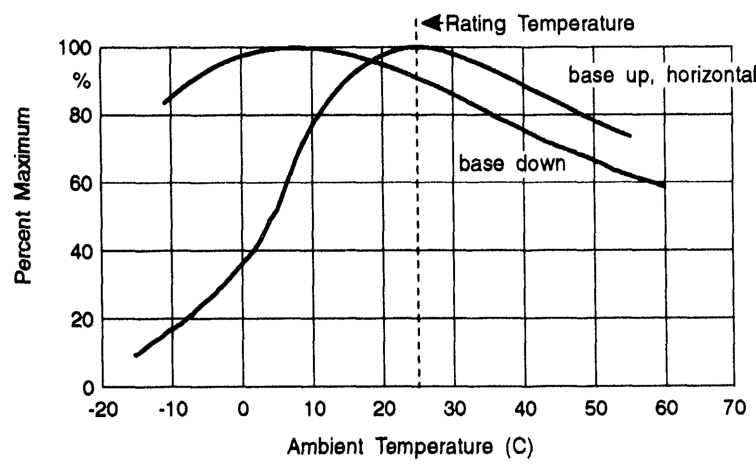


Figure 6-3

Typical ambient temperature and lamp orientation effects on lumen output of compact fluorescent lamps. Curves shown are for one specific lamp type in a draught-free environment. Performance – particularly in the base down position – will vary significantly depending on lamp configuration and wattage. (Source: Osram Corporation)

Current Products

As stated previously, compact fluorescent lamps are highly efficacious, have very good color rendering capabilities and are available in several color temperatures. Their performance is due to the use of high efficacy, high color rendering rare earth (RE) phosphors. The relative balance among these phosphors determines the color temperature of the lamp. RE phosphors are essential to the operation of the compact fluorescent lamp because of the high power density in the small diameter tube. The same loading of conventional halophosphors would result in rapid and severe lamp lumen depreciation.

Most compact fluorescent lamps are capable of generating about 50-60 lumens/watt. Their advantages notwithstanding, compact fluorescent lamps have similar overall efficacy as several other technologies of equal lumen output, such as low wattage metal halide and high pressure sodium lamps, and conventional straight, U-shaped, or circular fluorescent lamps.

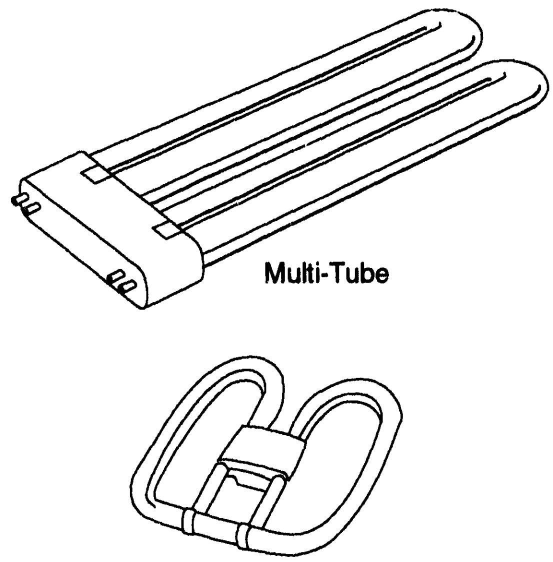


Figure 6-4
New Compact Fluorescent Lamp Products

New Lamp Products

In addition to the familiar types of compact fluorescent lamps, several new lamp configurations are becoming available. A new square-shaped "double-D" configuration is now available in three sizes and five different wattages. Its compact shape and size make it suitable for low profile surface and small recessed luminaires.

One lamp manufacturer is now producing a T-2 diameter, sub-miniature, wedge base fluorescent lamp in a wide range of lengths and wattages. It is available in both hot and cold cathode versions. As is true with all compact fluorescents, these lamps use RE phosphor coatings for good color rendering. T-2 lamp efficacy is more than 80 lumens/watt, exclusive of ballast losses. At this time, ballast and luminaire development for these lamps has been slow, thus limiting their application. Suitable applications for this lamp will probably include task, sign, and showcase lighting.

Several manufacturers are now offering compact fluorescent lamps consisting of 3 bent tubes (as opposed to single and quad tube configurations). This allows for more lumens in a smaller package. For example, one manufacturer has begun producing an electronically-ballasted 20-watt compact fluorescent, with high power factor and low THD. This package is only 6 inches long, and it produces similar lumens as a 75-watt incandescent lamp.

Current research into new compact fluorescent lamp configurations is concentrated on more varieties of lamps with higher powers, different shapes, and single-ended, 4-pin bases (2G7, 2G11, etc.). These lamps can use electronic ballasts, can be dimmed, and will eliminate much of the starting flicker that has been associated with the use of compact fluorescent lamps. This development promises to increase the number of compact fluorescent lamp applications.

Compact Fluorescent Luminaire Design

The exciting energy-saving possibilities of compact lamp luminaires have caused many manufacturers to rush products to market that are simply incandescent luminaires with fluorescent sockets. Specifiers should be cautious of the following potential problems:

- Use of reflectors and other hardware originally intended for incandescent lamp configurations (luminaire efficiency problem)
- Overheating, which causes short lamp and ballast life and reduced lumen output (luminaire design problem)
- Ballasts and lamps making acoustic noise (luminaire and application problem)
- Unusually low or high bulb wall temperature causing significant departure from rated lamp lumens (luminaire design and application problem)
- High THD, low ballast factor, and low power factor of particular lamp-ballast combinations (See also the *Energy-Efficient Fluorescent Ballasts* guideline)

Luminaire Types

Lower wattage compact fluorescent lamps are designed to be used in place of incandescent lamps in a wide variety of luminaire shapes and types. The twin-tube style is especially good for task lights, wall sconces, exit signs, step lights, and exterior path lighting. Two-lamp, horizontally aligned, twin-tube combinations have become an excellent substitute for incandescent recessed downlights, and many manufacturers of recessed luminaires have designed series of luminaires around this concept. The quad-tube lamp has similar applications as a downlight, wall washer, and sconce light.

Figure 6-5 illustrates some luminaires that use compact fluorescent sources.

Retrofitting

Modular and integral compact fluorescents systems with Edison screw-in sockets are generally not as efficient as their dedicated counterparts, but they do offer a means to upgrade existing incandescent lighting. Modular and integral lamps are available with either an electronic or magnetic ballast. The electronic ballast operates at a higher efficiency and without noise or flicker.

Application Guidelines

In general, compact fluorescent lamps are best applied in situations where incandescent or other small fluorescent lamps would be considered. They may be used in a wide variety of residential, commercial, retrofitting and new construction applications.

Incandescent Lighting Alternatives

Compact fluorescent lamps can generally be utilized in many areas where incandescent lamps would typically have been used before. Such areas can include recessed downlights, wall washers, desk lights, wall sconce type ambient fixtures, under cabinet fixtures, landscape lights, residential floodlights, and a variety of other applications. In most instances, compact fluorescent lamps produce 3 to 4 times more lumens per watt than incandescent lamps. For example, a 13-watt compact fluorescent will provide approximately the same light as a 40 to 60-watt incandescent lamp.

Retrofitting incandescent lighting with compact fluorescents offers significant cost savings to the user. Money saved through reduced energy use, fewer lamp replacements, longer lamp life, and related maintenance savings can quickly recoup the initial investment and provide continuing operating cost savings. Additionally, initial retrofit costs are often partially offset by utility rebates.

Alternatives to Other Fluorescent Lamps

In the lower wattages, other smaller fluorescent lamp types, such as circline configurations, lack the convenient single-ended plug base, color temperature options, and consistent good color rendition of compact fluorescent lamps. Many typical fluorescent applications for smaller lamps, such as task lights, surface mounted "drum lights," and corridor lights, will be more effective if compact fluorescent lamps are used. Also, the high color rendering quality of the compact lamp is maintained with every lamp replacement. See Figure 6-6 for more information on the color options and characteristics for compact fluorescent lamps.

Figure 6-5

Compact Fluorescent Luminaire Applications

	Recessed Downlights	Surface Units	Pendants	Sconces	Floodlights	Exit & Sign Lighting
T-4 Twin-Tube	○	○	○	●	●	●
T-4 Quad-Tube	● (a)	○	○	●	●	○
Globe Shaped Unit	○	○	●	--	--	--
Integral Lamp-Ballast	○	--	●	--	--	--
Reflector Unit	○	--	○	--	--	--
Electronically-Ballasted Integral Unit	○	○	●	○	○	--
Square	●	●	○	○	--	○

Key

● Superior Lamp Choice

○ Suitable Lamp Choice

-- Inappropriate Lamp Choice

Note:

a. with conversion kits complete with reflector

Figure 6-6
Color Options of Standard Compact Fluorescent Lamps

Color Temperature	Nominal CRI	Matches
2700 K	82	Warm White, Incandescent, White HPS
3000 K	85	Warm White, Incandescent, Halogen, Other 3000 K Fluorescent and HID lamps
3500 K	85	Halogen, Other 3500 K Fluorescent lamps
4100 K	85	Cool White, Metal Halide, Other 4100 K Fluorescent and HID lamps
5000 K*	85	C/D50 and all other high color temperature Fluorescent and HID sources

* not as many products available as other color temperatures

Limitations

Overall, compact fluorescent lamps are excellent choices for many residential and commercial lighting situations. The major limiting factor associated with compact fluorescent lamps in retrofit applications is their size. Compact fluorescent lamp-ballast packages are somewhat larger than incandescent lamps of the same lumen output, meaning that they may not fit properly in luminaires designed for incandescent sources. For example, in recessed downlights, a screw-in compact fluorescent package may protrude below the ceiling line, resulting in an objectionable appearance and creating glare. In addition, the base portion of a compact fluorescent lamp that contains the ballast is larger and of a different shape than the standard incandescent lamp. The luminaire's reflector may therefore not allow enough clearance for the adapter to be screwed into the socket. For these reasons, designers are encouraged to try out a test lamp of the intended configuration prior to attempting an entire retrofit. Many manufacturers of compact fluorescent lamps can provide sample products or cardboard templates that may be used to check for physical incompatibilities before purchasing.

Another limitation of compact fluorescent lamps is that they may not be suitable in very high ceilings (more than 12 feet), or in certain accent lighting applications requiring a tight beam spread or a point source sparkle. Additionally, the designer should be careful about using compact fluorescent lamps in exterior cold weather situations, as the operation of the smaller wattage lamps can be adversely affected by low temperatures (<0 °C [32 °F]) unless enclosed fixtures and/or electronic ballasts are used.

Residential Applications

In general, the use of compact fluorescent luminaires is especially appropriate for rooms such as kitchens and bathrooms, where high lumen output, good color rendering and adherence to local energy codes is required. Compact fluorescent lamps are also useful in all utility room lighting applications and in enclosed exterior fixtures (weather permitting) such as lanterns, and path lights. They are useful as ambient light sources in wall sconces. The extended lamp life of compact fluorescents makes them an intelligent design decision in hard-to-reach places. They are also appropriate for task lights, especially those types designed for the configuration of compact fluorescent lamps. A commitment to increased residential use of compact fluorescent lamps could be quite significant, in terms of energy conservation. A savings of 25% to 50% of the lighting electrical energy used by every home could be realized if all acceptable fluorescent applications were utilized. Figure 6-7 summarizes some of the residential applications suitable for compact fluorescent lamps.

The selection of compact fluorescent lighting equipment for residential design applications should be made carefully. Newer designs using electronically-ballasted compact fluorescent lamps are suitable for many residential applications, since these packages operate silently and start almost immediately without an initial flicker. An added benefit is the lighter weight and smaller size of the electronically-ballasted products. When magnetically-ballasted systems are used in residential applications, the benefits of energy efficiency and long life are sometimes outweighed by concerns for the acoustic noise of some ballasts, or by a negative reaction to starting flicker. In most residential applications, these conditions are not tolerable. In any case it is advisable to consult with and advise one's client about the overall benefits of compact fluorescent lighting.

Figure 6-7
Residential Applications for Compact Fluorescent Lamps

Kitchens	Living Rooms	Bedrooms	Bathrooms	Utility Areas	Exterior
Recessed downlights	Task lights	Task lights	Mirror lights	Stairways	Lanterns
Under cabinet lights	Swing arm lamps	Closet lights	Recessed downlights	Laundry rooms	Garage lights
	Under cabinet lights		Shower & tub lights	Attics	Path lights
	Recessed downlights			Closets	Security lights
	Wall washers			Crawl spaces	

Commercial Applications

Commercial lighting represents the best application for compact fluorescent technology. Compact fluorescent luminaires can be easily incorporated into lighting designs that are both aesthetically pleasing and energy efficient. It is now possible to design a first-class project using compact fluorescents in place of most incandescent lamps.

In office lighting design, not every incandescent luminaire has a compact fluorescent counterpart, but many do. Offices and other types of commercial and institutional spaces will look good and operate efficiently through the proper use of compact fluorescent troffers, downlights, wall washers, and task lights. As a result, designs will more easily comply with the applicable Title 24 standards contained in the California Code of Regulations. Incandescent lighting should be saved for a few key situations, such as locations where the wider dimming range of incandescent lamps is needed.

In retail lighting design, fluorescent light is appropriate for general illumination, wall washing, and some types of case lighting. The energy conscious designer uses standard incandescent or halogen sources only when point source sparkle or significantly more candlepower is required. Examples of this would include display lighting, jewelry case lighting, etc..

In restaurants and hotels, most of the circulation areas and other public spaces can be illuminated with compact fluorescent sources, unless ceilings are especially high, an application where HID sources might be more appropriate. Additionally, some pendant type luminaires and wall sconces can be equipped with compact fluorescent lamps. Incandescent lighting can then be used where it is especially important for full range dimming and special accents. Many fast food/fast action spaces can take advantage of the smaller general illumination fixtures made possible by compact fluorescent technology. In hospitals, laboratories, schools, and other institutions, compact fluorescent lamps can generally replace most incandescent applications.

In industrial lighting, most compact fluorescent lamps have limited applications. But the low heat of compact fluorescent lamps make them safer in hazardous environments where HID lamps might otherwise be used.

Figure 6-8 suggests some possible commercial applications for compact fluorescent lamps.

Figure 6-8
Commercial Applications for Compact Fluorescent Lamps

General Lighting	Accent & Specialty Lighting	Decorative & Portable Lighting	Utility Lighting	Exterior Lighting
Recessed downlights	Recessed & track-mounted wall washers	Wall sconces	Security lighting	Landscape floodlights
Suspended luminaires	Under cabinet lights	Chandeliers	Step lights	Pedestrian post top and bollard lights
Indirect lighting systems	Cove lights	Table & floor lamps	Exit signs	Step lights
	Case display lights	Makeup & dressing lights	Task lighting	Under rail lights
	Modular strip outlining			Vandal-resistant security lights
	Sign & display lights			

Examples

Cost Savings Retrofit Profile

Selling the idea of compact fluorescent lamps as effective, long lasting, energy saving replacements for incandescent lighting is much easier if the end user can see, in tangible terms, the benefits of such a strategy. Figure 6-9 shows one example of how a switch from incandescent to compact fluorescent lighting allows for significant energy savings and decreased operation costs. The table represents a hypothetical situation in which a facilities manager is considering a change from 75-watt incandescent downlights to 20-watt compact fluorescents with electronic ballasts. A total of 60 fixtures are involved.

Figure 6-9

Compact Fluorescent Retrofit Cost Savings Analysis

Existing Lamp: 75W A19/1210 Lumens **Replacement Lamp: 20W Quad-Tube with Integral Electronic Ballast**	
Existing Lamp Wattage	75
Replacement Lamp Wattage	20
Watts Saved/Lamp	55
Operating Hours/Year[1]	2600
kWh Savings/Year Per Lamp	143
Existing Lamp Rated Life	1,000 Hours
Replacement Lamp Rated Life	10,000 Hours (3.85 Years)
Electricity Cost/kWh[2]	0.12
Utility Savings/Year Per Lamp	$17.16
Savings Over Life of Lamp	$66.07
Relamping Cost of Existing Lamp[3]	$7.00
Avoided Cost of Relamping Over Lamp Life	$70.00
Relamping Savings/Year	$18.18
TOTAL YEARLY SAVINGS PER LAMP	**$35.34**
Cost of Retrofit[4]	$22.00
Utility Rebate[5]	$3.00
Net Cost of Retrofit Per Lamp	$19.00
Number of Fixtures	60
Total Cost of Retrofit	$1140.00
Payback Period	**6½ months**
Total Annual Savings	$2120.40
Net Savings Over Life of Lamps	$7023.54
Return on Initial Investment	186%

Notes:
1 Based on 10 hours/day, 5 days/week
2 Estimate, based on average commercial 1992 costs
3 Estimate, includes lamp cost and labor
4 Estimate, based on 1992 costs; includes integral lamp-ballast and labor
5 Estimate, varies by region and utility company

General Downlighting

Many corridors and lobbies are furnished with six or eight-inch round or square recessed downlights for general or wall wash lighting purposes. Typical designs call for incandescent "cans" or "tophat" luminaires. An energy-efficient alternative is to use modular type downlights designed specifically for compact fluorescent twin-tube or quad-tube lamps. By careful selection, the specifier can choose a fluorescent luminaire that appears similar to standard incandescent downlights. A general rule-of-thumb is to use about 25% of the required incandescent lamp wattage. In other words, use a downlight with one 26-watt or two 13-watt lamps to replace a 100-watt incandescent lamp, two 18-watt lamps to replace a 150-watt incandescent lamp, and two 26-watt lamps to replace a 200-watt incandescent lamp. Avoid using screw-in socket adapters in new construction, as they are not as efficient and are easily compromised by incandescent relamping at a later time.

Energy efficiency with a compact fluorescent downlight system is significant when compared with incandescent options. For example, to provide 15-20 footcandles in a corridor, luminaires are installed about every 30 square feet. The fluorescent scheme (two 13-watt twin-tube lamps) operates at about 1.0 watts/ft^2, while the incandescent scheme (one 100-watt A lamp) operates at over 3 watts/ft^2. The savings of over 6 kWh/ft^2/y saves $0.60/ft^2/y, or about $18/y/fixture. Added benefits result from a much longer lamp life and fewer maintenance costs associated with replacements.

Outdoor Floodlighting

Compact fluorescent lamp sources have excellent floodlighting capabilities, and there is a significant potential for savings over the use of traditional incandescent sources. Many floodlighting schemes for shorter walls, signs, etc. use an incandescent PAR-38 flood lamp. In many situations, a short fluorescent flood lamp luminaire will serve as an energy saving option, as long as ambient temperatures are high enough for proper operation. For example, a 22-watt quad-tube compact fluorescent luminaire with reflector would be a good alternative to an incandescent luminaire, supplied with a 100-watt PAR-38 lamp. The 22-watt quad-tube luminaire would use 60 watts less (including ballast) than a 90-watt PAR halogen lamp and 70 watts less than a standard 100-watt PAR lamp.

Decorative Lighting

Many pendant lights, wall sconces, and other types of decorative luminaires are available as compact fluorescent lamp sources. Manufacturers of wall sconces in particular have been quick to capitalize on the technology of compact fluorescent lamps, and many products are available.

Product Classifications

Lamp manufacturers tend to create "marketable" product names and identifications. These names make for better marketing, but make it more difficult to write a generic specification. However, the National Electrical Manufacturers Association (NEMA) has developed a generic designation system for non-integral compact fluorescent lamps. In most cases the specifier can easily relate the desired lamp product to the NEMA code. The code consists of the following elements:

CF + (Shape) + (Wattage) +(Base Designation)

The shape designator may [illegible] (twin-tube), "Q" (quad-tube), "S" (square shape), or "M," for any configurations not covered by the

Figure 6-10

Performance Characteristics of 2-Pin Twin-Tube and Quad Tube Compact Fluorescent Lamps

NEMA Lamp Code	System Input Watts (typical)	Rated Lumen Output	Typical Ballast Factor 120v	Actual Lumen Output	Ballast Type	Rated System Efficacy (L/W)
CFT5W/G23	9	250	.95-1.0	238-250	5W Reactor[5]	26-28
CFT7/G23[1]	11	400	.89-.90	356-360	7W Reactor[5]	32-33
CFT9W/G23[1]	13	600	.79-.83	474-498	9W Reactor[5]	36-38
CFT13W/GX23[1]	17	900	.95-1.0	855-900	13W Reactor	50-53
CFQ9W/G23	13	600	.79-.83	474-498	9W Reactor[5]	36-38
CFQ13W/GX23[2]	17	860	.95-1.0	817-860	13W Reactor	50-53
CFQ10W/G24d	16	600	.90-1.0	540-600	10/13W Auto.[3]	34-38
	13				10/13W React.[4]	42-46
CFQ13W/G24d	18	900	.90-1.0	810-900	10/13W Auto.[3]	45-50
	16				10/13W React.[4]	51-56
CFQ18W/G24d-[2]	25	1250	.90-1.0	1125-1250	18W Autotrans.[3]	45-50
	22				18W Reactor [4]	51-57
CFQ26W/G24d[2]	37	1800	.90-1.0	1620-1800	26W Autotrans.[3]	44-49
	31				26W Reactor [4]	52-58
CFQ15W/GX32d	20	900	.90-1.0	810-900	16W Reactor	41-45
CFQ20W/GX32d	27	1200	.90-1.0	1080-1200	22W Reactor	40-44
CFQ27W/GX32d	34	1800	.90-1.0	1620-1800	28W Reactor	48-53

Notes:
1 Most common lamps when standard twin-tube lamps are specified.
2. Most common lamps when standard quad-tube lamps are specified.
3. 120v operation
4. 277v operation
5. Multi-wattage ballasts available, but may result in low lumen output and shortened lamp life.
All lamps are rated for 10,000 hours @ 3 hours per start.

other designators. Base designators, on the other hand, are readily available from lamp manufacturers' catalogs.

Using the NEMA generic designation code, a 13-watt T-4 twin-tube lamp would be designated as:

CFT13W/GX23.

A 2-pin 26-watt T-4 quad lamp, on the other hand, would be described as:

CFQ26W/G24d.

Performance of Compact Fluorescent Lamps

The following table is included to provide information of the performance characteristics of some of the more compact fluorescent lamps. Values are included for twin-tube and quad-tube lamps. Before using the tables, it is important to realize that manufacturers of modular compact fluorescent lamps will usually list the lumen output of the lamp-ballast system as the rated lumen output of the manufacturer's lamp. In actuality, the lumen output of the modular compact fluorescent system is usually less than the lamp's rated lumens, because the ballast factor (a measure of a particular ballast's performance) is generally less than 100%. In using the tables, lamp lumen ratings should be multiplied by the ballast factor to determine the actual lamp lumens. If the ballast factor is not considered, the system may supply less illumination than anticipated. In integral systems, in which the ballast and lamp are inseparable, the manufacturer will usually give the corrected lumen output and no correction factors need be applied.

Guideline Specifications

Specifying compact fluorescent lamps is not difficult. There are several ways to insure that the preferred lamps and ballast requirement are clear to suppliers to avoid the substitution of inferior products. The designer may specify products by using lighting fixture schedules or by writing standard or extensive specifications.

Lighting Fixture Schedules

Most lighting designs list luminaires by type or "tag" in a fixture schedule included with construction documents. This schedule often completely specifies the luminaires, lamps, and ballasts. To properly specify compact fluorescent lamps, however, it is recommended that slightly more information be contained in the schedule than is often the case with other types of lamp products.

As has been previously noted, each manufacturer tends to create marketable product names for its lamps, making specifications difficult. For that reason, it is recommended that the specifier use the NEMA generic lamp designations whenever possible. For integral compact fluorescent lamps, it is best to identify a single manufacturer that makes all lamp products and use that manufacturer's nomenclature throughout. This way, the competitive bidder can easily list his/her corresponding lamp numbers in a general letter of proposed substitution.

Occasionally, there may be a specific lamp type that is unique to the manufacturer. For example, at the time of this guideline's printing only one manufacturer makes the square-shaped "double-D" compact fluorescent lamp. In situations like this, it may help to separately identify and list the unique lamp by naming the manufacturer in the lamp specification column.

Standard Specifications

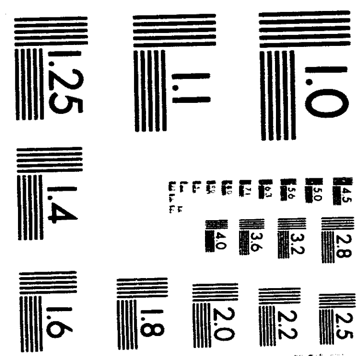
Most commercial projects use variations of standardized specifications based on the Construction Specifications Institute (CSI) recommended format. This shorter specification format is better for smaller or less complex projects. An example of this format follows.

Compact Fluorescent Lamps:

1. Rare Earth phosphor coating having a minimum CRI of 80 with a correlated color temperature of (2700) (3000) (3500) (4100), (5000) Kelvin, unless scheduled or noted otherwise.
2. Lumen output, rated lamp life, and lumen depreciation determined in accordance with IES testing procedures, and equal in performance to published values in (Manufacturer's Name) catalog.
3. Replace defective lamps occurring within 90 days of beneficial occupancy.
4. Approved Manufacturers: (List)

Extensive Specifications

CSI recommends that more extensive technical specifications be written for complex projects or projects which are being built overseas. Although significantly longer and more work for the specification writer, these specifications protect the design


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

2 of 2

against substitution by inferior, knockoff products made by manufacturers over whom the designer has no control.

Most products offered on the U.S. market have foreign counterparts. However, the systems of nomenclature differ. Also, the different operating voltages and frequencies of foreign electrical systems make it necessary to use totally different integral and modular components.

Manufacturer/Product References

Lamps (Most Types)	Electronic Ballasts	Magnetic Ballasts
General Electric	Advance Transformer	Advance Transformer
Mitsubishi	Electronic Ballast Technology	Magnetek Universal
OSRAM Corporation	ETTA Industries	Quality Services Electronics
Panasonic (Matsushita)	Innovative Industries	Radionic
Philips	Lutron Electronics	Robertson
Sylvania	Magnetek Triad	Schumacher
	OSRAM Corporation	Valmont Electric
	Valmont Electric	

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Tungsten-Halogen Lamps

Technology Description

Tungsten-halogen lamps have a whiter, brighter light and generally have longer lamp life than conventional incandescent lamps. They are also much more compact, making smaller, more compact reflector and luminaire designs possible. Although the tungsten-halogen lamp cannot compete with fluorescent or HID lamps in terms of energy efficiency or lamp life, it offers superb color, brilliance, and control characteristics. For these reasons, tungsten-halogen lamps are extremely popular with lighting designers.

Lamp Operation

Tungsten-halogen lamps are incandescent lamps made more efficient by the addition of a halogen gas, usually iodine or bromine. This gas suppresses tungsten filament evaporation by a chemical regeneration process known as the "halogen cycle." During lamp operation, the halogen gas combines with tungsten molecules that have evaporated off the filament. The evaporated tungsten molecules are then redeposited onto the filament, instead of on the bulb wall. As a result, lamp lumen depreciation due to bulb wall darkening is practically non-existent. Depreciation does occur, due to filament degradation, but it is significantly lower than in other incandescent lamps.

Proper operation of the halogen regenerative process requires operation of the tungsten-halogen lamp at an extremely high temperature. This increases lamp efficacy slightly, but it also requires that tungsten-halogen lamps have special glass envelopes -- usually quartz -- that will withstand the high bulb wall temperature. Lamps whose bulb walls are made of quartz require special handling, as quartz materials are extremely sensitive to oils and dirt from human skin. Handling of quartz lamps with bare hands can result in bulb wall

Figure 7-1
The Energy Policy Act of 1992

The U.S. Energy Policy Act of 1992 (Public Law 102-486), signed into law by President Bush on October 24, 1992, contains energy-efficiency standards and other regulations that will preclude certain lamps from being manufactured or imported into the U.S. after a transition period. Under the Act, reflectorized incandescent lamps, such as standard R and non-halogen PAR lamps will not be permitted (Ellipsoidal reflector ["ER"] are exempt). Tungsten-halogen type reflector lamps are the only reflector lamps that will comply to the Act. The transition period for compliance lasts until October of 1995. There are several categories of exempted lamps.

Contents

deterioration, significantly reduced lamp life, and/or premature lamp failure.

Lamp Configurations

Tungsten-halogen lamps are available in three basic configurations: double-ended; single-ended; and halogen capsule lamps.

Double-Ended Lamps

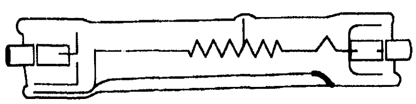


Figure 7-2
Double-Ended Tungsten-Halogen Lamp

Double-ended tungsten-halogen lamps are tube shaped. Most of the lamps in this category have tubes of small diameter: T-2½; T-3; T-4; T-6; and T-8. Double-ended tungsten-halogen lamps range from 45 to 2000 watts. These lamps typically have recessed single contact bases, one at each end of the lamp. Standard lamp life is generally around 2000 hours, and efficacy, at a low 15-25 lumens per watt, is fairly typical of incandescent lamps as a whole. However, efficacy can be increased to 32-38 lumens per watt by the application of infrared reflecting film to the bulb wall.

T-3 lamps are often used in contemporary chandeliers, wall sconces and torchieres. They offer high light output and are relatively inexpensive to purchase.

Single-Ended Lamps

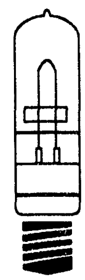


Figure 7-3
Single-Ended T-4 Minican Lamp

Single-ended tungsten-halogen lamps include a wide variety of sizes and characteristics. The one shared characteristic among these lamps is a single base at one end of the lamp. The most common base configurations are mini-candelabras, or "mini-cans," bayonets, bipins, and screw-ins. Lamp sizes range from T-3 to T-24, and wattages are from 5 to 10,000. In comparison with fluorescent and HID light sources, these lamps have short lamp lives (2000 hours), and low efficacy. However, at 20-25 lumens per watt, they are slightly more energy efficient than most incandescent lamps. IR-reflecting films are now available from at least one manufacturer of these lamps.

Single-ended tungsten-halogen lamps are commonly used in wall sconces, downlights and wall washers. The compact filament of this lamp type works especially well in complex optical systems, such as ellipsoidal reflectors and framing projectors.

Halogen Capsule Lamps

Tungsten-halogen capsule lamps include halogen PAR (Parabolic Aluminized Reflector) lamps, halogen PAR-IR (Infrared Reflecting) lamps, and low-voltage bud-shaped and projector type lamps, such as PAR-36, MR-11, and MR-16 lamps. Lamps designed to replace incandescent "A" lamps also fall into this category. This group of lamps contains a wide variety of lamp shapes, sizes, wattages, and base configurations. Although more efficacious than incandescent

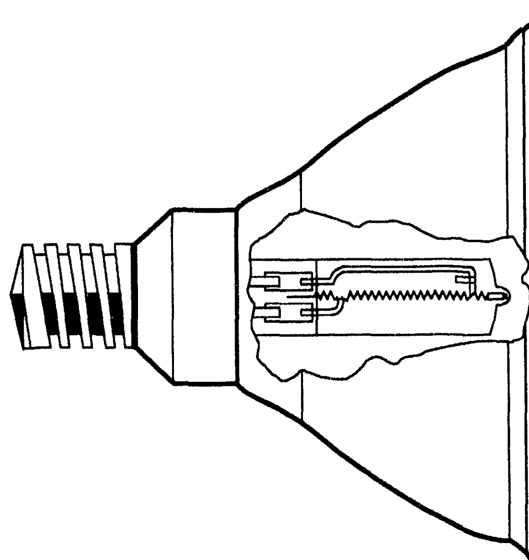


Figure 7-4
Cut-Away View Showing Tungsten-Halogen Capsule Within a PAR Lamp

lamps, this lamp family still falls far short of the energy efficiency provided by fluorescent and HID lamps.

Several varieties of tungsten-halogen capsule lamps can be called lamps within lamps: a small tungsten-halogen bud or capsule is mounted and sealed within a PAR or other type envelope. This makes it unnecessary to place a protective glass over the lamp, and in many cases, allows for greater beam control. See Figure 7-4.

Tungsten-halogen reflector lamps are generally used for accent and display lighting. Applications include lighting for restaurants, retail establishments, commercial displays, and artwork. The large, high-wattage PAR lamps can produce tremendous quantities of high quality light for these applications. The smaller low-voltage projector type lamps, on the other hand, are especially effective in design applications requiring compact track and recessed sources with more subtle illumination characteristics.

Infrared Reflecting (IR) Film Lamps

Up to 90% of the energy radiated by incandescent lamps, including tungsten-halogens, is invisible infrared (heat). However, some of this IR energy can be indirectly converted to light through the application of a dicroic film coating to the tungsten-halogen lamp (or capsule, in the case of PAR lamps). This coating consists of several layers of a micron-thin optical material. The coating reflects heat energy back onto the lamp filament while allowing visible light to pass through the bulb wall. The reflected infrared, in turn, further heats the tungsten filament. As a result, the necessary operating temperature for the halogen cycle is maintained with less input power. See Figure 7-5.

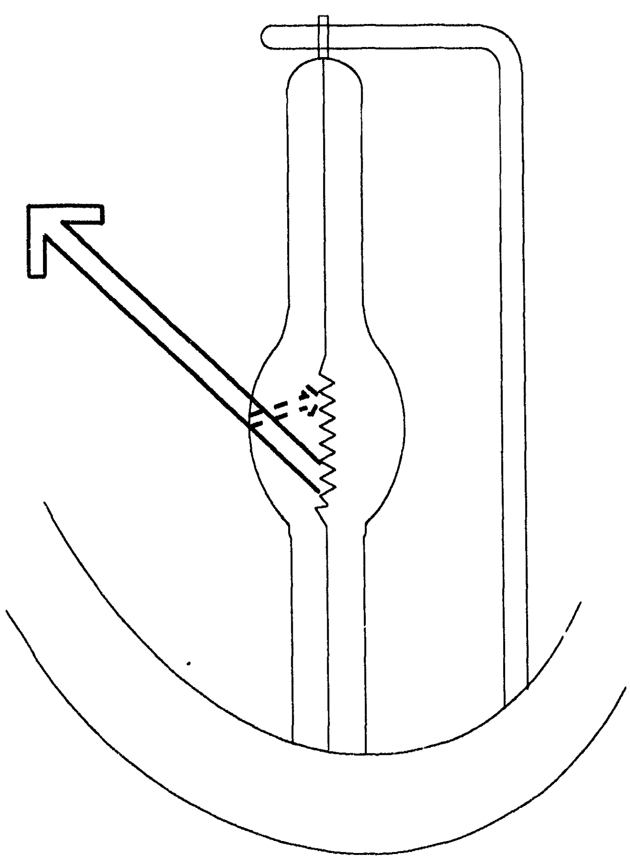


Figure 7-5

Dichroic film transmits visible light while reflecting infrared radiation (dotted line) back to the filament.

IR-reflecting lamps offer all of the benefits of standard tungsten-halogen lamps, including low lumen depreciation and high quality light. Tungsten-halogen lamps with infrared-reflecting films are presently offered in three configurations: single-ended T-4 lamps; double-ended, higher wattage T-3 quartz lamps (listed in Figure 7-5); and halogen PAR lamps. The energy savings potential with the double-ended and PAR lamp configurations is spectacular: a direct replacement of a standard incandescent lamp will, in some cases, reduce the wattage by 30% to 50% with no visible difference in light output or quality, though lamp cost is appreciably higher. However, the IR-reflecting single-ended quartz lamps offer no efficacy improvements over standard incandescent lamps.

Efficacy and Efficiency

Even though halogen lamps are generally more energy-efficient than standard incandescent lamps, they are only moderately efficacious. Most standard capsule halogen lamps have an efficacy of around 20 lumens per watt, while the efficacy of infrared-reflecting halogen lamps can exceed 30 lumens per watt. By comparison, the efficacy of a standard 1750 lumen, 100-watt A lamp is only 17.5 lumens per watt.

Figure 7-6

Double-Ended Infrared Reflecting Halogen Lamps

Lamp Designation	Watts	Rated Lamp Life (Hours)	Initial Lamp Lumens	Lumens Per Watt
Q500T3/350	350	2000	10,000	29
Q1500T3/900	900	2000	32,000	36

Notes:
Lamps require proper luminaires equipped with safety shields.
See Figures 7-11 for PAR halogen infrared reflecting lamps.

Nevertheless, while tungsten-halogen lamps are not particularly efficacious in terms of lumens per watt, the small filament of halogen lamps allows for extremely efficient optical systems and reflectors to be utilized. The result is potentially greater candlepower per watt than most other accent lighting or display lighting sources.

Color Temperature and Rendition

The halogen capsule lamps offer extremely attractive light at about 3000 K. This color temperature appears significantly "whiter" than other incandescent light sources.

The color rendering index (CRI) is approximately 100. When dimmed, the color temperature falls, as holds true with other incandescent lamps. Lamps with infrared-reflecting films generally have the same color characteristics, but a film's absorption may be varied to create slightly different color temperatures or tints.

Figure 7-7 compares the color temperature of tungsten-halogen lamps with other light sources.

