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ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Energy-Efficient Lighting

The quantity and quality of light around us determine how well we see, work, and play. Light affects our health, safety, morale, comfort, and productivity.

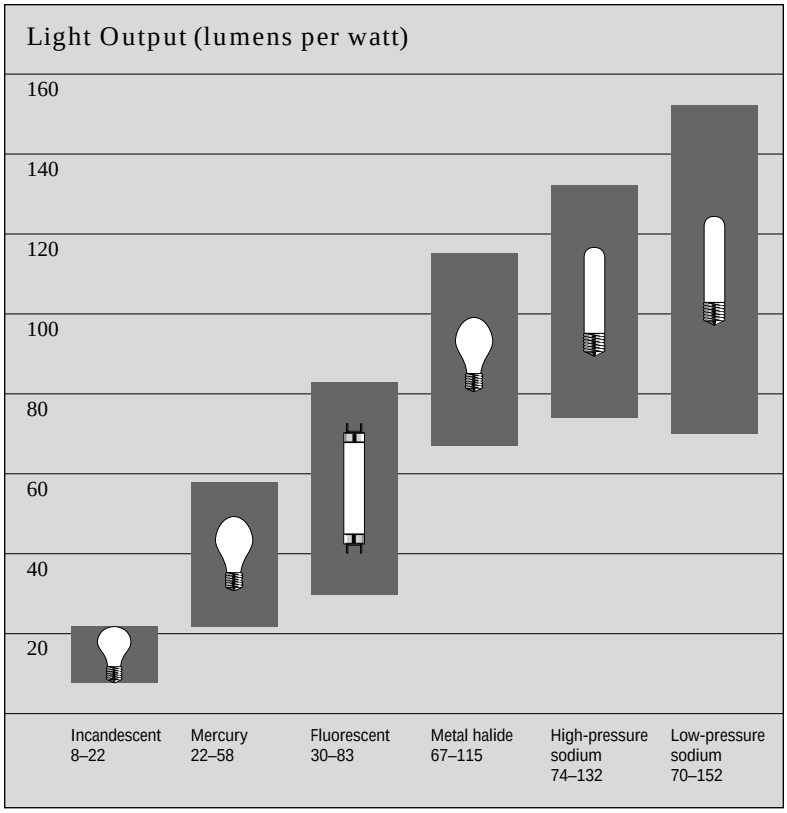
Lighting also directly affects our economy. As a nation, we spend about one-quarter of our electricity budget on lighting, or more than $37 billion annually. Yet much of this expense is unnecessary. Technologies developed during the past 10 years can help us cut lighting costs 30% to 60% while enhancing lighting quality and reducing environmental impacts.

This publication is an introduction to lighting technology and discusses how you can save energy while maintaining good light quality and quantity. Specifically, you will learn about:

- Lighting principles and definitions
- Types of lighting and how each works
- Energy-efficient lighting options, including daylighting, for new or retrofit applications.

Lighting Principles and Terms

To choose the best lighting options, you should understand basic lighting terms. This section explains terminology used in the industry, which will help you better understand the potentially confusing language you could hear in a lighting store.



Each type of lamp differs in the amount of light it delivers per watt.

Illumination

A *lumen* is a measurement of light output from a *lamp*, often called a tube or a bulb. All lamps are rated in lumens. For example, a 100-watt incandescent lamp produces about 1750 lumens.

The distribution of light on a horizontal surface is called its *illumination*. Illumination is measured in *footcandles.* A footcandle of illumination is a lumen of light distributed over a 1-square-foot (0.09-square-meter) area.

The amount of illumination required varies according to the difficulty of a visual task. Ideal illumination is the minimum footcandles necessary to allow you to perform a task comfortably and proficiently without eyestrain. The Illuminating Engineering Society says that illumination of 30 to 50 footcandles is adequate for most home and office work. Difficult and lengthy visual tasks—like sewing for extended periods of time—require 200 to 500 footcandles. Where no *seeing tasks* (i.e., tasks whose speed and accuracy of completion are affected by quality and quantity of light) are performed, lighting systems need to provide only security, safety, or visual comfort—requiring from 5 to 20 footcandles of illumination.

Another lighting term you will hear is *efficacy.* This is the ratio of light output from a lamp to the electric power it consumes and is measured in lumens per watt (LPW).

