LIGHTING

Energy Efficiency Reference Guide

BC Hydro
Power smart

The use of certified practitioners for the application of the information contained herein is strongly recommended.

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TABLE OF CONTENTS

1 INTRODUCTION

This practical guide has been designed to provide highly useful information on lighting technologies, components and devices that are commercially available. The content of the guide can be used to review lighting systems design and allows for identifying and capitalizing on energy efficiency opportunities through a design approach. This revised version includes information on several new developments that occurred in the lighting industry since the guide was first published in 2007.

Although standards and regulations presented in this guide apply mainly to the Canadian market, the technical content is of general relevance to utilities, companies and customers interested in identifying and tapping into energy-saving opportunities.

It is strongly recommended that individuals or companies undertaking comprehensive energy efficiency projects secure the services of professional energy efficiency specialists qualified in lighting design to maximize the benefits and return on investment by considering the internal rate of return and related benefits of a 'quality' design.

2 ENERGY SAVINGS

Increasing energy costs have become a significant concern, and costs are expected to continue to increase in the foreseeable future. Businesses, institutions and consumers will be searching for more efficient products and solutions. Business applications for more efficient products are available and even greater opportunities exist in the largely untapped residential market. Lighting is recognized as a major area for economic energy savings. It is often the most obvious and visible opportunity for energy conservation and efficiency improvements in a business operation. More efficient lamps or fixtures reduce energy cost. Moreover, well-designed lighting systems can greatly improve occupants' comfort and ease at performing their tasks.

Programs are in place to influence market and consumer choices towards more energy efficient products. For example, Energuide for Existing Houses, R2000 and the use of the Energy Star labeling program are some of the NRCan programs which promote energy-efficient lighting products. What follows is a comprehensive list of these programs, accompanied by a short description. This list is provided for information and present programs that are generally temporary. Before considering new lighting retrofit or replacement projects, users of this guide should check with their providers as to what programs are available.

Entity	Program Name	Description
NRCan	EnerGuide Rating System (New Homes)	The rating shows a standard measure of the new-home energy performance.
NRCan	R-2000	Aims to promote the use of cost-effective energy-efficient building practices and technologies.
ENSC	Business Energy Solutions	ENSC upgrades business with efficient products, including lighting, and can cover up to 60 % of the cost.
Hydro-Québec	Building Program (Custom and Prescriptive Measures)	Offers assistance tailored to individual projects to improve buildings' overall energy efficiency; provides simple solutions tailored to buildings smaller than 5,000 m^2 to assist in implementing predefined measures; encourages municipalities to become more energy-conscious by opting for LEDs for public lighting.
Hydro-Québec	Industrial Systems Program (Custom and Prescriptive Measures)	Financial assistance for electricity consumption analyses, electricity measurement and management, implementation of predefined EE measures, such as lighting replacement, retrofit and expansion projects.
OPA[1]	saveOnenergy	Tools, resources and incentives to help homeowners, businesses and industry conserve energy.
BC Hydro	Product Incentive Program	Provides financial incentives to small and medium businesses to replace inefficient technologies with new energy efficient products.
BC Hydro	Self-Serve Incentive Program	Incentives covering up to 75 % of project costs. Improvements on compressed air and lighting systems are eligible.

1 Ontario Power Authority

There are also national efforts to mandate and in some cases regulate energy efficiency which appear in various forms such as codes and standards and building guidelines to limit energy use within a building such as:

- ASHRAE-IES 90.1, which is updated every three years.
- DOE Standard for Federal Buildings.
- Equipment regulations - US National Appliance Energy Conservation Act Amendment of 1988 and Energy Policy Act of 1992 and 2005, etc.
- Novoclimat standards, which are a home program available to consumers interested in buying a home with a high energy efficiency rating.

Achieving lighting energy savings is considered one of the fundamental energy efficiency measures with numerous opportunities and supporting benefits. Choices include:

- Replacing incandescent with fluorescent or LED lamp types.
- Redesigning older fluorescent or HID lamp configurations to meet present applications, such as in industrial plants with upgraded fixtures or better technology or delamping where the illuminance level is higher than what is required by the IES illuminating standard.
- Implementing an automated control system with dimmers and occupancy sensors to make adjustments based on conditions such as occupancy or daylight availability.
- Adding task lighting instead of over-lighting an entire space.

Lighting projects executed properly and comprehensively can be easily justified for a number of reasons including:

- Energy savings and other savings such as maintenance - in some cases, payback is less than 1 year.
- Emission reductions, as there is a direct correlation between energy and emission reduction.
- Maintenance cost savings from replacing inefficient systems.
- Increase lighting levels for tenant comfort or improved safety considerations.
- Improved color rendering index (CRI) to enhance comfort.
- Overall optimized lighting that meets space utilization needs, with no wasted light and therefore no wasted energy.

3 LIGHTING APPLICATIONS

a. Lighting Project Management

The objective of a "**quality**" lighting design is to provide a safe and productive environment – whether for business or pleasure. This is accomplished by a redesign or upgrade to ensure that the appropriate quality and quantity of light is provided for the users of the space, at the lowest operating and maintenance cost.

A "**quality**" lighting design addresses more than just 'first cost' issues. Either Net Present Value (NPV) or the Internal Rate of Return (IRR) can properly evaluate life cycle costs.

Proper evaluation of the data, planning and execution are essential for the successful implementation of lighting systems. Building systems are inter-related. For example, removing 10 kW of lighting energy from a commercial building will have a significant impact on the heating, ventilation, and air conditioning systems. Cooling cost will be reduced, but replacement heating may be required. This phenomenon is called cross-effects or interactive effects. Interactive effects occur when the installation of an energy efficiency measure has an impact on the energy consumption of other elements in the facility, such as heating and cooling. It is necessary for the lighting designer to have a clear understanding of all the building systems and how they interrelate.

Typical 'lowest (first cost)' projects save energy, but they usually do not maximize the saving potential in the building. For example, a 're-lamping' exercise, which is a low cost solution, provides only 10 to 30 % savings, but prevents a lighting designer from returning to the project to maximize savings at a later date. *Valuable energy reductions are sacrificed.*

For example, in a commercial building in Toronto, the original scope of work, which consisted of a fixture to fixture replacement, would have resulted in electrical lighting savings of 37 %. At first glance, this appeared to be a respectable objective. However, a lighting designer was retained and a comprehensive design solution was provided. The project achieved:

- Lighting energy savings of 63 %.
- Reduced payback.
- Internal Rate of Return of more than 30 %.
- Solutions for related building issues such as maintenance, end of fixture life, etc.

The 'first cost' was higher, however the life cycle cost as calculated using either the Net Present Value or the Internal Rate of Return proved a significantly superior solution.

b. Evaluation Methods

The methodology used to evaluate the energy savings for a lighting project, either for a retrofit or a comparison for new projects, is critical to the success of installing a complete energy efficient solution. Too often, the simple payback method is used which undervalues the financial benefit to the organization. The following are brief descriptions of the various payback evaluation methods. It is important that the choice of method reflects the same principles that the company uses when evaluating other capital investments.

Simple Payback and Life Cycle Costing

A proper life cycle costing analysis will provide a more realistic financial picture of an energy retrofit project than a simple payback evaluation. Unfortunately, energy efficiency has been a low priority, and for convenience, the 'Simple Payback' analysis is often used to evaluate energy projects, particularly for lighting projects.