Lamp Life

Lamp life in tungsten-halogen lamps generally ranges from 2000 to 3500 hours. However, in PAR envelopes, lamps may last up to 6000 hours. In addition, lamp life can be extended by dimming, although the increased lamp life does not follow standard incandescent lamp curves, so manufacturers' data will need to be consulted. Periodic high power operation may be required to raise a lamp's temperature up to the level needed to activate the halogen cycle. Continuous dimming below 35% is not recommended.

Diodes

There is a controversy within the lighting industry between manufacturers who use series diodes in the design of tungsten-halogen lamps, and those who do not. Over the next two years, diodes will probably be phased out of all tungsten-halogen lamps, except for PAR-16 lamps, due to performance irregularities and competitive pressures.

Some PAR halogen lamps designed to operate from a line voltage of 120 volts incorporate a diode in series with the lamp filament. The object of the diode is to reduce lamp filament voltage to about 84 volts. This allows for increased filament thickness and decreased filament area, resulting in a smaller filament and greater optical control over distribution of the light.

Diodes reduce voltage through half wave rectification of the 60 Hz input supply voltage. This means that the diode, in effect, "eliminates" half of the sinusoidal wave form. This increases lamp flicker above the usual 5% flicker characteristic of incandescent lamps. Dimming of these lamps increases flicker further, often to a level that is objectionable.

Figure 7-7

Tungsten-Halogen Lamp Color Comparison Chart

Light Source	Color Temperature (K)	In Comparison, Tungsten-Halogen Lamps Appear
Standard Incandescent	2800 K	Slightly Cooler and Whiter
Standard Quartz	3000 K	Same
Low-Voltage Quartz (MR-16)	3100 K	Slightly Warmer
Warm White Fluorescent	3000 K	Slightly Warmer
Cool White Fluorescent	4100 K	Warmer and Redder
Rare Earth Phosphor Fluorescent	2700 K	Slightly Warmer
	3000 K	Same
	3500 K	Slightly Warmer
	4100 K	Warmer
Metal Halide	3100 K	Slightly Redder
	4100 K	Much Warmer & Redder
Standard HPS	2200 K	Much Whiter & Bluer
White HPS	2600 K	Whiter

Diodes block either the positive or negative cycles of the input voltage. As such, a single lamp will have a low power factor and high harmonics compared to a regular incandescent lamp. If diode lamps of the same polarity (positive or negative) make up a significant portion of the branch circuit power, power quality, and dimming capabilities may be adversely affected. However, if the diode polarities are randomly altered, so that half the diodes block the positive cycle of input voltage and the other half block the negative cycle, the power quality, and dimming capabilities are indistinguishable from incandescent lamps with no diodes. It would be helpful if manufacturers of diode lamps could somehow label those lamps so that the polarity of the diodes is recognizable. It is important that lighting maintenance staff be aware of the polarity requirements of this product when relamping. In any case, individual or small numbers of lamps should be dimmed with diode-rated dimmers only.

From a power quality standpoint, individual diode lamps have 100% current harmonic distortion. There is no distortion, however, if an equal wattage lamp with a diode of opposite polarity is added to the circuit.

Other Applicable Technologies

Halogen lamps are relatively low efficacy sources, so their use should be restricted to applications where the unique characteristics of these lamps are needed. A common misapplication with halogen lamps is the general lighting of large spaces with tungsten-halogen sources. Ideally, halogen should be used only in applications in which high levels of footcandles are only needed in small areas. Otherwise, designers should investigate other more energy-efficient options. For illumination of larger areas, consider one of the following:

- Compact metal halide and white high pressure sodium lamps in general lighting, wall washing, and display lighting situations
- Compact fluorescent lamps, especially in area lighting and wall washing situations
- High-wattage, high intensity discharge (HID) lamps for industrial and commercial situations where a high lumen, high efficacy source is needed

Limitations

In general, tungsten-halogen lamps are more efficacious than incandescent lamps, but they have some limitations when applied to architectural lighting. These include:

- Some lamp sockets and bases are unusual and, due to compact size and high heat, are prone to failures unless of good quality.
- Quartz envelopes must not be handled with bare hands.
- Lamps must be protected by a cover glass or have an integral glass envelope, to prevent damage from possible lamp rupture, and to protect against excess UV radiation.

Overall, tungsten-halogen lamps are somewhat more energy efficient than standard incandescent lamp sources. Nevertheless, it should be noted that, except for the specific lamp types discussed in the following section, most tungsten-halogen lamps (*except* for those used in theater and entertainment lighting) probably have a more energy-efficient alternative.

Current Products

Low-Voltage Tungsten-Halogen Lamps

Low-voltage tungsten-halogen technology derived from systems already in use in automotive and aircraft applications. Tungsten-halogen technology allows for an extremely compact lamp envelope and filament, making the source ideal for sealed-beam and replaceable lamp headlights.

Most low voltage halogen lamps use a compact quartz-glass envelope or "bud" with two vertical pin terminals. A few products employ bayonet or double contact bayonet bases, such as those used in flashlights and aircraft, or glass wedge bases. Bare "bud" lamps are designed for use in a variety of special purpose luminaires, and many different wattages are available.

The most common applications for low-voltage halogen lamps are as projector or reflector lamps. In these lamps the halogen bud is backed with a reflector of aluminum or glass. There are three distinct types of projector lamps: multi-mirror reflector (MR) lamps; aluminum reflector (AR) lamps; and low-voltage PAR-36 lamps. These lamps are described in terms of appearance and performance characteristics in the following pages.

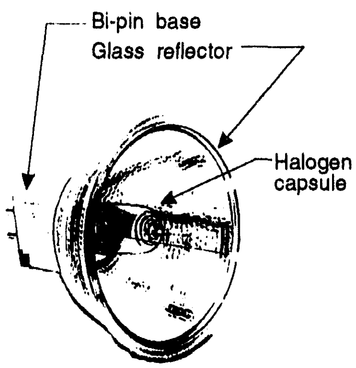


Figure 7-8
MR-16 Lamp

MR Lamps

MR lamps have dichroic-coated faceted glass reflectors, and they are available in many wattages and beam spreads for a variety of accent lighting applications.

The most popular low-voltage lamps are MR-16 bipin projector lamps. MR-16 lamps were originally developed as slide projector lamps, using forced-air cooling and 82 to-120-volt, 200-300-watt lamps. The architectural versions are 20-75-watt, 12-volt lamps. The reflector is made of faceted glass, coated with a dichroic film that reflects visible light and transmits infrared energy through the back of the lamp, making the MR-16 beam inherently a "cool beam" lamp. The reflector is the ellipsoidal type, making the MR-16 lamp especially good for framing and effects projectors. MR-11 lamps are smaller and generally of lower wattage, but offer similar performance.

The MR-16 lamp is made in very narrow spot, narrow spot, narrow flood, and wide flood beam spreads. Beam spreads are determined by the size and orientation of the facets on the lamp's reflector face. MR-16 lamps are available in standard wattages of 20, 35, 42, 50, 65, and 75. Additionally, there are a number of special MR-16 products, some of which are described below.

- Cover glass lamps are suitable for open lamp applications, such as open wire systems (note: tungsten-halogen luminaires must have a cover glass protector over the lamp to receive UL listing).
- Lamps with aluminum reflector coatings prevent lamp back glow, but eliminate the cool beam effect.
- Lamps with improved dichroic coatings provide constant color over lamp life, longer lamp life, and improved lumen maintenance.
- Lamps with color dichroic coatings (red, yellow, green, and blue) are used for special lighting effects..
- Square-shaped, MR lamps have been designed to provide similar candlepower as higher wattage round MR products.

Performance characteristics of MR-16 lamps are shown in Figure 7-9. MR lamps are also available in a smaller MR-11 (37 mm) configuration. As shown in Figure 7-10, MR-11 lamps are generally offered in 12, 20, 35, and 50-watt versions, with a similar choice of beam spreads. Unlike MR-16 lamps, however, some manufacturers make MR-11 lamps with double contact bayonet bases. The thin pins of the standard MR-11 bipin lamp are not as strong as the MR-16's, and some luminaire manufacturers recommend the double contact bayonet base lamp for durability and added corrosion resistance.

Figure 7-9

MR-16 Tungsten-Halogen Lamps

Proposed ANSI C78.1 Lamp Designation	Lamp Watts	Lamp Life	Beam Spread	Center Beam Peak Candlepower	Notes
MR-16 Lamps: Dichroic-coated multi-mirrored reflector, 51 mm (2") diameter, 12-volt operation, GX5.3 bipin base, no filament shield, "CG" = Cover Glass Option					
20MR16/7°	20	3000	VNSP 7 DEG	8200	
20MR16/13°	20	3000[1]	NSP 13 DEG	3350	CG
20MR16/25°	20	3000	NFL 23 DEG	950	CG, 880 CP
20MR16/40°	20	4000	FL 40 DEG	525	CG, 490 CP
30MR16/6°	30	2000	VNSP 6 DEG	8500	
35MR16/12°	35	4000	NSP 12 DEG	7900	CG, 7600 CP
35MR16/25°	35	4000	NFL 23 DEG	2500	CG, 2300 CP
35MR16/40°	35	4000	FL 40 DEG	1200	CG, 1100 CP
42MR16/9°	42	3500	VNSP 9 DEG	13,100	
42MR16/25°	42	3500	NFL 27 DEG	2100	
50MR16/15°	50	4000[2]	SP 14 DEG	10200	CG, 9500 CP
50MR16/25°	50	4000[2]	NFL 27 DEG	2900	CG, 2700 CP
50MR16/30°	50	4000[2]	NFL 32 DEG	2325	CG, 2250 CP
50MR16/40°	50	4000[2]	FL 40 DEG	1725	CG, 1500 CP
50MR16/55°	50	4000[2]	WFL 55 DEG	1150	
65MR16/15°	65	3500	SP 14 DEG	11500	CG OPTION
65MR16/25°	65	3500	NFL 23 DEG	4000	CG OPTION
65MR16/40°	65	3500	FL 38 DEG	2000	CG OPTION
75MR16/15°	75	4000	SP 14 DEG	12,300	CG, 12,300 CP
75MR16/25°	75	4000	NFL 24 DEG	4600	CG, 4600 CP
75MR16/40°	75	4000	FL 42 DEG	2100	CG, 2100 CP
Notes: (1) Lamp life increases to 4000 hours for lamps with improved constant color dichroic coatings. (2) Lamp life increases to 5000 hours for lamps with improved constant color dichroic coatings.					
Square MR-16 Lamps Dichroic-coated multi-mirrored reflector, 51 mm (2") diameter, 12-volt operation, GX5.3 bipin base, no filament shield; candlepowers are average center beam.					
	20	3000	SP 12 DEG	4500	
	20	3000	FL 36 DEG	700	
	39	3000	SP 12 DEG	9150	
	39	3000	NFL 24 DEG	3000	
	39	3000	FL 38 DEG	1500	
	49	3500	SP 12 DEG	11,500	
	49	3500	NFL 24 DEG	4800	
	49	3500	FL 38 DEG	2000	

Figure 7-10
MR-11 Tungsten-Halogen Lamps

Proposed ANSI C78.1 Lamp Designation	Lamp Watts	Lamp Life	Beam Spread	Center Beam Peak Candlepower	Notes
12MR11/8°	12	3000	NSP 8 DEG	1500	6 VOLT
20MR11/10°	20	3000	NSP 10 DEG	3900	
20MR11/15°	20	3000	SP 17 DEG	1550	
20MR11/30°	20	3000	NFL 30 DEG	600	
35MR11/10°	35	3000	NSP 10 DEG	5850	
35MR11/20°	35	3000	SP 20 DEG	2750	
35MR11/30°	35	3000	NFL 30 DEG	1300	

Notes:
Lamp designations are subject to change.
Except where noted, lamps are 12-volt operation.
Lamps with G-4 bipin bases are listed; optional DC bayonet base also available from some manufacturers.

AR Low Voltage Lamps

Aluminum reflector "AR" lamps with or without integral glass lens are available in configurations ranging from AR-40 (R-12 size) up to AR-111 (PAR-36 size). Some designers prefer using AR lamps over MRs due to their more consistent color characteristics. AR lamps are readily available in Europe, but are often difficult to find in the United States.

Performance characteristics of AR lamps are described in Figure 7-12.

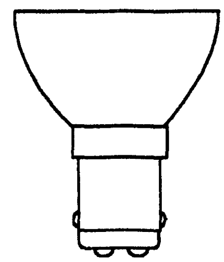


Figure 7-11
AR Type Lamp

Figure 7-12
Performance Characteristics of AR Type Tungsten-Halogen Lamps

Proposed ANSI C78.1 Lamp Designation	Lamp Watts	Lamp Life	Beam Spread	Peak Candlepower	Notes
AR-37 Lamps: Aluminum reflector, 37 mm diameter, 6 or 12-volt lamps, double contact bayonet base, no filament shield, integral cover glass..					
15AR37/6°	15	3000	NSP 6 DEG	5000	6 VOLT
20AR37/6°	20	3000	NSP 6 DEG	7000	
20AR37/20°	20	3000	SP 18 DEG	1400	
20AR37/30°	20	3000	FL 32 DEG	350	

Figure 7-12 (continued)

Performance Characteristics of AR Type Tungsten-Halogen Lamps

AR-48 Lamps, Aluminum reflector, 48 mm diameter, 12 or 24-volt lamps, G-4 bipin base, filament shield, no cover glass, optional 3100K silver color or 2600K gold color reflector, as noted.

20AR48/10°	20	2000	NSP 10 DEG	5000	
20AR48/15°	20	2000	SP 15 DEG	2000	
20AR48/10°	20	2000	NSP 10 DEG	4500	GOLD REFL.
20AR48/15°	20	2000	SP 15 DEG	1500	GOLD REFL.
20AR48/10°	20	2000	NSP 10 DEG	4500	24 VOLT

AR-58 Lamps: Aluminum reflector, 56-58 mm diameter, 6 or 12-volt lamps, double contact bayonet base, no filament shield, integral cover glass.

15AR58/4°	15	2000	VNSP 4 DEG	12,000	6 VOLT
15AR58/15°	15	2000	NFL 14 DEG	1400	6 VOLT
35AR58/6°	35	2000	VNSP 6 DEG	15,500	6 VOLT
35AR58/15°	35	2000	NFL 14 DEG	4000	6 VOLT
15AR58/8°	50	2000	NSP 8 DEG	11,000	
50AR58/15°	50	2000	NFL 16 DEG	4650	
50AR58/25°	50	2000	FL 25 DEG	1900	
50AR58/30°	50	2000	FL 32 DEG	1100	

AR-70 Lamps: Aluminum Reflector, 70 mm diameter, 12-volt lamps, double contact bayonet base, filament shield, no cover glass, 3100K silver color or 2600K gold color reflector, as noted.

20AR70/10°	20	2000	SP 10 DEG	7000	
20AR70/30°	20	2000	FL 30 DEG	1000	
50AR70/10°	50	2000	SP 10 DEG	15,000	
50AR70/30°	50	2000	FL 30 DEG	2000	
50AR70/10°	50	2000	SP 10 DEG	13,500	GOLD REFL.
50AR70/30°	50	2000	FL 30 DEG	1800	GOLD REFL.
75AR70/10°	75	2000	SP 10 DEG	19,000	
75AR70/30°	75	2000	FL 30 DEG	4000	

AR 111 Lamps: Aluminum reflector, 111 mm diameter, 12-volt lamps, screw and lug terminals, filament shield, no cover glass. In some cases, may be interchangeable with PAR-36 lamps.

35AR111/3°	35	2000	VNSP 3 DEG	45,000	6 VOLT
50AR111/5°	50	2000	NSP 5 DEG	50,000	
50AR111/10°	50	2000	SP 10 DEG	20,000	
50AR111/30°	50	2000	FL 30 DEG	3000	
75AR111/10°	75	2000	SP 10 DEG	25,000	
75AR111/30°	75	2000	FL 30 DEG	4500	
75AR111/60°	75	2000	WFL 60 DEG	1300	
100AR111/10°	100	2000	SP 10 DEG	45,000	
100AR111/30°	100	2000	FL 30 DEG	7000	
100AR111/60°	100	2000	WFL 60 DEG	2000	

Note: Lamp designations are subject to change

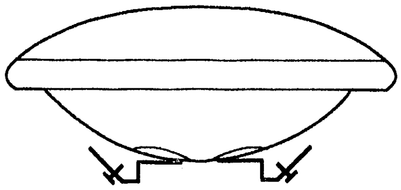


Figure 7-13
Par 36 Lamp

Figure 7-14
PAR-36 Halogen Low-Voltage Lamps

Proposed ANSI C78.1 Lamp Designation2	Lamp Watts	Lamp Life	Beam Spread	Peak Center Candlepower	Notes
Halogen PAR-36 Lamps: Aluminized glass reflector, sealed beam glass cover, 4-1/2" diameter, 12-volt lamps, filament shield, internal halogen "bud" element, screw and lug terminal					
35PAR36/5°	35	4,000	VNSP 5 DEG	25,000	
35PAR36/8°	35	4,000	NSP 8 DEG	8,000	
35PAR36/30°	35	4,000	WFL 30 DEG[1]	900	
50PAR36/5°	50	4,000	VNSP 5 DEG	40,000	Open Reflector
50PAR36/8°	50	4,000	NSP 8 DEG	11,000	Open Reflector
50PAR36/30°	50	4,000	WFL 30 DEG[1]	13,000	Open Reflector

Notes:
1. Beam spreads for WFL lamps measure approximately 35 DEG X 25 DEG
2. Lamp designations are subject to change

PAR-36 Lamps

Low-voltage PAR-36 lamps have been popular with lighting designers for many years. Halogen buds within PAR-36 glass envelopes provide similar performance to standard incandescent PAR-36 lamps but with improved color rendering, longer lamp life, and improved energy efficiency. In addition, low-voltage PAR-36 lamps provide exceptional beam spread control.

Figure 7-14 lists performance characteristics of low-voltage PAR-36 lamps.

Limitations of Low-Voltage Lamps

Halogen low-voltage reflector lamps have been responsible for considerable excitement in the lighting industry. However, there has been a great deal of misinformation and misrepresentation about the advantages of low-voltage lighting.

The actual advantages of low-voltage lighting include:

- Mostly very compact lamps
- Low-wattage lamps that are nevertheless able to create an intense, focused beam
- Traditional halogen color temperature and lamp life advantages
- Higher efficacy than most equivalent line-voltage incandescent lamps

The disadvantages of low-voltage halogen lamps, however, are seldom mentioned; they include:

- Low-voltage halogen lamps have low efficacy in comparison with most other advanced lighting technologies. Efficacy of these lamps is generally under 20 lumens per watt, which, like with most other incandescent lamps, makes them a poor source for general lighting applications.
- Low-voltage halogen lamps require a transformer to develop the low-voltage (usually 12 volts) for the lamp. This requirement may cause size, noise, cost, and potential dimming problems.
- Low-voltage halogen lamps are often expensive and lamp quality may be unreliable, especially from off brand MR lamps.

Halogen Capsule Lamps

To expand the applications of tungsten-halogen lamps, products were developed with a small tungsten-halogen capsule lamp within a standard lamp shape such as the PAR lamps shown in Figure 7-15. These lamps operate at 120 volts and most have common medium screw-in bases (a few side prong lamps are also available). Some manufacturers place a diode within the lamp assembly and operate the filament at the equivalent of 84 volts half-wave rectified (see earlier discussion on diodes).

This family of products has expanded the range of applications for tungsten-halogen lamps. Most of the halogen capsule lamps now available are reasonably priced, low-wattage alternatives to the standard incandescent lamps they are designed to replace. Virtually all of these lamps can be used in standard luminaire designs, as long as the lamp wattage does not exceed the luminaire rating.

There are two principal variations to the halogen capsule type of lamp: common lamp shapes designed to replace standard incandescent lamps; and PAR lamps in several configurations.

Common Lamp Shapes

Several varieties of capsule lamps are available in common shapes. Notable configurations include an A-lamp shape and a series of tubular (T) shaped lamps. These lamps are used primarily as retrofits for existing standard incandescent luminaires. Capsule lamps have much longer lamp life (up to 3500 hours) and use about 30% less electricity to generate about the same light output as the lamps they replace.

Halogen PAR Lamps

Halogen PAR capsule lamps, such as those illustrated in Figure 7-15, include both the traditional PAR-38 and newer, smaller PAR-30, PAR-20, and PAR-16 envelopes. They are useful in many new construction lighting applications, and they are valuable replacements for inefficient R and standard PAR lamps. Notable variations include the following.

- Long neck PAR-20 and PAR-30 lamps are designed to be used in existing luminaires that were originally designed for R-lamps.

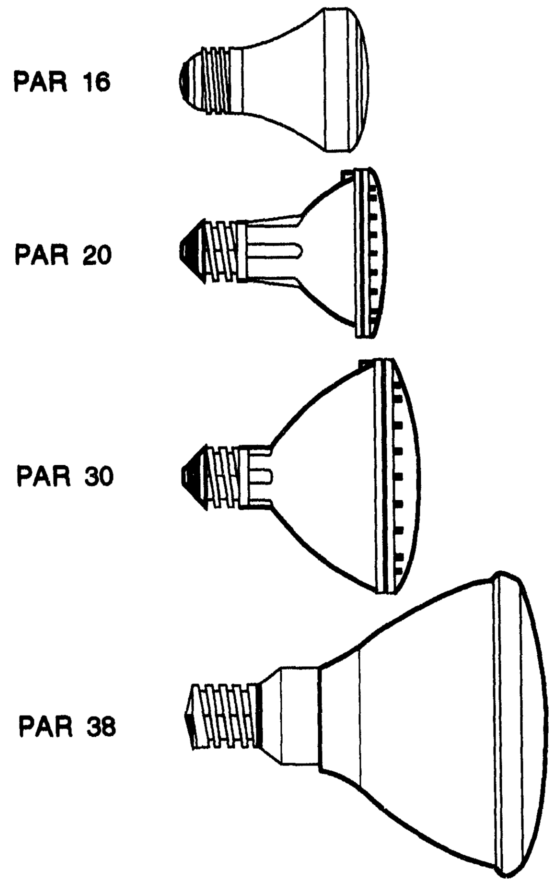


Figure 7-15
Halogen PAR Lamps

- "Cool beam" PAR lamps have dichroic reflectors similar to those supplied with MR-16 lamps. These lamps reduce heat on lighted objects by transmitting infrared radiation away from the object being illuminated.
- IR reflecting PAR lamps use the reflecting IR film to increase light output and efficacy.

Figures 7-16 and 7-17 list the performance characteristics of halogen PAR lamps.

Figure 7-16
Halogen PAR30 and PAR 38 Lamps

Proposed ANSI C78.1 Lamp Designation1	Watts	Lamp Life	Beam Spread	Center Beam Candle-power2	Notes
			PAR-30 Halogen Lamps		
50HPAR30/11°	50	2000	11 DEG	10,500	
50HPAR30/24°	50	2000	24 DEG	2700	Cool Beam Option
50HPAR30/35°	50	2000	36 DEG	1600	
50HPAR30/7°	50	2000	7 DEG	19,500	IR-Reflecting
50HPAR30/25°	50	2000	23 DEG	4000	IR-Reflecting
50HPAR30/35°	50	2000	33 DEG	2600	IR-Reflecting
50HPAR30/9°	50	2000	9 DEG	9900[3]	Long Neck
50HPAR30/15°	50	2000	16 DEG	4200[3]	Long Neck
50HPAR30/30°	50	2000	30 DEG	1900[3]	Long Neck
50HPAR30/40°	50	2000	40 DEG	1250[3]	Long Neck
75HPAR30/11°	75	2000	11 DEG	15,000	
75HPAR30/25°	75	2000	24 DEG	6000	Cool Beam Option
75HPAR30/35°	75	2000	36 DEG	2500	
			PAR-38 Halogen Lamps		
45HPAR/10°	45	2000	10 DEG	9300	
45HPAR/12°	45	2000	12 DEG	6900	
45HPAR/32°	45	2000	32 DEG	1700	
60HPAR/12°	60	3000	12 DEG	15,000	IR-Reflecting
60HPAR/30°	60	3000	32 DEG	3300	IR-Reflecting
60HPAR/55°	60	3000	53 DEG	1250	IR-Reflecting
75HPAR/10°	75	2500	10 DEG	17,500	
75HPAR/30°	75	2500	30 DEG	3,500	
90HPAR/10°	90	2000	10 DEG	19,000	
90HPAR/12°	90	2000	12 DEG	16,000	Cool Beam Option
90HPAR/30°	90	2000	30 DEG	3500	Cool Beam Option
90HPAR/55°	90	2000	55 DEG	2500	
100HPAR/10°	100	3000	10 DEG	28,000	IR-Reflecting
100HPAR/35°	100	3000	33 DEG	5500	IR-Reflecting
150HPAR/9°	150	3000	9 DEG	37,500	
150HPAR/10°	150	4000	10 DEG	29,000	
150HPAR/20°	150	4000	22 DEG	7200	
250HPAR/10°	250	6000	10 DEG	52,000	
250HPAR/20°	250	6000	22 DEG	12,000	

Notes:
Lamp designations are subject to change.
Values listed are typical for most manufacturers; however some variance is to be expected between manufacturers.
Candlepower values for long neck lamps are average center beam; all others are peak center beam.
Side prong 90HPAR/3 now available in some beam spreads.

Figure 7-17
Halogen PAR16 and PAR 20 Lamps

Proposed ANSI C78.1 Lamp Designation1	Watts	Lamp Life	Beam Spread	Center Beam Candlepower2	Notes
PAR-16 Halogen Lamps: Diode equipped with ceramic-backed reflector					
40PAR16/10°	40	2000	10 DEG	5000	
40PAR16/25°	40	2000	27 DEG	1300	
55HPAR16/12°	55	2000	12 DEG	5000	
55HPAR16/30°	55	2000	30 DEG	1300	
60HPAR16/10°	60	2000	10 DEG	7500	
60HPAR16/25°	60	2000	27 DEG	2000	
75HPAR16/12°	75	2000	12 DEG	7500	
75HPAR16/30°	75	2000	30 DEG	2000	
PAR-20 Halogen Lamps					
50HPAR20/10°	50	2000	10 DEG	6000	
50HPAR20/25°	50	2000	26 DEG	1850	Cool Beam Option
50HPAR20/9°	50	2000	9 DEG	6200[3]	Long Neck
50HPAR20/15°	50	2000	16 DEG	3200[3]	Long Neck
50HPAR20/30°	50	2000	30 DEG	1400[3]	Long Neck

Notes:
Lamp designations are subject to change.
Values listed are typical for most manufacturers; however some variance is to be expected between manufacturers.
Candlepower values for long neck lamps are average center beam; all others are peak center beam.

Application Guidelines

Halogen low-voltage lamps are an important and extremely popular specialty light source. Applications ranging from recessed "pin spots" to cove lighting strips make use of these low wattage white color sources. Low-voltage projector type lamps, such as MR-11s and MR-16s are an excellent display light source for art, jewelry, and other *precision* lighting situations. However, like regular tungsten-halogen lamps, low-voltage halogen lighting is often used when a more energy-efficient source, such as standard voltage halogen infrared-reflecting lamps or compact fluorescent lamps, may be a better choice. This is particularly true for general area lighting applications.

Halogen capsule lamps, infrared-reflecting film coated lamps, and low-voltage projector lamps have a broad range of applications. In new designs, the PAR and low-voltage MR lamps are excellent products for retail lighting and other forms of small area display and accent lighting. In retrofit situations, many PAR and IR-reflecting halogen lamps can be used for direct, immediate replacement of more traditional/less energy-efficient technologies, in everything from recessed downlights and wall sconces, to power floodlights and chandeliers.

Although many tungsten-halogen lamps are manufactured in typical incandescent lamp shapes, some are not suitable for unprotected exterior locations unless they are in enclosed luminaires.

In general, halogen capsule and infrared-reflecting film lamps are best applied in one of the following ways:

- *Cost-Effective and Efficient Display Lighting* The capsule PAR, infrared-reflecting film PAR, and low-voltage lamps all make excellent display sources for retail lighting installations, especially where tight control of beam spread is necessary.
- *Energy-Efficient Lamps in Conventional Luminaires* If design requirements preclude the use of more efficient technologies (such as fluorescent lamps and ballasts), consider halogen lamps in traditional luminaires such as downlights. This is most often justified when full-range dimming is required. Additionally, halogen PAR and PAR-IR lamps make excellent, inexpensive, and simple-to install retrofit solutions for luminaires that use standard reflector and PAR lamps.

Most tungsten-halogen lamps can be dimmed with conventional incandescent dimmers, although dimming can reduce the effectiveness of the halogen cycle. Continuous dimming below 35% may reduce lamp life and/or increase lumen depreciation. Series diode lamps may experience some dimming anomalies, such as increased flicker, but non-diode lamps will operate extremely well on most dimmers.

Residential Applications

Tungsten-halogen lamps make excellent light sources for many residential applications, including virtually every incandescent luminaire for which a suitable lamp style exists. In some instances, halogen lamps can replace standard incandescent with a significant reduction in wattage. For example, 90-watt halogen PAR lamps make excellent replacements for 150-watt R-40 lamps in recessed downlight luminaires. The flicker of halogen lamps with diodes may be most noticeable in these situations, so caution is urged.

Since halogen PAR and low-voltage lamps are display lamps, they can be used for residential accent situations, such as lighting artwork or accenting architectural and landscaping features.

Commercial Applications

The advent of the halogen PAR-IR lamp began a new era in retail display lighting. Situations traditionally lighted with 150-watt PAR lamps could be lighted with 60-watt PAR-IR lamps with no degradation of lighting quality. Replacement of traditional incandescent PAR lamps with halogen IR-reflecting technologies can be achieved without any need to change luminaires; the lamps simply screw into existing medium base sockets.

In some commercial situations, the halogen and halogen film lamps are the best choice only when fluorescent and HID options have been eliminated. Typical situations generally involve dimming where only incandescent and halogen sources can provide truly effective full-range dimming effects at reasonable expense.

In luminaires that use standard halogen lamps, direct replacement of the ordinary tungsten-halogen lamp with an infrared-reflecting film lamp provides a substantial savings. Even though the options are presently quite limited, several of the most common tungsten-halogen lamps (Q300T3, Q500T3, and Q1500T6) can be directly replaced with a savings of 30% to 40%.

Examples

Retail Display Lighting

Many stores use track lighting for retail display. The traditional light source has been PAR-38 lamps in 150-watt or 120-watt "energy-saving" sizes. However, by substituting more efficient standard halogen capsule lamps, suitable 60, 75, and 90-watt lamps may be used which will provide similar performance.

Savings potential is significant. The per unit reductions are from 60 to 90 watts per socket, or 40% to 60%, without any significant change in performance. Since in many stores the only lighting system is the track, this correlates to a direct energy savings of 40% to 60% for most of the property. The added cost of even the most expensive lamps, presently about $5.00, is amortized in one-third to one-half the normal life of the lamp for typical power costs.

Power Floodlighting

A common fixture design utilizes a double-ended 500-watt quartz lamp. Although an HID light source would be far more energy efficient, many applications call for an instant-on lamp. Specifying the infrared-reflecting film version of the double ended lamp results in virtually the same amount of light with a 350-watt lamp.

Savings potential is significant. Over the life of the lamp, more than 300 kilowatt hours are saved, which easily pays for the lamp cost premium several times over.

Guideline Specifications

In order to specify halogen capsule lamps, it is important to determine whether diode lamps are acceptable for the installation. Should the specifier have any concern over diodes, it is probably appropriate to write a proprietary specification designating the acceptable vendors.

Second, since halogen projector lamps are available in a variety of beam spreads, the specifier should be exacting in his or her selection. There is a distinct possibility of different beam spreads from different manufacturers, so caution is again urged in selecting between a generic specification and a proprietary specification.

Third, the market-driven lamp product development has made standardization of halogen lamp nomenclature difficult. At the time of this printing, the ANSI C78-1 committee was attempting to finalize nomenclature standards for many tungsten-halogen lamps. For instance, it has been proposed that the three-letter photographic code (BAB, EXZ, etc.) be eliminated for MR-16 lamp designations. Similarly, another proposed measure would categorize all reflector lamp beam spreads in degrees to replace the current lettering (FL, NSP, etc.). However, adoption of these standards is still pending. As such, while these guidelines should allow for reasonable accuracy, specifiers are urged to use manufacturer's advertised nomenclature and trade names if the differences in products are significant.

Finally, the specifier is reminded that the descriptions "halogen" and "quartz" do not necessarily refer to the same product, and they should therefore not be used interchangeably. Many of the capsule lamps do not use quartz glass (which keeps the cost down). Therefore, although most quartz lamps are tungsten-halogen lamps, not all tungsten-halogen lamps are quartz lamps.

Lamp Designations

The lamp designation can be specified as follows:

(Quartz)/Wattage/Shape/(Beam-spread)/(Manufacturer's Designation)

Specification Examples

- A 90-watt halogen capsule PAR-38 narrow spot (9°) would be: 90PAR38NSP/H or 90PAR38NSP/CAP. Under the proposed ANSI standard, the specification would change to: 90HPAR/9°.
- A 50-watt MR-16 lamp with a narrow flood (25°) beam spread (EXZ) would be as follows: 50MR16NFL, or 50MR16EXZ. Under the proposed ANSI standards, the specification would be: 50MR16/25°.

Manufacturer/Product References

Manufacturer	Products
Duro-Test	Halogen lamps
General Electric	Halogen lamps, Infrared-reflecting halogen lamps Constant color MR lamps
Iwasaki	Halogen lamps
OSRAM	Halogen lamps
Panasonic	Halogen lamps Infrared-reflecting halogen amps
Philips	Halogen lamps Long neck halogen PAR lamps Square MR-16 lamps
Sylvania	Halogen lamps

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Metal Halide and HPS Lamps

Technology Description

Metal halide and high pressure sodium (HPS) lamps are the preferred modern lamps of the family known as high intensity discharge (HID). (Mercury vapor lamps, another type of HID, are not as efficient and therefore not reported in this guideline.) Like fluorescent lamps, HID lamps require ballasts to provide proper starting and operating voltages, and they produce light through the discharge of an electric arc through a mixture of gases. HID lamps all utilize a compact "arc tube" in which very high temperature and pressure exist. This small arc tube closely resembles a point source of light, making HID lamps and their luminaires both compact and powerful.

Ballasts and Starters

HID lamps require ballasts to regulate the arc current flow and to deliver the proper voltage to the arc. Larger ("standard") metal halide lamps employ a starting electrode within the lamp to initiate the arc (see Figure 8-1). Smaller metal halide and HPS lamps, on the other hand, do not contain starting electrodes. Instead, the lamp is started by a high voltage pulse to the operating electrodes. An electronic starting circuit associated with the ballast generates this pulse. American National Standards Institute (ANSI) lamp-ballast system standards establish parameters for all HID components, except for newly introduced products.

A few electronic ballasts are now available for HID lamps. Electronic ballasts for HID lamps do not use the same principles as for fluorescent lamps -- the primary benefit of an electronic HID ballast is more precise management of the lamp's arc tube wattage over life. By better managing the arc tube wattage, more consistent color and longer lamp life usually occur. With few exceptions, high frequency operation does not increase HID lamp efficacy.

Striking and Warm-Up

It is not possible to instantly ignite a cold HID lamp to full brilliance. All HID lamps employ a mixture of gases and metals in the arc tube. As power is applied, temperature and pressure build gradually, causing vapors of the metals to enter into the arc and release light energy. The starting of the arc sometimes takes a few seconds, and the duration of the warm-up period varies depending on lamp type, ranging from 2 to 10 minutes. During this period, the lamp will exhibit different colors as the various metals vaporize.