Light Color and Color Rendering

Lamps are assigned a color temperature (according to the Kelvin temperature scale) based on their "coolness" or "warmness." The human eye perceives colors as cool if they are at the blue-green end of the color spectrum, and warm if they are at the red end of the spectrum.

Cool light is preferred for visual tasks because it produces higher contrast than warm light. Contrast is the brightness difference between different parts of the visual field, which is the expanse of space you can see at a given instant without moving your eyes. Warm light is preferred for living spaces because it is more flattering to skin tones and clothing.

Keep in mind, though, that artificial light sources vary widely in their color rendering indexes (CRI). The CRI is a measurement of a light source's ability to render colors the same as sunlight does. For example, incandescent lamps are rated at a CRI of 100—nearly equal to sunlight—while some high-pressure sodium lamps have a CRI of 22, which means they render colors very poorly.

However, a light's color-rendering ability is not related to whether it is a cool or warm color. For example, blue light from the northern sky, white light at noon, and red light from a sunset all have perfect color rendering (a CRI of 100) because our eyes are designed to read the colors of objects illuminated by sunlight.

Experts divide lighting uses into three categories: ambient, task, and accent lighting.

Lighting Uses

Experts divide lighting uses into three categories: *ambient, task,* and *accent lighting.* Ambient lighting provides security and safety, as well as general illumination for performing daily activities. The goal of task lighting is to provide enough illumination so that tasks can be completed accurately but not provide so much light that entire areas are illuminated. Accent lighting illuminates walls so they blend more closely with naturally bright areas like ceilings and windows.

Light Quality

Light quality describes how well people in a lighted space can see to do visual tasks and how visually comfortable they feel in that space. Light quality is important to energy efficiency because spaces with higher quality lighting need less illumination. High-quality lighting is fairly uniform in brightness and has no glare.

For example, direct intense sunlight streaming through the windows of a room with chocolate brown carpets and dark wall paneling will likely give too much contrast in brightness. The pupils of your eyes will constantly adjust to the differing brightnesses. Making this area visually comfortable would involve using lots of artificial lighting with a high illumination level.

On the other hand, in a pale-colored room bathed in soft light, you can hardly tell where the light is coming from because no one area of the room appears much brighter than another. The walls, ceiling, floor, and work surfaces are relatively the same light hue. People can perform tasks faster and with fewer mistakes with this type of high-quality lighting. Also, lighting such a room requires far less artificial lighting than the previous example.

Glare

Eliminating *glare* (i.e., excessive brightness from a direct light source) is essential to achieving good lighting quality. Types of glare include *direct glare, reflected glare,* and *veiling reflections.*

Direct glare results from strong light from windows or bright lamps shining directly into your eyes. Reflected glare is caused by strong light from windows or lamps that is reflected off a shiny surface into your eyes. Veiling reflection is a special type of reflected glare that can obscure contrasts and reduce task clarity. Veiling reflections occur when light is reflected into your eyes from a work surface, such as a printed page or a computer screen.

Incandescent lamps, the most common light source, are the least expensive to buy but the most expensive to operate.

Types of Lighting

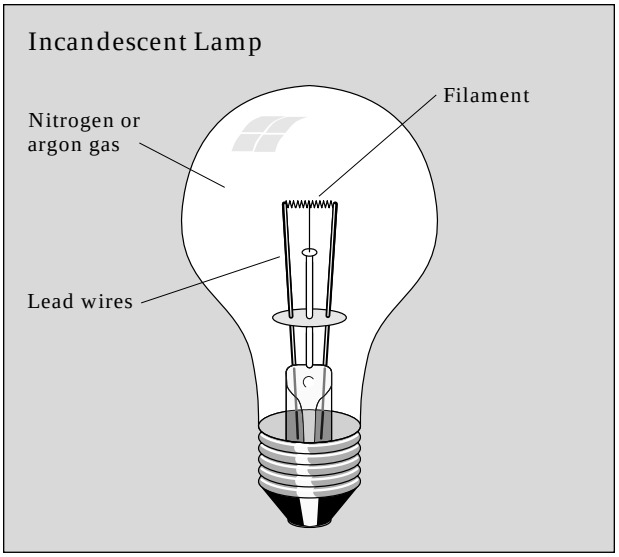
There are four basic types of lighting: *incandescent, fluorescent, high-intensity discharge,* and *low-pressure sodium.*

Incandescent lighting is the most common type of lighting used in residences. Fluorescent lighting is used primarily in commercial indoor lighting systems, while high-intensity discharge lighting is used only for outdoor lighting applications. Low-pressure sodium lighting is used where color rendering is not important, such as highway and security lighting. These lighting types vary widely in their construction, efficiency, color characteristics, and lamp life.