- Simple Payback consists of the project capital cost divided by the annual energy savings realized. The result is the number of years it takes for the savings to pay for the initial investment, e.g.; a $100,000 project that saves $35,000 annually has a three-year payback.

$$\text{Simple Payback} = \frac{\text{Project Capital Cost}}{\text{Annual Energy Savings}}$$

- Life Cycle Costing analysis is a similar calculation, however, it looks at a realistic timeline and includes the maintenance cost savings, the potential increased cost of replacement lamps, and the cost of money, and can only be properly evaluated by considering the cost of money by either the Internal Rate of Return, or the Net Present Value, as discussed below. For example, CFLs have an average life of 10,000 hours versus 1,500 for incandescent lamps. Therefore, CFLs will be replaced six to seven times less often than incandescent lamps. When doing a CFL life cycle analysis, the maintenance and replacement costs of six incandescent lamps should be added to the energy costs to ensure an accurate comparison.

Discounted Cash Flow

Discounted cash flow methods recognize the time value of money and at the same time provide for full recovery of investment in depreciable assets.

- The Net Present Value method discounts the stream of annual savings by the company's required return on investment or Cost of Capital.
- The Internal Rate of Return method finds the discount rate, which matches the cash inflows, and the cash outflows, leaving a Net Present Value of zero. A company can then make capital investment decisions based on the projects that have the highest Internal Rate of Return; e.g., with interest rates below 10 %, a project that delivers an IRR above 10 % creates a positive cash flow.

c. Light and the Environment

There are a number of methods for determining whether a lighting installation is appropriate. One method is for the lighting designer to check with the current version of the ASHRAE/IESNA 90.1 lighting standard. This document, which is revised regularly, provides a recommendation for the Lighting Power Density or watts per square meter or square foot attributable to lighting. It is usually possible for a capable lighting designer to achieve better results than the ASHRAE/IESNA 90.1 recommendations.

Listed below are the names and links to web pages of institutes offering general information about commercial, institutional, industrial and residential standards.

- ASHRAE (https://www.ashrae.org)
- American National Standards Institute (http://webstore.ansi.org)
- Techstreet (http://www.techstreet.com)

d. Technology Integration

While this handbook is divided into sections dealing with individual lighting technologies, it is essential to realize that the best lighting measures combine technologies to maximize the efficiency of systems. Experienced lighting designers will, for example, select the right combination between the type of lamp and the control system that provide the best possible results for the particular environment and client objectives.

The best solution is derived by matching client requirements with the technology. Therefore, one application may use T-5 technology; others may use LED, while another may use metal halide.

Occupancy and utilization of the space is a major factor when it comes to select the appropriate control strategy. For example, the use of occupancy sensors avoids unnecessary energy consumption by keeping the lights off when no occupant is in an area. Wireless control allows a very precise and localized control of light intensity in addition to minimizing the wiring costs for retrofit or replacement measures. Selecting the appropriate control strategy can generate important savings.

With fluorescent lamps, choosing a lower ballast factor can reduce the lamp lumen output, thereby proportionally reducing the input power and the energy consumption. For example, in retrofit applications or in areas with fewer important visual tasks, it is appropriate to choose a lower ballast factor to reduce the lumen output. Usually, a 20 % reduction in output cannot be detected by occupants.

Actually, having high ballast factors is generally a better choice in new buildings since fewer luminaires will be required to meet the light level requirements, thereby saving on energy, maintenance and construction costs.

Ballast factor selection is not an issue for LED systems. This technology allows dimming. This strategy can be used for both retrofit and new constructions in order to get the exact desired light output.

Another example of lighting technology integration is daylight harvesting. Daylight harvesting is a system that uses daylight to offset the quantity of electric lighting needed to properly light a space. To “harvest daylight”, lighting control systems are used to dim, turn on and turn off electric lighting in response to changing daylight availability. This technology helps reduce energy consumption while maintaining light quality.

The proper selection of lamps should be based on the specific characteristics of the environment. For example, when selecting products for street lighting, LED lamps can be considered because this technology offers a bright and well directed lighting, which is desirable for this type of application. LED will also minimize light pollution while keeping energy consumption low to reduce energy bills. Moreover, the lifetime of LEDs will help in reducing maintenance costs.

e. Case Studies

The following are three case study examples.

Residential

Replacing Incandescent Bulbs with CFLs in Homes

To encourage people to reduce their energy consumption, an energy distributor established a financial assistance program to encourage people to replace their incandescent light bulbs with more efficient compact fluorescent lamps. As part of this program, measurements were made to evaluate energy savings generated by these replacements and the impact of the program on the profitability of such a measure.

Situation:

The case of a typical one-story house was studied when evaluating the savings generated by replacing incandescent bulbs with CFLs.

Technology:

Incandescent lamps to be replaced were in the living rooms, the kitchen, all the bedrooms, the hall, bathrooms and the storage areas. A total of eighteen 40-watt and five 60-watt incandescent bulbs were installed.

Action:

All the incandescent bulbs were replaced with CFLs. The 60-watt incandescent bulbs were replaced with 13-watt CFLs and 40-watt bulbs were replaced with 9 watt CFLs.

Measurements:

Measurements were made to evaluate the operating time of each lamp in the house. Results showed that the average daily operating time was 2.6 hours for the 60 watt bulbs and 2.8 hours for the 40-watt bulbs.

Cross-effects:

Replacing incandescent bulbs with CFLs caused an increase in space heating demand in winter. Based on the measurements made to evaluate the impact of interior lighting on heating demand, a factor of -40 % was applied on the savings to take account of the cross-effects.

Project Cost:

A total cost of $60.22 was required to purchase CFLs.

Energy Savings:

Energy savings were 476 kWh after considering cross-effects.

Cost Savings:

$37/year

Financial support:

A $30 rebate was given by the energy distributor.

The payback time after considering the financial support of the energy distributor was 0.8 year. It would be 1.6 years without financial support. In either case, replacing incandescent bulbs with CFLs was an interesting measure. However, the financial program made an important difference since it could shorten the payback time of the measure by half. It could be anticipated that this program would encourage people to replace their old incandescent bulbs with new and more efficient CFLs.

Replacement of incandescent lights with CFLs is a common measure in the residential sector. However, it is expected that LED technology will eventually deploy and become a common measure for replacement of incandescent and CFLs. Local disposal authorities should be contacted for approved CFL disposal methods.

Institutional

A School Board Project in Ontario

School boards are usually the owners of their facilities, similar to municipalities, universities, schools and hospitals, i.e., the MUSH sector. In reaction to the 'baby boom' in the mid-sixties, there was a tremendous expansion in the construction of facilities for this sector. Thus, facility managers have inherited 45-year-old facilities, with much of the infrastructure needing replacement.

This is particularly true for schools. There are limited funds for replacement, so upgrading the systems in these facilities is often the only option.

Lighting systems, just like furnaces, chillers, motors and pumps, are part of the 45-year-old facilities and have a defined life span. Over time, lamp sockets and internal wiring deteriorate, and lenses become cracked and broken. Therefore, at some point it is more economical to replace rather than to continue to repair.

Another significant concern for the facility manager is change in use. Computers were unheard of in primary and secondary education when these facilities were constructed, but they are now in common use both in the classroom and for facility management. Curriculums have also evolved, and some facilities, such as science labs, now have very different uses. As a result, there are many classrooms where the lighting technology is outdated, the equipment is due for replacement, and the light fixtures are no longer appropriate for the illumination of the relevant task.

Lighting technology changes lead to more choice. School gymnasia provide a good example. Older schools may have incandescent, fluorescent or mercury vapour lighting in their gyms. In these facilities, 50 % or more of the energy in the gymnasium can be saved by redesigning the space with more efficient fluorescent systems using T8 or T5 lamps, combined with occupancy sensors. Some school boards prefer to use metal halide high bay fixtures because fewer fixtures are required, meaning lower maintenance costs. These fixtures can be specified with ‘high-low’ ballasts combined with occupancy sensors for additional savings.