Lamp Restrike

If power is interrupted, even briefly, an HID lamp's arc will extinguish. The lamp must then cool down before the arc can restrike. Lamp restrike periods

Contents

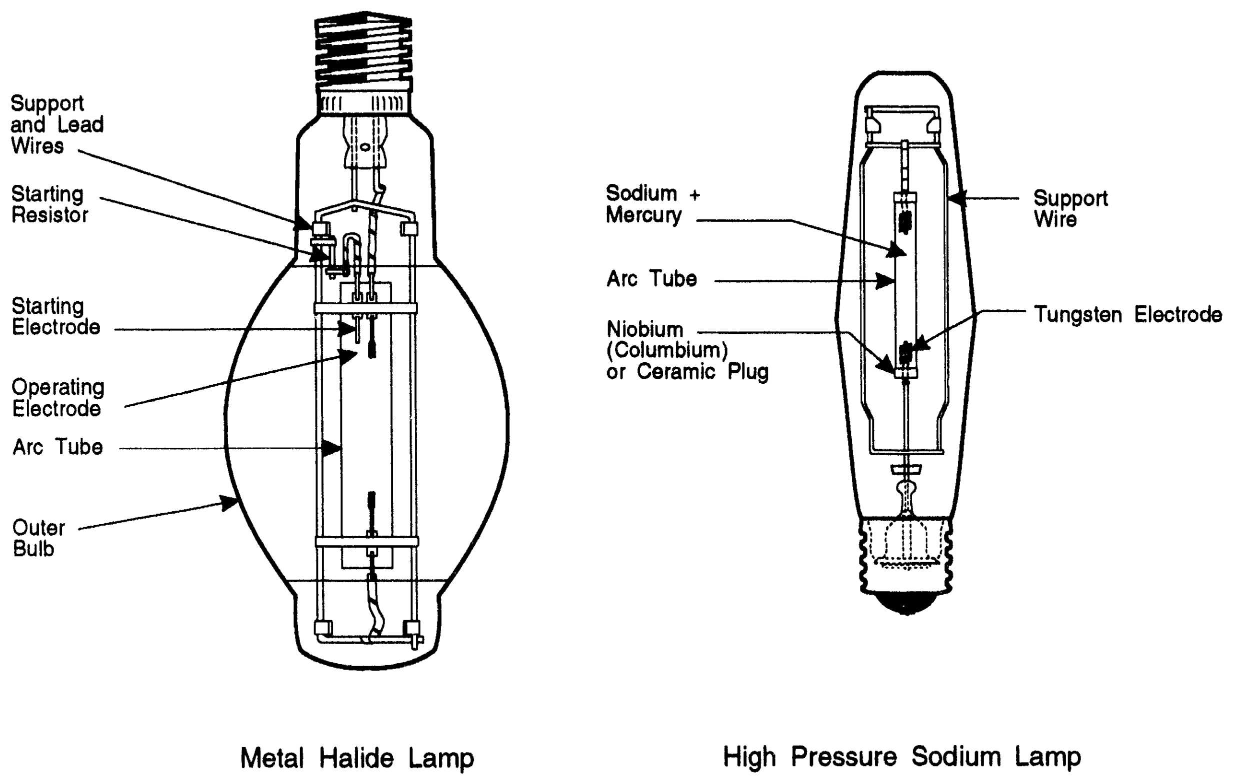


Figure 8-1
Metal Halide and High Pressure Sodium Lamp Construction

vary, depending on lamp type, and can last from 1 to 15 minutes. Restrike time is a major concern in applications where a prolonged lighting interruption could create hazardous conditions or a manufacturing shutdown. A few metal halide products are made with "instant restrike" capability, requiring special outboard electronics to generate extremely high voltages which overcome the elevated lamp temperature and pressure and regenerate the arc. In addition, some HPS lamps are available that will restrike immediately to approximately 10% of full light output. These lamps contain 2 arc tubes and will reach full light output in approximately 90 seconds. Alternatively, HID luminaires are available that contain supplementary high output quartz backup lamps. In the event of a brief power interruption the backup lamps ignite until the HID lamp's arc can restrike. The relative infrequency of power interruptions, as well as increased cost, make the use of instant restrike products relatively uncommon.

Dimming

It is possible to dim some HID lamps. Dimming requires specialized ballasts and dimming electronics, and operating HID lamps at less than full output will produce color shift and reduced lamp efficacy. For example, a metal halide lamp can be dimmed to about 40% power, but at this level it generates only about 25% of its rated lumens, and it will change color in an undesirable manner.

Energy Efficiency

HID lamps are among the most energy-efficient lamp technologies available. White sodium lamps have the lowest efficacy of the HID sources, producing between 40 and 50 lumens per watt. Metal halide lamps range from 55 (70-watt open fixture lamp) to 110 lumens per watt for a 1000-watt horizontal high output lamp. The most efficacious white light HID sources are standard high pressure sodium lamps, ranging from 65 (70-watt lamp) to 125 lumens per watt (1000-watt lamp). These values include ballast losses, and they are based on new, burned-in lamps.

Lamp Life

Lamp life of HID lamps varies considerably depending on type

(HPS vs. metal halide), burning orientation, size, and configuration. Generally, in similar applications, most HID lamps offer a lamp life duration comparable to most fluorescent lamps and much greater than any incandescent lamp. Lamp life may range from 3000 hours, for the 1500-watt metal halide sports lamp, to 24,000 hours and more for some of the standard HPS lamps. Near the end of lamp life, many HID lamps will exhibit a noticeable degree of color shift, which may be objectionable in some applications.

Lamp life ratings for applicable HID lamps are listed in the appropriate lamp charts in this document. It should be noted that lamp manufacturers publish HID lamp life ratings based on 10 hours per start operation (most other lamps are rated at 3 hours per start).

Color Characteristics

Manufacturers have taken advantage of new technologies in recent years to improve the color characteristics of HID lamps considerably. This development has allowed lighting professionals to use HID lamps in an ever-widening range of applications. In terms of lamp color temperature (CCT) and color rendering (CRI) capabilities, HID lamps can be summarized as follows:

Metal Halide Lamps

Some metal halide lamps are available in 2700-3200 K (warm) tones, but most lamps range from neutral to cool in color appearance, with a crisp white light of 3500-4300 K. Color rendering indices are usually between 65 and 70, although a few of the more recently-developed lamps achieve very high CRIs (up to 93).

High Pressure Sodium Lamps

Most HPS lamps have a distinctive, golden-pink color of 1900-2100 K, accompanied by a relatively poor CRI of less than 25. There are a few "deluxe" HPS products with a CRI of 65. In addition, "white" sodium lamps have color temperatures of 2500-2800 K and a CRI over 75. Neither deluxe nor white sodium lamps are as efficacious or as long-lasting as standard HPS lamps.

Temperature Sensitivity

Metal halide lamps are sensitive to low starting temperatures, and lamp life will be reduced if they are frequently started below -12 °C (10 °F). High pressure sodium lamps are fairly insensitive to temperature, and will start to about -30 °C (-22 °F).

Burning Orientation

Many HID lamps are designed to operate in a specific burning position, such as horizontal, vertical with base up, and vertical with base down. Lamp manufacturers usually designate the correct burning position for position-sensitive lamps in their catalogs. Operating HID lamps in burning positions other than those recommended by the manufacturer will adversely affect lamp life and lumen output. In particular, metal halide lamps are extremely sensitive to burning position. High pressure sodium lamps generally are not.

Other Applicable Technologies

HPS and metal halide lamps are the highest efficacy point sources in moderate lumen packages. However, in certain situations, other sources might be more applicable; these include:

- Halogen capsule, low voltage halogen projector, and infrared-reflecting halogen lamps, especially in small-scale display lighting situations
- Compact and full-size fluorescent lamps, particularly in general lighting and wall-washing situations

Current Products

As shown in Figure 8-2 HID lamps are available in a wide variety of sizes, shapes, and bases. HID lamp technology development is a continually evolving process, as manufacturers try to design lamp configurations and characteristics to meet an ever widening range of applications.

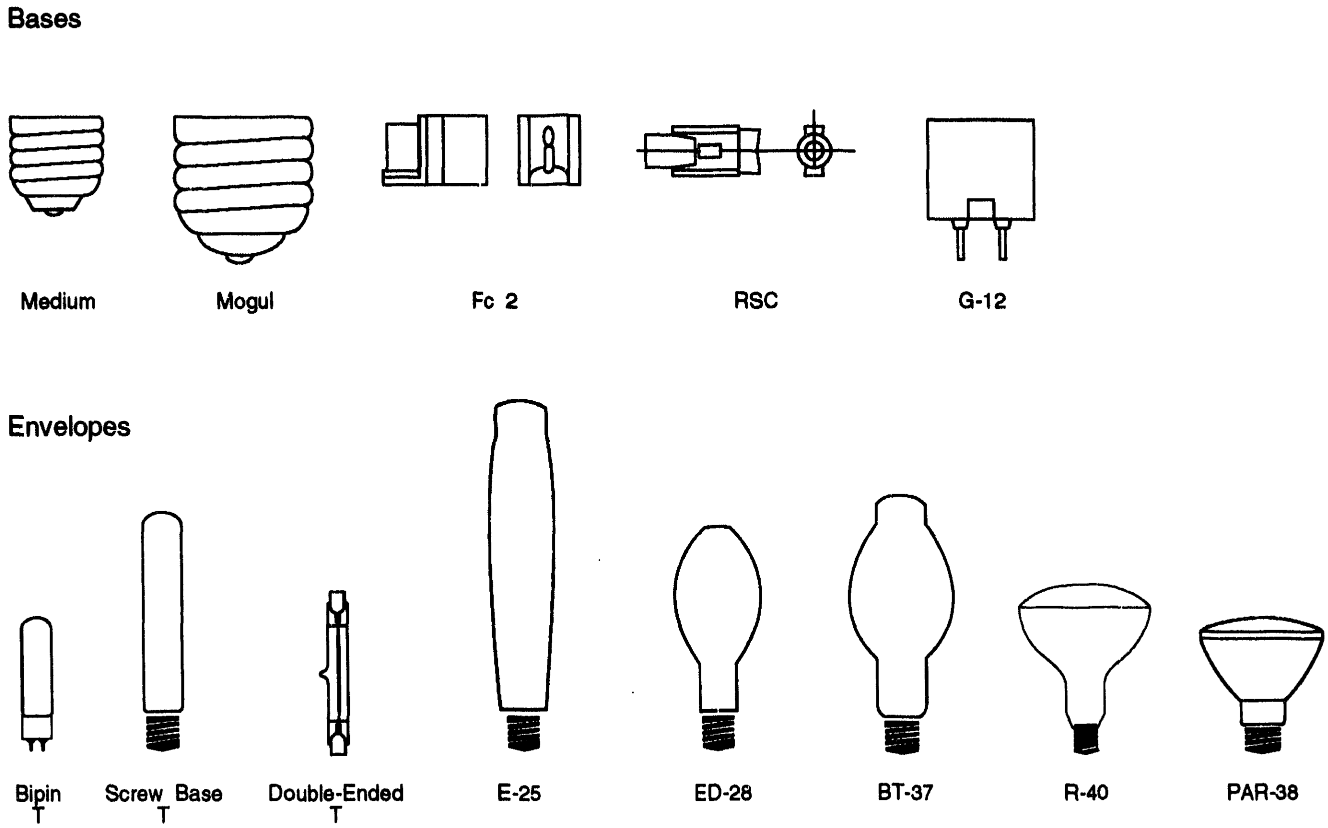


Figure 8-2
Typical HID Lamp Bases and Envelope Shapes (not to scale)

Metal Halide Products

Metal halide lamps were originally developed in 1965 for exterior and industrial lighting. Since that time the technology has expanded considerably to include lamps suitable for nearly any lighting application. Wattages range from 32 to 1500 watts, and a large number of envelope and base configurations are available, some of which are illustrated in Figure 8-3. Major variations of metal halide lamps include the following:

- Universal burning position lamps that are relatively insensitive to lamp physical orientation
- Position-specific lamps that have maximum efficacy and lamp life
- Choices of clear or phosphor-coated lamps in cool (3450-4100 K) color temperatures
- Optional warm (3000 K) phosphor-coated lamps in most sizes
- A few warm (3000-3200 K) clear lamps, especially in lower wattages
- Safety lamps that extinguish in the event of breakage of the outer envelope
- Lamps for open luminaires with internal arc rupture shields
- Silver-bowl lamps that minimize glare and light trespass from directional luminaires
- Compact lamps that produce a brilliant, high color rendering light in a comparatively small arc tube

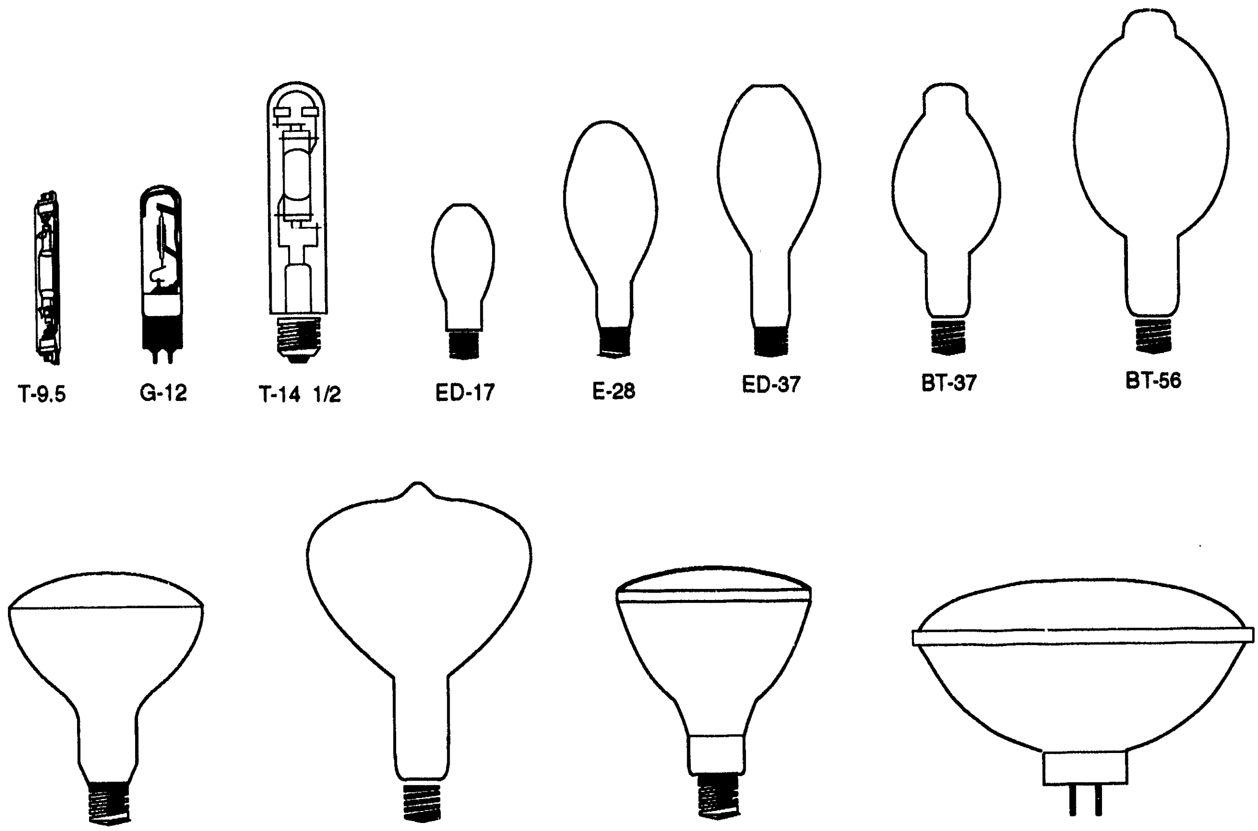


Figure 8-3
Metal Halide Lamp Configurations (not to scale)

Universal Position Screw Base Metal Halide Lamps (see Figure 8-4)

Because of their comparative insensitivity to operating position, the "universal" metal halide lamps are the most easily used. Generally, they perform best when the arc tube is in a vertical position, enjoying longer life and higher lumen output than when the arc tube is off vertical by more than 15 degrees.

Lamp color choice with universal metal halide lamps is generally limited to standard clear (4000-4500 K, 65 CRI) or coated (3700-4000 K, 70 CRI). Recent improvements include the addition of most wattages, as well as the development of medium-based compact lamps. These lamps operate on ANSI standard ballasts and generate 65-100 lumens per watt.

A few of these lamps are available with silver bowl arc-tube shields. These bowls act similarly to the familiar incandescent silver bowl lamps, by blocking unreflected arc tube radiation from the front hemisphere of the lamp.

Figure 8-4

Universal Position Screw Base Metal Halide Lamps

Watts	ANSI Code	Base	Envelope	CCT (K)	CRI	Coated or Clear	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)	Notes
50	M110	Medium	E/ED17	3700	70	Coated	3400	5000	
				4000	65	Clear	3400	"	
				4000	65	Clear	3200	"	Silver Bowl
70	M98	Medium	E/ED17	3700	70	Coated	5600	10,000	
				4000	65	Clear	5600	"	
				4000	65	Clear	5200	"	Silver Bowl
		Mogul	E/ED28	4000	65	Clear	5600	"	
100	M90	Medium	E/ED17	3700	70	Coated	7800	10,000	
				4000	65	Clear	7800	"	
				4000	65	Clear	7600	"	Silver Bowl
				5200	65	Clear	7000	7500	
		Mogul	E/ED28	4000	65	Clear	7800	10,000	
150	M57	Medium	E/ED17	3700	70	Coated	13,500	10,000	M107 Lamp
				4000	65	Clear	13,500	"	M107 Lamp
		Mogul	E/ED28	4000	65	Clear	13,500	"	M107 Lamp
175	M57	Medium	E/ED17	3700	70	Coated	15,000	10,000	
				4000	65	Clear	15,000	"	
		Mogul	E/ED28	3700	70	Coated	14,000	"	
				4000	65	Clear	14,000	"	
				4000	65	Clear	13,600	"	Silver Bowl
				5200	65	Clear	12,000	7500	
250	M58	Mogul	E/ED28	3700	70	Coated	20,500	10,000	
				4000	65	Clear	20,500		
				4000	65	Clear	20,000		Silver Bowl
				5200	65	Clear	19,000	7500	
			ED18	4000	65	Clear	20,500	10,000	
400	M59	Mogul	E/ED37	3700	70	Coated	36,000	20,000	
				4000	65	Clear	36,000	"	
				4000	65	Clear	35,000	"	Silver Bowl
				5200	65	Clear	32,500	15,000	
			ED28	3700	70	Coated	36,000	20,000	
				4000	65	Clear	36,000	"	
950	M47	Mogul	BT56	4000	65	Clear	105,000	12,000	
1000	M47	Mogul	BT56	3700	70	Coated	110,000	12,000	
				4000	65	Clear	110,000	"	
				4000	65	Clear	107,000	"	Silver Bowl
				5200	65	Clear	80,000	9000	
1500	M48	Mogul	BT56	3400	65	Clear	155,000	3000	
				4000	65	Clear	155,000	3000	

Notes:

Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
--All lamps must be used in enclosed luminaires;
--May be burned in any position, however,lamp life and lumen ratings apply to vertical burning position +/- 30 degrees;
--Lamp life is reduced to 75% of rated figures if burned in other positions; lumens decrease approximately 20% for horizontal burning position
--System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.

In addition to universal burning position products, metal halide lamps are also available that are designed to operate either vertically or horizontally. When designed for a specific burning position, metal halide lamps can generate more light and offer more color options than are available with universal position lamps.

Vertical Position Screw Base Metal Halide Lamps

The vertical burning metal halide lamp is optimized for base-up, base-down, or base-up/base-down operation, primarily for use in downlights. In addition to standard clear (4000-4500 K) and coated (3700-4000 K) lamps, warm color (2700-3200 K) clear and coated lamps are available in various wattages. The newest products tend to be lower wattages with medium bases and smaller envelopes. One product - the 32-watt lamp - is designed specifically for operation on an electronic ballast.

A principal advantage of vertical burning lamps is efficacy. Lamps

Figure 8-5

Vertical Burning Screw-Based Metal Halide Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Burn Pos.	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)	Notes
32	M100	Medium	E17	3000	70	Coated	BU15	2500	10,000	Proprietary ballast
70	M98	Medium	ED17	3200	65	Clear	BUBD15	6000	10,000	
				3200	70	Coated	BUBD15	5600	10,000	
75	M101	Medium	ED17	3200	65	Clear	BU15	5600	5000	
				3200	70	Coated	BU15	5200	5000	
100	M90	Medium	ED17	3200	65	Clear	BUBD15	9000	10,000	
				3200	70	Coated	BUBD15	8500	10,000	
150	M57	Medium	ED17	3200	70	Coated	BUBD15	12,500	10,000	M107 type lamp
175	M57	Medium	ED17	3200	70	Coated	BU15	14,000	10,000	
		Mogul	ED23½	3200	65	Clear	BUBD15	16,600	10,000	
				3200	65	Coated	BUBD15	15,750	10,000	
			E/ED28	3200	65	Clear	BU15	14,000	10,000	
				4000	65	Clear	BU15	14,000	10,000	
				3200	70	Coated	BU15	13,000	10,000	
				3700	70	Coated	BU15	14,000	10,000	
250	M58	Mogul	E/ED28	3200	70	Coated	BU15	20,500	10,000	
				3700	70	Coated	BU15	23,000	10,000	
				4000	65	Clear	BU15	23,000	10,000	
400	M59	Mogul	E/ED37	3200	70	Coated	BU15	36,000	20,000	
				3700	70	Coated	BU15	40,000	20,000	
				4000	65	Clear	BU15	40,000	20,000	
				4000	65	Clear	BD15	40,000	20,000	
1000	M47	Mogul	BT56	3400	70	Coated	BU15	117,000	12,000	
				3900	65	Clear	BU15	117,000	12,000	
				3900	65	Clear	BU15	117,000	12,000	
1500	M48	Mogul	BT56	3400	65	Clear	HBU105	155,000	3000	
				3400	65	Clear	HBD105	155,000	3000	

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
Lamps must be used in enclosed fixtures.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
Lamps must be used within operating conditions listed:
-BUBD15 = base up or base down +/- 15 degrees
-BU15 = base up +/- 15 degrees (optimized for downlighting)
-BD15 = base down +/- 15 degrees (optimized for uplighting)
-HBU105 = horizontal to base up +/- 105 degrees (optimized for sports lighting)

generate 70-110 lumens per watt, or about 10% more than universal burning lamps. However, operation in any other position will reduce both lamp life and lumen output.

Performance characteristics of vertical position screw base lamps are noted in Figure 8-5.

Horizontal Position Screw Base Metal Halide Lamps **(See Figure 8-6)**

As in vertical burning metal halide lamps, optimum lamp design in horizontal lamps is achieved when operating position is predetermined. Horizontal high output or "super" lamps often have bowed arc tubes, and use a position-fixing pin in the base,

Figure 8-6

High Output Horizontal Burning Position Mogul Screw Base Metal Halide Lamps

Watts	ANSI Code	Bulb Shape	CCT (K)	CRI	Coated or Clear	Burn Pos.	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)
175	M57	E/ED28	3200	70	Coated	HOR45	14,000	10,000
			3700	70	Coated	HOR45	15,000	10,000
			4000	65	Clear	HOR45	15,000	10,000
			4200	70	Coated	HOR45	15,000	10,000
			4700	65	Clear	HOR45	15,000	10,000
250	M58	E/ED28	3200	70	Clear	HOR45	20,500	10,000
			3700	70	Coated	HOR45	23,000	10,000
			4000	65	Clear	HOR45	23,000	10,000
400	M59	E/ED37	3200	70	Coated	HOR45	36,000	20,000
			3700	70	Coated	HOR45	40,000	20,000
			4000	65	Clear	HOR45	40,000	20,000
			4000	65	Clear	HOR20	40,000	20,000
			4000	65	Clear	HOR20	40,000	20,000
1000	M47	BT56	3400	65	Clear	HOR60	117,000	12,000
1500	M48	BT56	3400	65	Clear	HOR60	162,000	3000
1650	*	BT56	3400	65	Clear	HOR60	177,000	3000

Notes:
All lamps have a special mogul base.
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
Lamps must be used in enclosed fixtures.
Lamps must be used within operating conditions listed:
- -HOR45 = horizontal +/- 45 degrees
- -HOR20 = horizontal +/- 20 degrees (optimized for signs)
- -HOR60 = horizontal +/- 60 degrees (more flexible for sports)

* indicates non-standard type

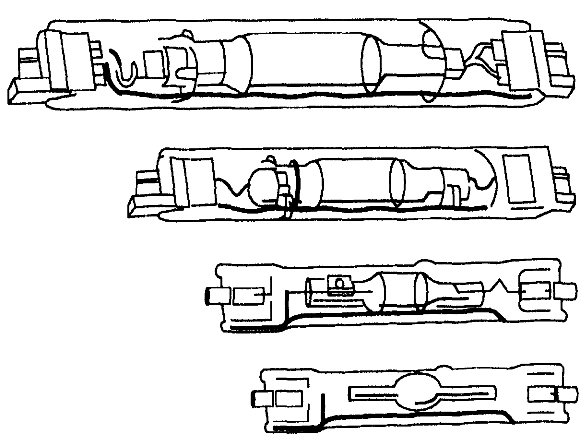


Figure 8-7

Double Ended Metal Halide Lamps with FC2 and RSC Bases

called a prefocus or position-orienting mogul (POM) base. This base and matching socket assure correct positioning of the lamp.

Since these lamps are primarily used in outdoor lighting, the smallest wattage product available is 175 watts. Special versions have been developed for signs and sports lighting. The most popular metal halide lamp colors are offered (3200 K coated, 3700 K coated, and 4100 K clear). As for vertical lamps, output is 70-110 lumens per watt.

Horizontal Position Double-Ended Metal Halide Lamps

Double-ended metal halide lamps in compact packages, illustrated in Figure 8-7, were originally introduced in Europe and have been very successful there. Some manufacturers produce these lamps with rare earth metals, resulting in lamps with very high CRIs of 80 or more, while others make the lamps with the more conventional 65-70 CRI associated with metal halide technology. The lamps with lower CRIs may be less sensitive to American power supply variations than the higher CRI lamps. These lamps operate in the range of 65-95 lumens per watt, and the 70-watt lamp with electronic ballast achieves about 75 lumens per watt -- more than 10% more than with magnetically-ballasted operation. In addition, the 70-watt lamp operated on the electronic ballast virtually assures consistent light color and lamp life. Moreover, the reduced ballast package lends itself to smaller luminaires, especially track lighting equipment. An electronic ballast for the 150-watt lamp is rumored to be in development at this time.

Figure 8-8

Double-Ended Horizontal Burning Metal Halide Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Burn Pos.	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)	Notes
70	M85	RSC	T6.5	4200	65	Clear	HOR45	5500	7500	
				3500	65	Clear	HOR45	5500	7500	
				3000	65	Clear	HOR45	5000	7500	
				4200	85	Clear	HOR45	5500	10,000	
				3000	81	Clear	HOR45	5000	10,000	
100	M91	RSC	T7.5	4200	65	Clear	HOR45	6800	7500	
150	M81	RSC	T7.5	4200	65	Clear	HOR45	12,000	10,000	
				3500	65	Clear	HOR45	12,000	10,000	
				3000	65	Clear	HOR45	11,500	10,000	
				4200	85	Clear	HOR45	11,250	10,000	
				3000	81	Clear	HOR45	11,000	10,000	
250	M103	RSC	T9.5	4200	65	Clear	HOR45	20,000	10,000	Special Igniter
				4200	85	Clear	HOR45	20,000	10,000	Special Igniter
	M80	RSC/Fc2	T9.5	5400	93	Clear	HOR45	19,000	10,000	
				4200	85	Clear	HOR45	20,000	10,000	
				4200	65	Clear	HOR45	20,000	10,000	
				3500	65	Clear	HOR45	20,000	10,000	
400	M108	RSC	T10	4200	65	Clear	HOR45	34,000	15,000	Special Igniter
		Fc2D	T10	4200	65	Clear	HOR45	40,000	15,000	Special Igniter
		Fc2	T10	5400	93	Clear	HOR45	33,000	10,000	
1000	M47*	RSC	T9.5	3800	65	Clear	HOR15	100,000	3000	Special Igniter
1500	M48*	RSC	T7.5	3800	65	Clear	HOR15	150,000	2000	Special Igniter
			T9.5	3800	65	Clear	HOR15	150,000	2000	Special Igniter

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
Lamps must be used in enclosed fixtures with UV absorbing lens.
Lamps must be used within operating conditions listed:
-HOR45 = horizontal +/- 45 degrees
-HOR15 = horizontal +/- 15 degrees)
* lamps operate on a standard ballast with a special igniter

Double-ended lamps must be operated with the arc tube within 45 degrees of horizontal, end-to-end. Performance characteristics of these lamps are shown in Figure 8-8.

Open Fixture Screw Base Metal Halide Lamps

Most metal halide lamps require enclosed luminaires to protect people and property from lamp rupture. Although rare, there are documented cases of metal halide lamps exploding. In most instances, this has occurred with near end-of-life lamps that have been continuously operated without having been switched off. These rare instances affect luminaire design requirements and restrictions.

There are a few metal halide lamps that are listed for non-enclosed use. These lamps typically employ an inner glass shield that can contain a violent failure within the combination of the inner shield and the normal bulb envelope. This technology is especially important for vertical position lamps, because many downlights in high ceilings are relamped using extension poles, and the cover glass required for most metal halide lamps hampers this operation.

Figure 8-9

Open Fixture Screw Base Metal Halide Lamps (except PAR-38 lamps)

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Burn Pos.	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)
50	M110	Medium	E/ED17	3200	65	Clear	UNIV	3300	5000
				3200	65	Coated	UNIV	2800	5000
70	M98	Medium	E/ED17	3200	65	Clear	UNIV	5200	10,000
				3200	65	Coated	UNIV	4800	10,000
				3200	65	Clear	BUBD15	6000	10,000
				3200	65	Coated	BUBD15	5600	10,000
		Mogul	E/ED17	3200	65	Clear	BUBD15	6000	10,000
100	M90	Medium	E/ED17	3200	65	Clear	UNIV	8500	10,000
				3200	65	Coated	UNIV	8000	10,000
				3200	65	Clear	BUBD15	9000	10,000
				3200	65	Coated	BUBD15	8500	10,000
		Mogul	E/ED17	3200	65	Clear	BUBD15	9000	10,000
400	M59	Mogul	E/BT37	3200	70	Coated	BU15	35,000	20,000
				3500	70	Coated	BU15	35,500	20,000
				3700	65	Clear	BU15	35,500	20,000
1000	M47	Mogul	BT56	3400	65	Coated	BU15	110,000	12,000
				3400	65	Clear	BU15	110,000	12,000

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
Lamps may be used in open fixtures.
Lamps must be used within operating positions listed:
-BUBD15 means base up or base down +/- 15 degrees
-BU15 means base up +/- 15 degrees (optimized for downlighting)
-UNIV = universal burning position; values given are vertical burning; horizontal life 25% less, horizontal lumens 15% less

Most open fixture lamps are designed for universal or vertical burning. There is a slight reduction in lumen output as compared to standard vertical burning lamps.

Performance characteristics of open fixture metal halide lamps are described in Figure 8-9.

Instant Restrike Metal Halide Lamps

Metal halide lamps exhibit fairly long warm-up and restrike times, generally the longest of all standard HID lamps. Even a momentary fluctuation of input power can cause a 10-15 minute interruption to the space being illuminated. For applications where such a possibility is intolerable (such as lighting for televised professional sports), an immediate restrike is needed. Instant restrike metal halide lamps are manufactured for such applications.

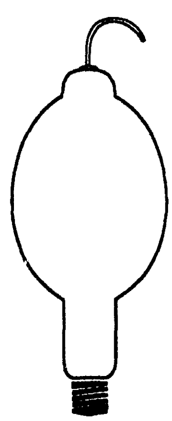


Figure 8-10

Instant Restrike Metal Halide Lamp

By building the lamp, ballast and socket to withstand extremely high voltages (up to 30,000 volts), metal halide lamps can be reignited "hot", returning to full light in seconds. Designed for the larger envelopes and wattages, instant restrike lamps utilize special wiring of the lamp to allow for the high voltage reignition across the arc tube. A separate anode wire, as shown in Figure 8-10 carries the 30,000 volt pulse without failing. Instant restrike metal halide lamps are described in Figure 8-11.

Figure 8-11
Instant Restrike Screw Base Metal Halide Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	Burn Pos.	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)	Notes
175	M57	Mogul	BT28	4000	UNIV	14,000	10,000	
250	M58	Mogul	BT28	4000	UNIV	20,500	10,000	
400	M59	Mogul	BT37	4000	UNIV	36,000	20,000	
1000	M47	Mogul	BT56	4000	UNIV	110,000	12,000	
1500	M48	Mogul	BT56	3400	HBU105	155,000	3000	
		PO Mogul	BT56	3400	HOR60	162,000	3000	
1650	n.a.	PO Mogul	BT56	3400	HOR60	177,000	3000	Not-standard wattage

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
All lamps listed are clear and have a CRI of 65.
Lamps must be used in enclosed fixtures.
Lamps used with special restrike igniter requiring fixture safety interlock and special high voltage wiring to anode cap.
Lamps must be used within operating positions listed:
-UNIV = universal burning position
-HOR60 = horizontal +/- 60 degrees
-HBU105 = horizontal to base up +/- 105 degrees (optimized for sports lighting)
n.a. = not available

Universal Position Directional Metal Halide Lamps

Directional metal halide lamps utilize familiar R and PAR lamp shapes to provide metal halide efficiency in a compact enclosure with its own reflector. Only in the last few years have these lamps become available in lower wattages. Now, metal halide directional lamps can be used in many applications previously limited to low-efficacy incandescent or mercury vapor lamps.

Metal halide PAR-38 lamps are especially important because they can be operated without a protective cover glass. This permits the lamp to be used in track lights, landscape lights, and other similar applications. The lack of a cover glass also makes relamping and maintenance easier.

The metal halide R lamps require a cover glass, but provide a reasonable-cost alternative for situations such as landscape lighting. The larger metal halide PAR-56 and PAR-64 lamps also require a cover glass, but offer relatively compact sources of high intensity, energy-efficient light. These could be particularly effective when used in recessed, track, and surface-mounted general and highlighting applications.

Note in Figure 8-12 that most metal halide directional lamps have shorter lamp lives than standard metal halide lamps.

High Pressure Sodium Lamps

High pressure sodium lamps were developed and introduced in 1968 as energy-efficient sources for exterior, security, and industrial lighting applications. HPS lamps were rapidly placed into street lighting service, and most street lighting today is HPS. HPS lamps are the most efficient of the white HID lamp sources, and they are useful in most applications where high color rendering is not a crucial concern.

Figure 8-12

Universal Burning Position Directional Metal Halide Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Beam Type	Beam Spread Degrees	Center Beam CP (nominal)	Nominal Lamp Life (Hrs.)	Notes
70	M98	Medium	R40	4000	65	Spot	15	60,000	10,000	
						Flood	70	1500	10,000	
		Med. Skt.	PAR38	4300	65	Spot	15	40,000	5000	Open fixture
						Flood	35	12,000	5000	Open fixture
				3200	65	Spot	20	18,000	7500	Open fixture
						Flood	35	10,000	7500	Open fixture
						Flood	65	3000	7500	Open fixture
		Mog. Prong	PAR56	4300	65	Spot	20	105,000	5000	
100	M90	Medium	R40	4000	65	Spot	15	80,000	10,000	
						Flood	70	3300	10,000	
		Med. Skt.	PAR38	3200	65	Spot	20	26,000	7500	Open fixture
						Flood	35	12,000	7500	Open fixture
						Flood	65	4500	7500	Open fixture
		Mog. Prong	PAR56	4300	65	Spot	20	106,000	5000	
175	M57	Medium	R40	4000	65	Spot	15	95,000	10,000	
						Flood	70	6500	10,000	
		Mog. Prong	PAR56	4300	65	Spot	20	108,000	5000	
250	M58	Mog. Prong	PAR64	4300	65	Spot	15	210,000	5000	
400	M59	Mog. Prong	PAR64	4300	65	Spot	30	120,000	5000	
1000	*	Mog. Prong	PAR64	4000	88	Spot	8	1,500,000	5000	*CSI Type
				5600	92	Spot	8	1,200,000	5000	*CID Type

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
Except where noted, lamps must be used in enclosed fixtures.
Lamp performance values listed for the following burning positions:
-R lamps, for vertical arc tube +/- 30 degrees
-PAR lamps, for horizontal arc tube +/- 45 degrees
Lamp life, lumens approximately 80% 75% in other positions.

Unlike metal halide lamps, HPS lamps do not contain starting electrodes. Due to the HPS ballast's electronic starting circuit, warm-up and restrike periods are much shorter than those of metal halide lamps.

Universal Position Screw Base HPS Lamps

HPS lamps, unlike most metal halides, do not require enclosure except to prevent moisture from accumulating on the lamp. This makes HPS lamps especially easy to use in many fixture types. Moreover, the virtual insensitivity of HPS lamps to operating position means that fewer lamp types are needed as compared to metal halide.

Lamp color temperature in HPS lamps does not vary much. While the "deluxe" HPS lamp has a relatively high CRI (65) for HPS technology, its color temperature of 2100-2200 K is not much different from standard HPS, which varies between 1900 K and 2100 K. All HPS lamps except "white" sodium appear a golden-pink color, and are not recommended for non industrial interior lighting.

HPS lamps are offered in many wattages. Lumens per watt,

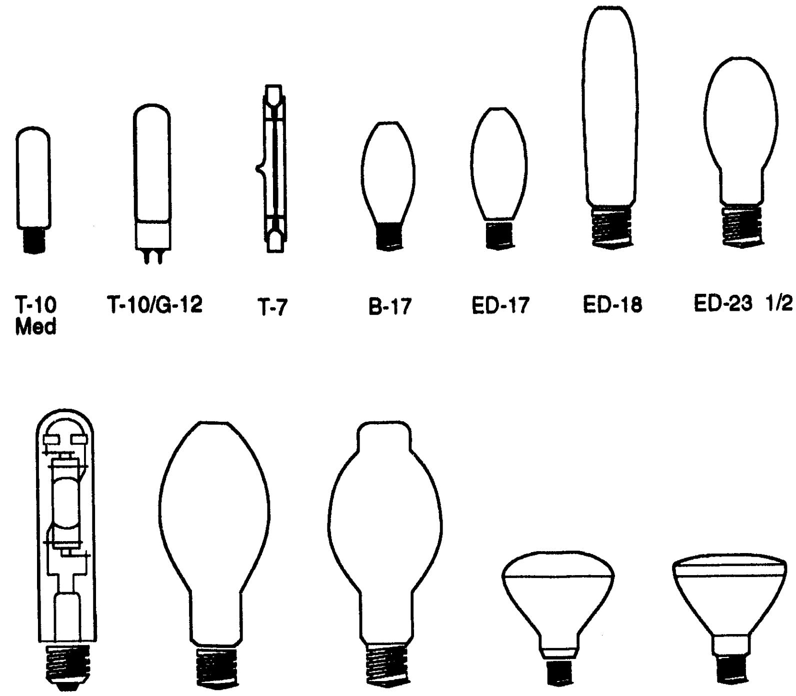


Figure 8-13
Typical High Pressure Sodium Lamp Configurations (not to scale)

ranging from 70 to 120 (including ballast), increases with wattage, . Electronic ballasts are rumored to be in development and will likely provide a small increase in system efficacy.