Incandescent

Incandescent lamps are the least expensive to buy but the most expensive to operate. Incandescent light is produced by a tiny coil of tungsten wire that glows when it is heated by an electrical current.

Incandescent lamps have the shortest lives of the common lighting types. They are also relatively inefficient compared with other lighting types. However, significant energy and cost savings are possible if you select the right incandescent lamp for the right job. The three most common types of incandescent lights are standard incandescent, tungsten halogen, and reflector lamps.



The incandescent lamp is the oldest and most common type of lamp. Light is emitted when electricity flows through—and heats—a tungsten filament.

Standard incandescent

Known as the "A-type light bulb," these lamps are the most common yet the most inefficient light source available. Larger wattage bulbs have a higher efficacy than smaller wattage bulbs. Note that a larger wattage lamp or bulb may not be the most energy- or cost-effective option, depending on how much light is needed. "Long- life" bulbs, with thicker filaments, are a variation of these A-type bulbs. Although long-life bulbs last longer than their regular counterparts, they are less energy efficient.

Tungsten halogen

This newer type of incandescent lighting achieves better energy efficiency than do standard A-type bulbs. It has a gas filling and an inner coating that reflect heat. Together, the filling and coating recycle heat to keep the filament hot with less electricity. These lamps are considerably more expensive than standard incandescents and are primarily used in commercial applications: theater, store, and outdoor lighting systems.

Reflector lamps

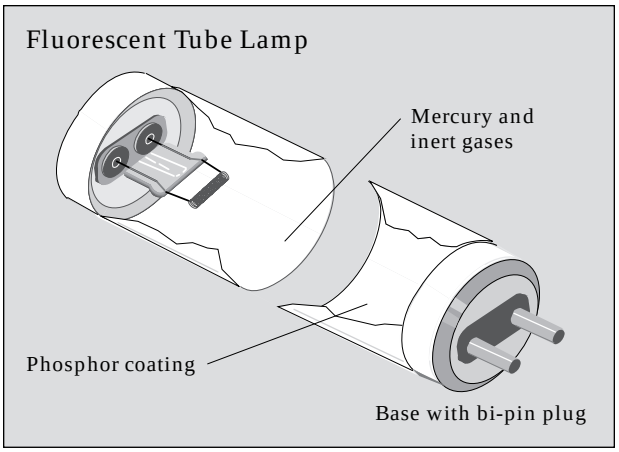
Reflector lamps (Type R) are designed to spread light over specific areas. They are used mainly indoors for stage / theater and store applications, as well as floodlighting, spotlighting, and downlighting.

Parabolic aluminized reflectors (Type PAR) are used for outdoor floodlighting. The ellipsoidal reflector (Type ER) focuses the light beam about 2 inches (5 centimeters) in front of its enclosure and is designed to project light down from recessed fixtures. Ellipsoidal reflectors are twice as energy efficient as parabolic reflectors for recessed fixtures.

Fluorescent

The light produced by a fluorescent tube is caused by an electric current conducted through mercury and inert gases. Fluorescent lighting is used mainly indoors—both for ambient and task lighting—and is about 3 to 4 times as efficient as incandescent lighting. Fluorescent lamps last about 10 times longer than incandescents. But, to gain the most efficiency, you should install fluorescents in places where they will be on for several hours at a time.

Fluorescent lights need *ballasts* (i.e., devices that control the electricity used by the unit) for starting and circuit protection. Ballasts consume energy. You can increase the energy savings for existing fluorescent lighting by *relamping* (e.g., replacing an existing lamp with one of a lower wattage), replacing ballasts, and replacing fixtures with more efficient models.