Situation:

This project consisted of a survey of 130 building evaluations, including administration, secondary and elementary schools. The challenge in most school board projects is the relatively low hours of building use compared to commercial projects.

Area:

5,750,000 square feet.

Action:

A company specializing in the design and delivery of energy programs retained a lighting specialist to help the school board provide a full assessment of savings and costs to achieve a comprehensive energy project.

Technology:

Existing lighting throughout the 130 buildings consisted of 34 W T12 lamp fluorescent fixtures, some mercury vapour fixtures in gymnasiums, and incandescent exit signs and decorative lighting.

Solutions:

The design team specified a comprehensive approach including lighting upgrades and redesign, lighting controls, building automation, fuel change, envelope improvements, HVAC upgrades, and solar panels.

- In the classrooms, the fluorescent fixtures were upgraded to T8 fluorescent systems with electronic ballasts, and where appropriate, replaced with new, more efficient fixtures. Where the patterns of use made it economical, occupancy sensors were installed.

- In the washrooms, the existing systems were replaced or retrofit to T8 lamps with electronic ballasts. Occupancy sensors were installed where appropriate.
- In the gymnasia, most locations received new luminaires, either T8 fluorescent or metal halide high bay fixtures. Occupancy sensors were installed where appropriate.
- In offices, the fluorescent fixtures were upgraded to T8 fluorescent systems with electronic ballasts, and where appropriate, replaced with new, more efficient fixtures. Where the patterns of use made it economical, occupancy sensors were installed.
- Exit signs were replaced with new Light Emitting Diode (LED) exit signs.
- Outdoor lighting systems were upgraded with new controls, using timers and in some cases, photocells, and new luminaires were installed with high pressure sodium lamps.

Results:

Total Project Cost: $12,000,000

Energy Savings:

21.9 million ekWh (equivalent kilowatt hours)

Cost Savings:

$1,500,000 per year.

Internal Rate Return greater than 11 %.

Note: The owner included other measures that provided better results and still exceeded their hurdle rate.

Measures:

Lighting retrofit, fuel change, building automation system, envelope improvements, HVAC upgrades, solar panels.

Commercial

A Commercial Building in Downtown Toronto

Commercial property managers are constantly looking for opportunities to enhance tenant comfort and decrease costs. Lighting is considered a proven technology that meets both objectives.

Commercial buildings commonly use variations on the fluorescent solution. There are a number of issues for the lighting designer to consider. The lighting layout, the arrangement and geometry of light fixtures, may no longer suit the location of work stations. The light levels may be too high for use in computer environments. The light fixtures may have lenses which create reflections on computer screens. The controls are often limited to circuit breakers in an electrical room on each floor. The use of 347 V systems in Canada can also limit the options available to the lighting designer.

A major consideration for building owners and tenants is the disruption caused by a lighting project. Issues requiring substantial cooperation and coordination include:

- Access to secure floors or rooms.
- Elevator access.
- Storage of tools and equipment.
- Disposal of packaging materials.
- Cleanup at the start and end of each shift.

In order to expedite a project in a timely manner with a minimum disruption for tenants, skilled project management is required. Obtaining spot energy consumption measurements for both ‘pre’ and ‘post’ conditions are recommended.

Situation:

This project was for a Class A building in Toronto, with 35,000 existing ‘base building’ luminaires.

Area:

2,670,000 square feet.

Action:

The building owner hired an engineering firm specializing in energy-efficient systems to provide a cost analysis for retrofitting existing lighting systems with more efficient T8 lighting systems.

Technology:

Existing base building light fixtures were an inefficient design which used a costly ‘U-Tube’ fluorescent lamp. Each fixture contained 3 lamps and 2 electromagnetic ballasts.

Solutions:

The lighting designers provided a redesign of the fixture, incorporating a reflector, an electronic ballast and linear T8 lamps. On-site testing proved that light level requirements were met and that a savings of 63 % of the lighting energy compared to the existing system were achieved. This solution also avoided the cost premium of the ‘U-Tube’ lamps.
Other measures undertaken as part of the overall program included boiler replacement, fresh air improvements, and water

measures. This project shows the value of integrating measures. For example, 3,500 kW of lighting load was removed from the building, as well as the resulting heat. This created significant cooling savings but also made boiler upgrades essential. Modern, more efficient boilers and controls replaced the required heat with substantial savings, and provided improvements to indoor air quality.

Project Cost:
$17,000,000

Energy Savings:
19.4 million ekWh (equivalent kilowatt hours)

Cost Savings:
$1,800,000 per year

Internal Rate Return greater than 10 %.

Note: the owner included other measures that provided better results and still exceeded their hurdle rate.

The 3,500 kW reduction translated to about a 1 million dollar annual saving, and the lighting project cost was about 2.5 million dollars; an internal rate of return of 30 %. As is usually the case with these projects, the owner bundled other measures with significantly longer paybacks into this project to maximize the improvements to the building and to better accommodate 'required' system upgrades such as the new boilers.

Industrial

Industrial Facility in Quebec

Situation:

An industrial facility in the province of Quebec had some problems with its lighting system. Operators had the feeling that the lighting levels were poor. This feeling was confirmed by the measurements made, which showed lighting levels 50 % lower than the prescribed level for the type of activity performed in the facility. Maintenance costs of annual lamp replacements made in the plant because of a dusty environment were also unusually high. The facility managers wanted to find a solution that would offer a stable lighting level and help save maintenance costs and reduce energy consumption. Another major concern expressed by the manager of the facility was the fact that lights were always kept on at full capacity all day long, while lower lighting or no lighting would be acceptable 10 % to 20 % of the time. It was thus decided to evaluate the possibility of using control strategies to adjust light intensity since it was estimated that 10 % of the time, tasks could be performed without requiring a lighting level as high as the rest of the day.

Action:

A lighting system designer was contacted by the facility to find a permanent and efficient solution to replace actual lighting systems with lamps having a longer lifetime and higher efficiency.

Technology:

The facility consisted of three locations. Lighting in the working areas was provided by open metal-halide fixtures installed in a standard "grid" pattern. Each lamp consumes 400 W and uses an electromagnetic ballast requiring an additional power of 54 W.

Solution:

An engineering firm was hired by the lighting designer to make an assessment that provided data on the existing situation including light levels, the number of fixtures installed, the types of lamp, and the types of ballast and fixture. The assessment was to also present details about the solution that would involve replacing existing metal halide lamps with high-bay dimmable LED lights consuming 250 W each and providing higher light output than the metal halide 400-W lamps currently being used. It reported on the potential savings of such a solution, as well as the additional savings that could be generated by including occupancy sensors and a control system to adjust lighting intensity according to work schedules.

At the time when this project was being considered, the LED was a relatively new technology and the results of the project, if implemented, could not be used to ensure that the proposed solution would produce the targeted light level, color rendering and lifespan. Tests were first performed by replacing a few metal halide lamps with high-bay LEDs. The result showed that these lamps offered the light level required, and that needs for maintenance were lower than with metal halide lamps. Encouraged by these results, the facility management had all metal halide lamps and fixtures in the three locations of the facility replaced with LEDs. This measure alone generated savings of more than 50 % on energy usage for lighting. By adding a control system to adjust lighting intensity according to working schedules in each of the working locations, 11 % more energy savings were generated. In addition, a significant reduction in maintenance needs was observed in the months and years after the project had been implemented. Thus, this project met all the expectations of the client. The payback time of this project was 5 years considering energy savings and financial support.