Some HPS lamps can be obtained with 2 arc tubes. These so-called "standby" lamps are a reasonable alternative to instant restrike circuits, providing rapid restrike cycles while offering extended lamp life. It should be noted that lamp warm-up time will still be in effect in the event of a power interruption. However, the lamp will not have to cool down before the second arc can be struck. These lamps are especially applicable for roadway and parking lot applications. In normal operation, standby lamps alternate operation between the arc tubes. This may in effectively double lamp life, although lamp life of these products has not been fully tested, and manufacturers' published lamp life values do not, as yet, reflect an increase for double arc tube lamps.

Performance characteristics of screw base HPS lamps are listed in Figures 8-14 and 8-15. "Deluxe" HPS lamps with a CRI of 65 are described in Figure 8-14, while standard screw base HPS lamps are noted in Figure 8-15.

Figure 8-14

'Deluxe' Type Universal Burning Position HPS Lamps

Watts	ANSI Code	Base	Bulb Shape	Coated or Clear	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)
70	S62	Medium	B17	Clear	3800	15,000
				Coated	3600	15,000
			ED17	Clear	4400	15,000
				Coated	4180	15,000
		Mogul	ED23½	Clear	4400	15,000
				Coated	4180	15,000
100	S54	Medium	ED17	Clear	7300	15,000
				Coated	6940	15,000
		Mogul	ED23½	Clear	7300	15,000
				Coated	6940	15,000
150	S55	Medium	B17	Clear	10,500	15,000
				Coated	9900	15,000
			ED17	Clear	12,000	15,000
				Coated	11,000	15,000
		Mogul	E23½	Clear	10,500	15,000
				Coated	9900	15,000
			ED23½	Clear	12,000	15,000
				Coated	11,000	15,000
250	S50	Mogul	E/ED18	Clear	23,000	15,000
			E28	Coated	20,000	15,000
400	S51	Mogul	ED18	Clear	37,500	15,000
			E28	Clear	37,400	10,000
				Coated	35,500	10,000

Notes:
All lamps have CCT of approximately 2100-2200 K and CRI of 65.
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.

Figure 8-15
Universal Burning Position Screw Base HPS Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)	Notes
35	S76	Medium	E/B17	2000	18	Clear	2250	24,000	
				2000	18	Coated	2150	24,000	
			T10	2000	18	Clear	2100	24,000	
50	S68	Medium	E/B17	2050	20	Coated	3800	24,000	
				2050	20	Clear	4000	24,000	
			T10	2050	20	Clear	3700	24,000	
		Mogul	ED23½	2050	20	Clear	4000	24,000	
				2050	20	Coated	3800	24,000	
70	S62	Medium	E/B17	2050	20	Coated	5985	24,000	
				2050	20	Clear	6300	24,000	
			T10	2050	20	Clear	6300	24,000	
		Mogul	E/ED23½	2050	20	Coated	5985	24,000	
				2050	20	Clear	6300	24,000	
				2050	20	Clear	6300	24,000	
100	S54	Medium	B17	2050	20	Coated	8500	40,000	Double arc tube
				2050	20	Clear	9500	24,000	
		Mogul	E/ED23½	2050	20	Clear	9500	24,000	
				2050	20	Coated	8800	24,000	
				2050	20	Clear	9100	40,000	Double arc tube
150	S55	Medium	B17	2100	22	Coated	15,000	24,000	
				2100	22	Clear	16,000	24,000	
		Mogul	E/ED23½	2100	22	Clear	16,000	24,000	
				2100	22	Coated	15,000	24,000	
				2100	22	Clear	15,600	40,000	Double arc tube
	S56	Mogul	E28	2100	22	Clear	15,000	24,000	
200	S66	Mogul	E/ED18	2100	22	Clear	22,000	24,000	
				2100	22	Clear	22,000	40,000	Double arc tube
250	S50	Mogul	E28	2100	22	Coated	26,000	24,000	
			E/ED18	2100	22	Clear	27,500	24,000	
				2100	22	Clear	30,000	24,000	
				2100	22	Clear	27,500	40,000	Double arc tube
			T14.5	2100	22	Clear	29,000	24,000	
				2100	22	Clear	28,500	40,000	Double arc tube

Figure 8-15 (continued)

Universal Burning Position Screw Base HPS Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Initial Lumens (nominal)	Nominal Lamp Life (Hrs.)	Notes
310	S67	Mogul	E/ED18	2100	22	Clear	37,000	24,000	
400	S51	Mogul	E/ED37	2100	22	Coated	47,500	24,000	
			E/ED18	2100	22	Clear	50,000	24,000	
				2100	22	Clear	50,000	40,000	Double arc tube
			T14.5	2100	22	Clear	50,000	24,000	
				2100	22	Clear	50,000	40,000	Double arc tube
600	S106	Mogul	T16	2100	22	Clear	90,000	24,000	
750	S111	Mogul	BT37	2100	22	Clear	110,000	24,000	
1000	S52	Mogul	E-25	2100	22	Clear	140,000	24,000	
				2100	22	Clear	140,000	40,000	Double arc tube
			T21	2100	22	Clear	140,000	24,000	

Notes:
All lamps are universal burning position.
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.

Figure 8-16

Universal Burning Position Directional High Pressure Sodium Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Beam Type	Beam Spread	Center Beam CP (nominal)	Nominal Lamp Life (Hrs.)	Notes
35	S76	Medium	R-38	2100	18	WFL	65 DEG	1000	16,000	
75	S62	Med. Skt.	PAR-38	2100	21	WFL	65 DEG	2200	10,000	
		Med. Prong	PAR-38	2100	21	WFL	65 DEG	2200	10,000	
		Medium	R-38	2100	65	WFL	65 DEG	1800	10,000	"Deluxe"

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
These lamps are not weatherproof.

Universal Position Directional HPS Lamps **(See Figure 8-16)**

PAR and R-configured HPS lamps are useful for compact directional light sources, such as track lighting and outdoor lighting luminaires. The poor color rendition of these lamps, however, limits the usefulness to specific industrial and security floodlighting and general lighting applications.

Figure 8-17
Double-Ended High Pressure Sodium Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Burn Pos.	Initial Lumens	Lamp Life (Hrs.)	Notes
70	S88	RSC	T6.5	2100	22	Clear	HOR45	7000	10,000	Replaces M85 lamp
150	M81	RSC	T7.5	2100	22	Clear	HOR45	15,000	10,000	Replaces M81 lamp
250	S50	RSC	T7	2100	22	Clear	HOR45	27,000	24,000	
400	S51	RSC	T7	2100	22	Clear	HOR45	50,000	24,000	

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.
Lamps must be used within operating positions listed:
--HOR45 = horizontal +/- 45 degrees

Double-Ended HPS Lamps

The double-ended HPS lamp was designed to take advantage of luminaires and lighting installations originally designed for the double-ended metal halide lamp. The double-ended HPS lamp offers comparable lumen output, but offers HPS' longer lamp life and excellent lumen maintenance characteristics. These lamps, which are relatively uncommon at this time, are described in Figure 8-17.

White Sodium Lamps

White HPS lamps offer lamp life and lumen maintenance characteristics similar to those of other HPS lamps whose color temperatures and CRIs may be unsuitable for many interior spaces. However, ballast designs for "white" HPS lamps employ electronic circuits designed to increase color temperature and CRI. The color temperature of white sodium lamps, at 2600 K to 2800 K, closely resembles incandescent lighting. During the lamp's stable color-life, the color performance is more consistent and appealing than most metal halide lamps (including 3000 K lamps). Although efficacy is a relatively low 35-45 lumens per watt, the white sodium lamp is in many ways the best (if not the only) high-efficacy substitute for incandescent lamps.

Figure 8-18
White Sodium Lamps

Watts	ANSI Code	Base	Bulb Shape	CCT (K)	CRI	Coated or Clear	Initial Lumens	Lamp Life (Hrs.)
35	S99	PG12 Bipin	T10	2700	80	Clear	1250	10,000
50	S104	PG12 Bipin	T10	2700	80	Clear	2300	10,000
		Medium	ED17	2700	80	Coated	2190	10,000
95	Special	Medium	T10	2700	80	Clear	5200	10,000
95	Special	Medium	B17	2700	80	Coated	4800	10,000
100	S105	PG12 Bipin	T10	2700	80	Clear	4700	10,000
		Medium	ED17	2700	80	Coated	4470	10,000

Notes:
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.

Note that white sodium lamps are incompatible from manufacturer to manufacturer. No significant new white sodium products have been announced since the 1990 *Advanced Lighting Guidelines.* The performance characteristics of these lamps are described in Figure 8-18.

Figure 8-19
Interchangeable HID Lamps

Watts	Replaces	ANSI Ballast	Bulb Shape	CCT K	CRI	Coated or Clear	Burn Pos.	Initial Lumens	Lamp Life (Hrs.)	Notes
					Metal Halide Lamps					
250	250w HPS	S50	E/ED28	3700	70	Coated	BU15	20,500	5000	Must be enclosed
				4000	65	Clear	BU15	20,500	5000	Must be enclosed
400	400w HPS	S51	E/ED28	4000	65	Clear	UNIV	36,000	5000	
			E/ED37	3700	70	Coated	BU15	40,000	10,000	
				4000	65	Clear	BU15	40,000	10,000	
325	400w MV	H33*	E/ED37	4000	65	Clear	UNIV	28,000	20,000	
				3700	70	Coated	UNIV	28,000	20,000	
400	400w MV	H33*	E/ED37	4000	65	Clear	UNIV	36,000	15,000	Works on M59 Ballast
				3700	70	Coated	UNIV	36,000	15,000	Works on M59 Ballast
950	1000w MV	H15/H36	BT56	4000	65	Clear	BU15	100,000	12,000	Works on M47 Ballast
				4000	65	Clear	BD15	100,000	12,000	Works on M47 Ballast
					High Pressure Sodium Lamps					
150	175w MV	H39	BT28	2100	22	Clear	UNIV	13,000	24,000	
215	250w MV	H37	BT28	2100	22	Clear	UNIV	20,000	16,000	
360	400w MV	H33	BT37	2100	22	Clear	UNIV	38,000	12,000	
880	1000w MV	H15/36	E25	2100	22	Clear	UNIV	102,000	12,000	

Notes:
*Not all mercury ballasts are suitable for interchangeable lamps.
Metal halide lamps values are for vertical burning position.
Open fixtures for all HPS and vertical metal halide lamps; other metal halide positions require suitable enclosed luminaire.
Lumen and lamp life ratings are nominal and are based on specific manufacturer data. Check with individual manufacturers for exact data.
System input watts will vary depending on the ballast used. Contact the ballast manufacturer for actual input wattage.

Interchangeable Lamps

Metal halide lamps have superior color when compared to either mercury vapor or high pressure sodium technologies. For interior spaces where either of the poorer color lamps were originally used, it may be desirable to retrofit with metal halide without having to change the ballasts in the existing luminaires. Specific products are available in a few configurations and wattages to serve this function.

Similarly, some high pressure sodium lamps can be retrofitted into existing mercury vapor luminaires, particularly street lights, with reduced wattage and substantially increased lumen output. The lamps are available from most manufacturers to replace the traditional high wattage mercury street light lamps.

Performance characteristics of exchangeable metal halide and HPS lamps are noted in Figure 8-19.

Application Guidelines

HID lamps are point sources that lend themselves to projection and floodlighting situations, as well as to general illumination. The best interior applications are those where lights are left on for long periods or are controlled by a time switch. Examples would include manufacturing, corridor, and display lighting, as well as commercial area lighting. Some of the best applications for HID lamps are in all kinds of exterior lighting sources. HID sources are especially suitable for roadway, architectural, landscape, parking lot, security, and sports lighting.

Typical Applications

In general, HID lamps are best applied in one of the following ways:

- *Energy-Efficient Flood and Display Lighting* In suitable modern luminaires, HID lamps can be used for a wide variety of display and floodlighting situations, including track, recessed, and surface installations.

- *Energy-Efficient Lamps in General Lighting Luminaires* As long as switching is not a concern, a wide variety of opportunities exist to use HID lamps for area lighting in both interior and exterior situations. HID lamps are particularly well-suited to large rooms with high ceilings, such as gymnasiums, industrial plants, and warehouses.

General Limitations

All HID lamps require warm-up and restrike periods, so applications requiring frequent switching should not utilize HID lamps. Additionally, as noted previously, lamps of these types can only be dimmed with highly-specialized dimmers and ballasts. The effect of dimming is not nearly as appealing or as extensive as it is with incandescent or fluorescent light sources. Lamp efficacy and color stability suffer when HIDs are operated at less than full output.

Residential Applications

Because frequent switching is common to residential operation, HID lamps are not commonly used in homes. Nevertheless low wattage HID lamps may be useful in outdoor security and landscaping lighting applications, particularly if these sources are controlled by timers or photocells.

Commercial Applications

HID lamps offer the designer an alternative to incandescent downlights, uplights, and accent lights. Unlike fluorescent alternatives, HID lamps are point sources of light that give sparkle to polished surfaces and produce dramatic shadowing when used to accent displays. The compact lamp size of the smaller HID lamps allows for the use of many traditional luminaire types and shapes while employing a reasonable lumen package.

Special Interior Applications

The best interior applications for HID lamps are for corridor and lobby downlighting, commercial wall washing, lobby and office uplighting, and commercial and general lighting. The smaller HID lamps are valuable in accent and display lighting applications, as well. In addition, some types of highly decorative fixtures, such as wall sconces and pendant chandeliers, can be designed for compact HID lamps.

Exterior Applications

There is a wide range of exterior applications for HID lamps. In addition to those listed previously, HID lamps can be used in many landscape applications, such as bollards and tree uplights, as well as in wall lights, step lights, and architectural facade and floodlighting luminaires. The large 1500-watt metal halide lamp with a lamp life of 2000 to 3000 hours is widely used in sports lighting applications where television cameras are used.

Additional Application Considerations

There are several precautions to be considered when employing HID lamp technology in certain situations. Manufacturers' literature on this subject is extensive, and trouble shooting guides, engineering, and technical bulletins are available. Some of the most important considerations are noted below.

Lamp Restrike Time and Backup Lighting

In HID applications where a brief power outage could cause hazardous conditions or a major manufacturing shutdown, and where no backup non-HID emergency lighting system is in place, it is a good idea to specify that some portion of the luminaires be furnished with either instant restrike or quartz backup lamps. This will insure that some type of backup lighting will be in place until the HID lamps can be reignited.

Strobe Effects in Manufacturing Environments

All HID lamps are turned on and off 120 times per second in synchronization with the 60-Hz alternating current power supply. Because of this, the use of HPS lamps in general lighting luminaires near rotating machinery may produce a stroboscopic effect, making the machinery appear to be motionless -- a potentially hazardous situation. This can occur when the moving object rotates at any speed which is a multiple of 60 (i.e. 2400 revolutions per minute). Strobe effects of this type can be mostly eliminated by the proper phasing of the luminaire power supply circuits, so that none of the machinery is lighted solely by luminaires on the same phase circuit.

Continuously-Operated Metal Halide Lamps

Metal halide lamps may rupture if they are operated continuously (24 hours/day, 7 days/week). In continuous operation-type applications, metal halide lamps should be extinguished at least once a week for a minimum of 15 minutes to avoid the risk of potentially violent rupture. If this is not feasible, then a different light source should be specified, or the metal halide lamps should be group relamped well in advance of rated lamp life.

Replacement of HPS Lamps

HPS lamps signal the end of lamp life by cycling -- starting, warming up, going out, cooling down, and starting again. The electronic starting circuit in HPS ballasts continues to pulse when the lamp is removed from the luminaire Therefore, HPS luminaires should not be left energized when lamps are not in place, and cycling lamps should be replaced, or damage to the starter and ballast will occur. A special device is available to prevent HPS cycling at the end of lamp life. (Note: this precaution also applies to other HID lamps -- such as medium-based metal halide lamps -- operated by external starting circuitry.)

Example

A high-ceilinged hotel lobby might employ recessed incandescent downlights supplied with 250-watt PAR-38 quartz lamps to provide general illumination for the space. If, instead, 70-watt double-ended metal halide (3000 K, 81 CRI) electronically-ballasted lamps were used, the following benefits could be realized:

- > 160 watts per socket saved, including ballast losses
- Fewer luminaires needed, due to increased lumen output (5500 lumens to 3300 lumens)
- Decreased maintenance charges for relamping, due to increased lamp life of 67% (10,000 hours to 6000 hours)

The metal halide luminaires in this application will use much less energy than the incandescent downlights, while providing an essentially similar aesthetic to the hotel lobby. Although the initial costs for luminaires and lamps will be higher than would be the case for the incandescent design, the reduced quantity of luminaires needed, combined with the energy savings achieved by the design, will more than offset the higher start-up cost, while producing significant long-term savings.

Guideline Specifications

Specifications of HID lamps should generally follow a designation system authorized and determined by ANSI. All such designations begin with a letter ("M" for metal halide, "S" for HPS), followed by an ANSI number identifying the electrical characteristics of that lamp's ballast. After the number, there is a letter-number combination to designate the lamp envelope shape and size (ED-17, BT-28, etc.). Optional added designations may include base type, wattage, clear or coated, warm or neutral color, and/or standard or deluxe color rendering. For instance, a 70-watt double-ended metal halide warm (3000 K) colored lamp with deluxe color rendering could be designated as:

M85/T7/RSC/70/WDX

Similarly, a standard 250-watt mogul-based ellipsoidal-shaped HPS lamp with diffusing coating might bear the following designation:

S50/E28/MOG/250/COATED

There are important and popular HID lamps for which ANSI designations are still pending. This is true for many of the more recent lamp developments such as compact metal halide and white sodium lamps. In these cases, it may be necessary to use a proprietary specification to designate acceptable lamp and ballast manufacturers.

Manufacturer/Product References

Manufacturer	Product
General Electric	Metal halide lamps HPS lamps Deluxe HPS lamps White sodium lamps
Iwasaki	White sodium lamps
OSRAM	Metal halide lamps HPS lamps
Philips	Metal halide lamps HPS lamps Deluxe HPS Lamps White sodium lamps
Sylvania	Metal halide lamps HPS lamps
Venture Lighting International	Metal halide lamps HPS lamps

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Daylighting and Lumen Maintenance

Introduction

The use of daylight as a source of illumination in commercial buildings offers tremendous potential for energy savings. Daylight may be able to supply some or all of the required illuminance needed for the performance of many visual tasks in commercial buildings. Nonetheless, daylighting, per se, saves no energy unless the electric lighting system is appropriately controlled. To be effective, this requires a dimmable lighting system that is linked to the ambient lighting levels by means of a control photocell. Photoelectrically-controlled lighting systems automatically reduce electric light levels during times when daylight is available, and supply most or all of illumination needs when daylight is negligible or absent.

Since daylight is present in many spaces of commercial buildings for many hours of the day, photoelectrically-controlled lighting systems have considerable potential for reducing lighting energy usage. Equally important, since daylight availability is typically coincident with the utility's peak demand profile, daylight controls can also reduce peak demand charges. However, the additional cost of daylight-linked controls over a conventional lighting system is not inconsequential. Given the added complexity of these systems, they should only be pursued if there is a considerable commitment to the resources required to properly design, commission, and maintain the system.

The term "daylight control," as it is used here, refers to the relationship between electric light and the presence or absence of daylight in commercial spaces. This guideline presents information on daylight control technologies and design methods. Although the emphasis is on the control of electric lighting systems, some discussion is devoted to building design strategies aimed at obtaining and controlling daylight. Daylighting controls integrate well with lumen maintenance strategies. As such, lumen maintenance will be included in the discussion on daylighting control.

Lumen maintenance also relies on a photo-electrically linked lighting system. Lumen maintenance saves energy by limiting input power when lamps are new and fixtures clean. (When new and clean, lighting systems produce more lumens for less input watts than when they are at the end of their maintenance cycle). As the control photosensor detects the gradual drop in electric lighting efficiency, the control system automatically provides just the right light level to meet design requirements.

Contents

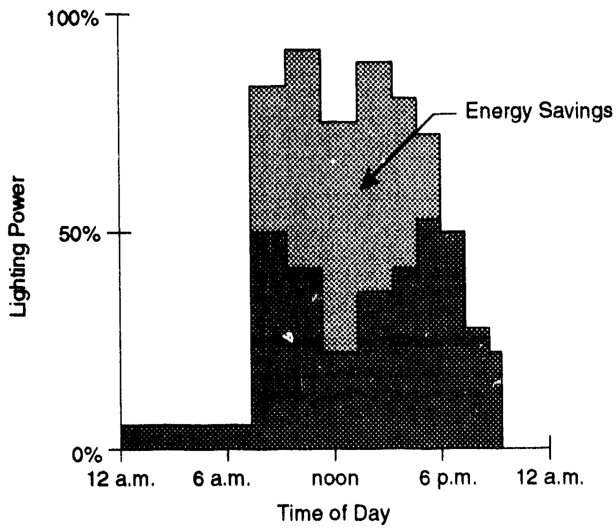


Figure 9-1
Potential Energy Savings Due to Daylighting Controls

There are several obvious advantages to the use of daylighting in commercial buildings:

- Daylighting costs nothing, and can be used to supplement, or even, in some cases, replace electric light.
- Daylighting is the most complete and "natural" color spectrum light source available.
- Daylighting can allow occupants a greater connection to the outdoor environment. Research on worker productivity has suggested a link between daylight in the work environment and a general sense of psychological well-being.
- Daylighting design increases interest in the visual environment.

This guideline addresses daylighting and lumen maintenance as lighting control strategies, and the equipment necessary to achieve these strategies. It is organized around the following sections:

Getting Daylight to the Task reviews various architectural daylighting patterns such as clerestories, roof monitors, sidelights, and light shelves. This section also presents guidelines on selecting the fenestration material, controlling daylighting through the use of interior shading devices and determining the right amount of fenestration for each daylighting pattern and application.

Lumen Maintenance reviews this strategy for lighting control, while providing data on assessing potential energy savings.

Control of Electric Light presents principles for designing the supplemental electric lighting system and controlling it in response to available daylighting or light output (for lumen maintenance).

Calibration and Maintenance presents the procedures and methods for accurately calibrating daylighting and lumen maintenance controls.

Energy Savings provides a means of estimating the electric energy saved by daylighting and lumen maintenance controls.

Resources may be used to obtain further information about control hardware for these lighting control strategies. In addition, a list of daylighting software manufacturers is provided.

Getting Daylight to the Task

The major architectural challenge in the design of daylighted buildings is to bring daylight illumination to the task. The ideal daylighting design will bring the appropriate amount of light to the work plane (the design illuminance), without creating discomfort or disability glare. It will also provide a relatively even level of illuminance throughout the space -- all the tasks will get about the same amount of daylighting. The best daylighting designs are considered early in the design process of new buildings.

Daylighting is introduced through apertures or openings in the building envelope. The location, orientation and size of the daylighting apertures is of paramount importance as is the selection of the glazing materials used in the apertures. When possible, it is always better to locate the apertures above the visual task -- a process known as *toplighting*. This reduces the likelihood for glare and allows for the more even distribution of daylighting within the space. Toplighting, of course, can only be provided for one-story buildings or for the top floor of multi-story buildings. The other basic strategy is *sidelighting* -- where daylight enters in through windows. With windows, uniform illuminance is more difficult to provide, as there is always more light next to the window, and glare is hard to control. There are, however, design techniques that can substantially reduce the problems associated with sidelighting.

Daylighting is highly variable throughout the day and the year, requiring careful design to provide adequate illumination for the maximum number of hours while contributing the least amount possible to the cooling load. The ideal daylighting design would have variable apertures that respond to changes in the availability of daylighting. The apertures would become smaller when daylighting is abundant and larger on cloudy days or at times when daylighting is less available. While electrochromic glazing materials may permit variable daylighting apertures in the future, with today's technology, the size of the aperture and its transmission are fixed. The principal means of control is through the use of shades or blinds located inside or outside the window.

Daylighting is more thermally efficient than electric lighting. This means that the cooling load created by daylighting illumination is much less than that created by electric lighting providing the same level of illuminance. Since electric lighting is a major contributor to the cooling load in commercial buildings, substituting daylighting for electric lighting reduces cooling loads as well as lighting loads.

Obviously, daylighting will only achieve energy savings if power to the electric lighting system is reduced during times when daylighting is available.

Sidelighting Patterns

The basic sidelighting pattern is window apertures located on one or more walls of a space. When possible, it is best to have apertures on more than one side in order to provide more uniform daylight distribution. This is usually only possible for corner rooms or "high perimeter" buildings designed for maximum daylighting. Windows should be located as high as possible along the wall and be as continuous as possible adjacent to the daylighted spaces. The depth of daylighting penetration into a space is largely dependent on the height of the window head -- the top of the window.

Several sidelighting patterns are illustrated in Figure 9-2. These show a section through a typical classroom with the illuminance level through the center of the room overlaid for the space oriented along each major compass point. The graphs show daylighting illuminance only with no contribution from the electric lighting system.

The basic sidelighting pattern shows very high levels of illuminance near the window with a rapid reduction in illuminance as the visual task is moved away from the window. Daylighting distribution can be improved through the use of diffuse glazing, but this occurs at the expense of lost views and reduced contact with the outside.

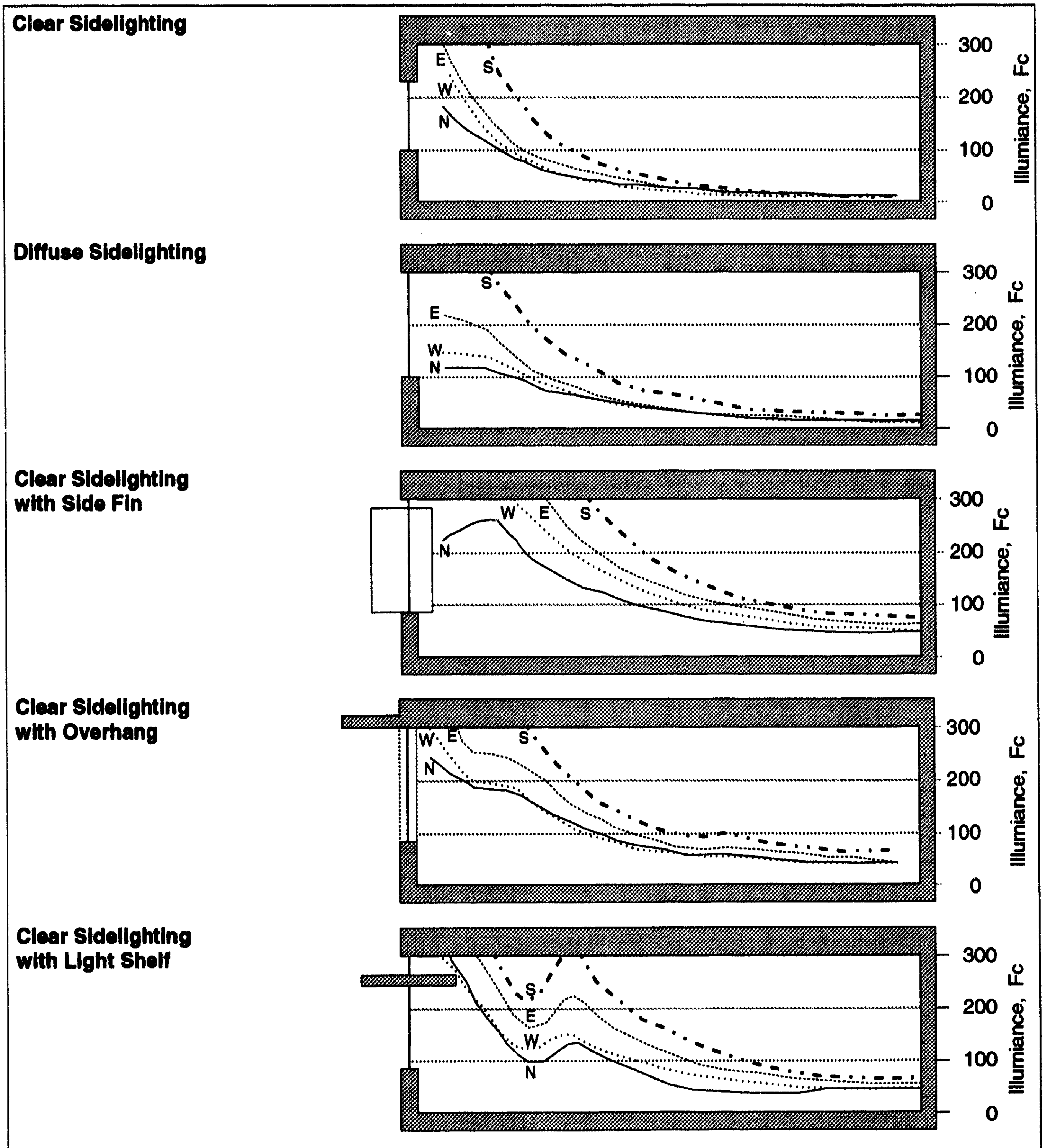
Building designers may use several techniques to improve the distribution of daylight into a building's interior and control solar gain. Truly effective techniques are able to decrease solar heat gain, direct sun penetration and glare, while increasing the amount of daylight illumination in a space. Some of these techniques are described below.

The orientation of the daylighting aperture strongly affects the quantity, quality, and distribution of daylight. For sidelighting and no shading, north facing windows provide the most even illuminance. The quantity of light is diminished, but a larger aperture will compensate, providing the same illuminance distribution pattern.

Daylight is affected by site surroundings in the form of obstructions, such as trees and other buildings. Reflectance factors on the building site will also play a role. Illuminance levels from north facing apertures can be enhanced by light colored surfaces positioned to reflect the south sun. Care must be taken, however, because bright surfaces located outside the window, such as a neighboring light-colored building, can be a major source of glare.

Figure 9-2 -- Sidelighting Patterns

All of the following sidelighting patterns are calculated for a 30 x 30 classroom with a 9 foot ceiling height. Room reflectances are 80% ceiling, 50% wall, and 30% floor. Calculations are for clear sky conditions and no direct sun at 11:00 am near the equinox at a latitude of about 34 degrees. Ground reflectance is assumed to be 40% (about like concrete). Illuminance levels are presented for the center of the room.



While building orientation affects daylighting illuminance levels, a more significant factor is its impact on cooling loads. It is much easier to control solar gains when buildings are laid out along an east-to-west axis (most of the surfaces face north and south). Solar gains are much more difficult to control on east and west orientations because the sun is low in the sky and overhangs or other fixed shading devices are of limited utility. A good example of poor orientation is the United Nations building in New York. Laid out in a north-south orientation, this structure requires over 12,000 tons of air conditioning to handle the heat load generated by east and west facing windows.

Overhangs

Overhangs -- especially those on the south -- reduce direct solar radiation into the interior space. This reduces the probability of discomfort and/or disability glare and controls cooling loads. When the ground outside the window is reflective, overhangs can also increase daylighting penetration into the space and provide more uniform illuminance (see Figure 9-2).

Side Fins

Side fins are effective in controlling solar gains, especially on the east and west building facades during much of the day. When the sun is low in the sky with an azimuth directly east or west, however, even side fins do little good. Side fins also affect daylighting distribution into the space and like any reflecting surface near the window, improve daylighting distribution (see Figure 9-2).

Light Shelves

Light shelves are a classic approach to daylighting. They consist of a horizontal panel with windows above and below. Light shelves help in two ways. First, they act as overhangs and protect against the penetration of direct sunlight into the space. This function also serves to even out light distribution in a space by reducing light levels at or near the windows. Second, a light shelf increases the penetration of daylight into a space by reflecting light from its upper surface onto the ceiling and back into the building. While windows alone allow light to penetrate a distance equal to approximately 1.5 times the window header height, light shelves can increase this penetration to a distance 2.5 times the window header height.

Sloped Ceiling Construction

As discussed earlier, the top of the window should be located as high as possible to increase daylight penetration into the space. One technique to elevate the window head without increasing the floor-to-floor height is to slope the ceiling at the perimeter of the space. In effect, the sloping ceiling steals some of the plenum space and leaves less room for HVAC ducts, luminaires, and other equipment, but with coordinated design, a full height plenum can be maintained in the center of the building to adequately serve these purposes.

Toplighting Patterns

Lighting distribution quality for toplighting schemes is superior to anything that can be provided by sidelighting. Several skylight configurations have been used successfully in daylighting designs, including "sawtooth"

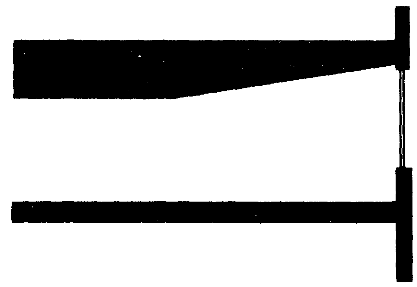


Figure 9-3
A sloping ceiling at the building perimeter provides a means of elevating the window head to increase daylighting penetration without increasing the floor-to-floor height.

monitors, vertical and splayed wells, and light boxes. A relatively new type of skylight configuration uses solar technology to track the movement of the sun through the sky. Toplighting should be implemented for most one-story building applications.

Four toplighting patterns are shown in Figure 9-4. These include skylights, clerestory windows, light boxes and sawtooth roof monitors. The pattern of illuminance created by each toplighting approach is illustrated for one or more orientations.

Proper spacing of skylights is important for uniform daylight distribution. The space between the skylight wells should not exceed one and one-half times the floor to ceiling height. There are exceptions to this rule, such as when the well is broadly splayed. As shown in Figure 9-4, the pattern of daylighting illumination is much more uniform with all the toplighting patterns when compared to the sidelighting patterns. The north facing sawtooth roof monitor produces the most uniform pattern of daylighting illuminance. This pattern is also excellent at controlling solar gain into the space and in minimizing the load on the air conditioning system.

Clerestory windows also provide excellent daylighting distribution, especially when they face north.

Optimizing the Design

The design of the building envelope will determine the daylighting patterns -- the location, orientation, and size of the daylighting apertures and their relationship to the building spaces and visual tasks. Once the patterns are set, the design can be optimized through the sizing of the apertures, the selection of the glazing materials, equipment and controls for window management, the planning of interior spaces, and the choice of materials and colors for interior surfaces. This section presents general guidelines in these areas.

Glazing Materials

High performance glazing techniques, including double glazing, reflective and low-emissivity coatings, and tinting, have become a very important means of energy conservation in modern construction, and they are extremely important in daylighting design, as well. Glazing materials have three principal performance characteristics:

- ***U-Value*** measures the heat conductance of a window assembly. The lower the U-value, the lower the rate of heat loss and of heating energy consumption. Ideally, for daylighting, this number should be as low as possible, combined with a high VLT (see below) value. Single-pane windows typically show a U-Value in the range of 1.0 to 1.2; double pane windows range from 0.65 to 0.45.
- ***Shading Coefficient (SC)*** measures the solar heat gain through a window in reference to a 1/8" thick, clear, double-strength glass (which has a SC of 1.00). A perfectly opaque window would have a SC value of 0. SC affects daylighting indirectly, and designers seek to maximize useful daylight while minimizing solar heat gains which, if unchecked, can cause cooling energy costs to outweigh the energy saving benefits of daylighting.
- ***Visible Light Transmittance (VLT)*** refers to the fraction of light within the visible spectrum that is transmitted through the glazing. Obviously, for maximum daylighting, it is desirable that this value be as high as possible. Clear single pane glass has a VLT of 0.89; reflective or very darkly tinted glass may have a VLT as low as 0.20.

For daylighting, glazing should ideally have the highest possible VLT with the lowest possible SC. The efficacy of the glazing material is a term used to define the ratio of VLT to SC. The higher the efficacy, the better the glazing material is in allowing daylight and reducing solar gains. Glazing materials with a high efficacy are known as selective glazing materials because they selectively allow radiation in the visible portion of the spectrum to pass while blocking solar radiation in the ultraviolet and infrared spectrums.

A high glazing efficacy is achieved through several technologies. First, many glazings are tinted by the addition of a rouge added to the silicon when the glass is manufactured. Tints such as bronze or gray reduce the glazing efficacy, while other tints can increase the efficacy. The greatest glazing advances in recent years have been in the area of special coatings applied to the surface of the glazing. While the most common coating is reflective, and usually with a very low efficacy, many coatings have been designed especially to have a high efficacy. These coatings include most low-emissivity coatings applied to either the glazing itself or to mylar film suspended between double glazing. Most low-e coatings are relatively soft and must be located on the second or third surfaces of double glazing so that they are protected from abrasion.

Green tinted glass is a good inexpensive glazing material for California climates; in either a single or double glazing assembly, it has a reasonably high efficacy. When double glazing can be justified for thermal reasons in colder climates, then a low-e coating should be considered on the second or third surface.