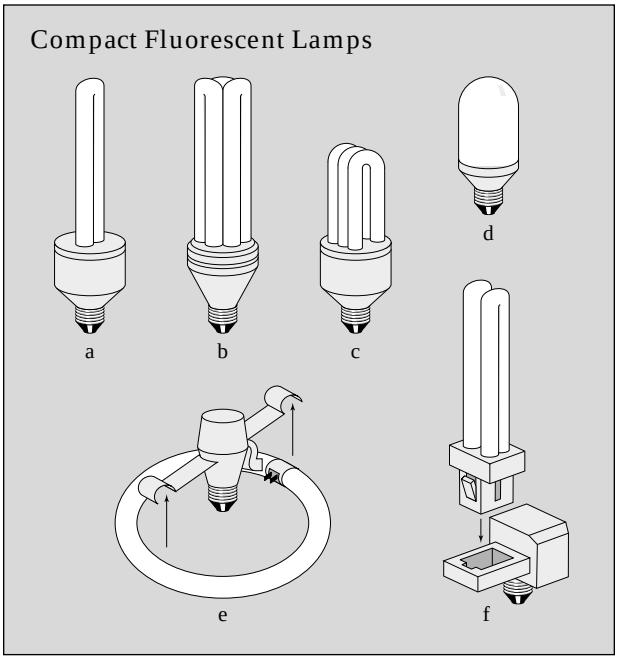
In fluorescent tubes, a very small amount of mercury mixes with inert gases to conduct the electrical current. This allows the phosphor coating on the glass tube to emit light.

Tube fluorescent

These lamps are the next most popular lamps after A-type incandescent lamps. The two most common types are 40-watt, 4-foot (1.2-meter) lamps and 75-watt, 8-foot (2.4-meter) lamps. Tubular fluorescent fixtures and lamps are preferred for ambient lighting in large indoor areas because their low brightness creates less direct glare than do incandescent bulbs.

Compact fluorescent

Compact fluorescent lamps (CFLs) are the most significant lighting advance developed for homes in recent years. They combine the efficiency of fluorescent lighting with the convenience and popularity of incandescent fixtures. CFLs can replace incandescents that are roughly 3 to 4 times their wattage, saving up to 75% of the initial lighting energy. Although CFLs cost from 10 to 20 times more than comparable incandescent bulbs, they last 10 to 15 times as long. This energy savings and superior longevity make CFLs one of the best energy efficiency investments available.



Compact fluorescent lamps (CFLs) come in a variety of sizes and shapes including (a) twin-tube integral, (b and c) triple-tube integral, (d) integral model with casing that reduces glare, (e) modular circline and ballast, and (f) modular quad-tube and ballast. CFLs can be installed in regular incandescent fixtures, and they consume less than one-third as much electricity as incandescent lamps do.

When introduced in the early- to mid-1980s, CFLs were bulky, heavy, and too big for many incandescent fixtures. However, newer models with lighter electronic ballasts are only slightly larger than the incandescent lamps they replace.

CFLs come in *integral* and *modular* designs. Integral CFLs have a ballast and a lamp in a single disposable unit. Modular designs feature a separate ballast that serves about five lamp replacements before it wears out.

High-Intensity Discharge

High-intensity discharge (HID) lamps provide the highest efficacy and longest service life of any lighting type. They are commonly used for outdoor lighting and in large indoor arenas.

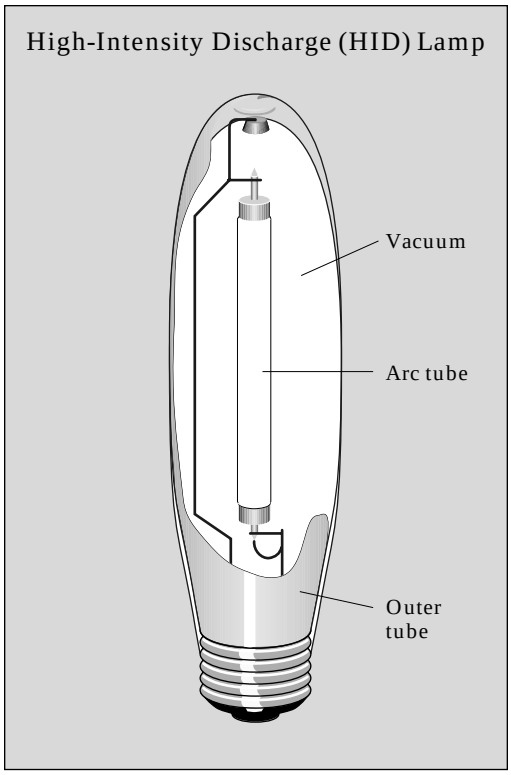
HID lamps use an electric arc to produce intense light. They also require ballasts, and they take a few seconds to produce light when first turned on because the ballast needs time to establish the electric arc.