Project Cost:
$125,635

Energy Savings:
116,800 kWh (equivalent kilowatt hours)

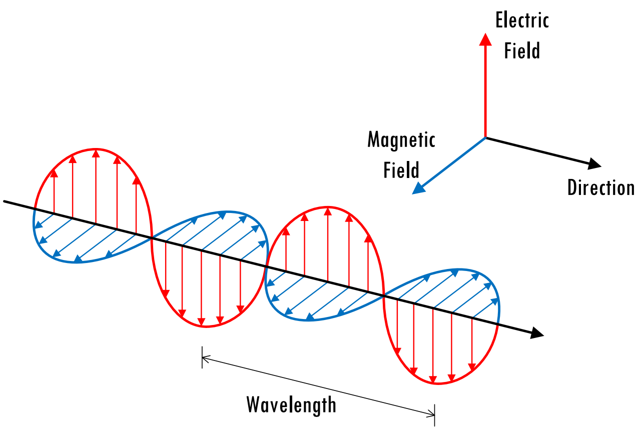
Cost Savings:
$16,975 per year (including maintenance)

4 UNDERSTANDING THE THEORY

a. Definition of Light

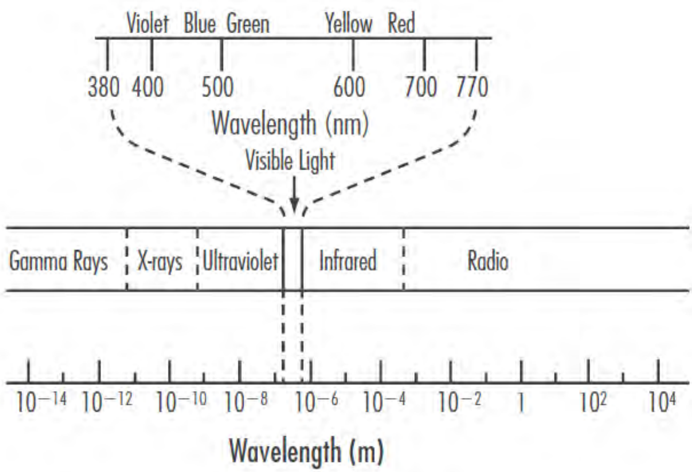
Definition

- Light is what makes things visible.
- Light is defined as electromagnetic radiation or energy transmitted through space or a material medium in the form of electromagnetic waves (definition in physics).
- Light is defined as visually evaluated radiant energy. Light is the portion of the electromagnetic spectrum visible to the human eye.
- The picture below illustrates an electromagnetic wave, such as light, composed of an electric and a magnetic field.



Electromagnetic Spectrum

- The electromagnetic spectrum is shown in the figure below.
- The visible portion of the spectrum covers a narrow band of wavelength from approximately 380 nm to 770 nm (1 nm = 10^{-9}m). Wavelengths shorter or longer than these do not stimulate the receptors in the human eye.



b. Visual Effect of Light

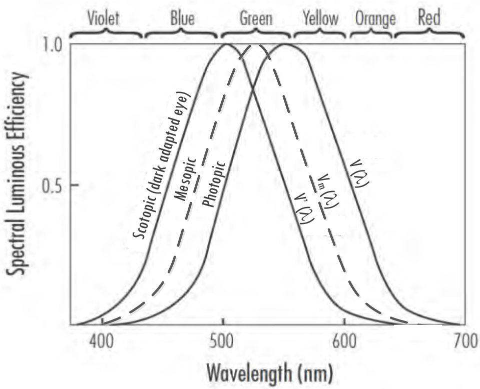
- Light is defined as visually evaluated radiant energy.
- The visible portion of the radiant energy that reaches the eye is absorbed by special receptors (rods and cones) in the retina, which covers the inner wall of the eye.
- In the retina, the rods and cones convert the radiant energy into electrical signals. The nerves transmit the electrical impulses to the brain where the light sensation is created.

Spectral Sensitivity of the Eye

- The sensitivity of the human eye to light of a certain intensity varies widely over the wavelength range between 380 and 800 nm. Different wavelengths give different color impressions and different brightness intensity impressions.
- The "relative spectral luminous efficiency curves" (shown on page 31) illustrate the ratio of the sensitivity of the eye to each wavelength. By convention, the maximum sensitivity of these curves is normalized to a value of 1.
- When the eye is in bright viewing conditions, the curve for photopic (or day) vision applies. The curve is denoted by V (λ). The maximum sensitivity is in the yellow-green region of the spectrum at a wavelength of 555 nm, indicating that green light at this wavelength produces the impression of the strongest "brightness" when compared with light at the other wavelengths.

- When the eye is in dark-adapted conditions, the curve for scotopic (or night) vision applies. The curve is denoted by V' (λ). The maximum sensitivity is in the blue-green region of the spectrum at a wavelength of 507 nm.
- When the eye is under low lighting but not quite dark situations, the curve for mesopic vision applies. Mesopic vision is a combination of photopic and scotopic visions. Most night-time outdoor and traffic lighting scenarios are in the mesopic range. The maximum mesopic sensitivity is not constant and varies with light level and viewing conditions. However, the normalized sensibility curve, denoted by $V_m(\lambda)$, has its maximum somewhere between 507 and 555 nm, which are the wavelengths at which scotopic and photopic sensitivity reach their maximum. The curve presented below is an example of a mesopic sensitivity curve.
- For example, the photopic sensitivity of the human eye to monochromatic light at 500 nm amounts to 50 % of its sensitivity at 555 nm. Consequently, the source of monochromatic light at 500 nm needs twice as much power (expressed in watts) as an otherwise identical source of monochromatic light at 555 nm to produce the impression of the same "brightness" to the human eye.

Relative Spectral Luminous Efficiency Curves



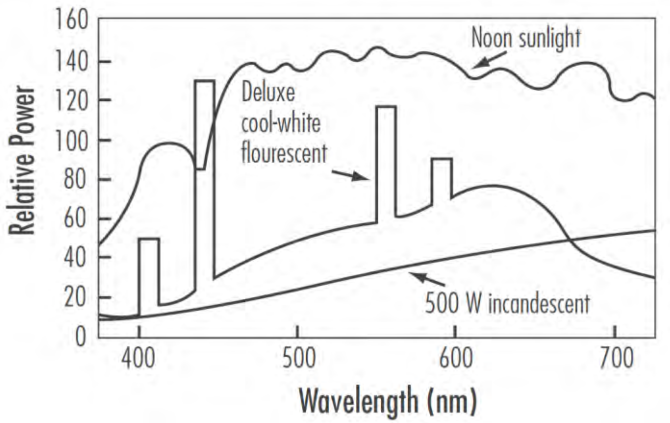
c. Spectral Power Distribution

Introduction

- Each light source is characterized by a spectral power distribution curve (SPD) or spectrum. The SPD can be measured by a spectrophotometer.

Spectral Power Distribution Curve

- The SPD curve, or spectrum, of a light source shows the radiant power that is emitted by the source at each wavelength, over the electromagnetic spectrum (primarily in the visible region).
- With color temperature and color rendering index ratings, the SPD curve can provide a complete picture of the color composition of a lamp's light output.



Incandescent Lamp Spectrum

- Incandescent lamps and natural light produce a smooth, continuous spectrum.

High Intensity Discharge Lamp Spectrum

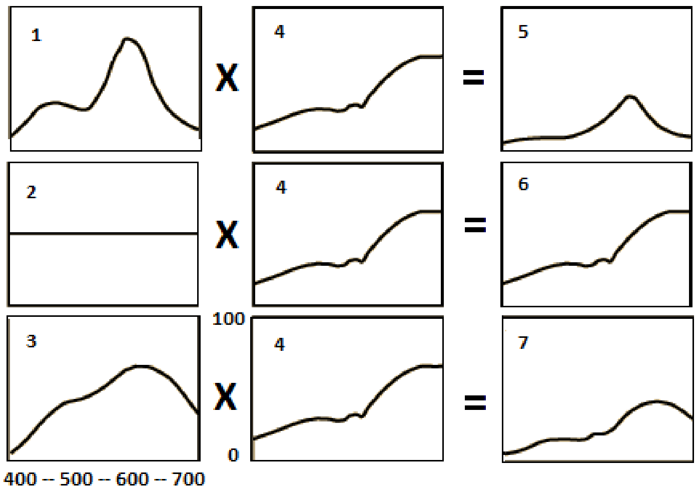
- HID lamps produce spectra with discrete lines or bands.