Performance characteristics of several different glazing assemblies are shown in Figure 9-5.

Figure 9-4 -- Toplighting Patterns

All of the following sidelighting patterns are calculated for a 30 x 30 classroom with a 9 foot ceiling height. Room reflectances are 80% ceiling, 50% wall and 30% floor. Calculations are for clear sky conditions and no direct sun at 11:00 am near the equinox at a latitude of about 34 degrees. Illuminance level is presented for the center of the room.

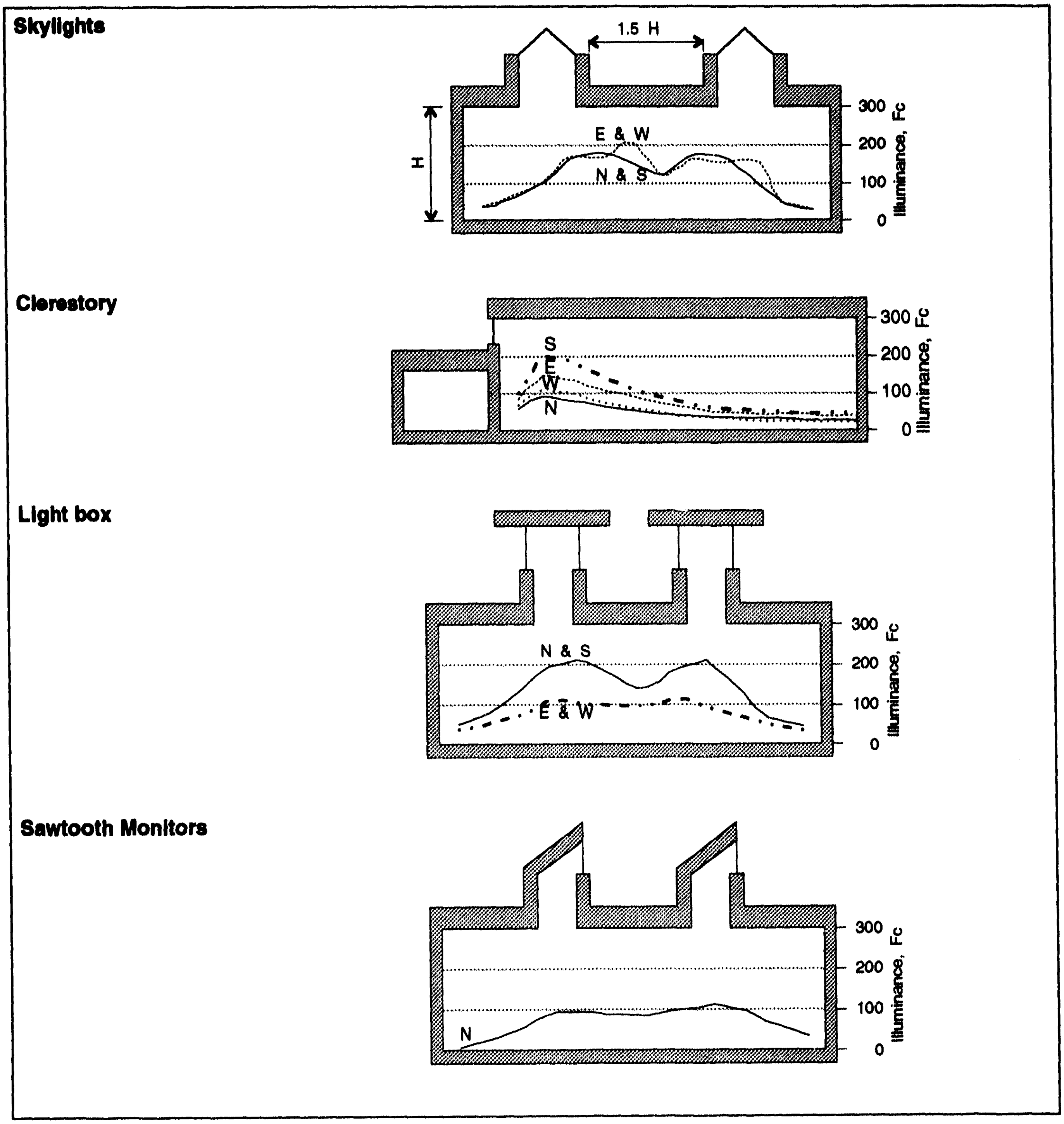


Figure 9-5

Solar Optic Properties of Glazing Materials

Number of Panes	Tint	Special Coatings or Films	Visible Light Transmission (VLT)	Shading Coefficient (SC)	Glazing Efficacy (VLT/SC)
Single	**Clear**	**None**	**0.88**	**0.95**	**0.93**
	Green	None	0.75	0.71	1.06
	Bronze	None	0.53	0.71	0.75
	Special	None	0.72	0.61	1.18
Double	**Clear**	**None**	**0.78**	**0.81**	**0.96**
	Green	None	0.66	0.57	1.16
	Bronze	None	0.47	0.57	0.82
	Special	None	0.64	0.47	1.36
Double	**Clear**	**Low-e**	**0.73**	**0.72**	**1.01**
	Green	Low-e	0.62	0.49	1.27
	Bronze	Low-e	0.44	0.48	0.96
	Special	Low-e	0.59	0.39	1.51
Double	**Clear**	**Mylar Film**	**0.46**	**0.34**	**1.35**
	Green	Mylar Film	N/A	N/A	N/A
	Bronze	Mylar Film	N/A	N/A	N/A
	Special	Mylar Film	N/A	N/A	N/A

Notes:
Values are for standard metal frame construction
Special tint glass refers to high performance reflective tint
N/A = Not Available

Size of the Apertures

The optimum size of the daylighting aperture depends on a number of factors, including the overall pattern (light shelves, sawtooth roof monitor, etc.), the desired illuminance level, and the type of glazing material selected (see above). Climate and internal loads (heat given off by people and equipment) are also important considerations since the optimum aperture size is the one that minimizes the total operating cost.

For a given daylighting pattern, glazing material, occupancy pattern, lighting level, electric lighting control system, and climate, the total operating costs can be calculated and plotted for various window areas, as shown in Figure 9-6. As glazing area increases, the energy use for lighting is steadily reduced until the window area is about 25% of the exterior wall. After that, daylight saturation is achieved for much of the time, and lighting energy savings are much smaller with increased window area. However, both cooling load and

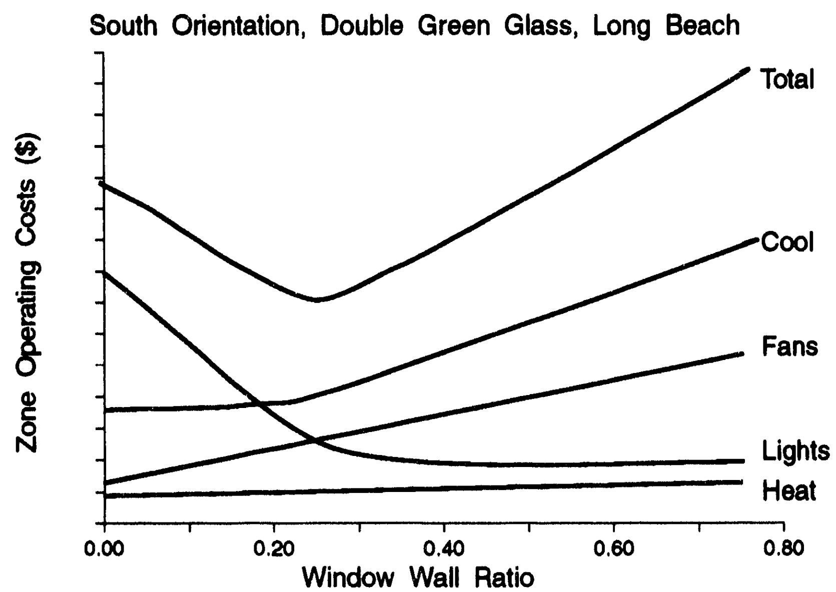


Figure 9-6

Optimum Aperture Area

fan energy increase steadily throughout the entire range of window-wall ratios. Note that cooling energy increases at a more rapid rate after daylighting saturation is achieved at a window-wall ratio of about 25%. Heating energy is relatively flat in this example, but it also increases with window-wall ratio. In cold, sunny climates, heating energy might actually decline for part of the window-wall ratio range, especially for south facing orientations.

Generalizations should not be drawn from Figure 9-6 since it is for a single condition of climate, lighting conditions, fenestration, etc. Daylighting experts can prepare a similar analysis for specific building designs and design conditions.

For typical office illumination levels and double green low-emissivity glass, a window-wall ratio of about 0.30 is optimum for most California climates. The optimum area is larger for glazing materials with a lower VLT and smaller for glazing materials with a higher VLT (e.g. clear glass).

For skylights, the optimal glazing area is much smaller, depending again on the design illuminance and the glazing material, as well as on the size, shape and color of the skylight well.

Window Management

Window management is important in controlling the amount of daylighting emitted through daylighting apertures and to control glare and direct solar radiation. There are three basic methods to control light at the window:

- *Shades* can range from diaphanous lace curtains to heavy draperies. They are mostly effective in diffusing and blocking light.
- *Shade screens* can be installed to decrease the shading coefficient of the glazing material by further blocking of direct sunlight through the window. These screens can be installed either inside or outside the building.
- *Blinds* are especially popular for controlling window light due to their adjustability and ability to reflect light. Ranging from interior mini-blinds to large exterior rolling louvered shutter systems, blinds are perhaps the most flexible and comprehensive method of controlling window light.

Daylighting in VDT Spaces

When video display terminals are located in daylighted spaces, the designer must take great care to minimize daylight reflections in the VDT screen. This problem is especially acute when the computer screen is oriented so that the screen is facing opposite the daylighting aperture (i.e. the operator's back is to the window or skylight). Under these conditions, reflected glare may completely wash out the intrinsic luminescence of the screen, making work impossible without completely blocking off the aperture with blinds or drapes. Since blocking off the window prevents the occupant from seeing outside and reduces the daylight resource to zero, this solution should only be used as a last resort. If the VDT screen orientation cannot be changed, it may be possible to add a low transmittance film to the window so that the external view may be preserved while the overall transmittance of daylight is substantially reduced. If the VDT screen is located so that the screen viewing orientation is parallel to the windows (the preferred orientation), reflected glare poses less of a problem and, if present, can usually be reduced through appropriate screen treatment (polarizing filters or meshes attached directly to the screen).

Automatic Controls

Very good daylighting systems, especially top lighting (skylights) approaches, employ automatic controls to regulate the amount of daylight that passes through a daylighting aperture. These systems work much like electric lighting controls: a photocell closes the daylighting aperture when more than enough daylighting is available. The photocell opens the aperture to increase the level of daylighting. The logic for such automatic controls must be carefully integrated with the logic for the electric lighting controls (discussion later in this guideline) to avoid unstable conditions.

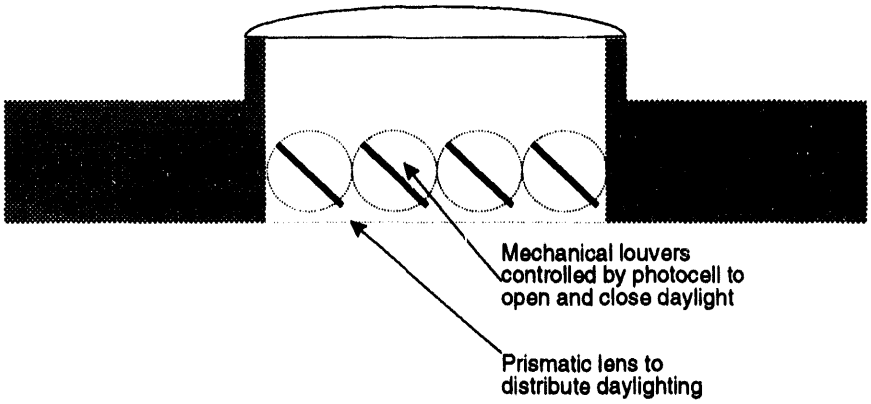


Figure 9-7
Variable Aperture Skylight

Space Planning

Successful daylighting designs must include careful consideration of interior space planning. Since daylighting illuminance can vary considerably within the space, especially with sidelighting, it is important to locate work areas where there is appropriate daylighting. Perhaps more importantly, visual tasks should be located to reduce the probability of discomfort or disability glare. In general, work areas should be oriented so that daylighting is available from the side. Facing a window may introduce direct glare into the visual field, while facing away from a window may produce shadows or reflected glare.

Surface Materials

Daylighting illuminance is strongly affected by the configuration and reflectances of the room surfaces and furnishings. In general, visual discomfort can result from high levels of contrast between dark and light objects within the field of view. When the pupil of the eye must constantly adjust to different levels of brightness within the line of sight, eyestrain and visual discomfort are caused. The designer should try to anticipate and control these effects in daylighted buildings by reducing contrast within the field of view. Bright surfaces should be used on interior surfaces, especially when they are located near windows or skylights. Window management systems, such as those described previously, will reduce contrast by controlling the amount of brightness at the windows. Increasing the electric illuminance inside the building will work to decrease contrast as well, though this reduces energy efficiency.

Lumen Maintenance

Electric lighting systems are usually designed to produce more than the required light level so that as the lamps age and the amount of light delivered by the luminaires decreases, the illuminance will always exceed or at least equal the required level. Because of this necessary "overdesign," conventional lighting systems generally provide excess light much of the time, and the design light level is only achieved near the end of the lamp-luminaire maintenance cycle. Light losses occur because lamp phosphors produce less light as they age and because of the accumulation of light-absorbing dirt on luminaire and room surfaces. These light losses are recovered when relamping and cleaning occur. See Figure 9-8.

Lumen maintenance is the strategy of using a photocell to detect the actual illuminance in the space and adjusting the light level accordingly, so that the design illuminance is maintained at all times, not just at the end of the maintenance cycle. Thus, at the beginning of the maintenance cycle, when lamps are new and fixtures and room surfaces are clean, a lumen maintenance correction system will reduce lighting power to provide the design illuminance level and no more. Over time, as the photocell detects the slow decrease in light level, the input power is automatically increased to maintain the design illuminance. Not until the end of the maintenance cycle will the lighting system actually consume full power. See Figure 9-9.

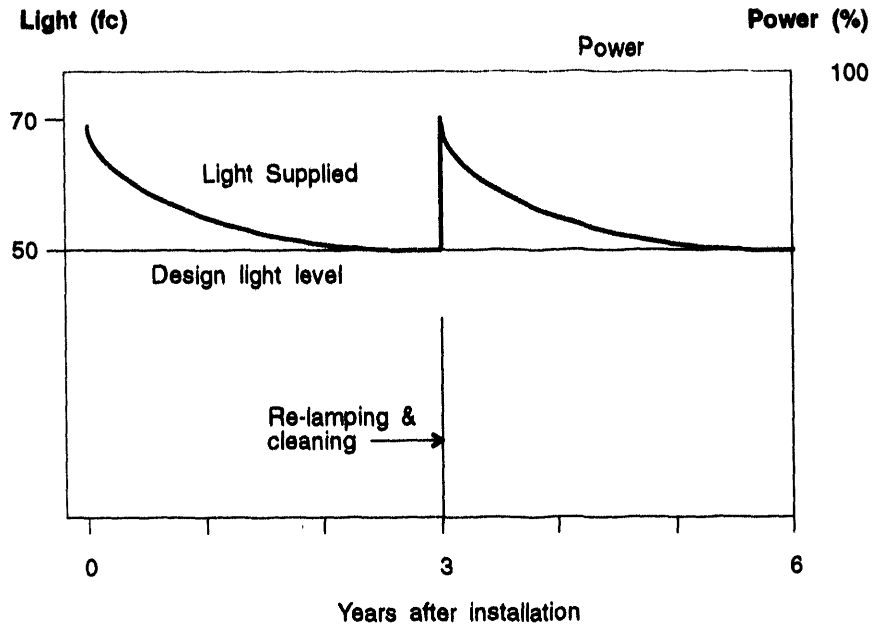


Figure 9-8
For most conventional lighting systems, light levels drop over time, yet input power remains constant

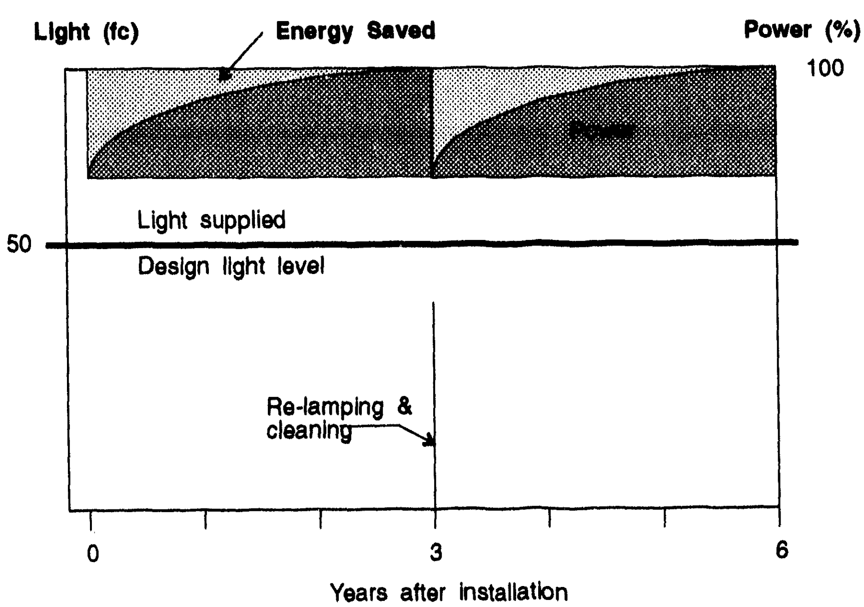


Figure 9-9
With a lumen maintenance system, light levels stay constant, while input power is adjusted, thereby saving energy.

Control of Electric Light

The function of a lighting control system is to provide the required amount of light where and when it is needed, while minimizing electrical energy consumption. There are several different lighting control approaches. This guideline covers daylight-following and lumen maintenance strategies.

Integration of Electric Lighting

The electric lighting system in a daylighted building should be designed from the start with daylighting in mind. The lighting system should be laid out in zones that mimic the availability of daylight. For example, in a room with widely-spaced windows, the designer would plan for groups of luminaires to be associated with each window. Continuous strip windows, on the other hand, would call for rows of luminaires parallel to the windows. The existence of light shelves in the building might be enhanced by a lighting system of indirect luminaires located atop the light shelves.

It is generally desirable to match the spatial distribution patterns of daylight and electric light. For example, in buildings that use light shelves, the daylight bouncing off the light shelf and diffusing from the ceiling serves as a form of indirect lighting. This type of daylighting is well-matched with an indirect electric lighting system that also uses the ceiling to diffuse and distribute the light.

The zoning of the electric lights should also correspond with the manner in which the fenestration controls are used. For example, if adjacent windows are fitted with individually controllable operable blinds, it is best to control the lights in front of each window separately. With the electric lighting zones formed this way, an occupant adjusting their blinds will only cause the electric lighting to change in his or her own area, and not in adjacent zones.

Control of the luminaires themselves should also follow a strict pattern. Luminaires closer to the windows should be controlled separately from those farther back. Ideally, each parallel row of luminaires should be circuited separately, so that each row can be controlled in direct response to the availability of daylight in that particular zone. If adjacent rows of luminaires are controlled together, the designer must make sure that the back wall of the space is adequately lit or else the room will appear gloomy even if the design light level is rigorously maintained at the control point. This can be achieved with judiciously placed wall wash luminaires (non-dimming).

Luminaires and other equipment selected for use in daylighted buildings must be compatible with the daylighting control system. Fluorescent lamps are the rule in most commercial applications, because of their efficacy and economy, and because they are easily controlled by either step switching, partial dimming (to 20%), or full-range dimming (to 1%).

Daylight-Following

Energy savings cannot be realized in daylighted buildings unless the electric lights are dimmed to correspond with the amount of available daylight. Daylight-following is the strategy of automatically lowering electric light levels as the amount of daylight in a space increases. Conversely, as available daylight diminishes, electric light levels are increased to maintain the same illuminance. Daylight-following is best accomplished with dimming hardware. However, in certain limited applications, switching hardware may be used.

Control Components

Daylight-following and lumen maintenance correction are closely coupled strategies, since both require photosensors that are responsive to the amount of available light in the controlled building space. In both strategies, the photoelectric lighting control system consists of the following components:

- A *photosensor* or *photocell* measures the light level within the controlled building space. The photosensor generates an electric signal in proportion to the illuminance striking it. The particular geometry of the photocell and its housing determines the sensitivity of the cell to light from different directions. The photosensor should be color-corrected so that it responds to spectral distribution of the light source in a similar manner as does the human eye. This is known as photopic correction.
- A *controller* incorporates an algorithm to process the signal from the photosensor, converting it into a command signal received by the dimming or switching unit.
- A *dimming unit* varies the light output of the electric lights by altering the amount of power flowing to the lamps. Switches can also be used instead of dimmers, but since building occupants usually find the switching on and off of lamps to be objectionable, it is not recommended except for certain limited applications.

Control components may be integrated to form a single package. For example, some dimming electronic ballasts are supplied with a fiber optic photosensor which can directly control the ballast without the need for additional control gear. This particular product requires on photosensor for each ballast used.

Note: Several manufacturers are now offering occupant sensors that incorporate a photosensor to respond to ambient light levels in the control space. It is important to note that wallbox versions of these combination units do not receive photocell control credits under Section 119(g) of California's 1992 *Energy Efficiency Standards for Residential and Nonresidential Buildings* (Title 24). (Note: Reference to Title 24 or any other regulatory standard is intended for informational purposes, and any such reference is not intended to be authoritative when applying any standard.)

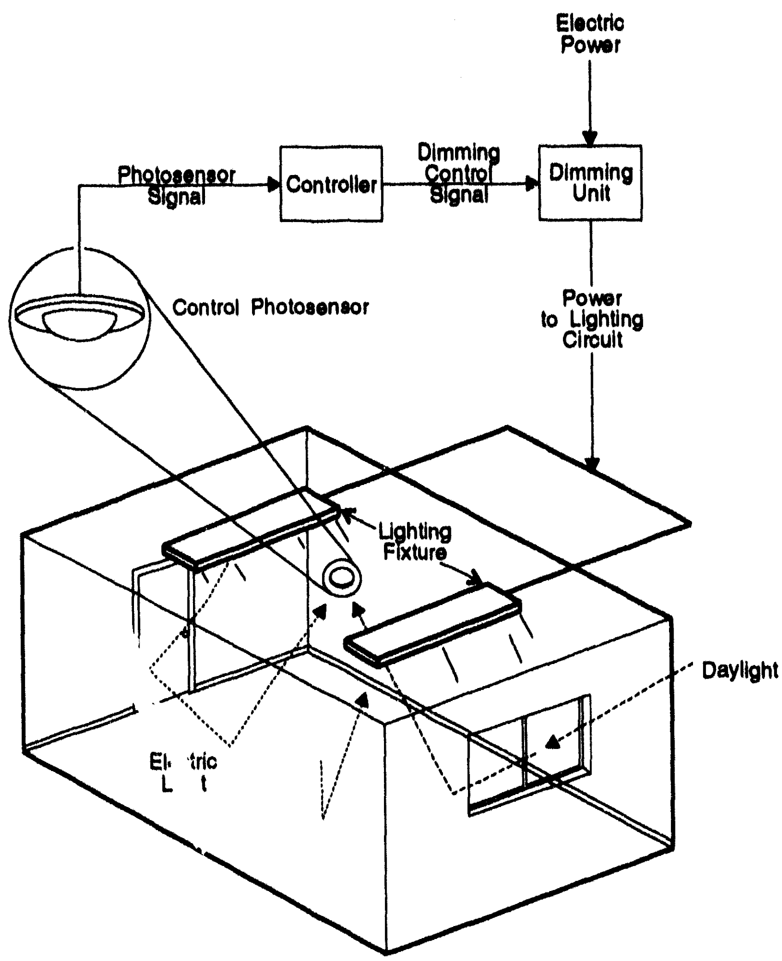


Figure 9-10

Graphic representation showing relationship between photoelectric dimming system components in a typical application. The ceiling-mounted control photosensor is sensitive to both electric light and daylight within the space.

Figure 9-10 illustrates how daylighting control components are interconnected in a typical building application with a standard mounting configuration for the control photosensor. The ceiling-mounted photosensor links the ambient light levels in the space (both electric and daylight) to the controller, which then adjusts the electric light output according to its built-in algorithm. The placement of the photosensor, the form of the control algorithm, and the interaction between the two largely determine how the system as a whole will perform.

To assure that energy will, in fact, be saved, controlling electric light in synchrony with daylight should be accomplished automatically, without requiring human intervention. This requires the use of photosensors that detect the amount of available light within the controlled space and a controller that commands the electric light dimmer to a particular setting based on the photosensor output.

Although the control photosensor is the most visible part of a lighting control system, the controller plays a critical role by transforming the signal from the photosensor into a command signal for the dimming unit. The specific functional form of this transformation, which we term the *control algorithm*, is a critical circuit design consideration. If the algorithm used by the controller is inappropriate for the desired strategy, satisfactory results cannot be obtained.

Control Algorithms

Photoelectric control systems today generally use one of the following control algorithms:

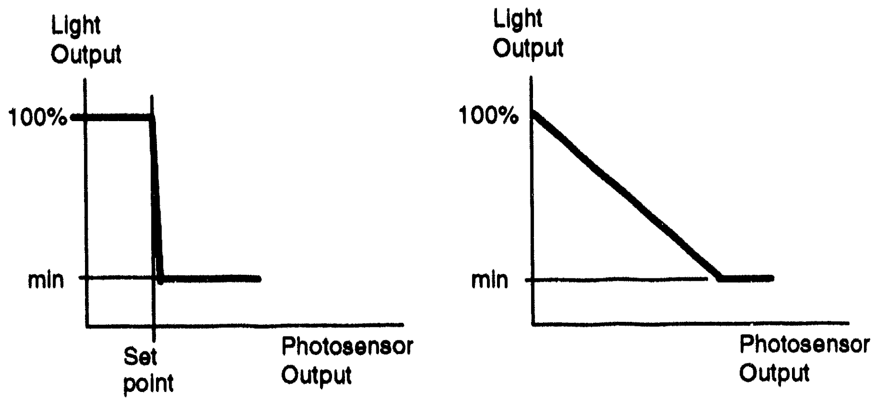
- Closed-loop integral control
- Open-loop proportional control

The calibration and the photosensor location requirements are quite different for these two systems, as each algorithm expresses a different relationship between the photosensor output and the output of the electric lights. These relationships are plotted in Figure 9-11.

The integral control is considered to be a closed-loop system, because the photosensor is located so that it is able to detect both the electric light that the system controls, as well as available daylight. Conversely, with open-loop control, the photosensor is designed and located so that it detects only daylight and is insensitive to the electric light that it controls.

Closed-Loop Integral Controllers

A closed-loop integral controller continuously adjusts the output of the electric lights so that the photosensor output is maintained at the setpoint level. As the photosensor detects, for example, an increase in light due to daylight,



A) Closed-Loop Integral B) Open-Loop Proportional

Figure 9-11

The relationship between the photosensor signal output and light output for: A) Closed-Loop Integral and B) Open-Loop Proportional control algorithms. The light output can vary between minimum and 100% (full light output).

the controller reduces the electric light level to once again restore the photosensor signal to the setpoint level. In practice, this setpoint is empirically determined by operating the electric lights to provide desired illuminance level at night. (This process of determining the setpoint at the site is referred to as the "night-time calibration"). The photosensor's output value under this special condition then becomes the setpoint level to be maintained under all conditions. This algorithm only works if the photosensor can "see" the electric light it controls (closed-loop).

Open-Loop Proportional Controllers

With open-loop proportional control, the photosensor is mounted so that it does *not* detect the light that is controlled. Rather, the photosensor is used solely to detect the independent stimulus of daylight. The open-loop proportional control algorithm generally establishes a linear (or variable, in some units) relationship between the detected photosensor signal and the dimming level. In some units, the relationship between light output and photosensor signal is under user control. During calibration, the end user may assign an arbitrary one-to-one relationship between these two variables. As the daylight stimulus exceeds zero, the electric lights dim along a sloped line as shown in part B of Figure 9-11. By calibrating the system during the day ("daytime calibration"), the installer sets the slope of system response to a specific value that accommodates the particular room and daylighting conditions. The daytime calibration, which needs to be performed only once for each control zone, is done during the commissioning of the lighting system.

It is the responsibility of the specifier to recommend the correct type of control system for the application. This is unfortunately made more complex because the terminology for these systems is not yet standardized. The table shown in Figure 9-12 provides guidance in selecting the correct type of control system for the application:

Figure 9-12

Electric Light Controller Applications

Strategy	Controller Type	Applicability	Notes
Daylight compensation	Open-loop proportional	OK	Photosensor should not be able to detect electric light
Daylight compensation	Closed-loop integral	Fair	Currently available systems tend to supply too little illumination
Lumen maintenance correction	Closed-loop integral	Good	Group relamping required
Lumen maintenance correction	Open-loop proportional	No	Not recommended
Daylight + lumen maintenance	Open-loop proportional	No	Not recommended
Daylight + lumen maintenance	Closed-loop integral	Good	Requires specially-configured photosensor

Photosensor Spatial Response and Placement

For a closed-loop system that is intended to work with daylight entering from sidelighting, the ceiling-mounted photosensor should have a large field of view while being blocked from direct light from the window. Some sensor manufacturers supply an optional "sun shield" that serves this function. If the photosensor provided by the manufacturer is not adequately shielded from the window, the photocell should be placed sufficiently far away from the window so that it does not "see" any of the ground outside the building. It is important that a sensor's field of view not be overly restricted, since it will then be very sensitive to changes in luminance, such as those caused by papers being placed on a desk underneath it, or even by someone simply standing nearby.

With an open-loop proportional control system, an unshielded ceiling-mounted photosensor should be used. Although the photosensor for an open-loop system can be pointed out the window, the output of the sensor, when so located, may not track the changes in interior daylight very well. This is especially true if the sensor is placed outside of a shading device on the window. In this situation, the sensor -- and by extension, the electric lighting system -- will be unable to detect the effect of the shading device. It then becomes virtually impossible to maintain a constant light level in the building space. Although some have suggested that this will force building occupants to use the shading device "correctly," there is no evidence for this.

In a room where there is only one task area of interest, the ceiling-mounted control photosensor should be located above the task. If there are several tasks areas separated by some distance, the photocell should be located above a task area that receives a representative amount of daylight. An even better (but more expensive) solution is to use separate control zones for each area. For buildings with light shelves that redirect daylight deep into the building space, mounting the photosensor above the light shelf is a good solution. See, for instance, Benton, C. "The Lockheed Building 157 Monitoring Project Phase 2: The Lighting Control System," *PG&E R&D Report Number 008.1-89.7,* 1989.

Two rules of thumb for locating control photosensors are:

- Locate the photosensor at a distance away from the window equivalent to approximately two-thirds the depth of the daylight control zone.
- With indirect and direct/indirect lighting systems, make sure that the photosensors cannot directly "view" the electric lights they control unless the system being used is designed to accommodate such inputs. Generally, the photosensor should be located at the lower plane of the fixtures facing downwards if indirect lighting is used.

Dimming Hardware

There are many ways to dim fluorescent lamps. In general it costs more to dim small groups of lamps than large groups, and a system with a large dimming range costs more than a system with a restricted range.

Dimming control methods include the following :

- *Auto Transformers* are the simplest forms of dimming controls. Auto transformers are usually applied on a large-scale, with one unit controlling many branch circuits. These units can dim most sources, including HID. However, they have severely restricted dimming range: typically from 100% light output to about 75%. Because of their restricted range, they are generally not too effective for daylighting strategies. However, they are useful for lumen maintenance control, if coupled with a photosensor.
- *Branch Circuit-Based Dimmers* dim entire branch circuits of lights and do not require that the ballasts be changed. These devices are usually solid-state dimmers, employing wave form-shaping dimming circuits. They generally dim lamps from full light output to about 50%. At 50% intensity, most of these units drop lamp operating characteristic below ANSI specs. This can negatively affect lamp life.
- *Dynamic Controllers* dim individual ballasts or small groups of ballasts. Typically, these devices use wave form-shaping electronic dimming circuits. These controls do not require changing ballasts, they generally dim between 30% and full light output, and they may increase lamp flicker.
- *Dimming Core-Coil Ballasts* dim individual lamps or lamp pairs. Depending on the lamp and control circuit topology, dimming core-coil ballasts can provide full-range dimming (from 100% down to about 5-8% of full light output). Other systems using specific combinations of standard (non-dimming) energy-efficient magnetic ballasts, specific lamps, and proprietary solid-state wave form-shaping controllers, provide control from about 20% to full light output. Dimming of core-coil ballasts may increase the audible hum of these ballasts.
- *Dimmable Electronic Ballasts* dim individual lamps or groups

of two, three, or four lamps. Depending on the control circuit , dimming electronic ballasts can provide full range dimming (from <10% to 100% of full light output).

Dimming Efficacy Considerations

Most light sources become less efficient as they are dimmed. The primary cause of this inefficiency is the need to supply full electrode heater power (see *Energy-Efficient Ballasts* guideline for further discussion) even when the fluorescent lamp is heavily dimmed. If full electrode heater power is not supplied during dimmed operation, lamp life will be unacceptably compromised. Dimming systems that are capable of switching lamps entirely off when the control photosensor detects that daylight is significantly above the design light level are currently available. In some cases, these auto-off systems can switch lamps back on at the dimmed level.

Switching Hardware

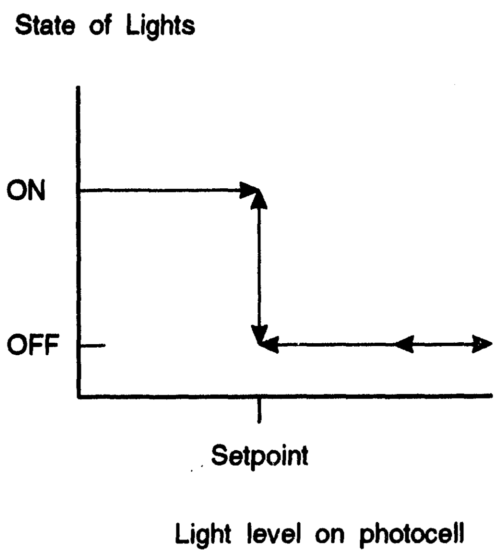
Photoelectric control switches can be used to switch off lights in daylight perimeter zones. These can be field adjusted to control the light level at which they switch. These switches usually incorporate a "dead-band" so that the lights will not cycle between levels if the ambient light level is near the sensor trip level. See Figure 9-13.

Some switches also allow the user to adjust a time delay constant that reduces the likelihood of cycling. These switches have significant energy savings potential of up to 50% in new construction applications, where daylight is abundant and where the wiring can be done correctly. Switches installed on a fixture-by-fixture basis may be cost-effective in retrofit situations, but the ability to switch banks of lights (which is less costly than individual control) is largely constrained by the existing branch circuit wiring. See the *Retrofit Control Technologies* guideline for more details.

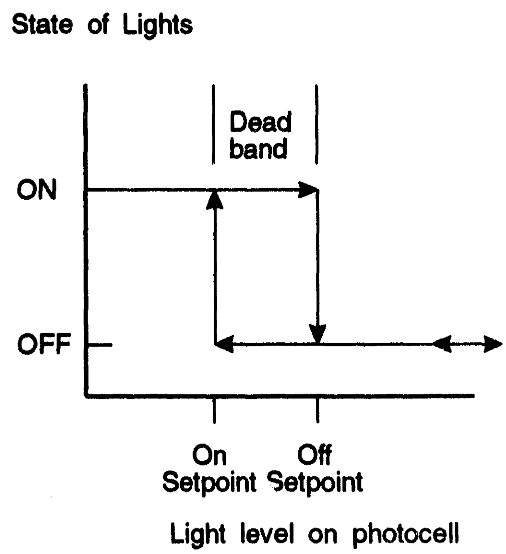
Photoswitches are an inexpensive method of implementing light level switching based on the amount of ambient daylight. One advantage of photoswitches over dimming systems is that when lights are switched off they consume no electric energy, while most dimmers continue to consume power even when maximally dimmed.

A disadvantage of photoswitches over dimming systems in daylighting applications is that occupants often react negatively to having their lights automatically switch on and off during the day, particularly if the switching is frequent. Thus, photoswitches should not be used in occupied spaces unless the daylight levels are very high throughout the entire course of the day. In this case, the lights will be off during the day anyway, and the occupants will not be bothered by the lights cycling. If the photocell can detect the electric light that it controls, though, (as might be the case of a photoswitch that is wall-mounted), the deadband can be compromised. If the detected light level change caused by the lights switching on and off is large enough, there can even be light levels at which the system will be unstable. This will cause the lights to cycle between on and off states until the ambient light level increases enough to bring the system out of the unstable region.