The three most common types of HID lamps are mercury vapor, metal halide, and high-pressure sodium. HID lamps and fixtures can save 75% to 90% of lighting energy when they replace incandescent lamps and fixtures. Significant energy savings are also possible by replacing old mercury vapor lamps with newer metal halide or high-pressure sodium lamps.

Mercury vapor—the oldest type of HID lighting—is used primarily for street lighting. Mercury vapor lamps provide about 50 lumens per watt. They cast a very cool blue/green white light. Most indoor mercury vapor lighting in arenas and gymnasiums has been replaced by metal halide lighting, which has better color rendering and efficiency.

Metal halide lamps are similar in construction and appearance to mercury vapor lamps. The addition of metal halide gases to mercury gas within the lamp results in higher light output, more lumens per watt, and better color rendition than from mercury gas alone. Metal halide lamps are used to light large indoor areas such as gymnasiums and sports arenas, and for outdoor areas such as car lots or anywhere that color rendition is important.

High-intensity discharge (HID) lamps provide the highest efficacy and longest service life of any lighting type.



In a high-intensity discharge lamp, electricity arcs between two electrodes, creating an intensely bright light. Mercury, sodium, or metal halide gases act as the conductor.

Compact fluorescent lamps (CFLs) are the most significant lighting advance developed for homes in recent years.

High-pressure sodium lighting is becoming the most common type of outdoor lighting. It provides 90 to 150 lumens per watt—an efficiency exceeded only by low-pressure sodium lighting. High-pressure sodium lamps are also reliable and have long service lives. Their color is a warm white, and their color rendition ranges from poor to fairly good depending on design and intended use.

Low-Pressure Sodium

Low-pressure sodium lamps work somewhat like fluorescent lamps. They are the most efficient artificial lighting, have the longest service life, and maintain their light output better than any other lamp type. Low-pressure sodium lighting is used where color is not important because it renders all colors as tones of yellow or gray. Typical applications include highway and security lighting.

Energy Efficiency with Lighting

Lighting accounts for 20% to 25% of all electricity consumed in the United States. An average household dedicates 5% to 10% of its energy budget to lighting, while commercial establishments consume 20% to 30% of their total energy just for lighting.

In a typical residential or commercial lighting installation, 50% or more of the energy is wasted by obsolete equipment, inadequate maintenance, or inefficient use.

Saving lighting energy requires either reducing electricity consumed by the light source or reducing the length of time the light source is on. This can be accomplished by:

- Lowering wattage, which involves replacing lamps or entire fixtures
- Reducing the light source's on-time, which means improving lighting controls and educating users to turn off unneeded lights
- Using *daylighting*, which reduces energy consumption by replacing electric lights with natural light
- Performing simple maintenance, which preserves illumination and light quality and allows lower initial illumination levels.

Replacing Lamps and Fixtures

Relamping means substituting one lamp for another to save energy. You can decide to make illumination higher or lower when relamping. But be sure that the new lamp's lumen output fits the tasks performed in the space and conforms to the fixture's specifications.

When relamping an entire store or office, first test the new lamps in a small area to ensure adequate illumination, occupant satisfaction, and compatibility of the new lamp and the old fixture.

Matching replacement lamps to existing fixtures and ballasts can be tricky, especially with older fixtures. Buying new

fixtures made for new lamps produces superior energy savings, reliability, and longevity compared with relamping.

Relamping incandescent fixtures

Much has been learned about fixture design since the energy crises of the 1970s. Many indoor fixtures trap a significant portion of light inside the fixture, while many outdoor fixtures tend to disperse much of their light beyond the intended area, which causes light pollution.

New incandescent fixtures are designed to push all their light out into the room. Others use smaller tungsten halogen lamps. Advances in indoor fixture design include brighter reflectors and better reflecting geometry.

Many incandescent lamps are mismatched to their tasks. Some have excessive wattages—creating unnecessarily high illumination. This can be corrected by using lamps with smaller wattage.