Fluorescent Lamp Spectrum

- Fluorescent lamps produce spectra with a continuous curve and superimposed discrete bands.
- The continuous spectrum results from the halophosphor and rare earth phosphor coating.
- The discrete band or line spectrum results from the mercury discharge.

Spectral Power Distribution Application

- Sometimes, the color of certain items may appear to be different under interior and exterior lighting. This effect can be explained by the SPD of the light under the different circumstances and is shown in the following figure. Graphs 1, 2 and 3 depict the SPD curves corresponding to 3 different interior fluorescent lighting conditions (i.e., Graph 1 = cool white fluorescent; Graph 2 = white light; and Graph 3 = deluxe cool white fluorescent). Graph 4 shows the reflectance percentage of the skin and those in the last column illustrate the reflected SPD.



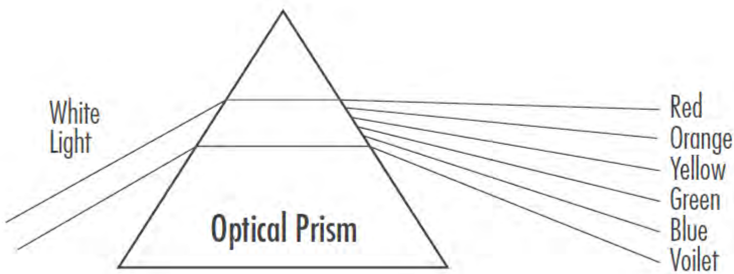
Source: Williamson and Cummins, Light and Color in Nature and Art

Under cool white fluorescent light, the skin color will be altered by a significant loss of red colors, as can be seen in Graph 5. Graph 6 would represent the real skin color as seen in white light and Graph 7 would represent the skin color under a source of lighting that closely matches white light.

d. Lighting and Color

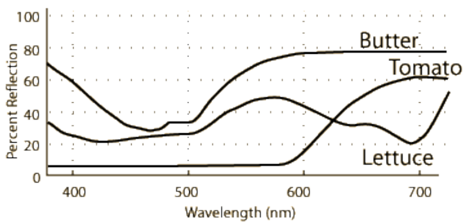
Introduction

- Each wavelength of light gives rise to a certain sensation of color.
- A light source emitting radiant energy, relatively balanced in all visible wavelengths, such as sunlight, will appear white to the eye.
- Any color can be imitated by a combination of no less than three suitable primary colors.
- A suitable set of primary colors usually chosen is red, green and blue.
- A beam of white light passing through a prism is dispersed into a color spectrum.



Surface Colors

- The perceived color, or color appearance, of a surface is the color of the light reflected from the surface.
- Certain wavelengths are more strongly reflected from a coloured surface than others, which are more strongly absorbed, giving the surface its color appearance.
- The color depends on both the spectral reflectance of the surface and the SPD of the light source. In order to see the color of the object, that color must be present in the spectrum of the light source used. One seemingly uniform color actually arises from a range of different wavelengths. As can be seen in the following figure, the red color of a tomato spans a range of wavelengths in the red region.



Source: Williamson and Cummins, Light and Color in Nature and Art

Color Properties of a Light Source

- The color properties of a light source depend on its SPD.
- The color properties of a light source are described by three quantities:
    - Chromaticity - or color temperature (CT).

- Color rendering index.
- Efficacy (lumen/watt).

Chromaticity or Color Temperature

- All objects will emit light if they are heated to a sufficiently high temperature.
- The chromaticity or color temperature of a light source describes the color appearance of the source.
- The correlated color temperature of a light source is the absolute temperature, in Kelvin (K), of a black-body radiator, having the same chromaticity as the light source.
- Sources with low color temperatures - below 3,000 K have a reddish or yellowish color, described as warm color.
- Sources with high color temperatures - above 4,000 K have a bluish color, described as cool color.
- Warm color is generally more acceptable at low lighting levels and cool color at high lighting levels.
- The color description and application is summarized as follows:
    - Below 3,000 K►warm►reddish►lower lighting levels.
    - Above 4,000 K►cool►bluish►higher lighting levels.

Color Temperature of Common Light Sources

Light Source	Color Temp (Deg K)	Description
Sky – extremely blue	25,000	cool
Sky – overcast	6,500	cool
Sunlight at noon	5,000	cool
LED – cool white	4,000	cool
Fluorescent – cool white	4,100	cool
Metal halide (400 W, clear)	4,300	cool
LED – warm white	3,000	warm
Fluorescent – warm white	3,000	warm
Incandescent (100 W)	2,900	warm
High Pressure Sodium (400 W, clear)	2,100	warm
Candle flame	1,800	warm
Low Pressure Sodium	1,740	warm

Color Rendering Index (CRI)

- Color rendering is a general expression for the effect of a light source on the color appearance of objects, compared with the effect produced by a reference or standard light source of the same correlated color temperature.
- The color rendering properties of a light source are expressed by the (CRI).
- The CRI is obtained as the mean value of measurements for a set of eight test colors.
- The CRI has a value between 0 and 100.
- A CRI of 100 indicates a light source, which renders colors as well as the reference source.
- The CRI is used to compare light sources of the same chromaticity (or color temperature).

- The CRI is used as a general indicator of color rendering: a higher CRI means a better color rendering.
- It is essential to understand that the CRI value has no reference to 'natural' light, although colors under a high CRI lamp will appear more natural.
- Energy Star requires a minimum CRI of 80 for fluorescent and LED lamps to receive the certification.

Color Rendering Description

CRI	Color Rendering Description
80-100	Excellent
60-75	Good
50-60	Fair
0-50	Poor (not suitable for color applications)

Color Rendering Index and Efficacy of Common Light Sources

The chart below shows the general range of CRI values for various light sources.

Category	CRI
Incandescent	+95
Mercury Vapor (HID)	20 to 45
Light Emitting Diode	50 to 95+
Fluorescent	60 to 90
Metal Halide (HID)	65 to 90
High Pressure Sodium (HID)	20 to 30 (60)
Low Pressure Sodium	N/A - Low
Induction	80 to 85
Plasma	70 to 85

Technology and Performance

- Incandescent lamps produce smooth, even SPD curves and outstanding CRI values.
- Halogen versions of incandescent lamps produce whiter light with +95 CRI.
- Today's best LED lamps can produce white light with +95 CRI.
- With gaseous discharge technology, color characteristics are modified by the mixture of gases and by the use of phosphor coatings.
- HID lamps are chosen mostly for their exceptional energy efficiency; metal halide versions have acceptable CRI levels.

Application Notes

- Warm color light is associated with indoors, nighttime and heat, and fits better indoors and in cool environments.
- Warm color light makes warm color objects (red-yellow colors) look richer.
- Cool color light is associated with outdoors, daytime and cold, and fits better in warm environments.
- Cool color light mixes better with daylight (daytime lighting).
- Cool color light makes cool color objects (blue-green colors) look refreshing.
- Matching a light source color with room objects' color (interior decoration).
- Sources with high CRI cause the least emphasis or distortion of color.