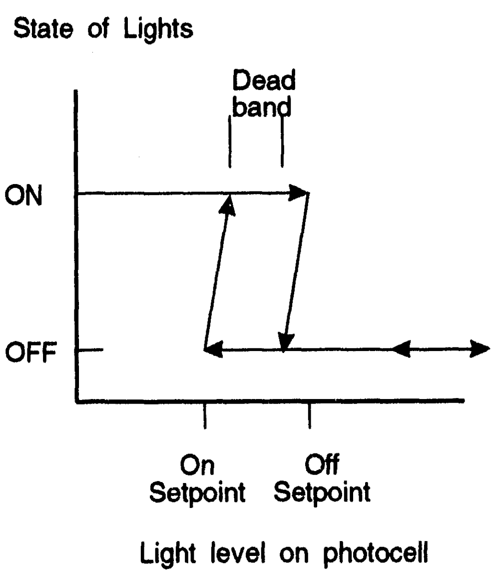
A few electronic ballast manufacturers have products that can supply several intermediate light levels but cannot dim continuously to any level. This level of control may be adequate for daylighting. But for multi-level systems, it is preferable that there be considerable damping to enable gradual transitions between level changes. This will tend to make the transition between levels less noticeable to the occupants.



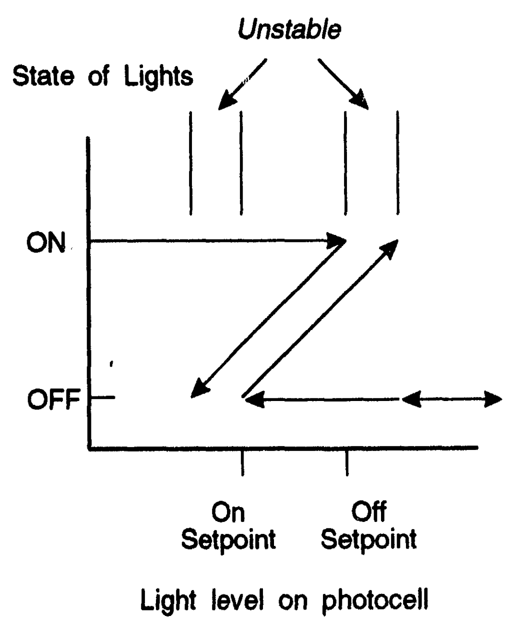
Response of simple photo-switch without deadband; cell insensitive to controlled light



Response of simple photo-switch with deadband; cell insensitive to controlled light



Response of photo-switch with deadband; cell sensitive to controlled light. System stable but effective deadband compromised



Response of photo-switch with compromised deadband; cell sensitive to controlled light and conditionally unstable

Figure 9-13
Deadband Photo-Switch Performance

Calibration and Maintenance

Photoelectric control systems must be properly calibrated to obtain good results. The calibration should be performed during the commissioning of the lighting control system, preferably after furniture and equipment are in place. For a lumen maintenance correction system, the calibration should be performed shortly after installation and after cleaning. (New fluorescent lamps that are intended to be dimmed should always be burned in for at least 100 hours at full light output to assure stable lamp operation. Calibration should be performed after this initial break-in period). The manufacturer's calibration instructions should always be followed.

The following techniques describe the general process involved in calibration.

General Calibration Guidelines

Calibration of a photoelectric lighting system involves adjusting the output of the electric lights so as to achieve a specified light level at a specific location(s) in each control group. The location where calibration is performed is generally referred to as the control point or station point. The station point should be representative of the task locations in the controlled space. If practical, the station point should be located near the control photosensor that controls the lights in that area. Generally, the station point is at desk level (30") and is within a range of one to two mounting heights away from the control photosensor. It may be desirable to define more than one station point for each control zone. In this case, it is necessary to average light level readings over all station points in the control zone.

It is good practice to use a recently calibrated photometer when calibrating a control system. Also, a diagram should be made of the location of the station points so that calibration can be checked from time to time.

Calibration of Closed-Loop Control Systems

For closed-loop systems, a "nighttime calibration" is always required. To calibrate, the installer places a photometer at the station point and adjusts the output of the electric lights until the desired illuminance level is obtained. This adjustment knob is usually on the controller. If the station point is not visible from the controller, a second individual assist in the calibration, using walkie-talkies or a similar device. For new lamps, it should not be necessary to set the electric lights to maximum to achieve the design level. If the output level must be set to maximum to achieve the design level, the calibrator should ascertain that the design was, in fact, intended to supply that level at the station point. For example, in task-ambient lighting design where partitions are present, the designer may not have intended that the overhead lights alone comprise the design in the partitioned spaces. In this case, the station point should be chosen at a location that is unobstructed by partitions.

Calibration of Open-Loop Control Systems

In selecting the time at which to perform the daytime calibration, the following guidelines generally apply:

- The calibration should be done when the sun is shining and not blocked by clouds. If the local climate rarely has sunny days, the calibration may be performed under bright overcast conditions.
- There should be no direct sun shining into the space at the time of calibration. In particular, direct sun on the task is to be avoided.
- The contribution of daylight to the required illuminance at the task surface at the time of calibration should be sufficiently large to cause significant but not full dimming of the electric lights. For example, if the electric lights can supply 700 lux (70 footcandles) at full light output and dim maximally to 100 lux (10 fc), and the total light level desired is 700 lux, then the system should be calibrated when the daylight level at the task is slightly under 600 lux (700 - 100 = 600).
- If the space contains an operable shading device (such as a shutter or blind) that can be controlled by the occupant, the occupant should set the shading device to a comfortable position prior to calibration.

Once the appropriate daytime condition has been selected using the guidelines given above, the daytime calibration may be performed. A photometer is placed at the task surface, and the adjustment knob that controls the gain of the system response is adjusted until the total light level indicated by the photometer (daylight plus electric light) equals the design illuminance level (generally the design illuminance level at night, as supplied by electric lighting only). If this light level appears too low compared to the brightness outside, it is permissible to adjust the electric light level slightly higher. Some caution is required here since, if the electric light level is set too high, energy savings may be minimal.

If the light level from daylight alone is sufficient to exceed the design level, it will be necessary to calibrate later in the day when the daylight levels have dropped below the design level. The calibration procedure described above need only be performed once in each individually controlled space. If initial calibration is performed correctly, adjustments should be necessary only if the furnishings change significantly.

Maintenance

Once properly installed and calibrated, a photoelectric lighting control system should not require significantly more maintenance than a standard lighting system. However, it is appropriate to check the calibration of the controls if there are significant changes to interior furnishings and partitions. In addition, to obtain the maximum benefit from lumen maintenance controls, group relamping should be practiced. Recalibration of the photosensors is not required after group relamping and/or cleaning. However, if fixtures very close to the control photosensor must be spot-relamped because of lamp failure, it is good practice to recalibrate the affected photosensors.

The same maintenance principles that apply to luminaires and room surfaces should be followed for daylight photosensors. Periodically, the control photosensor should be cleaned. Ideally, this cleaning should coincide with cleaning the luminaires.

For the lumen maintenance strategy to work effectively, building management should be committed to a consistent policy of group relamping. Although group relamping is not required to achieve energy savings, by replacing all lamps at the same time (at least within a given control zone), one assures that the light measurement made by the control photosensor is representative of the lighting elsewhere in the zone. This is especially important in the large control zones that are required to make lumen maintenance control strategies cost effective.

Energy Savings

The energy savings from daylighting and lumen maintenance control strategies are highly dependent on the specific application, especially in regards to the base case assumptions. That is, the amount of energy that would be used in the absence of controls must first be either measured or estimated before the energy savings can be calculated. Some studies indicate between the hours of 6:00 a.m. and 6:00 p.m. that daylighting controls can save 30-40% lighting energy in a typical office space daylighted with vertical windows. During the summer, the energy savings can be much larger (over 50%), especially if the dimming system can dim efficiently over a wide range of light levels.

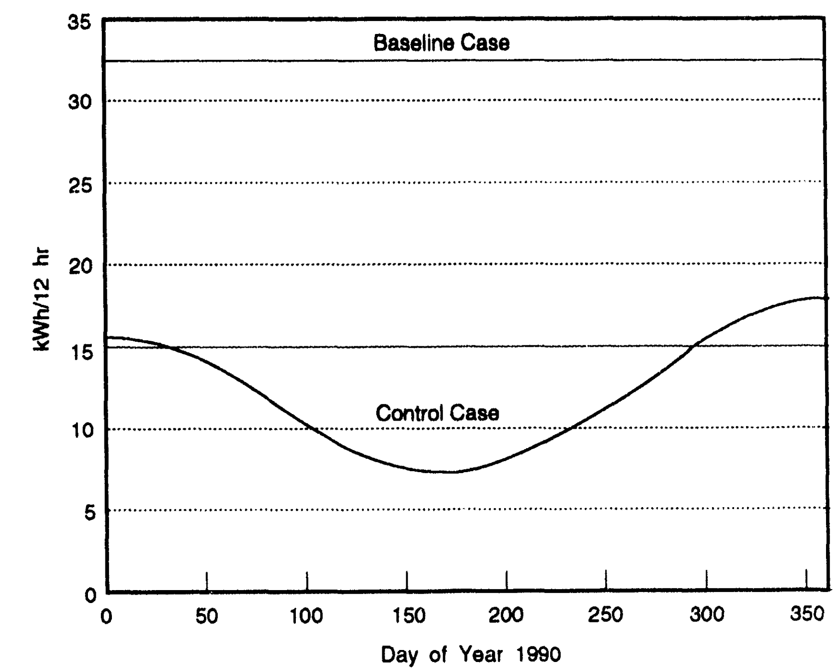


Figure 9-14

Energy savings from daylighting and lumen maintenance strategies as demonstrated at a commercial office building in Emeryville, CA. Daily lighting energy use (6:00 a.m. to 6:00 p.m.) in north daylighted zone with advanced lighting control system as compared to a reference zone without controls. Note the increased usage at the end of the year relative to the beginning of the year. This indicates that the lumen maintenance strategy operated as expected.

Information on energy savings produced by lumen maintenance control strategies is very scarce. The results of a recent study of an advanced lighting control system in the Bay Area indicate an annual savings of 8% to 13%, as shown in Figure 9-14. See Rubinstein, F. "Automatic Lighting Controls Demonstration: Long-Term Results," *PG&E R&D Number 008.1-91.21*, 1991.

Resources

Several manufacturers make components used for daylighting and lumen maintenance controls. Unfortunately, space requirements limit our ability to list all of them here. The following lists of manufacturers and software distributors is, at best, only a partial guide to the availability of this technology.

Manufacturer	**Product**
Conservolite, Inc.	Fiber optic photosensor controllers
Controlled Environmental Systems,	Fiber optic photosensor controllers
Davis Controls	Lighting controllers
ETTA Industries, Inc.	Fiber optic photosensors, dimming electronic ballasts
General Electric	Photosensors, lighting controllers
Honeywell, Inc.	Photosensors, lighting controllers, dimming electronic ballasts
Lithonia Control Systems	Photosensors, lighting controllers
Luminoptics	Photosensors, lighting controllers, dimming electronic ballasts
Lutron	Lighting controllers, dimming electronic ballasts
Multipoint Control Systems, Inc.	Photosensors, lighting controllers
Pass & Seymour/Legrand	Photosensors
Unenco	Photosensors, lighting controllers
The Watt Stopper	Photosensors, lighting controllers

(List does not imply applicability or endorsement by the California Energy Commission, the U.S. Department of Energy or the Electric Power Research Institute. Additional companies also manufacture these products.)

Daylighting Software

Calculating the energy savings produced by daylighting design and electric lighting controls can be a difficult process. However, several computer calculation programs are available that calculate various daylighting factors and compute energy savings.. Some of the more advanced programs integrate daylighting calculations with point-by-point and/or zonal cavity illuminance calculations (See *Computer-Aided Lighting Design* guideline for more information on computer-assisted illuminance calculations).

Each year, the Illuminating Engineering Society conducts a survey of lighting software, the results of which are printed in the publication *Lighting Design + Application.* In June of 1992, the IES listed five software packages that integrate daylighting analysis with electric lighting calculations:

The following list represents a partial inventory of currently-available daylighting software packages. Products that integrate daylighting analysis with electric illuminance computations are marked with an asterisk (*).

AAMASKY* American Architects and Manufacturers Assoc. Des Plaines, IL	MICRO-DOE 2.1 Acrosoft International, Inc. Denver, CO
BEEM R.A. Rundquist Associates Northampton, MA	PWCLITE Public Works Canada Ottawa, Ontario
CONTROLITE 1.0* Lawrence Berkeley Laboratories University of California Berkeley, CA	RADIANCE 2.0* Lawrence Berkeley Laboratories Lighting Research Group MS-46-125 University of California Berkeley, CA
EASYDAYS 2.0* PRC Krochmann GmbH Berlin, Germany	SUPERLITE-PC* Lawrence Berkeley Laboratories University of California Berkeley, CA
LUMEN-MICRO 5.1* Lighting Technologies, Inc. Boulder, CO	

For further information, contact the above manufacturers. (Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, the U.S. Department of Energy or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Occupant Sensors

Technology Description

Occupant sensors are switching devices that respond to the presence and absence of people in the sensor's field of view. The system consists of a motion detector, an electronic control unit, and a controllable switch (relay). The motion detector senses motion and sends the appropriate signal to the control unit. The control unit then processes the input signal to either close or open the relay that controls power to the lights.

The basic technology behind the occupant sensor derived from security systems developed for residential and commercial applications to detect intruders. However, the motion sensor has been refined so that it responds not only to the presence of occupants, but also to the absence of occupants in the space. Other enhancements of the technology have centered on reducing costs, increasing control intelligence, improving ability to detect minor motion, and increasing adjustment capabilities.

System Components

While the entire occupant sensing and switching system is commonly referred to as an occupant sensor, the sensor itself is a system that is made up of several components, including a motion detector, electronic control unit, relay and power supply.

The motion detector uses either ultrasonic sound waves or infrared radiation technologies for sensing motion. The electronic control unit collects the information supplied from the sensor and determines the occupancy status of the space. In some cases, the control unit can be calibrated to adjust the sensitivity of the sensors to motion. The controller also incorporates a programmable timing device that will turn off the lights after the room is unoccupied for a specific period of time. Output from the control unit energizes or de energizes the electromagnets of a relay. The relay opens or closes the lamps' circuit. Relay contacts must be properly sized to handle the line voltage and current. A power supply is also an element of the system and is needed to transform the 120 or 277 AC line voltage for powering the control unit's circuit and for sending output to the relay. The relationship between the power supply, relay, controller and motion detector are shown in Figure 10-1.

In most occupant sensor systems, the motion detector and controller are housed in one package; the power supply and relay comprise another integral unit, sometimes called a control unit or switchpack. In wallbox-type sensors, components are all integrated into one compact package, designed to fit into an existing switch box. The solid state switches often used in these packages are rated for relatively small loads.

Contents

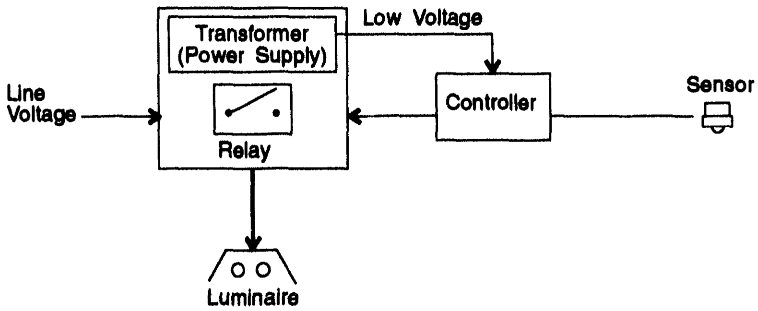


Figure 10-1
Occupant Sensor Control System

Occupant sensors can also be connected to low-voltage relay and building automation systems. If the sensor is connected to a low-voltage relay system, the low-voltage operating power is derived from the relay panel's low-voltage supply.

Passive Infrared (PIR) Sensors

Passive infrared (PIR) sensors react to the infrared heat energy emitted by people. PIR sensors are passive devices in that they only detect radiation; they do not emit it. They are designed to be maximally sensitive to objects that

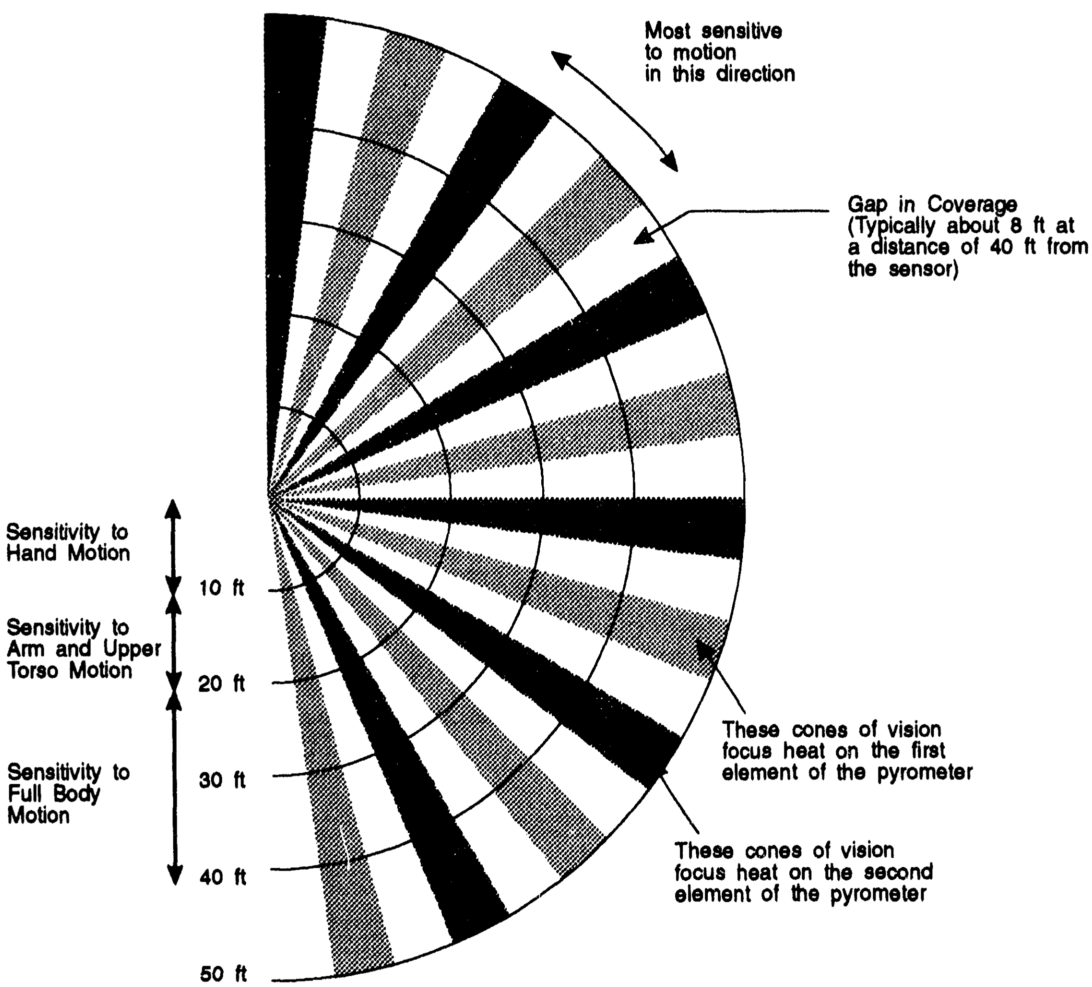


Figure 10-2
Operation and Sensitivity of Passive Infrared Sensors

(Source: *Proceedings of the North Texas Association of Energy Engineers*, May 13-14, 1991) emit heat energy at a wavelength of around 10 microns (the peak wavelength of the heat energy emitted by humans). PIR sensors are strictly line-of-sight devices. They cannot "see" around corners and a person will not be detected if there is an obstruction, such as a partition, between the person and the detector.

PIR sensors employ a pyroelectric transducer to detect infrared radiation. The device converts the IR energy into a voltage signal. A many faceted lens surrounds the transducer and focuses heat energy onto the detector. The lens views the area with a multitude of narrow and discrete beams or cones. As such, it does not view the area in a continuous fashion. As an occupant moves a hand, arm, or torso from one cone of vision to another, a positive signal is generated and sent to the controller.

The detection pattern of PIR sensors is fan shaped -- formed by the cones of vision seen by each segment of the faceted lens. As shown in Figure 10-2, coverage gaps occur between the cones of vision of alternate segments of the lens. These gaps widen with distance. At 40 feet from the sensor, for instance, coverage gaps of up to 8 feet wide may be present. Since the sensor is most sensitive to motion that moves from one sensing cone to another, its sensitivity decreases with distance as the gaps between sensing cones widen. Most PIR sensors are sensitive to hand movement up to a distance of about 10 feet, arm and upper torso movement up to 20 feet, and full body movement up to about 40 feet. The sensitivity range of PIR sensors can vary substantially, however, depending on product quality and electronic circuiting design.

Ultrasonic Sensors

Ultrasonic occupant sensors activate a quartz crystal that emits ultrasonic waves throughout space. The unit then senses the frequency of the reflected waves. If there is motion, the reflected wave's frequency will shift slightly (Doppler effect). Ultrasonic sensors operate at frequencies that are above human sensitivity (20 kHz). Typical operating frequencies are 25, 30, and 40 kHz.

Figure 10-3 shows the detection pattern of an ultrasonic sensor. The ultrasonic sound waves cover the entire area in a continuous fashion -- there are no blind spots or gaps in the coverage pattern. For this reason ultrasonic sensors are somewhat more sensitive to movement. For example, hand motion can be detected at a distance of about 25 feet, arm and body torso detected out to 30 feet and full body motion can be detected out to over 40 feet. (The sensitivity range of different products will vary significantly.)

Detector Comparisons

Passive infrared and ultrasonic occupant sensors offer very similar characteristics in terms of overall performance. Ultrasonic sensors are more expensive, as a rule, but provide greater coverage than PIR detectors. However, increased sensitivity means that ultrasonic sensors are more susceptible to false triggering due to any movement in the space. For example, unless carefully calibrated, ultrasonic sensors will react to non-occupant movement such as breezes from open windows or HVAC systems. In most cases the sensitivity of the ultrasonic system, like the PIR system, is line of site. In some circumstances, however, the movement of occupants behind partitions may be detectable by ultrasonic sensors, due to reflectance of the emitted sound waves around the partitions.

Performance characteristics of various types of ultrasonic and PIR occupant sensors are noted in Figure 10-4.

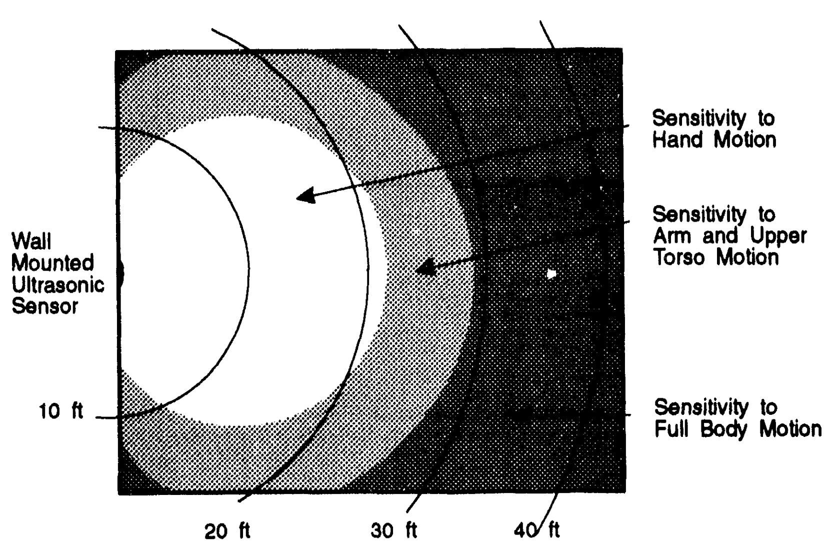


Figure 10-3
Typical Sensitivity Pattern for Wall-Mounted Ultrasonic Sensor

(Source: *Proceedings of the North Texas Association of Energy Engineers,* May 13-14, 1991)

Figure 10-4

Occupant Sensor Performance Characteristics

Mounting Location	Sensor Technology	Angle of Coverage	Typical Effective Range1	Optimum Mounting Height
Ceiling	Ultrasonic	360°	500-2000 ft^2	8-12'
Ceiling	Passive Infrared	360°	300-1000 ft^2	8-12'
Wall Switch	Ultrasonic	180°	275 -300 ft^2	40-48"
Wall Switch	Passive Infrared	170-180°	300-1000 ft^2	48"
Corner Wide View	Passive Infrared	110-120°	To 40 feet	3-10'
Corner Narrow View	Passive Infrared	12°	To 130 feet	6-7'
Corridor	Ultrasonic	360°	To 100 feet	8-12'
High Mount	Passive Infrared	12°	To 100 feet	To 30'

[1]Sensitivity to minor motion may be substantially less than noted here, depending on environmental factors

Other Sensor Technologies

In the lighting controls industry, passive infrared and ultrasonic sensors currently dominate the occupant sensor market. Sensors that use microwave technology are also available; however, at the present time, these are primarily limited to the security and alarm industries. Other sensors may be based on sensing motion indirectly. One type responds to audible noise; others are tripped by either a foot pad, lever, or light beam. Indirect motion sensors can only be used in special applications, and so far, they have been of limited utility.

Hybrid occupant sensors, now available from at least one manufacturer, employ both infrared and ultrasonic capabilities in the same unit, offering improved operation with a minimum of false triggering.

Life Span

It is difficult to adequately assess the life span of occupant sensor systems. Only one manufacturer has been making occupant sensors for 15 years, so any manufacturer's claim of life spans in excess of 15 years have yet to be proven empirically. Life cycle testing procedures seem to suggest that a reasonable life span estimate for most occupant sensors would range between 12 to 15 years. Control units, on the other hand, are estimated to have a life expectancy of between 6 and 10 years. Generally, control unit failures are caused by a deterioration of the transformer or relay within them. Deterioration may be exacerbated by high humidity environments and/or temperature extremes.

Current Products

There are a wide variety of occupant sensors on the lighting controls market. Sensors fall into one of two categories. Ceiling-mounted sensors employ an independent controller and/or power supply. They may be mounted on the wall or in a corner as well as on the ceiling. Wallbox sensors are relatively new products, primarily designed as retrofit replacements for common wall switches. Both ceiling-mounted and wallbox occupant sensors are available with either PIR or ultrasonic sensing units.

Ceiling-Mounted Sensors

Ceiling-mounted occupant sensors were the first type of motion detector to be used in lighting applications, and they remain the most popular type of sensor in use today. Applications for ceiling-mounted sensors are nearly universal: they may be used for either small or large areas, and they have few limitations.

The typical ceiling-mounted system consists of a motion detector/controller unit connected to a "switchpack" housing, containing the power supply and relay. Class II (low voltage) wiring is all that is required for communication between the switchpack and the sensor.

The high mounting position of ceiling-mounted sensors allows good coverage of large areas with obstructions, such as partitions and furniture in open office spaces. Multiple sensors can be networked to cover large areas that exceed the range of a single unit. Ceiling-mounted sensors may also be installed high on the wall or in corners. Installation of these units requires opening the ceiling or wall, since they must be hardwired to the electrical distribution system. This results in a relatively high installation cost for retrofit applications which must be considered in any economic analysis.

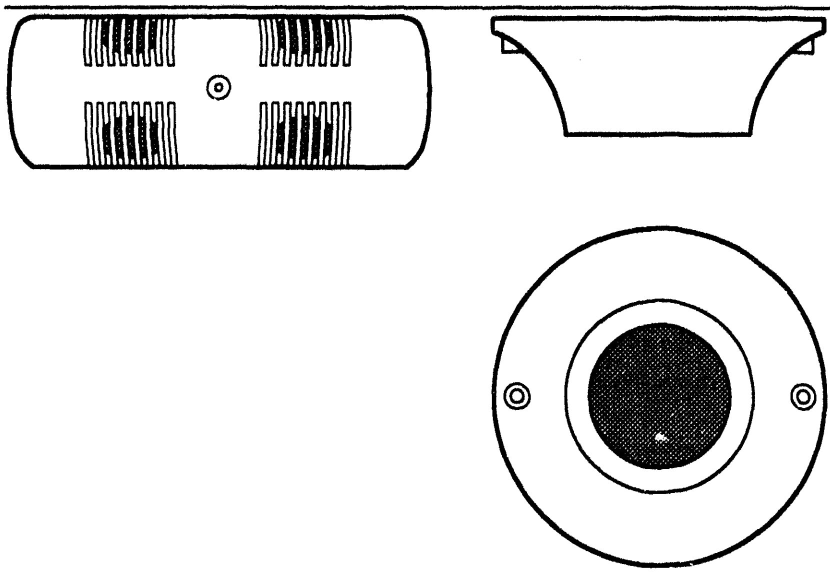
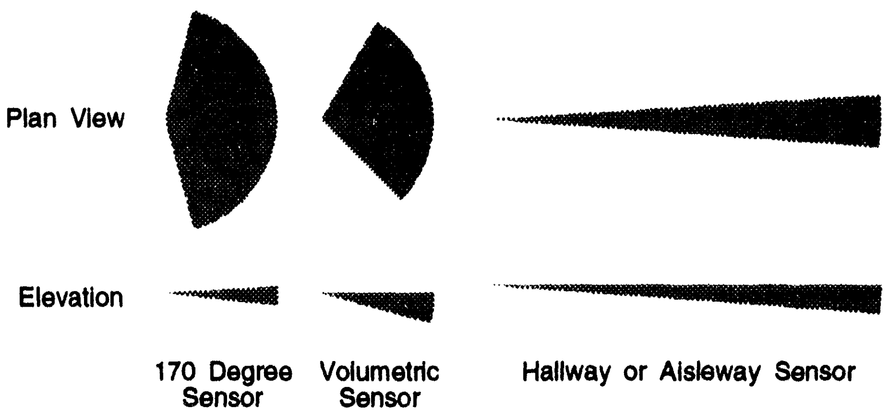


Figure 10-5
Ceiling-Mounted Occupant Sensors



Ceiling-mounted ultrasonic occupant sensor devices are available in coverage patterns ranging from about 250 ft^2 to 2000 ft^2. Ultrasonic sensors are also available for applications in narrow spaces, such as corridors and warehouse aisles. These will detect occupants up to about 100 feet from the sensor.

The cone of vision can be controlled for ceiling-mounted PIR sensors, enabling a variety of different sensitivity patterns. The narrower the cone of vision, the greater the range of distance.

Units intended for open areas have a cone of vision of about 90 to 110 degrees, and will cover areas from about 300 ft^2 to 600 ft.^{2} Linear sensitivity in these units is about 40 feet. Units with a narrow cone of vision are often mounted high on a wall or in a corner, and are intended for use in corridors and aisle ways. Passive infrared units with a 12 degree cone of vision can detect occupants up to a distance of about 120 feet. See Figure 10-6.

Wallbox Sensors

Wallbox-mounted occupant sensor units such as those shown in Figure 10-7 were introduced for smaller offices and similar applications where the higher cost ceiling mounted units were considered too expensive. These units have all components in a single housing and can be easily wired into existing switch boxes in the room. There is little design flexibility since the wall box location is fixed, in most cases, at 42 inches above the floor. Another drawback is that room partitions and furnishings will limit coverage. However, in the appropriate spaces (small offices and open conference rooms that have wall switches) wallbox sensors are very cost effective, as the devices are relatively inexpensive and the installation cost is almost negligible.

Wallbox sensors are available in both PIR and ultrasonic technologies. Both ultrasonic and PIR wallbox sensors have a typical effective range of sensitivity to minor (hand) motion of up to about 300 ft^2. In addition, PIR wallbox sensors may be sensitive to gross motion in areas of up to 750 ft^2. The field of view for wallbox PIR sensors is usually about 120 degrees, but some units are available with a wider range up to 180 degrees. Some sensors can be masked to limit the field of view when this is desirable.

The time delay before turning the lights off is adjustable in most wallbox units. The range of adjustment varies, however. For example, a typical adjustment range is from 30 seconds to 15 minutes. Shorter and longer adjustment ranges of from 10 seconds to 30 minutes are available.

The maximum load rating for wallbox sensors ranges from 800 to 1000 watts, at 120 volts, and up to 2000 watts with 277 volt service. In addition, most wallbox sensor units have a minimum loading requirement, which should be reviewed when selecting sensors. If the minimum loading requirement is not met, the sensor will not work at all.

Wallbox sensors employ different circuit approaches to accomplish lighting control. Some approaches may affect the performance of some brands of electronic high frequency ballasts. The sensor manufacturer can provide the necessary information as to this limitation.

Common Features

Both ceiling-mounted and wallbox occupant sensors may operate in one or more of three modes described below.

- *Always Off Mode* essentially overrides the occupant sensor to turn lights off even when occupants are present. This mode might be selected, for instance for an audio visual presentation requiring lights to be off.
- *Always On Mode* also overrides the sensor unit so that lights remain on whether the space is occupied or not. Occupants who are displeased with the performance of their sensors may engage this option to override the devices. (Note: sensors that may be easily and permanently overridden in this manner may not be certifiable for Title 24 compliance.)
- *Automatic Mode* means that the sensor unit turns lights on when occupancy is detected, and turns them off sometime after all occupants have vacated the space. A variation of the automatic mode requires that the lights must be turned on manually. (The lights are still extinguished by the sensor unit after the room is vacated.) This helps to avoid false triggering and encourages occupants to turn on the lights only when they are needed.

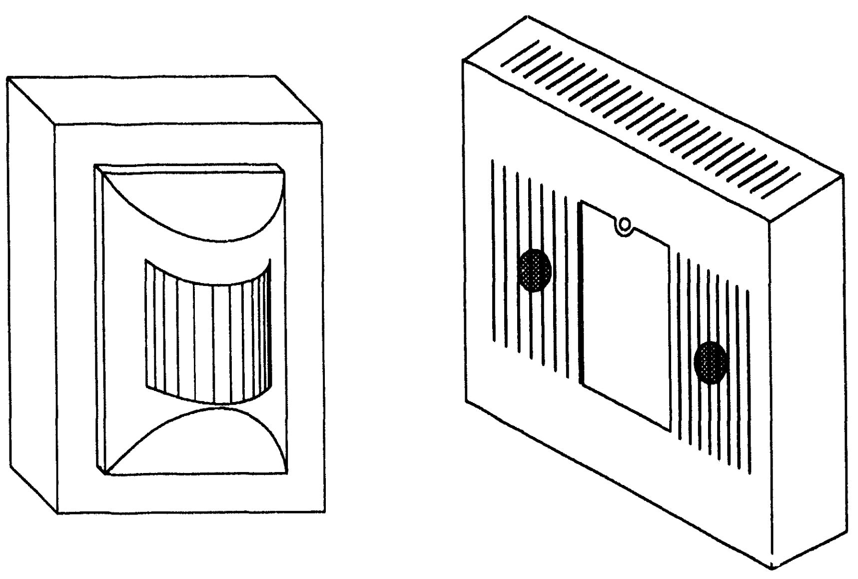


Figure 10-7
Wallbox Occupant Sensors

Many of the better occupant sensors on the market are available with some or all of the following features. Desirable features from this list should be specified by the designer.

- *Sensitivity Calibration* The ability to adjust ultrasonic occupant sensors for sensitivity is vital to their proper operation and is required by California's 1992 *Energy Efficiency Standards for Residential and Nonresidential Buildings* (Title 24). This is particularly important to reduce or eliminate false triggering caused by air motion or building vibrations or to tune coverage to match a control space.
- *Programmable Time Delay* Most occupant sensors incorporate a programmable time delay that controls the period of time between last occupancy and turning off the lights. The typical delay time for most sensors ranges from 30 seconds to 15 minutes, though this figure may vary widely, depending on the manufacturer. Title 24 requires that sensors may be calibrated and that they extinguish the lights in a control zone no more than 30 minutes after the area has been vacated.
- *Indicator Light* Most occupant sensors contain a visible LED or other indicator to indicate when the sensor is actually detecting motion or body heat. Status indicators on occupant sensors are required under California's Title 24.

- *Audible Alarm* Occupant sensors equipped with this feature sound an alarm shortly prior to extinguishing the lights. This allows an occupant to initiate a triggering motion or to manually override the sensor. This is useful for situations when the occupant has remained unusually still for a period of time, or for applications where the sensitivity of the sensor has been calibrated to respond only to a high level of movement. This feature is particularly important for sensors that are operated in the manual on/automatic off mode.
- *Grace Timer* In lieu of an alarm signal, some occupant sensors employ grace timers that allow an occupant 5 to 10 seconds to make enough motion to reactivate the lights once they have been extinguished in a manual on/automatic off mode. With this feature, the occupant does not have to walk to the switch to turn the lights back on.
- *Fail On Function* Sensors supplied with this feature are designed to keep the lights on if the sensor fails. (Emergency and safety illumination should not be controlled by sensors due to the remote chance that a sensor should fail and cause the lights to be extinguished). Since no system is foolproof, it is still a good idea to hold some luminaires back from occupant sensor control, so as to have available safety illumination if a system failure extinguishes the lights.
- *Masking Labels* Occupant sensors supplied with masking labels allow the occupant to "fine tune" the coverage range of the sensors in applications where extraneous motion causes a sensor to false trigger. An example of this would be when an open door leading to a hallway is within the line of sight of the sensor. A masking label could be used to restrict the field of view in the direction of the doorway.