Some existing incandescent lamps may not be the best type of lamp for their application. A-type light bulbs can often be replaced with improved lamp designs, such as reflectors or tungsten halogen lamps. And, for energy savings of 60% to 75%, many incandescent lamps can be replaced by CFLs.

When used in recessed fixtures, standard A-type lamps and reflector lamps waste energy—their light gets trapped. To save energy, you could replace a 150-watt standard reflector with a 75-watt ellipsoidal reflector (ER). Remember, though, that ER lamps are less efficient at delivering light from shallow fixtures, so use reflectors or parabolic reflectors for these purposes.

You can also replace standard A-type lamps with CFLs in spaces where lights are needed for long periods of time. A standard 18-watt CFL replaces a 75-watt A-type lamp. CFLs are also packaged in the same glass reflector lamps as incandescent lamps. Use CFLs packaged as ellipsoidal reflectors (type-ER) in recessed fixtures. Use reflector (R) or parabolic reflector (PAR) CFLs for flood and spotlighting. New CFL fixtures have built-in electronic ballasts and polished metal reflectors.

Relamping fluorescent fixtures

Although fluorescent lamps are generally energy efficient, there are new, even more efficient lamps that use better electrodes and coatings than do older fluorescent lamps. They produce about the same lumen output with substantially lower wattage.

Common 40-watt and 75-watt lamps can be replaced with energy-saving lamps of 34 watts and 60 watts, respectively. Energy-saving lamps for less-common fluorescent fixtures are also available.

If you need to replace the ballasts in your fluorescent fixtures, consider using one of the improved varieties. These fluorescent ballasts, called improved electromagnetic ballasts and electronic ballasts, raise the efficiency of the fixture 12% to 30%.

The new electromagnetic ballasts reduce ballast losses, fixture temperature, and system wattage. Because they operate at cooler temperatures, they last longer than standard electromagnetic ballasts.

Electronic ballasts operate at a very high frequency that eliminates flickering and noise. They are even more efficient than improved electromagnetic ballasts. Some electronic ballasts even allow you to operate the fluorescent lamp on a dimmer switch, which usually is not recommended with most fluorescents.

Improving Lighting Controls

Lighting controls are devices for turning lights on and off or for dimming them. The simplest type is a standard snap switch. Other controls are photocells, timers, occupancy sensors, and dimmers.

- Snap switches, located in numerous convenient areas, make it easier for people in large, shared spaces to turn off lights in unused areas.
- Photocells turn lights on and off in response to natural light levels. Photocells switch outdoor lights on at dusk and off at dawn, for example. Advanced designs gradually raise and lower fluorescent light levels with changing daylight levels.

Fluorescent Lamp Disposal

All fluorescent lights contain small amounts of mercury, and some compact fluorescent lamps with magnetic ballasts contain small amounts of short-lived radioactive material. Because of these hazardous materials, you should not toss burned-out lamps into the trash. Find out if there is a recycling program for them in your community—they are becoming more common—or dispose of them with other household hazardous wastes such as batteries, solvents, and paints at your community's designated drop-off point or during a designated day when you can put such materials with your curbside trash pickup.

Lighting accounts for 20% to 25% of all electricity consumed in the United States.

- Mechanical or electronic time clocks automatically turn on and off indoor or outdoor lights for security, safety, and tasks such as janitorial work.
- Crank timers, which are spring-driven and similar to old oven timers, limit lights to short durations where the need for light is brief.
- Occupancy sensors activate lights when a person is in the area and then turn off the lights after the person has left. They are popular for areas used infrequently, such as warehouses. They also offer security advantages over continuous lighting: when lights suddenly come on, they startle intruders and alert residents and neighbors to motion in the area.
- Dimmers reduce the wattage and output of incandescent and fluorescent lamps. Dimmers also increase the service life of incandescent lamps significantly. However, dimming incandescent lamps reduces their lumen output more than their wattage. This makes incandescent lamps less efficient as they are dimmed. Dimming fluorescents requires special dimming ballasts and lamp holders, but does not reduce their efficiency.

Daylighting

Daylighting means using daylight for indoor lighting. Modern buildings designed for daylighting typically use 40% to 60% less electricity for lighting needs than do conventional buildings.