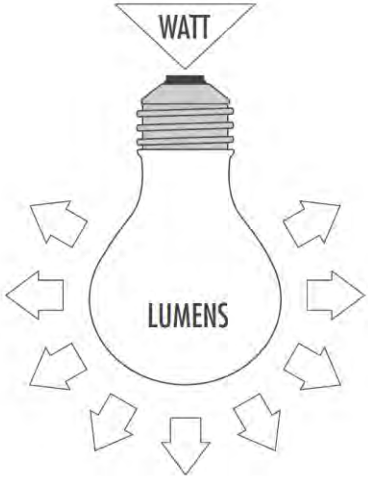
e. Lighting Quantities and Units

Luminous Flux or Light Output

- The luminous flux, or light output, is roughly defined as the total quantity of light emitted per second by a light source.
- Sensitivity of the human eye varies, reaching its maximum at a wavelength of 555 nm during daytime (photopic vision) and 507 nm for night vision (scotopic vision).
- The unit of luminous flux is the lumen (lm).
- The lumen is defined as the luminous flux associated with a radiant flux of 1/683 W at a wavelength of 555 nm in air.
- Lamp Lumens (lm) = the quantity of light emitted by a light source.

Luminous Efficacy

- The most important characteristic of a lamp, from an energy viewpoint, is its ability to convert electrical energy into light.
- The luminous efficacy of a light source is defined as the ratio of the light output (lumens) to the energy input (watts). It is expressed in lumens per watt.
- The efficacy is measured in lumens per watt (lm/W).
- The efficacy of different light sources varies dramatically; from less than 10 lumens per watt, to more than 200 lumens per watt.



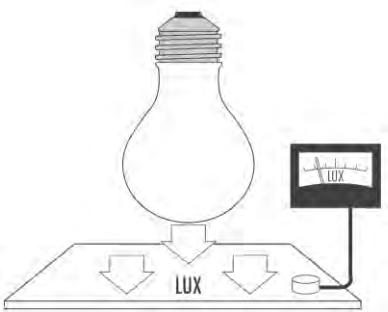
Efficacy of Common Light Sources

The chart below shows the general range of efficacy for various light sources.

Category	Efficacy (Lumen/Watt)
Incandescent	10 to 35
Mercury Vapor (HID)	30 to 80
Light Emitting Diode	40 to 150
Fluorescent	40 to 100
Metal Halide (HID)	50 to 115
High Pressure Sodium (HID)	85 to 150
Low Pressure Sodium	100 to 200
Induction	50 to 100
Plasma	70 to 150

Luminous Flux Density or Lighting Level

- The luminous flux density at a point on a surface is defined as the luminous flux per unit area.
- The luminous flux density is also known as the illuminance, or quantity of light on a surface, or lighting level.
- The SI unit of the lighting level is the lux (lx), $1\ lx = 1\ lm/m^2$.
- When measurement is in imperial units, the unit for the lighting level is the foot candle (fc): $1\ fc = 1\ lm/ft^2$.
- The relation between the fc and lux is 1 fc = 10.76 lux.
- This is the same relationship as the one between square meters and square feet: $1\ m^2 = 10.76\ ft^2$.
- The lighting level is measured by a photometer, as shown in the figure below.
- Minimum recommended lighting levels for different tasks are included below.
- Lux = the unit of illuminance at a point of a surface.
- Lux = lumens/area.



f. Lighting Levels

Light level, or more correctly, illuminance level, can be easily measured using an illuminance meter. Illuminance is the light energy striking a surface. It is measured in lux (SI) or foot candles (imperial). The Illuminating Engineering Society of North America (IESNA) publishes tables with recommended illuminance levels for all possible applications, as well as guidelines on how to adjust the illuminance level according to the room characteristics and occupant needs.

Recommendations for lighting levels can be found in the most recent edition of the IESNA Lighting Handbook. The IESNA (www.ies.org) is a recognized technical authority on illumination.

The data and figures given in the following tables are approximate and describe common and typical applications.

Lighting Levels by Visual Task

Type of Visual Task	Lighting Level fc	Lighting Level Lux	Comments
Tasks occasionally performed	3	30	Orientation & Simple Visual Tasks
Simple orientation/short visits	5	50	Orientation & Simple Visual Tasks
Working spaces/simple tasks	10	100	Orientation & Simple Visual Tasks
High contrast/large size	30	300	Common Visual Tasks
High contrast/small size or inverse	50	500	Common Visual Tasks
Low contrast/small size	100	1,000	Common Visual Tasks
Task near threshold	300-1,000	3,000-10,000	Special Visual Tasks

Examples of Lighting Levels by Building Area and Task

Building Area and Task	Lighting Level fc	lux	Comments
Auditoriums	10	100	Include provision for higher levels
Banks – Tellers' Station	50	500	
Barber Shops	50	500	
Bathrooms	30	300	
Building Entrances (Active)	5	50	
Cashiers	30	300	
Conference Rooms	30	300	Plus task lighting
Corridors	5	50	
Dance Halls	5	50	
Drafting – High Contrast	50	500	
Drafting – Low Contrast	100	1,000	
Elevators	5	50	
Exhibition Halls	10	100	Include provision for higher levels
Floodlighting – Bright Surroundings (Vertical)	5	50	Less for light surfaces – more for dark
Floodlighting – Dark Surroundings (Vertical)	3	30	Less for light surfaces – more for dark
Hospitals – Examination Rooms	50	500	High color rendition
Hospital – Operating Rooms	300	3,000	Variable (dimming or switching)
Kitchen	50	500	
Laundry	30	300	
Lobbies	10	100	
Office – General	30	300	
Parking Areas – Covered	2	20	Lower at night
Parking Areas – Open	0.2	2	Higher for enhanced security
Reading/Writing	50	500	Varies with task difficulty
Restaurant - Dining	10	100	
Stairways	5	50	
Stores – Sales Area	30	300	
Streetlighting – Highways	0.9	9	Varies with traffic density
Streetlighting - Roadways	0.7	7	Varies with traffic & pedestrian density

Lighting Level Adjustment

Under certain circumstances, a reduction in recommended level can be accepted depending on factors such as the age of the occupants or the required accuracy of the task performed in the area. These same factors may also require an increase in lighting level. Some examples of factors and the criteria under which lighting level should be reduced or increased are presented in the following table.

Factor	Reduce Lighting Level by 30 %	Increase Lighting Level by 30 %
Reflectance of task background	Greater than 70 %	Less than 70 %
Speed or accuracy	Not important	Critical
Workers' age	Under 40	Over 55

It is important to be aware that the *illuminance level is not directly related to lighting quality*. In other words, it is entirely possible to experience strong visual discomfort in a location despite the recommended illuminance level having been already installed. Factors such as glare and light distribution are no less important than the illuminance level. Quite often, these two factors are responsible for many issues with either excessive or inadequate light.

Areas of high brightness right next to areas of low brightness cause glare, making people uncomfortable. When using daylight as a lighting source, it is quite often necessary to control glare, since direct sunlight is very bright. Light distribution is of two kinds: ambient lighting and task lighting. Modern light control methods can serve multiple purposes, including: providing uniform illumination, eliminating excessive and unnecessary light concentration beneath the luminaire, eliminating light pollution through backlight or up-light, and providing exceptional thermal management.

Illuminance uniformity is another important factor. The uniformity ratio is the ratio of the minimum illuminance to the average illuminance on a plane, and low uniformity ratios must be avoided. The frequent changes of contrasting high-lit and low-lit surfaces cause eye discomfort, leading to stress and tiredness.