Integration with the Daylighting Control Function

Several manufacturers have recently begun to combine occupant sensors with photocell sensors for daylighting control. Integrated devices are now available for both ceiling-mounted and wallbox units (see Figure 10-8). However, Section 119(g) of California's Title 24 allows control credits for both the occupant sensor and photocell for ceiling-mounted units *only*. No daylighting control credit is allowed for combination wallbox units (these units are, however, eligible for occupant sensor credits). Furthermore, photocells used in wallbox integral units are not capable of accurately measuring illuminance in the task area.

Integration of daylighting controls with occupant sensors in the same control spaces is, at best, of limited utility. While there are some good potential applications, such as in warehouses and malls, where simple controls will be effective, the utility of these units is severely limited in spaces that contain more precise and/or difficult visual tasks. In addition, integrated daylighting-occupant sensing schemes limit lighting control to on/off switching (as opposed to dimming). This can be annoying to occupants. Dimming is, quite simply, the superior approach in daylighting applications. See the *Daylighting and Lumen Maintenance* guideline.

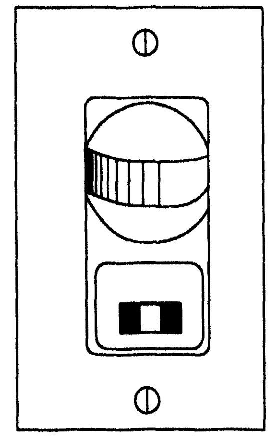


Figure 10-8
Wallbox Occupant Sensor with Daylighting Photocell.

Regulatory Requirements

Occupant sensors, like all other lighting equipment, should be listed by Underwriters Laboratories (UL), and they should meet ANSI requirements. Ultrasonic sensors must also meet the U.S. Food and Drug Administration's standards for decibel levels and must be inaudible to human hearing. Moreover, under Section 119 of California's Title 24, occupant sensors must meet the following additional requirements:

- Shall extinguish the lights no longer than 30 minutes after last occupancy
- Shall have adjustable calibration for sensitivity to movement (non-PIR sensors))
- Shall be equipped with a visual and/or auditory status indicator

(Note: Reference to Title 24 or any other regulatory standard is intended for informational purposes, and any such reference is not intended to be authoritative when applying any standard.)

Application Guidelines

In the past, the biggest application pitfalls associated with occupant sensors have been problems caused either by using inappropriate sensor sensitivity patterns for the application at hand, or by the improper mounting location of sensor units. This is particularly true when operation of the sensing devices is entirely automatic. Studies suggest that when occupants find lighting controls of any type to be obtrusive, they will disable them, thus negating any potential energy savings. In most applications, sensor types, sensitivity patterns, mounting heights, and locations should be based on the recommendations of the manufacturer.

Generally Occupied Spaces

The important application criterion for generally occupied spaces is the amount of time that the space is unoccupied. Areas going unoccupied for long periods of time (overnight, for instance), and/or spaces where lights are likely to be left on inadvertently, offer the best application opportunities for occupant sensors.

In commercial applications, single offices and conference rooms will tend to have the most unoccupied periods. Energy savings may be realized by the installation of wallbox occupant sensors in manual on/automatic off operation mode. Multiple offices or open office spaces will generally be occupied for longer periods of time than single offices. However, occupancy patterns in these areas are usually either constant and/or predictable (see Figure 10-9), and a time scheduling system might be a more effective control strategy.. Nevertheless, occupant sensors would also help to save lighting energy outside of normal work hours. Other generally occupied spaces that could benefit from occupant sensors include school classrooms, processing areas, and corridors.

Intermittent Occupancy

There are many areas in offices, manufacturing, schools and other commercial buildings where there are no permanent occupants. These include reproduction rooms, filing areas, school classrooms, storage areas, conference rooms, warehouses and restrooms. Full lighting is required when in use, but often there is a general forgetfulness about turning off the lights when the space is left. As such, these are excellent spaces for occupant sensors.

Fail Safe or Backup Lighting

For safety's sake, it is important that a failure in the control unit of an occupant sensor will not cause the lights to switch off. In addition, since complete fail safe operation cannot be guaranteed, it is recommended either to leave some of the lighting uncontrolled by occupant sensors or to install an emergency lighting system, so that people can safely leave the area in the event of an emergency. Backup "stumble" lighting in some form is recommended for any completely enclosed area, such as filing rooms, reproduction rooms, corridors, and washrooms.

Sensor Locations and Limitations

When the decision has been made to employ occupant sensors the most important design consideration is determining the location of the detector. We have seen that the wallbox sensor is effectively limited to the position of the wall switch. As such, one must be certain that there are no

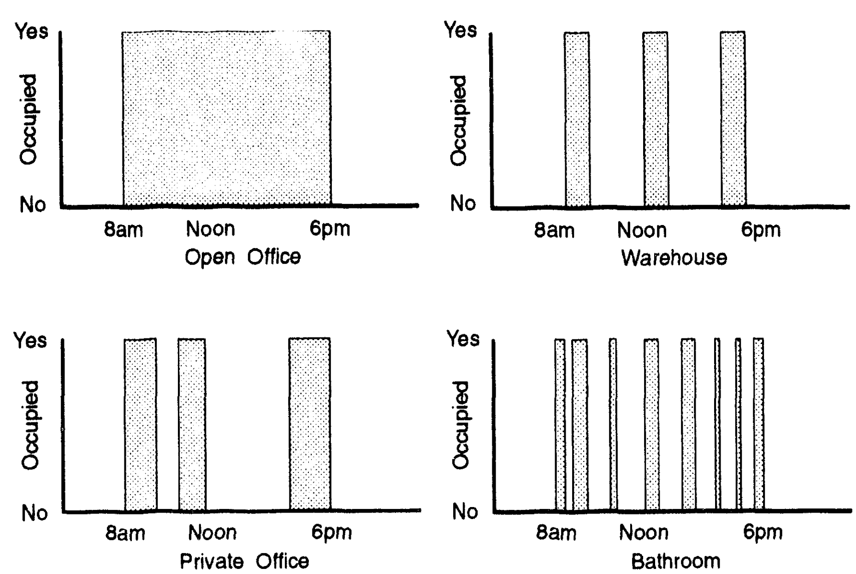


Figure 10-9
Typical Patterns of Occupancy

obstructions to limit its effectiveness. For the wallbox sensor to effectively monitor a space with obstructions, it may be easier to simply move the obstructions rather than relocating the wallbox.

Ceiling-mounted sensors in automatic mode should always be mounted and aimed so that they activate the lighting system as soon as a person enters the space. Ceiling-mounted sensors may be mounted high on the wall as well as on the ceiling. Mounting the system high has two advantages: there are fewer possibilities of obstructions, and the system will be near to the electrical distribution system, thus easing installation. Sensors should not be mounted in locations, such as behind door swings, that may temporarily obstruct the detection pattern. Neither should they be mounted so that they monitor areas outside of the controlled space. This could be a problem, for example, if a sensor were facing a doorway leading to a corridor.

To reduce the possibility of false detection, PIR sensors should be mounted no closer than four to six feet from HVAC vents or other heat sources. Ultrasonic sensors should not be placed in close proximity to ventilation ducts or open windows, where air movement may cause false triggering.

The most critical measure of an occupant sensor's performance is its sensitivity to minor (hand) motion. This information is usually available from the manufacturers' literature. However, while manufactures specify the area and shape of the detection pattern in their literature, there may be limiting environmental factors associated with the application at hand. For example, temperature and/or high humidity can affect the electronics of occupant sensors and reduce the detector's range of sensitivity. The monitoring range of ultrasonic sensors, for instance, may be reduced by temperatures under 0 °C (32 °F). Similarly, the rated range of ceiling-mounted sensors should be derated when they are located in partitioned spaces, where barriers block the line of sight of the devices. For example, in spaces equipped with partitions of 48 inches or higher, the range of ceiling-mounted sensors will be reduced by a minimum of 50%. The rated range of occupant sensors will also be reduced if the mounting height is more than 13 feet.

In any case, installed occupant sensors in all applications should be tested for sensitivity both initially and at intervals to insure that specified performance is met and has not deteriorated or been compromised by environmental factors.

Limitations and Compatibility with Lamp-Ballast Systems

Occupant sensors are appropriate for controlling both incandescent and rapid start fluorescent lamps. With these lamps, reduced lamp life due to frequent switching in minimal. While lamp life in rapid start lamps may be significantly reduced by constant switching, in most occupant sensor applications, average switching cycles (>15 minutes apart) are usually long enough to avoid problems.

Occupant sensors are less compatible with both preheat and instant start fluorescent lamp-ballast systems, such as compact flourescent lamps, F96T12 slimline systems, and F32T8 lamps operated in instant start mode. Lamp life in these lamps is much more sensitive to frequent switching applications than is the case for rapid start lamps. In applications with occupant sensors, it may be wise to consider the use of rapid start electronic ballasts for T-8 lamps rather than the more typical instant-start ballasts.

Manufacturers of occupant sensors have argued that although frequent switching may reduce lamp operating life, the overall service life of the lamp will be increased. This analysis is complex, as one must compare the lamp life lost due to frequent

Figure 10-10

Recommended Applications for Occupant Sensors

Sensor Type	Applications	Notes
Ceiling Mount	Open Partitioned Areas, Small Open Offices, File Rooms, Reproduction Rooms, Conference Rooms, Restrooms, Garages	Provides for 360° coverage; derate range by 50% if partitions >48" are in place
Corner Mount/Wide View	Large Office Spaces, Conference Rooms	Mount high on wall
Wall Switch	Private Offices, Copy Rooms, Residences, Closets	Especially suitable for retrofits. Not recommended for areas with obstructions.
Narrow View	Hallways, corridors, aisle ways	Work best if mounted on centers with range control
High Mount Narrow View	Warehouse aisle ways	Must be set back from aisle so that they do not detect motion in cross aisles

switching and the life lost due to the evaporation of the low work function material from the tungsten electrodes. In reality, the true measure of the cost effectiveness of an occupant sensor control system is the cost of the system and the energy savings it produces over time.

The use of certain wallbox sensors with compact fluorescent lamps may cause reduced lamp life, as some of these devices do not completely shut off the current to the lamp's ballast, causing the lamp to remain partially energized. In most cases, lamps controlled by wallbox sensors supplied with a separate neutral connection will not experience any problems. For other devices, the designer should examine the sensor's specifications (often printed right on the box) for application limitations. Often, the specifications will list minimum loading requirements or state that the device is intended for incandescent use only. When in doubt, contact the manufacturer.

Some wallbox sensor circuitry designs may not be 100% compatible with certain electronic ballasts when combined with solid state switching devices. Before using electronic ballasts in combination with occupant sensors, the designer is urged to check with the respective component manufacturers for compatibility.

Occupant sensors should not be used with high intensity discharge (HID) source lamps except in a few specific circumstances. Since HID lamps have extended long warm-up periods and can take several minutes to restrike after having been extinguished, occupant sensors are impractical for these sources. A few manufacturers of HID equipment, however, offer two-level (stepped dimming) HID systems specifically designed to be used with occupant detectors. In these applications, the low light level is provided when no occupancy is detected. When the occupant detector senses motion, it triggers the lighting system to go to the high level. Since the lamps are already warm, these systems can go to full light output very quickly, provided they start from a low light level rather than from off. These two-level systems may be quite useful in warehouse aisles, prisons, gymnasiums, and other interior applications where a low light level is desirable even when the space remains unoccupied.

Energy Savings and Cost Effectiveness

Energy savings for any particular occupant sensor application will vary considerably depending on the size of the area covered and the occupancy pattern. Claims made by manufacturers of occupant sensors range from 5% to 75%. Energy saving potential is highly dependent on baseline assumptions and operation, but values of 35% to 45% are typical. A recent study showed significant energy savings made possible by the installation of occupant sensors in an existing building. Figure 10-11 demonstrates the savings that occurred.

In order to determine the cost effectiveness of occupant sensors, the designer should have some knowledge of the expected occupancy patterns of the spaces under consideration and of the amount of the power to be controlled. It may not be cost effective, for instance, to use occupant sensors in spaces where occupancy is constant and predictable. A better choice, in these cases, might be a time scheduling system. Figure 10-12 shows a range of energy savings that manufacturers claim can be expected in typical spaces.

In retrofit applications, it is important that the designer know layout of the wiring system is in use. If the installation of occupant sensors requires extensive rewiring, it may not be cost effective. See the *Retrofit Control Technologies* guideline for an explanation of the various wiring systems used in existing buildings and to determine which approach can be more cost effective.

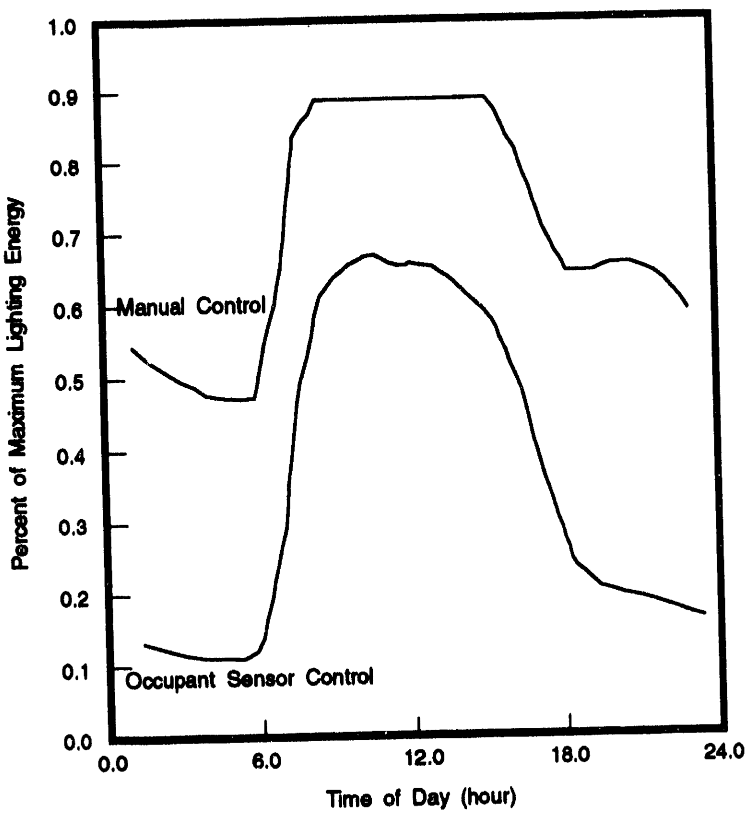


Figure 10-11

The top line shows floors with conventional lighting control, while the bottom line shows floors with occupant sensors. Both plots are a percentage of the maximum lighting load that is on at each hour in a typical day. The difference between the two lines in the savings. (Source: [draft paper] Rick Diamond, et. al.: "Performance of the Energy-Edge Buildings: Energy Use and Savings," 1992)

Figure 10-12

Energy Saving Potential With Occupant Sensors

Application	Energy Savings*
Offices 1-2 Persons	25-50%
Offices (Open Space)	20-25%
Rest Rooms	30-75%
Corridors	30-40%
Storage Areas	45-65%
Meeting Rooms	45-65%
Conference Rooms	45-65%
Warehouses	50-75%

*Note: Figures listed represent a maximum of energy savings potential which may be obtained under optimum circumstances. Figures are based on manufacturers' estimates. Actual savings may differ.

Guideline Specifications

In general, for important applications, all lighting equipment, including controls, should be carefully specified. Ideally, the specification will include manufacturer and model number. The following sample specifications may be used as generic models for the specification of occupant sensors.

Ceiling-Mounted Occupant Sensors

1. U.L. Listed.
2. Acceptable manufacturers: (list).
3. Detector: (passive infrared) (ultrasonic) (combination PIR/ultrasonic).
4. Detector mounting: (ceiling semi-recessed) (ceiling surface) (wall bracket).
5. Detector head with LED positive detection indicator.
6. Detector head to have relay adjustment 30 seconds to 30 minutes.
7. Detector head with sensitivity adjustment.
8. (Two-piece systems) (Transformer/relay) (Switchpack) input rating (120) (277) volts AC. Contacts rated (6) (20) amps.
9. Low-voltage wiring between devices: multi-conductor, plenum rated.
10. In the event of device failure circuit designed to fail with lights on.
11. Two year warranty.
12. Detector head to have setup bypass switch.

13. Ultrasonic devices to comply with (Section 119[d] of California's *Energy Efficiency Standards for Residential and Nonresidential Buildings*) (FDA reporting requirements under 21 *Code of Federal Regulations*, Section 1002.10 [1990]).
14. Infrared detector with field-adjustable mask to set the pattern of detection to match the room.
15. Sensors and control units supplied with teflon leads to comply with NE and UL codes for plenum ceilings.

Wallbox Occupant Sensors

1. Power supply, relay, and sensor/controller unit to be UL Listed for (120/277/240) VAC operation.
2. Acceptable manufacturers: (list).
3. Rating: (120) (277) volts AC, 60Hz, load (rating of chosen device) (amps or VA).
4. Mounting: (single gang Decora) (single gang recessed) (single gang semi-recessed) (double gang semi-recessed).
5. Cover plate (describe color, other features).
6. Manual activation by switch on cover.
7. Automatic extinguishing of lights after delay. Delay adjustment under cover switch, 30 seconds to 15 minutes.
8. Means of detection: (passive infrared) (ultrasonic) (combination of infrared and ultrasonic).
9. Ultrasonic devices equipped with sensitivity adjustment.
10. Ultrasonic devices to comply with (Section 119[d] of California's *Energy Efficiency Standard for Residential and Nonresidential Buildings)* (FDA reporting requirements under 21 *Code of Federal Regulations*, Section 1002.10 [1990]). .
11. Positive detection device, LED or equal.
12. In the event of device failure, circuit designed to fail with lights on.
13. Two year warranty.
14. (optional) Lighting high-low switch.
15. (optional) Audible warning device to signal when lights are to be extinguished.
16. Auto-off switch on cover.

Occupant Sensor Installation

1. According to manufacturer's instructions.
2. Mounted a distance more than four feet from HVAC ducts and windows.
3. Set up and test for coverage zone as per manufacturer's instructions.

Manufacturer/Product References

Ceiling-Mounted Sensors	**Wallbox Sensors**
Bryant Electric Company	Byrant Electric Company
Earlwood Technologies	Earlwood Technologies
Honeywell, Inc.	Honeywell, Inc.
Hubbell, Inc.	Leviton Manufacturing Co.
Leviton Manufacturing Co.	Lightolier Controls
Lightolier Controls	Lithonia Controls Systems
Lithonia Controls Systems	MyTech Corporation
MyTech Corporation	Novitas, Inc.
Novitas, Inc.	Pace Technologies
Pass & Seymour/Legrand	Pass & Seymour/Legrand
Sensor Switch, Inc.	Unenco, inc.
Unenco, Inc.	The Watt Stopper
The Watt Stopper	

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional Companies may also manufacture these products, and the above companies may manufacture products other than those listed here.)

Time Scheduling Systems

Technology and Components

Time scheduling systems are designed to reduce wasted lighting energy by effectively managing the on and off times of building lighting systems. Scheduling systems function by turning off (or dimming) lights during times when a building space is either unoccupied or is occupied by workers performing tasks that do not require full light levels (e.g. cleaning tasks after normal building operation hours). To accommodate off hours lighting needs, these systems require overrides, either by low voltage switches or telephone overrides, so that lighting control can be regained by building users.

System Components

A time scheduling system consists of the following components:

- *The central processor* is a control unit capable of independently controlling several output channels; each group of lights to be controlled together is assigned to a single output channel
- *Relays* are simple switches that are controlled electrically; they are series-wired to the controlled lighting zones and are controllable from the central processor. In some cases *dimming units* are used instead of relays; these are also controlled by the central processor
- *Overrides* to the system consist of some type of user-activated switches.
- *Control wiring* (generally low voltage) links all components in the system.

Some vendors provide time scheduling systems that consist of all the above components along with all the engineering, programming, and commissioning necessary to create a workable system. These are known as "turnkey" systems. However, systems are often comprised of separate components from different manufacturers.

Central Processor

The central processor in a time scheduling system is essentially a multiple circuit controller. It consists of a real time clock, a microprocessor, a keyboard or keypad, and terminal blocks for connecting inputs and outputs. Processors range in size from systems controlling only a few circuits, to those capable of controlling several thousand. The processors can be programmed by building maintenance personnel to schedule on and off loads on each output channel at arbitrary times throughout the day. In office buildings, for example, the lights would typically be programmed to switch off after workers had left for the day.

Contents

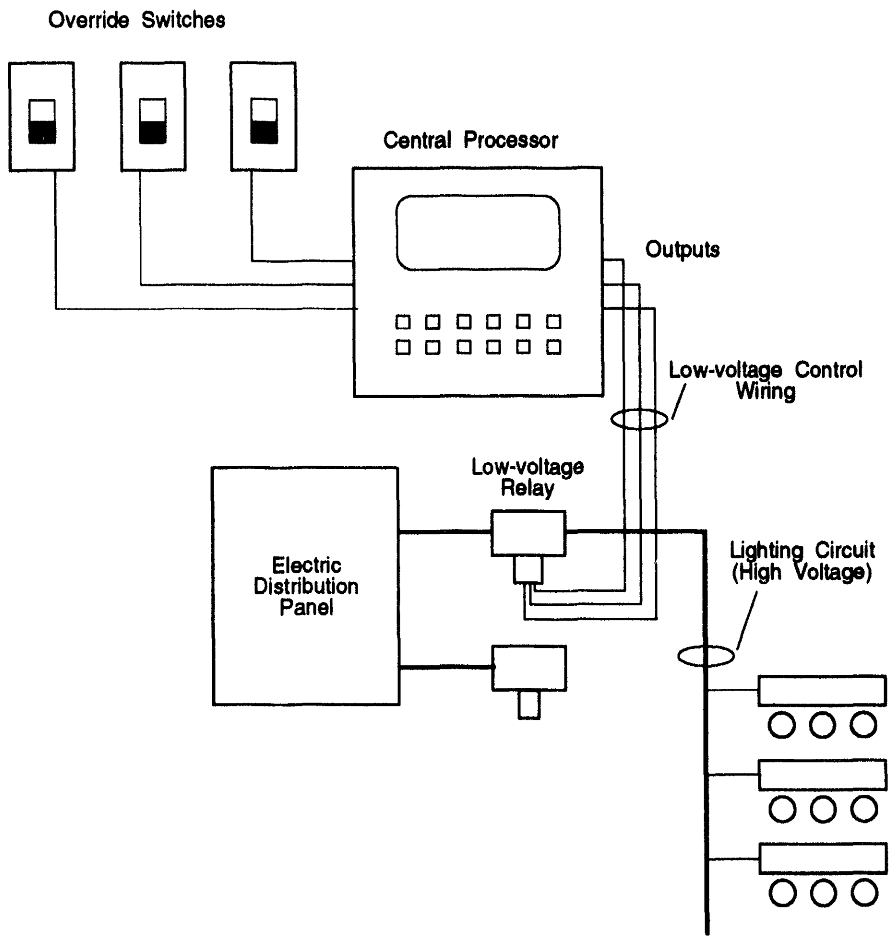


Figure 11-1
Time Scheduling System Components

Most processors allow separate scheduling for weekday vs. weekend operation, as well as for special holiday operation. Processors should be equipped with a battery-operated backup so that the programmed schedule will remain in memory in the event of a power outage. These features all are required by California's 1992 *Energy Efficiency Standards for Residential and Nonresidential Buildings* (Title 24). Title 24 also requires that central processors are able to automatically return to normal "sweep off" mode at regular intervals to prevent overridden lights from being left on after the occupant has left.

Switch Inputs

The central processor must be capable of accepting an appropriate number of switch inputs (usually low voltage). There should be at least as many inputs as there are required override switches. Additionally, it is usually beneficial to allow several extra inputs to accommodate photo-switches or other inputs that may be added later.

Switch Outputs

The central processor must be capable of switching at least as many outputs (or channels) as there are independently controlled lighting zones in the installation. If all the lighting in the building is to be controlled at the circuit breaker level, then the processor should be equipped with at least as many outputs as there are lighting branch circuits. If the luminaires contain more than one ballast each, then it is generally best to allow two outputs per controlled zone to allow split-level wiring for improved lighting control (see below).

It is important to note that many processors are only capable of switching loads on and off. These processors are appropriate for scheduling applications when continuous dimming of lighting loads is not required. On the other hand, if dimming is required, the processor must be able to provide a variable signal on each output dimming channel. In most cases this function in a processor will cost considerably more than simple on/off output switching, since each channel will require a digital-to-analog (D/A) converter.

Relays and Dimmers

The least costly method of scheduling lighting system operation is to use relays to switch connected lighting loads on and off. A latching, low voltage-activated relay is most often used for the control component. Latching relays require power only when being switched open or closed -- no power is expended at other times. The processor sends a low voltage signal to the relay, which in turn opens or closes the lighting circuit that is series-connected to the lighting load to be controlled.

Depending on the application, relays may be mounted in a number of locations. In retrofit applications, the relays are almost always located in panels in the electric room to minimize installation costs (see the *Retrofit Control Technologies* guideline for a more complete discussion). In new construction, however, relays may be mounted closer to the lights they control. This allows for expanded lighting control.

Dimming units may be used to dim banks of lights, instead of simply switching them on and off. Dimming units are available that do not require the changing of existing ballasts. However, except for the more expensive versions, most dimming hardware has a limited dimming range, and is generally unable to switch lights off without an additional relay. Since on-off control ability is almost always desirable, relays are usually required in addition to the dimming units, resulting in higher costs.

For time scheduling control, it is not required that the dimming unit be able to vary light output continuously. The simple ability to switch to a significantly reduced light level is sufficient. If the unit can supply an appropriately low light level, then energy can be saved during times when less visually demanding tasks are being performed. Some manufacturers of electronic ballasts offer two-level ballasts that can be easily used in this manner. These ballasts typically have two additional low voltage control wires. The ballast supplies one light level if the control leads are shorted and another if they are open.

Control Wiring

Control wiring forms the electrical connection between the central processor and the low voltage relays (or dimmers). Since only low voltage (less than 30 volts) is necessary to operate the relays, the wiring may be plenum-rated Class 2 wiring. If building codes permit, this type of wire need not be run in conduit; this significantly reduces installation costs. This is especially important in cases where the central processor is not centrally located, and the relays are far from it.

Override Methods

Since central processors for time scheduling systems are programmed to schedule lighting operation according to expected occupancy patterns, it is usually necessary to install override switches so that occupants needing to work beyond programmed work hours can switch on the lights in their local areas. These overrides are often low voltage switches located near the lights that they affect.

Designers should make sure that override switches are conveniently located with respect to occupancy flows. For example, from the standpoint of energy conservation, it is often best to program the processor only to switch lights off, and to require the occupants to switch lights on via override switches when they first arrive. In this way, lights will never be turned on unless actually needed by the occupants. Since the lights will not be on when occupants arrive, the appropriate override switches should be adequately lit (using either the emergency lighting circuits or night lights), so that they can be quickly and safely located when the lights are off.

Telephone Overrides

An alternative method of providing time scheduling overrides is through a telephone override system. In this scenario lights can be turned on by the use of a touchtone telephone. In a typical installation of this type, an individual needing to switch on his or her lighting zone would dial an access number on the telephone, enter in a code corresponding to their lighting zone and enter a code corresponding to lights on (or off).

One distinct advantage of the telephone override system is that it removes the need to install a network of low voltage override switches. This may amount to a considerable cost savings. A disadvantage to telephone overrides, however, is that the occupant may be using the telephone when the lights are shut off, requiring that person to terminate his or her phone call before the lights can be restored. A second disadvantage is that if several people try to access the telephone override system simultaneously, the system may bottleneck, resulting in delays in restoring lighting levels.

Latching Switches

Latching or "smart" switches are another means of providing occupants with override controls for time scheduling systems. These switches are installed in wall boxes like any other wall switch. However, unlike a wall switch, which can only be controlled by manually flicking the switch, a latching switch turns off its load if power to the switch is interrupted for 5 seconds. By switching off a branch circuit for 5 seconds and then restoring power, a whole circuit of smart switches can be swept off. The latching switch becomes a very effective override if the branch circuit is controlled using the type of low voltage controlled relays described previously. When an entire branch circuit is swept off by means of a controllable relay, then the individual in an occupied space can restore his lights simply by switching on the latching switch. Furthermore, the individual only affects his or her own local area, and not the entire circuit controlled by the relay. Depending on the size of the zones and the override usage patterns, the latching switch override may allow a time scheduling system to capture significantly more energy savings than would be achievable with either the low voltage switches or telephone overrides.

A few companies currently market, or will market, light switches and dimmers that are activated by infrared signals. In their simplest forms, these devices would allow overriding of lights with the use of a hand-held remote control similar to those used for home televisions. This would permit occupants to access nearby (i.e. within the line of sight) controls. In a more elaborate implementation, hand held controls can be used to activate a desired preset light level.

Application Guidelines

Time scheduling systems are effective at reducing after hours lighting energy waste in building spaces if the following two conditions are met:

- The occupancy patterns in the space are relatively predictable
- There are some hours when the lights can be off (or at low level) without adversely affecting productivity, safety, or security

Since the above two conditions are often met in offices, where most people work from 8 a.m. to 5 p.m., time schedulers tend to be effective at reducing lighting energy waste in these applications. However, in a factory with an assembly line operating 24 hours a day, a scheduling system would be ineffective at obtaining any energy savings. Also, in spaces where occupancy cannot be well-predicted, or where occupancy is intermittent (i.e. conference rooms, warehouses, supply rooms, bathrooms, etc.), much greater savings can be realized through the use of occupant sensors rather than scheduling systems (see the *Occupant Sensors* guideline). Hybrid systems that use time scheduling in combination with occupant sensors in selected areas may be the optimum choice in many building applications. To develop the most efficient lighting control strategy, the designer must first carefully consider how the building spaces will be used.

If a time scheduling system is to be effective at reducing unnecessary hours of lighting operation, the importance of a good override system cannot be over stressed. A well-conceived override system will allow a tight lighting schedule to be imposed, because building operators will be assured that individuals needing lights during programmed OFF times will be adequately accommodated. If, on the other hand, override switches are hard to find or access, then building operators will use a much looser schedule to avoid occupant complaints. This will result in a significant increase in the hours of lighting operation, thus reducing the potential energy savings and greatly increasing the length of payback periods.

Split-Wiring

Although most time scheduling systems permit on-off control only, it is possible to provide several light levels per zone by appropriate switching of "split-level" lighting circuits. For example, as shown in Figure 11-2, 4 light levels (off, 1/3, 2/3 and full) can be provided in zones with 3-lamp luminaires by appropriate switching of the connected relays. Similarly, in 4-lamp fixtures, 3 light levels (off, 1/2 and full) may be obtained. Split-wiring is only cost-effective in new construction or major renovation since the fixtures must initially be wired correctly.

In employing split-wiring systems, it is important to pay attention to the order in which the switching occurs. For example, in switching from full on to 2/3 light level (in a 1/3, 2/3, 3/3 system), the relays controlling the inboard lamps are simply switched off. But in switching from 2/3 to 1/3 light level, the inboard lights should be switched on prior to switching off the outboard lamps, or there will be a brief interval of total darkness when the switching takes place.

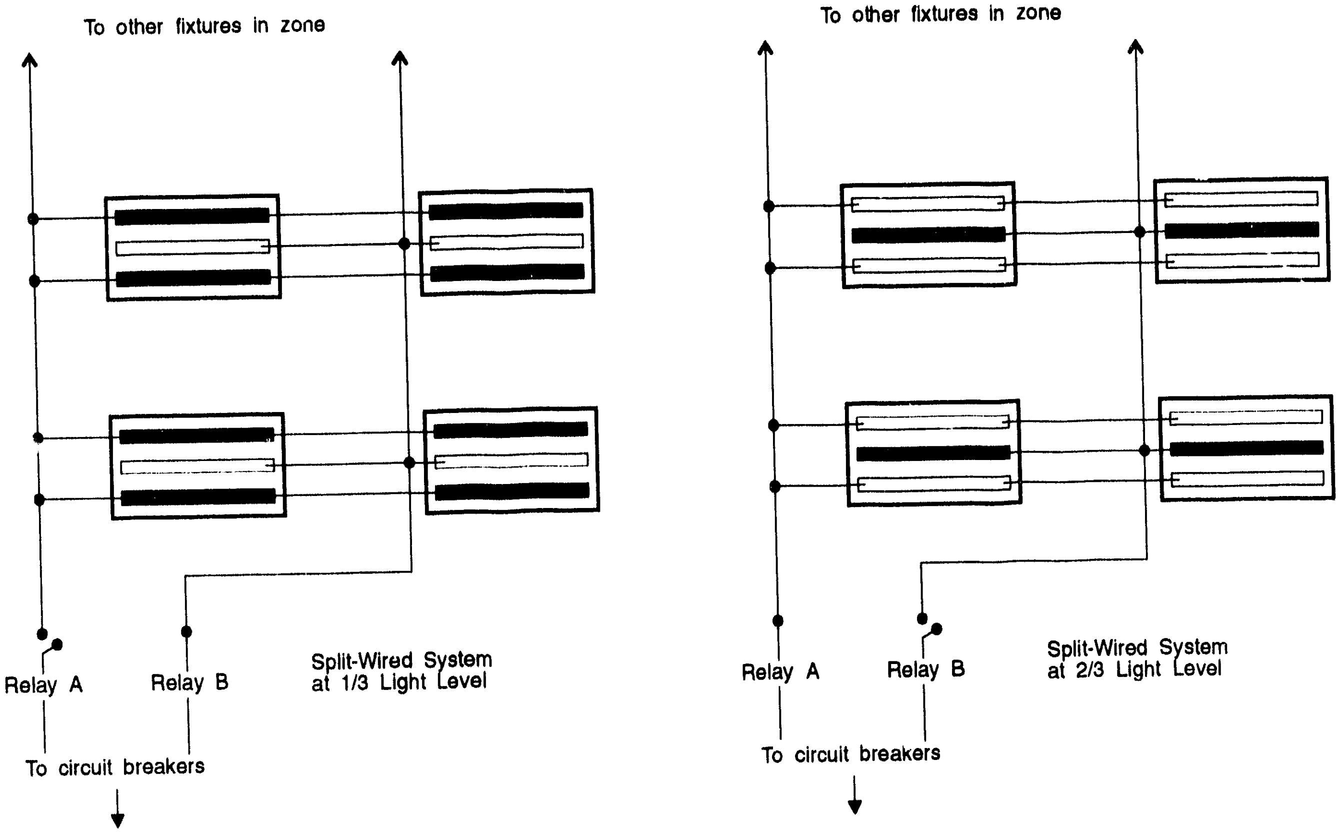


Figure 11-2
Split Wired 3-Lamp Luminaire Possibilities

Warning Signals

It is unacceptable practice to plunge occupants into darkness when scheduling the operation of the lighting system. Occupants should be forewarned when lights are about to be shut off automatically. Split-wired systems allow for the shutting off of one circuit (the outboard tubes, for example) first, followed by a programmed wait period of five minutes or so, before the second circuit is shut off. This wait period allows any remaining occupants time to call in their overrides before their lights are completely extinguished. Alternatively, some schedulers allow the lights to be flicked on and off as a warning to occupants that the lights are about to go out.

Off-Hours Lighting

Time scheduling systems are useful for assuring that certain tasks performed during non-normal operating hours (cleaning, security, etc.) are not over-illuminated. For example, if cleaning crews work after hours, it is often appropriate to switch off some lights (say the outboard tubes in a split-wired system) during those hours. Thus, a lighting time schedule, as shown in Figure 11-3, will provide some energy savings during the evenings while still providing sufficient lighting for the cleaning crew.

Although all time scheduling processors permit control of both off and on times, it efficient practice to use the processor only to turn lights off. This requires the lights to be switched on manually (using the override switches) by occupants when entering the space. This practice may increase energy savings in the morning hours, since some lights will remain switched off, due to absenteeism or other reasons.

Another energy-saving technique is to take advantage of the fact that some individuals will leave during the lunch hour, and their lights may be switched off. If, however, a reduced light level is imposed, as opposed to switching the lights off altogether, some individuals may elect not to restore the lights to full level upon their return, either because adequate daylight is available, or because the occupant feels that the existing electric light level is

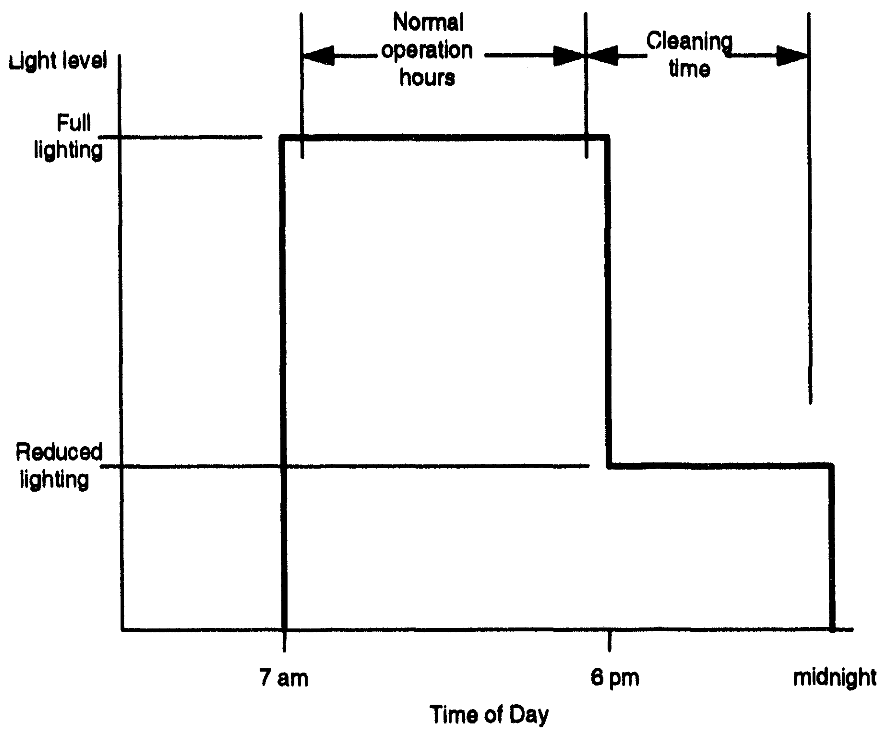


Figure 11-3
Lighting Time Schedule for a Typical Office Building

sufficient. This technique may therefore afford thus affording additional energy savings, particularly if VDT screens are present.