Sunlight and daylight are free and readily accessible. However, using sunlight without causing glare and without overheating a building can be difficult. Glare can be avoided by using window sills, walls, louvers, reflective blinds, and other devices to reflect light deep into the building. Be careful to locate windows and skylights away from the sun's direct rays to avoid overheating. For example, placing skylights on the north slope of your roof rather than on the southern exposure may reduce heat transfer. In addition, look for windows with new selective glazings that transmit the most visible light while excluding the most solar heat.

For more information on daylighting and windows, contact the Energy Efficiency and Renewable Energy Clearinghouse (EREC—see *Source List*).

Lighting Maintenance

Maintenance is vital to lighting efficiency. Light levels decrease over time because of aging lamps and dirt on fixtures, lamps, and room surfaces. Together, these factors can reduce total illumination by 50% or more, while lights continue drawing full power. The following basic maintenance suggestions can help prevent this.

- Clean fixtures, lamps, and lenses every 6 to 24 months by wiping off the dust. However, never clean an incandescent bulb while it is turned on. The water's cooling effect will shatter the hot bulb.
- Replace lenses if they appear yellow.
- Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect.
- Consider group relamping. Common lamps, especially incandescent and fluorescent lamps, lose 20% to 30% of their light output over their service life. Many lighting experts recommend replacing all the lamps in a lighting system at once. This saves labor, keeps illumination high, and avoids stressing any ballasts with dying lamps.

Optimizing Energy Efficiency and Lighting Quality

When making changes designed to increase the energy efficiency of lighting, it often pays to redesign the building's entire lighting system. This can improve lighting quality, make visual tasks easier, and save 50% or more on energy costs.

Often, you can reduce light levels without reducing light quality by following these procedures.

- Redesign visual tasks. For example, use a better printer with darker printing.
- Reduce light levels where there are no visual tasks. Provide the minimum light necessary for safety, security, and aesthetics.
- Reduce light levels for visual tasks where those levels are currently excessive.

If you want to cut energy consumption from lighting while enhancing light quality, consider the following.

- Establish ambient illumination at minimum acceptable levels.
- Provide task lighting at the optimal level depending on the difficulty of visual tasks. For example, sewing requires more light than cooking.
- Increase the efficiency of lamps, ballasts, and fixtures.
- Improve light quality by reducing glare and brightness contrast.
- Use daylighting where possible and practical.

Better Light, Less Cost

Using just a few of these ideas will help lower your electricity costs from lighting and make your home or workplace more comfortable and efficient.

Source List

There are many groups that can provide you with more information on energy-efficient lighting. The following are just a few of the organizations that can assist you.

Illuminating Engineering Society of North America (IESNA)
345 East 47th Street
New York, NY 10017
(212) 705-7913

IES is a technical society dealing with the art, science, and practice of illumination.

Lawrence Berkeley National Laboratory
Windows and Daylighting Group
Mail Stop 90311
Building 90, Room 3026
Berkeley, CA 94720
(510) 486-5605

Lawrence Berkeley National Laboratory is among America's foremost authorities on daylighting.

The National Lighting Bureau (NLB)
2101 L Street NW, Suite 300
Washington, DC 20037
(202) 457-8437

The NLB provides information and publications on energy management of lighting and offers the publication, *Getting the Most From Your Lighting Dollar.*

Rensselaer Polytechnic Institute
Lighting Research Center
110 8th Street
Troy, NY 12180
(518) 276-8716

The Lighting Research Center provides scientists and educators with in-depth publications on the topic of lighting, including *The Lighting Pattern Book for Homes.*

Rocky Mountain Institute (RMI)
1739 Snowmass Creek Road
Snowmass, CO 81654
(970) 927-3851
Fax: (970) 927-3428

RMI is a nonprofit research and educational organization that fosters the efficient, sustainable use of resources, and publishes a series of Home Energy Briefs on a variety of topics.

For more information on energy-efficient lighting, daylighting, and other topics, contact:

The Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
(800) DOE-EREC (363-3732)
Fax: (703) 893-0400

This free service provides general and technical information to the public on a wide spectrum of energy efficiency and renewable energy topics.

Reading List

Advanced Lighting Guidelines: 1993, U.S. Department of Energy. Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Buildings that Save Money with Efficient Lighting, published for local government agencies. Produced for the U.S. Department of Energy (publication number DOE/CH10093-212), by the National Renewable Energy Laboratory, Document Distribution Center, 1617 Cole Boulevard, Golden, CO 80401, 1993.

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