5 LIGHT GENERATION

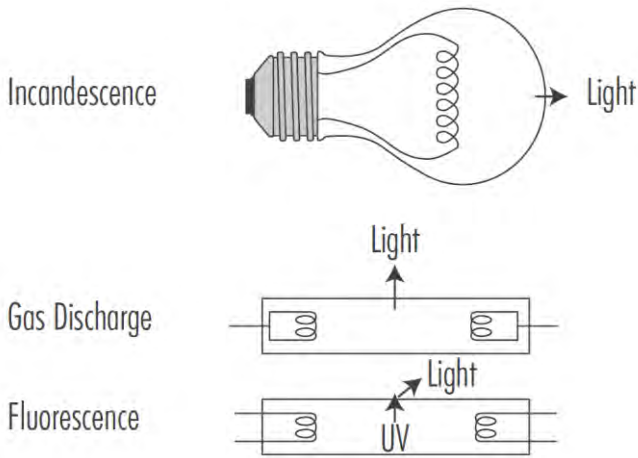
a. Light Sources

Introduction

Many different processes convert energy into visible radiation (light).

Some basic processes are described below.

Generation of Light



Incandescence

- Solids and liquids emit visible radiation when they are heated to temperatures above 1,000 K.
- The intensity increases and the appearance becomes whiter as the temperature increases.
- This phenomenon is known as incandescence or temperature radiation.
- Application: Standard incandescent lamps, tungsten halogen lamps, IR halogen lamps, and infrared heat lamps.

Luminescence

- Luminescence is the emission of light not ascribed directly to incandescence.
- Two important types of luminescence are electric or gas discharge, and fluorescence.

Electric or Gas Discharge

- When an electric current passes through a gas, the atoms and molecules emit radiation, whose spectrum is characteristic of the elements present.
- In low pressure discharge, the gas pressure is approximately 1/100 atm or 0.147 PSI.
- In high pressure discharge, the gas pressure is approximately 1 to 2 atm or 14.7 to 29.4 PSI.
- Application: Metal halide lamps, high-pressure and low-pressure sodium lamps, and mercury vapor lamps.

Fluorescence

- Radiation at one wavelength is absorbed, usually by a solid, and is re-emitted at a different wavelength.
- When the re-emitted radiation is visible and the emission happens only during the absorption time, the phenomenon is called fluorescence.
- If the emission continues after the excitation, the phenomenon is called phosphorescence.
- In the fluorescent lamp, the ultraviolet radiation resulting from the gas discharge is converted into visible radiation by a phosphor coating on the inside of the tube.
- Application: T12, T10, T8 and T5 lamps, compact fluorescent lamps, and phosphor-coated HID lamps.

Electroluminescence

- Electroluminescence is the emission of light when low voltage direct current is applied to a semi-conductor device containing a crystal and a p-n junction.
- The most common electroluminescent device is the LED.

Induction

- A gas submitted to a radio frequency magnetic field is excited and emits ultraviolet radiation.
- Visible light is emitted by fluorescence when induction generated UV radiation is re-emitted at a different wavelength when it passes through a phosphor coating.

b. Lamp Types

Definition

An electric lamp is a device converting electric energy into light.

Lamp Types by Light Generation Method

- Incandescent lamps
    - Standard incandescent lamps
    - Tungsten halogen lamps
    - IR halogen lamps
    - Infrared heat lamps
- Gas discharge lamps
    - Low pressure discharge
        - Fluorescent lamps
        - Compact fluorescent lamps
        - Cold-cathode fluorescent lamps
        - Induction lamps
        - Low pressure sodium (LPS) lamps
    - High pressure or HID
        - Mercury vapour (MV) lamps
        - Metal halide (MH) lamps
        - High pressure sodium (HPS) lamps
    - Plasma lamps
- Electroluminescent lamps
    - LEDs
    - Organic LEDs
- Electron-stimulated lamps

Lamp Types by Standard Classification

- Incandescent lamps
- Halogen lamps
- Compact fluorescent lamps
- Fluorescent lamps
- HID lamps
    - Mercury vapour (MV) lamps
    - Metal halide (MH) lamps
    - High pressure sodium (HPS) lamps
- Low pressure sodium (LPS) lamps
- Plasma lamps
- LED sources
- Induction lamps
- Electron-stimulated lamps

Lamp Efficacy or Efficiency

The efficacy of the various types of lamps is shown below:

Category	Efficacy (Lumen/watt)	Rated Average Life (hours)
Incandescent	10 to 35	1,000 to 4,000
Mercury Vapour (HID)	30 to 80	24,000+
Light Emitting Diode	40 to 150	See below
Fluorescent	45 to 100	6,000 to 30,000
Metal Halide (HID)	65 to 115	6,000 to 20,000
High-pressure Sodium (HID)	85 to 150	24,000 to 80,000
Low-pressure Sodium	100 to 200	18,000
Induction	50 to 100	60,000 to 100,000
Plasma	70 to 150	3,000 to 50,000

Rated Average Life

- Rated average life is the total operated hours when 50 % of a large group of lamps still survive; it allows for individual lamps to vary considerably from the average.
- Incandescent lamp life can be extended by the use of dimming to reduce maximum power.
- Compact fluorescent lamps have relatively long lives of about 10,000 hours.
- Gas discharge lamps have long lives of about 20,000 hours or more.
- The lifespan of LED sources is based on lumen maintenance criterion that compares the light output from a brand new luminaire to the amount of light output in the future. Lumen maintenance can be specified as L50, L70, L80 or L90. The number represents the percentage of light output remaining. This methodology is used by most manufacturers, and L70 is generally established as the accepted lifespan, which means that when the lamp has lost 30 % of its original output, it is considered failed. Lifespan of LED sources range from 10,000 to 100,000 hours.

c. Lighting Systems

Lighting Unit or Luminaire

The following is a list of the basic components of a luminaire:

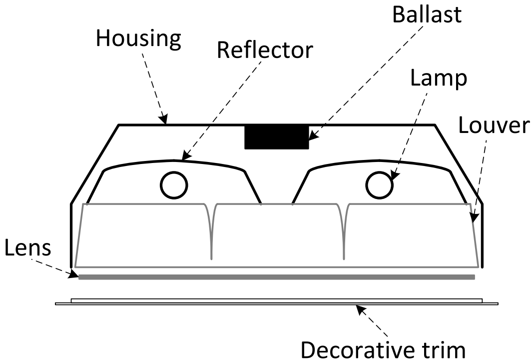
- Lamp or lamps
- Ballast (for gas discharge lamps)
- Driver (for LED)
- Fixture or housing
- Internal wiring and sockets
- Optics (relfectors, lens, diffusers)
- Mounting hardware

The lamps generate light. Descriptions of various available lamp types are given in Chapter 6.

The housing holds and protects the components of the lighting system from the environment. This part of the luminaire can also help dissipate heat generated by lamps. Electrical wiring is required to connect lamps to a power supply, and lamps are connected by wiring into the sockets. Mounting hardware is used to install the luminaire on a wall or a ceiling. A ballast may be required to provide the right electrical operating conditions (see Chapter 6, Section B). For LED, a driver is required to supply a constant amount of power to the LED, as its electrical properties change with temperature. A luminaire can also contain a reflector and a lens or a louver to optimize and achieve the right light distribution.

Illustration of Some Components of a Luminaire

The following figure illustrates some typical components of a luminaire equipped with fluorescent tubes.