Maintenance Considerations

Time scheduling systems are most effective if in-house building personnel are willing and able to program, maintain, and reprogram the system when necessary. At the very least, the system must be programmed when the installation is being initially commissioned. In addition, it is often necessary to reprogram the operation of selected zones as requirements change. It is important, therefore, to specify a system that can be easily reprogrammed, since this avoids the need to employ expensive outside expertise when scheduling needs change. For instance, the twice yearly change between daylight savings and standard time is particularly frustrating for building managers to accommodate. This is because the real time clock in the central processor must be reset twice a year at a time when it is usually inconvenient. Some central processors provide automatic compensation for daylight savings time (as well as leap year correction). This feature tends to simplify the building manager's tasks and minimizes occupant complaints.

Estimated Energy Savings

The energy savings obtainable from time scheduling controls are affected, in part, by the way in which lighting was used before the controls were installed (i.e. the building's baseline condition). The actual savings also depend on how effectively the time scheduler is programmed to curtail lighting energy waste. Since neither of these factors is usually accurately known, it is difficult to predict the energy savings from time scheduling. Energy savings of 10% to 35% have been reported at various monitored installations in the U.S. (For an example, see: Rubinstein and Karayel, "Measured Energy Savings from Two Lighting Control Strategies", IEEE-IAS Transactions on Industry Applications, Vol. IA-20, No. 5 and PG & E Customer Systems Report # 008.1-91.21, "Automatic Lighting Controls Demonstration: Long-Term Results", July 1991.)

Costs

Time scheduling systems are generally priced on a cost per control point basis (each control point corresponds to one relay). Costs of \$125-\$150 per control point are typical for commercial building applications. The added installed cost of the control system will be approximately \$0.30/ft.^{2} (assuming 2 control points for each control zone of 1000 ft^2 at \$150/control point).

In typical office applications with lighting power densities of 1.5 watts/ft^2, each hour shaved off the weekday lighting interval saves \$0.04-\$0.05/ft^2 in lighting energy cost. Thus acceptable paybacks can be achieved if the lighting schedule can be reduced by two to three hours per day. (\$0.30/ft^2 / [2.5 hrs avoided/weekday x 1.5 w/ft^2 x 280 days/yr x \$0.10/kWh] = 3 year simple payback). Since many offices are lit more than 14 hours/weekday, time scheduling can be cost-effective in many applications.

Guideline Specifications

Section 131(d) of California's 1992 *Energy Efficiency Standards for Residential and Nonresidential Buildings* (Title 24) requires automatic time scheduling controls (or other automatic shut off device) for every floor of all new nonresidential buildings. It is recommended that any written specifications for time schedulers incorporate Title 24, which stipulates that time scheduling control units must meet the following requirements:

- Able to program separate schedules for weekdays and weekends
- Equipped with an automatic holiday shut off feature that suspends turning on the lights (except by override) for at least 24 hours, then resets to normal scheduling procedures
- Supplied with backup capabilities (usually battery-operated) that keep the device's memory intact for at least 10 hours in the event of a power loss

Title 24 also requires that all automatic time schedulers be installed so that they may be overridden by occupant-accessible switching devices. Overrides must meet the following criteria:

- Must be readily accessible to occupants and manually operated
- Must allow the lights to remain on for a maximum of 2 hours, once an override command has been initiated
- Must control an area of no more than 5000 ft.^{2}
- Must be located in the same general area as the lights it controls

In applications where latching "smart" switches will be used to override the time scheduler, the system designer should contact the manufacturer to verify compatibility of the switch with the scheduling hardware. In these applications, the processor must have the additional capabilities listed below:

- Capable of switching off connected relays for an interval of 1 second, then restoring power in less than 5 seconds
- Able to switch off relays for a 5-second interval, followed by a resumption of power

(Note: Reference to Title 24 or any other regulatory standard is intended for informational purposes, and any such reference is not intended to be authoritative when applying any standard.)

Manufacturer/Product References

The list of manufacturers and products is a representative sampling of the time scheduling hardware available at the time of printing this document. While this list is representative, it is by no means complete. Technological advances and a competitive market for energy-saving control hardware require manufacturers of this equipment to constantly update and improve their product lines.

Manufacturer	Representative Product
Enercon Data Corporation	Remote Control Signal System
General Electric	*TLC* Lighting Control System
IDMA, Inc.	2100 Series
Leviton Manufacturing Company	6300 Series
Lithonia Control Systems	*Panelmax* Series
Paragon Electric Company	*EC128* Series Control System
Powerline Communications, Inc.	*WatchKeeper* Panel Controller
Schlage Electronics	*Control Plus* Series
Sentry Switch	Latching Switches

(Inclusion in this list does not imply applicability or endorsement by the California Energy Commission, The U.S. Department of Energy, or the Electric Power Research Institute. Additional companies may also manufacture these products.)

Retrofit Control Technologies

Introduction

Prior to 1978, nonresidential buildings in California were not required by code to incorporate accessible controls for lighting systems. Many buildings, particularly office buildings, were designed to have guards and cleaning crews switch on circuit breakers very early in the morning, and switch them off again very late at night. Facility users did not have access to these breakers, much less the ability to control lighting in their own offices or work spaces. It is conceivable that these lighting systems might use up to 100% more energy than is needed, suggesting a substantial opportunity for energy conservation. Additionally, most spaces were over lighted, or had no means to compensate for daylighting in portions of the space, and electric lights were often operating at full power when not needed.

With the introduction of California's Building Energy Efficiency Standards (Title 24) in 1978, all individual spaces were required to have accessible switches to encourage users to reduce energy by turning out the lights manually. It is estimated that this alone saved half of the wasted energy. Moreover, Title 24 required two-level switching, encouraging users to reduce lighting power to the level required. This saved an estimated 10% to 15% of the unnecessary lighting power, due to the presence of daylight or other factors.

On a national scale, the model energy code ASHRAE/IES Standard 90.1-1989 requires that all lighting systems, excepting emergency and exit lighting, be supplied with lighting controls. Many states and municipalities use Standard 90.1 for lighting energy use compliance. The Standard assigns a minimum number of lighting *control points* for all commercial spaces. Control points are defined as the quantity of on/off switches or equivalents assigned to a device used to control luminaires or individual lamps within luminaires. Certain devices are worth more points than others. Minimum control points are determined by space partitioning, task locations, and square footage.

Despite Title 24 and ASHRAE/IES Standard 90.1-1989, even more opportunities to reduce lighting energy use in existing buildings remain viable and cost-effective:

- In pre-Title 24 buildings, the addition of modern controls can save up to 50% of the electric lighting energy consumption with little or no user impact.
- In most buildings built during the "first generation" of Title 24 (1978-87), more modern controls and techniques can save up to 25% of the electric lighting energy consumption with little or no user impact.
- In many "second generation Title 24" office buildings (1987-92) and retail

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establishments (1988-92), opportunities still exist to save energy with lighting controls.

- Opportunities exist to exceed the standards listed in the current (July, 1992) generation of Title 24.

Technology Description

Energy use consists of two components: *power*, which is the rate of electricity consumption; and *time*, which is the period of consumption. To reduce lighting energy consumption, both lighting power and time of use can be reduced.

Lighting energy use is managed by lighting controls, ranging from manual on/off switches to complex control systems. Most lighting controls reduce time of operation; however, the advent of sophisticated electronics also permits the reduction of power in some situations.

Demand

Electric power cost is often divided into energy (kilowatt-hours, or kWh) and demand (kilowatts, or kW). A given utility company's peak period (typically weekday afternoons) bears the highest rates for both demand and energy.

Demand, which usually is determined by the average power over a customer's greatest 15 minute peaks in the month, often comprises a large portion of the electric bill. In many situations, employing techniques to reduce electrical power consumption during the peak period (demand-shaving) may save more in electrical costs than other energy-saving strategies. Potential savings produced by demand-shaving techniques are illustrated in Figure 12-1

Retrofitting

Cost-effective retrofitting of lighting controls consists of installing lighting control devices and systems into an existing, occupied (usually) building, with little or no rewiring required to install the new controls in the existing space. The lighting controls are wired into the electrical service panel area and control branch circuits. Minimization of labor costs is essential in making lighting control retrofits cost-effective.

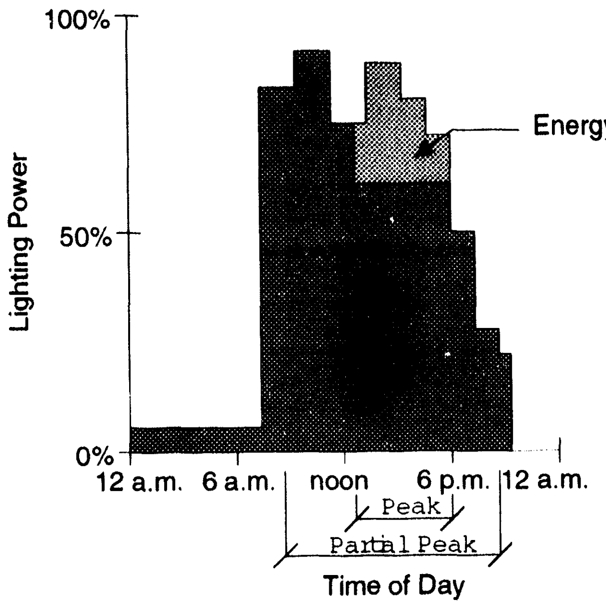

Figure 12-1
Demand-Shaving Energy Savings

Zoning

A lighting control zone is the area affected by a lighting control device. Usually, a small room has only one zone, or may be a part of a zone; a large room may have several zones, especially if some are influenced by daylight. In general, the smaller the zone, the greater the potential for energy savings.

Lighting control zones are defined by the existing wiring methods in the building. The following wiring methods may be employed:

- *Panel Board Switching* is an economical wiring technique in which circuiting is laid out regardless of space partitioning. No occupant-accessible controls are available; the circuit breakers in the electrical panel are used for switching. As such, no definable zoning is in place.
- *Standard Switching* creates relatively small control zones. Each zone contains at least one switch or other occupant-accessible control device.
- *Contactor and/or Multiple Relay Switching* are systems generally designed to serve several control zones at once. Separate control of small individual zones does occur, but most systems in retrofit candidate buildings are likely to be less sophisticated in scope, and control zones tend

to be very large or grouped together.

- *Low Voltage Relay Switching* is a relatively sophisticated wiring scheme often used in buildings that employ energy management controls. The relays used allow for local override of centralized automatic control. Although zone size may be as small as in standard switching, in practice the zone is usually defined by the size of the branch circuits used.

Lighting Control Strategies

There are six common lighting control strategies:

- *Scheduling* is the strategy of turning lights on or off according to need or program. Manual scheduling involves switching by building occupants, while automatic scheduling may include time switches, occupant sensors, photocell switches and other means of switching lights by automatic control devices.
- *Tuning* is reducing power to electric lights in accordance with the exact lighting needs of the user and work task. For instance, older workers and workers performing highly-detailed tasks need more light to perform their respective visual tasks. Younger workers, workers performing fairly easy-to-see tasks, and workers using video display terminals (VDTs) can often work with less light than is being generated by their respective lighting systems. Tuning is accomplished with dimming devices.
- *Daylighting* is the act of turning lights off or reducing power to electric lights in the presence of natural daylight from windows and skylights. Daylighting controls employ a photosensor-controller device, linked to a switching or dimming unit that varies electric light power in response to natural light.
- *Lumen Maintenance* Most lighting systems are designed to produce maintained foot candles -- a "worst case" design strategy, which produces excess illuminance until the end of the lamp-luminaire maintenance cycle is reached. As a result, at the beginning of the maintenance cycle, when lamps are new and luminaires are clean, most properly-designed lighting systems produce 25% to 30% more light than is needed. Over the anticipated maintenance cycle (usually 24-26 months), light levels fall steadily until the design illuminance level is reached. A lumen maintenance control strategy reduces lighting power at first, gradually increasing to reach full power at the end of the maintenance cycle. Illuminance remains constant throughout the cycle. Savings are typically 12% to 20% of the energy that would have been consumed had the lights been operated at full power throughout the maintenance cycle. Control is achieved through the same type of hardware used for daylighting controls.
- *Demand-Limiting* Costly power demand peaks can be reduced by shaving or shedding non-essential loads, or by cycling semi-essential loads. Electric lighting levels can be reduced by 10% or more with a minimal impact on visual performance or productivity. Because lighting can consume 40% to 50% of many office buildings' total electric load, even a slight reduction in lighting can result in a significant decrease in demand. Most any type of control device can be employed to limit demand. However, automatic dimming controls allow this to occur without occupant awareness.
- *Adaptation Compensation* In extended-hour interior applications, such as 24 hour markets, and in exterior applications like tunnels, electric lighting must be brighter during daylight hours to enable people with daylight-adapted eyes to see in darker or covered areas. However, lighting power can be reduced substantially at night, as human eyes are night-adapted and do not require as much light in those same areas. Electric power, in these cases, could be reduced as much as 80% for 10 to 12 hours each day. Adaptation compensation control strategies employ dimming devices or switching relays combined with automatic timers to vary illuminance accordingly.

Current Products

Retrofit lighting controls comprise a wide range of different products. A control device may be as simple as a single pole switch, or as complex as a comprehensive, multi-zone centralized energy management system. In this section, retrofit controls are discussed in two categories: single control zone devices, and centralized building control systems, comprised of a wiring method which employs one or more of the single zone devices.

Single Zone Control Devices

Single zone devices are generally applicable only to applications where the wiring is sectioned into relatively well-defined control zones. Many devices are designed to be occupant-accessible, allowing users in each zone to directly control the lights. Other single zone devices operate automatically and can be integrated into centralized control systems, such as low voltage switching relays.

Latching Switches

Latching switches are replacements for manual toggle switches. These devices are valuable as low cost upgrades to simple "off" scheduling strategies. Upon arriving, the user turns the lights on normally. If the user leaves and forgets to switch off the lights, a short power interruption to the lights causes the switch to unlatch and mechanically return to the off position.

Latching switches require the installation of a timer-controlled contactor or multi-pole relay in series with each controlled circuit. Suitable applications include any office or institutional building with existing manual switching systems. The principal disadvantage to the use of latching switches is that a power interruption will affect the operation of all lights and latching switches. In addition, there is no warning signal to the occupant when the lights are to be extinguished, and no override.

Wallbox Occupant Sensors

Wallbox occupant sensors, such as the device shown in Figure 12-2, replace existing toggle switches. When an occupant enters in a space controlled by one of these sensors, the device will energize the lights in the control zone. In some lighting control strategies, the occupant must switch the lights on manually. In any case, the sensor will automatically extinguish the lights a predetermined time after the last motion is detected.

Wallbox occupant sensors are low cost upgrades to standard switching. They integrate well with other control strategies and are suitable in most office and institutional buildings with existing manual switching systems. Their principal disadvantages are that they require calibration of time of delay and/or sensitivity, and they are often misapplied, leading to occupant dissatisfaction.

Ceiling Occupant Sensors

Ceiling occupant s[illegible] include a detector modul[illegible] on the ceiling or wall, alo[illegible] transformer relay mounted onto a junction box above the ceiling or in some other remote location. In the automatic "on" mode, detection of a human presence in the room causes lights to be energized. In the manual on mode users much turn on the lights manually. Lights are extinguished after a predetermined pause following cessation of occu[illegible] in the space. Severa[illegible] connected to [illegible] transformer r[illegible] coverage of lar[illegible] complex room co[illegible]ons.

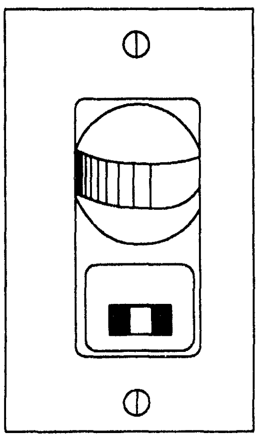

Figure 12-2
Wallbox Occupant Sensor

Both ceiling and wallbox occupa[illegible] sensors are suitable for office, commercial and some industrial buildings with a reasonable correlation between wiring and lighting control zones. Existing manual switch wiring may result in easier installation, particularly with wallbox devices. Installation of occupant sensors may require additional rewiring in older, economically wired, and uncontrolled buildings. Devices usually require calibration and attention to mounting details and product selection for optimum performance.

For further information on occupant sensors, see the *Occupant Sensors* guideline.

Small Zone Ceiling Daylight Sensors

Ceiling daylight sensors include a photo detector head or fiber optic wand that is mounted on or recessed into the ceiling. Additionally, some systems require a control module to be mounted onto a junction box above the ceiling. A separate on/off control must be provided. The module either varies the power delivered to the luminaires, or sends a signal to electronic dimmable ballasts (which must also be installed). A wall switch with manual dimming adjustment may also be provided.

Ceiling daylight sensors are suitable in buildings with substantial fenestration and with a correlation between wiring and daylighting control zones. Existing manual switch wiring is almost mandatory, and installation will require rewiring in buildings wired without controls. Systems designed to operate with existing electromagnetic ballasts may increase lamp flicker, have limited dimming range, and/or reduce lamp life.

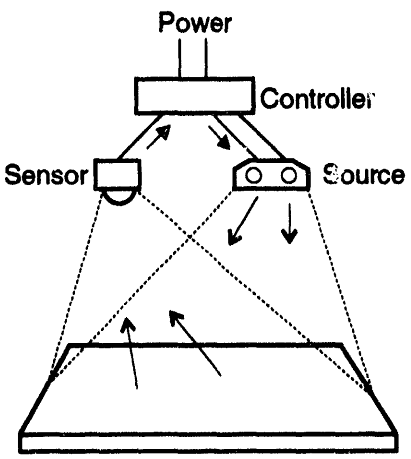

Figure 12-3
Daylighting Control System

Large Zone Daylight and Lumen Maintenance Sensors

These sensors control the operation of large zone dimming. The sensors are located in the zone to be controlled, and a signal is fed back to a comparatively large dimming module, usually located near the electrical service panel. The sensor modifies the power supplied to all luminaires in the control zone, either by solid-state or auto transformer dimming. Separate on-off switching is required.

Large Zone daylight and lumen maintenance sensors are suitable in larger spaces with substantial daylight presence or in applications with significant opportunities for lumen maintenance savings. They can be extremely effective in buildings wired economically without controls, provided all spaces controlled in a particular zone have similar daylight and/or lumen maintenance characteristics. Additionally, most controls can be directly connected to programmable time controllers.

Dimming modules for large zone daylight and lumen maintenance sensors are often large and unwieldy. Large zone dimming systems do not work well when controlling several zones with individual switches (down-stream switching) because if the entire system is dimmed, switching on an individual room's lights causes all the lights in the zone to go to high level and then dim back to the original setting.

For more information on daylighting controls, consult the *Daylighting and Lumen Maintenance Controls* guideline.

Fixed Program Large Zone Dimming

The same central equipment used for daylight and lumen maintenance controls can be installed for tuning or adaptation compensation strategies. In these cases, photocells are not required, and control is accomplished in time-programmed or fixed light level mode. This type of control is suitable for large spaces containing large groups of luminaires, while having the same lighting needs and schedules. The same pros and cons apply as described previously for large zone daylighting and lumen maintenance control strategies.

Programmable Timers

Programmable timers like the ones shown in Figure 12-4 are similar in effect to other wall-mounted control devices. Some

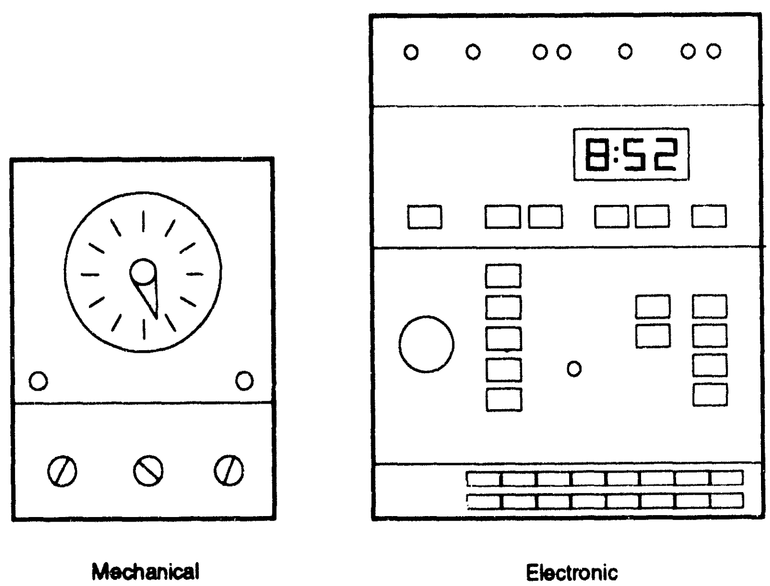

Figure 12-4
Programmable Timers

timers use micro circuitry to allow multiple time scheduling programs for the switched and/or dimmed lights. Timers are often used in comprehensive energy management lighting controls, as well, where they integrate well with other control strategies.

For further information on programmable timers, see the *Time Scheduling Systems* guideline.

Centralized Lighting Control Systems

Centralized lighting controls are generally designed for multi-zone lighting management. Often, they comprise a portion of entire building energy management systems, which incorporate lighting management with controls for heating, ventilation, air conditioning, and other significant loads.

Low Voltage Relay Systems

In low voltage relay control strategies, 6-amp or 20-amp 120/277 volt relays and related control and communications circuits are employed. In most systems, a relay cabinet is usually located adjacent to the existing electrical panel. Occasionally, however, relays may be remotely located in the ceiling plenum to minimize rewiring. Each 20-amp relay can control up to a complete branch circuit, although the preferred configuration is often a relay per zone, regardless of load. 6-amp relays are used for smaller loads. Remote manual and automatic controls activate the relays. These may include photocells, time programmers, building automation computers, wall switches, and occupant sensors. Controls may interconnect with telephone systems.

Low voltage relay systems are especially good in buildings wired without consideration for zones and without existing controls. They are also appropriate in multi-schedule and multi-use buildings. Low voltage relay systems are moderately priced, convenient, and comprehensive systems that can give a building the ultimate in versatility and flexibility. They accommodate most energy management strategies not requiring dimming. Installation costs can be minimized by the use of low voltage, plenum-rated wiring between control panels and from panels to control devices.

The effectiveness of a given low voltage relay system is largely dependent on how a building is wired. In economically-wired buildings, the system's principal control functions will probably be limited to large zone time scheduling. Low voltage systems can often become prohibitively expensive when controlling many small zones. This is particularly true when using relay cabinets adjacent to breaker panels, since each control group must be home run to the relay panel. However, if the relays can be remotely installed in the plenum space, power wiring costs may be substantially less.

Power Line Carrier (PLC) Control Systems

A power line carrier system is potentially the easiest to install and most powerful control type of lighting control system. Control devices are simply hard-wired into the building's electrical systems wherever it is convenient. In a PLC system, signals are sent between transmitters (time programmers, master switches, occupant sensors, etc.) and receivers (individual switches or relays), causing the system to operate in a coordinated manner. Dimming is possible for incandescent loads. Since transmitters and receivers are individually addressable, central programmable controllers can operate remote lights easily.

PLC control systems work in buildings with all types of wiring methods. They are useful in both uncontrolled and manually-switched buildings. Other features include moderate cost, convenient installation, and comprehensive service. PLC control systems will accommodate most energy management strategies not requiring fluorescent or HID dimming.

PLC control systems may be highly susceptible to some forms of power line interference. (Note: although power line conditions may be acceptable when the PLC control system is installed, the situation may change substantially with time.) PLC systems may behave erratically when used in conjunction with solid-state ballasts and other electronic devices, and they may even experience brief periods of failure due to strong interference from other systems. Interference is also possible between systems and between zones. Finally, dimming PLC devices are generally unsuitable for dimming of low voltage loads.

Other Retrofit Lighting Controls

In addition to the zonal lighting controls described above, some lighting controls are available that are designed to replace or augment specific luminaire components. Generally, these components can be used with any existing wiring methods.

Industrial HID Control Systems

Products providing multiple-level switching or dimming control can be added to some metal halide and high pressure sodium (HPS) lamp-ballast systems. Systems that do not require a change of ballasts can be economically effective; systems requiring ballast changes usually are not.

When HID control systems are economically viable, they enable lumen maintenance (significant for metal halide), occupant sensing, daylighting, and tuning control applications. Suitable applications would include industrial and warehousing facilities. Generally, these systems are effective with any wiring methods.

Without special, expensive dimming ballasts, HID dimming control range is much more limited than the dimming capabilities of fluorescent systems. In addition, lamp life and color characteristics of HID lamps may suffer under these conditions.

Fluorescent Dimming Retrofits

Many full-size and compact fluorescent lamps lend themselves well to downlight, wall sconce and other traditional incandescent applications. Special adapters that convert the incandescent dimmer wave for the proper operation of fluorescent lamps can be used. Be certain, however, that the products used by the manufacturer of the particular adapter are used throughout.

Application Guidelines

Selecting and applying lighting controls in existing buildings is often different from designing new construction. The primary concern in the retrofitting of buildings with lighting controls is the nature of the existing wiring. Usually, it is neither practical nor cost-effective to rewire buildings; the decisions must be based on the premise that the equipment and wiring will mostly remain in place.

In order to assess the opportunities of retrofitting controls, the following issues should be completely understood.

General Lighting Systems

Although nearly every lighting system in a building will offer an energy saving opportunity, the large-scale general lighting systems are the most important. These systems should be fluorescent or HID, except for some retail displays and a few other incandescent- specific situations. Additionally, these systems should be retrofitted with cost-effective improvements, such as energy saving lamps and ballasts, before determining the proper lighting control devices.

Existing Wiring Methods

Determination of the predominant wiring methods used in the building is essential in selecting a control strategy. When assessing a building's existing wiring, it is important to determine whether or not the circuiting layout or existing controls relate well to the space partitions or use areas, as the characteristics of a building's lighting control zones are determined by its wiring methods. Different wiring methods require different lighting control strategies. Types of wiring commonly found in older buildings are discussed below.

Panel Board Switching and/or Undefined Control Zones

Prior to the energy crisis of 1973, buildings were often wired as economically as possible. Thus, branch circuits were laid out in rows or areas irrespective of space partitioning, and with no regard to user control. For instance, two luminaires in one office might be on different circuits, with each circuit sharing several other offices' luminaires. There are no local switches or other controls; often, the only switching employed is to use the circuit breakers in the lighting panel board as switches. This economical wiring strategy is the cheapest -- and most energy wasting -- wiring method employed in older buildings. Each circuit is a "zone;" a 277 volt, 20-amp circuit might serve an area as large as 2500 ft^2.

Panel board-switched buildings are usually good candidates for centralized retrofit lighting controls. The use of more effective and sophisticated occupant-accessible controls will usually require extensive rewiring of existing circuits to create smaller control zones. As such it is important to determine whether or not automated common control of the entire circuit would be more cost-effective than rewired smaller zones.

Standard Switching

When Title 24 first came into effect in 1978, switches were required in every room larger than 100 ft^2 or with more than 1 watt/ft^2 of lighting power density. Therefore, a building with standard switching already has relative small control zones, which usually allows for the retrofit installation of more sophisticated lighting control systems. Installation of most controls can usually be accomplished with little or no rewiring.

The wiring method for buildings with standard switching usually includes a junction box in or above the ceiling of each control zone, into which the "hot" circuit enters and leaves. This creates a switch leg that routes to a switch or other occupant-accessible control device, as well as to all luminaires in the zone. Standard switching wiring lends itself well to local wallbox control devices, such as switches and occupant sensors. However, without some rewiring, such systems are not easily controlled using central energy management techniques. (See also "Device Loads" in Other Application Considerations Section.)

Contactor And Relay Control Systems

Some buildings are equipped with relays or contactors in central locations, often next to the distribution panel board. Centralized relay systems with many individual 20-amp relays, capable of being independently switched, are used in conjunction with energy management systems and are very powerful and flexible. Buildings wired with centralized relays, or those already employing building automation systems, will probably lend themselves well to lighting control system expansion.

Relays with many poles operating together, or contactors switching entire lighting panel boards are much less flexible, but are also less expensive. In this wiring method, large groups of lights, often a whole panel, are switched together -- usually by a programmable time controller or mechanical time switch. Zones can be substantially larger than in any other system, and to reduce zone size, rewiring may be substantial. However, in certain applications, such as factories with specific working hours, large zone multi-pole relay or contactor wiring systems may be sufficient to allow for certain centralized controls.

Low Voltage Relay Switching

Buildings designed for central energy management control often employ centralized low voltage relays as switching devices. In most cases, the relays are located in a cabinet next to the lighting panel board. Low voltage relays allow for central automatic control of on/off functions, with local controls or overrides in each zone. This makes low voltage systems the most flexible and powerful of switching systems. Nevertheless, depending on how the building is wired, low voltage relay systems are usually large-zoned in a manner similar to panel board-switched buildings. In these cases, the smallest control zone is determined by the size of the branch circuit.

Most existing buildings are not equipped with low voltage switching systems, unless an automated building management system is already in place. However, because low voltage systems are so flexible and powerful, they are often considered, in and of themselves, as a retrofit lighting control strategy. See the *Current Products* section of this guideline for more details.

Building Assessment

Some buildings either have a fairly effective lighting control system, or they do not really require the addition of controls. In general, retrofit controls make sense only in cases where at least one of the following is true:

- Unnecessary lights are on for more than one hour per day and/or lighting levels could be lowered or extinguished for long periods due to the presence of daylight
- Lighting could be dimmed in response to daylight, lumen-maintenance cycles, or other factors
- Lights could be tuned to a much lower lighting level most or all of the time

Candidate Buildings for Retrofit Controls

It is important that the designer determine as early as possible whether or not retrofit lighting controls are a pragmatic possibility for the building in question. There are several clues to suggest that a building may be a good candidate for retrofit controls:

- Buildings with zones employing circuit breakers or switch banks that are located in electrical closets or other non-user accessible locations
- Buildings that do not employ photoelectric daylighting controls, despite having skylights or windows in most rooms
- Buildings, such as retail stores, that operate on specific schedules without employing automatic on/off time controls
- Spaces within buildings that are occupied only intermittently (i.e. storage areas and warehouses), but which generally have the lights left on due to a lack of lighting controls
- Public areas, such as airports, which have large areas of periodic use, but do not yet have any type of photoelectric or need-controlled system

- Office and institutional buildings with wall switches but without automatic controls

Figure 12-5

Applications for Retrofit Lighting Controls

	Existing Wiring Method and Zoning				
Control Strategy	**Panel Board Switched-Unzoned**	**Standard Switching Small Zone**	**Low Voltage Relay Large Zone**	**Low Voltage Relay Small Zone**	**Contactor & Relay Large Zone**
Latching Switches	○	●	--	--	○ (a)
Wallbox Occupant Sensors	--	●	--	○	--
Ceiling Occupant Sensors	○ (b)	●	●	○	○
Small Zone Daylighting	○ (b)	○	--	○ (b)	--
Large Zone Daylighting & Lumen Maint.	○	--	●	○	●
Large Zone Dimming	○	--	●	○	●
Wall Mounted Timers	--	●	--	--	--
Large Zone Time Scheduling	●	○	●	○	●
Power Line Carriers	○	○	○	○	○

Key:

● Good Application

○ Possible Application

-- Not Recommended

Notes:

a. Good application if the latching switch is installed to create a downstream small zone.

b. Good application depending on wiring method.

Cost-Effectiveness of Retrofit Controls

A retrofit control system must be installed easily and quickly to be cost-effective. Even if the components are inexpensive, major hidden costs, including wiring, rewiring, labor, and "opportunity costs" associated with retrofitting a functioning business can literally destroy the economic benefits that the controls were originally designed to produce. Factors that will affect the installation costs of retrofit control devices are discussed below.

Ceiling Materials

An inspection of a candidate building's existing ceiling materials can often determine immediately whether or not a retrofit control installation is economically feasible. For instance, the presence of asbestos-bearing materials in or above the ceiling may add substantially to the cost of a retrofit project *if such material must be removed.* (It should be noted however that it is not always necessary to remove asbestos.)

Exposed type construction affords the ultimate ease of control retrofit. Similarly suspended lay-in acoustic panel ceilings are generally a good indication that there is a potential versatility for retrofit control installation. Access to wiring is usually accomplished simply by lifting the tile panels off their frames. This also allows for the rapid inspection of the type of wiring method that is in place. On the other hand, gypsum wallboard and other "hard" ceilings are much more difficult to inspect and work on, while existing wiring in poured-in-place concrete will virtually guarantee that extensive rewiring will be necessary.

Existing Wiring Methods

When accessing existing wiring methods it is most important to determine whether or not the branch circuit layout or existing controls relate well to the space partitions or use areas. In terms of cost effectiveness, the designer should select control strategies that can be effective with the existing wiring methods with a minimum of rewiring.

Figure 12-5 is intended as a rough guide for selecting the appropriate retrofit controls for a given building's existing wiring method.

Wiring Voltages

Mixing the wiring of systems of different voltages in the same cabinet or electrical box is not permitted under some codes. Permitted or not, it is not advisable at any time. Many buildings have both 277 volt power for fluorescent lighting and 120 volt power for incandescent luminaires. Separate controls will be required for each voltage system in each space, if this is the case.

Wiring Materials

Wires are required to be within protective conduit or armor. In most commercial buildings, pipe-like conduits terminate in junction boxes, that in turn feed power into luminaires through fixed or flexible conduits. Changing permanently constructed or "hard-wired" systems is generally labor-intensive and not cost-effective. However, buildings having "soft-wire" flexible conduit systems may have wiring circuits easily reconfigured.

Other Application Considerations

The installation of retrofit lighting controls into an existing building can save as much as 50% of that building's electric lighting consumption. Based on this fact alone, it is easy to endorse the concept of lighting controls to a building owner or manager. However, the designer must be aware of other factors which will influence the decision-making process.

Economics

Retrofits make sense if they save energy. The amount of energy saved should pay for the retrofit installation after a reasonable period of time. Most demand side management and utility incentive programs are based on direct payback within 5 years or less. However, many building owners and managers are accustomed to making decisions based on a payback period of three years or less. Sometimes the length of a payback period can be reduced by the proper use of utility rebates to help subsidize the purchase of new equipment. It is the designer's responsibility to be knowledgeable about utility rebate policies, in regard to retrofit lighting controls, and to communicate that information to the client.

Prevention of Power Line Quality Problems

Many power control devices, such as lamp ballasts and electronic switching devices, can introduce power line harmonic distortion -- a growing area of concern among utilities and other lighting professionals. It is the responsibility of the retrofit designer to determine, from the manufacturer of any product, potential problems that may be created by the control system under consideration. Power quality should be carefully considered in design decisions.

Flicker, Hum and Other Annoyances

Although the products described in this guideline have never been shown to introduce any significant human health problems, some lighting control devices can produce flicker and/or hum, resulting in annoyance and/or inconvenience to the user. In addition, in some manufacturing environments, flicker can produce potentially hazardous conditions. See the *Metal Halide and HPS Lamps* guideline for details. The designer should recognize potential problems with controls and avoid situations likely to cause difficulties.

Device Loads

Many wallbox devices, including time switches, programmable timers, and occupant sensors derive operating power from the load by permitting a small current to pass continuously through the load, even when it is "off." In these cases the switching for the load is usually "solid-state," containing a triac or other thyristor. In order for these devices to work properly, a minimum amount of electrical load, rated in VA or watts, must be connected.

Some wallbox devices may not work with electronically-ballasted fluorescent loads, even at the minimum VA/wattage rating. Other devices are not compatible with anything other than an incandescent load. For these reasons, the specifier should check to make certain that the device and the load are compatible.

Devices having "air gap" contacts for normal operations, especially if a neutral connection is required, are usually not load sensitive. However air gap contacts should not be confused with the air gap safety disconnect on solid-state switching devices.

Resources

Manufacturers' product references, as well as additional applications for most of the lighting control devices discussed in this document, may be found in other sections of the *Advanced Lighting Guidelines* series. In addition, manufacturers of lighting controls equipment can provide helpful product descriptions, sample specifications, and application procedures to specifiers of lighting equipment.

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