Lighting System

A typical lighting system consists of:

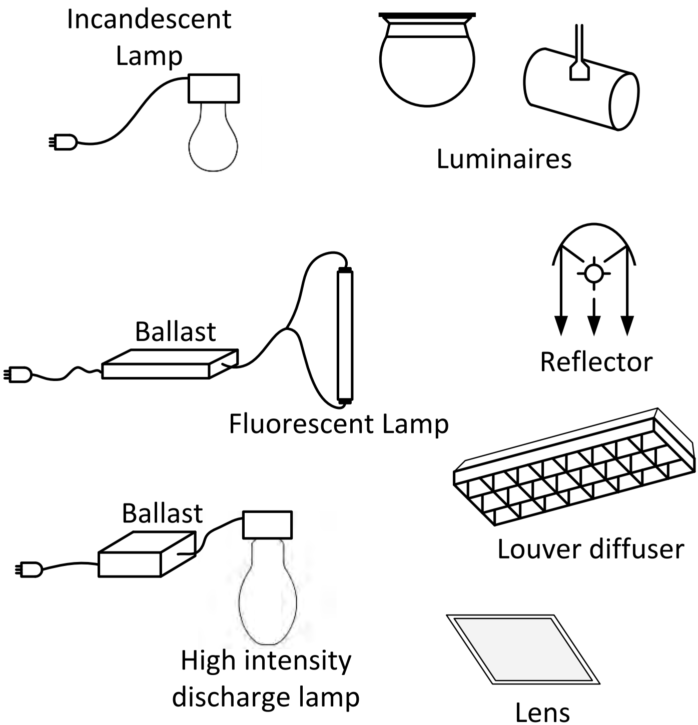
- Luminaires
- Lighting control system(s)

Lighting System Environment

A lighting system environment consists of:

- Room (ceiling, wall, floor)
- Room objects

Lighting System Illustration



6 LIGHTING TECHNOLOGIES

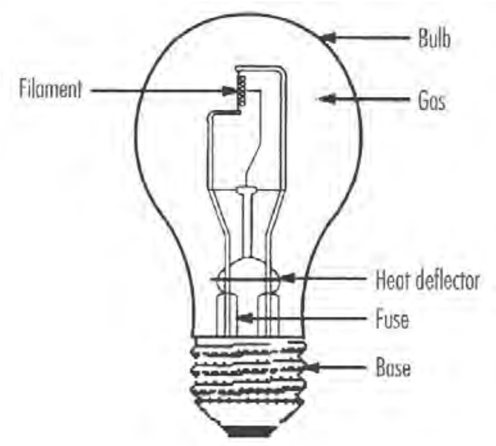
a. Incandescent Lamps

Standard Incandescent Lamps

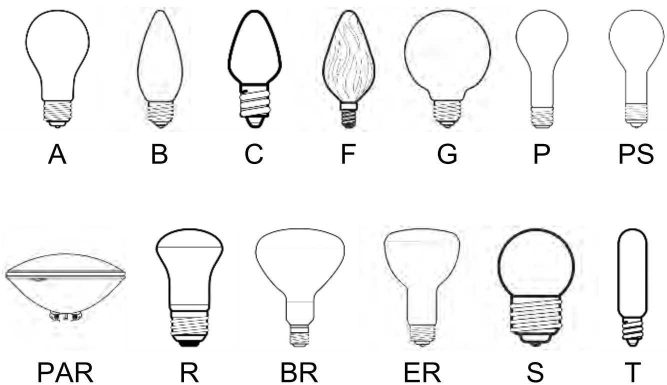
Construction

- A typical construction of an incandescent lamp is shown in the figure on the next page.
- An incandescent lamp produces light by using electric current to heat a metallic filament to a high temperature (around 2,200°C/4,000 F).
- A tungsten filament is used because of its high melting point and low rate of evaporation at high temperatures.
- The filament is coiled to shorten the overall length and to reduce thermal loss.
- The filament is enclosed in a glass bulb filled with inert gas at low pressure.
- The inert gas permits operation at higher temperatures, compared to vacuum, resulting in a smaller evaporation rate of the filament.
- The bulbs are often frosted on the inside to provide a diffused light instead of the glaring brightness of the unconcealed filament.

Typical Construction of an Incandescent Lamp



Shapes and Designation



(Source: GE Lighting Product Catalog)

Shape Code

A	Arbitrary (standard)	Universal use for home lighting
B	Bullet	Decorative
BR	Bulging reflector	For substitution of incandescent R lamps
C	Cone shape	Used mostly for small appliances and indicator lamps
ER	Elliptical reflector	For substitution of incandescent R lamps
F	Flame	Decorative interior lighting
G	Globe	Ornamental lighting and some floodlights
P	Pear	Standard for streetcar and locomotive headlights
PAR	Parabolic aluminized	Used in spotlights and floodlights reflector
S	Straight	Lower wattage lamps - sign and decorative
T	Tubular	Showcase and appliance lighting

Lamp Designation

A lamp designation consists of a number to indicate the wattage, a shape code, and a number to indicate the approximate major diameter.

Example: 60A19
60: Wattage (60 W)
A: Bulb shape
19: Maximum bulb diameter, in eighths of an inch.

Characteristics

Colour rendering index	- 97 and higher (CRI) - Excellent CRI
Colour temperature	- 2,500 to 3,000 K - Warm color
Luminous efficacy	- 10 to 35 lumens per watt - Lowest efficacy of all light sources - High power lamps have higher efficacy than less powerful ones
Lamp life (hours)	- 1,000 to 4,000 (typical 1,000) - Shortest life of all light sources - Longer life lamps have lower efficacy
General	- First developed and most common lamps
Lamp configuration	- Point source
Lamp watts	- 1 to 1,500 W
Lamp lumen	- 80 % to 90 lamp lumen depreciation factor (LLD)
Warm-up time	- Instant
Restrike time	- Instant
Lamp cost	- Low - Lowest initial cost - Highest operating cost
Main applications	- Residential - Merchandising display lighting

Legislation and Phase-out of Incandescent Lamps

The Government of Canada established new energy efficiency regulations in order to phase out the use of inefficient light bulbs. This standard, which will take effect in 2014, will set out minimum performance levels for bulbs imported to Canada, thereby resulting in the phase-out of screw-based general-service incandescent light bulbs ranging from 40 to 100 watts.

Other countries have developed or are developing similar standards aimed at eliminating inefficient incandescent light bulbs from the market. The United States has established standards that set out maximum wattage requirements for all general-service lamps of 40 to 100 watts producing between 310 and 2,600 lumens. Individual states are also making efforts to phase out inefficient incandescent lamps from the market.

More Information

- Refer to lamp manufacturers' catalogs.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp (Deg K)	LLD
Standard								
25 A 19	25	1,000	270	10.8			2,550	0.79
40 A 19	40	1,000	510	12.8			2,650	0.87
60 A 19	60	1,000	855	14.3			2,790	0.93
100 A 19	100	1,000	1,650	16.5	1,535	15.4	2,870	0.90
150 A 23	150	1,000	2,780	18.5	2,585	17.2	2,925	0.89
200 PS 30	200	1,000	3,400	17.0			2,925	0.85
300 PS 30	300	1,000	5,720	19.1	5,205	17.4	3,000	0.82
500 PS 35	500	1,000	10,750	21.5	9,783	19.6	3,050	0.89
1000 PS 52	1,000	1,000	23,100	23.1	21,252	21.3	3,030	0.89
1000 PS 52	1,500	1,000	33,620	22.4	28,241	18.8	3,070	0.78
R Lamps								
30 R 20	30	2,000	200	6.7				
50 R 20	50	2,000	320	6.4				
75 R 20	75	2,000	500	6.7				
BR & ER Lamps								
50 ER 30	50	2,000	320	6.4				
75 ER 30	75	2,000	580	7.7				
120 ER 40	120	2,000	1,475	12.3				
PAR Lamps								
65 PAR 38	65	2,000	765	11.8				
75 PAR 38	75	2,000	1,040	13.9				
120 PAR 38	120	2,000	1,370	11.4				
150 PAR 38	150	2,000	1,740	11.6	1,462	9.7		0.78
200 PAR 46	200	2,000	2,300	11.5				
300 PAR 56	300	2,000	3,840	12.8				
500 PAR 64	500	2,000	6,500	13.0				

Notes:

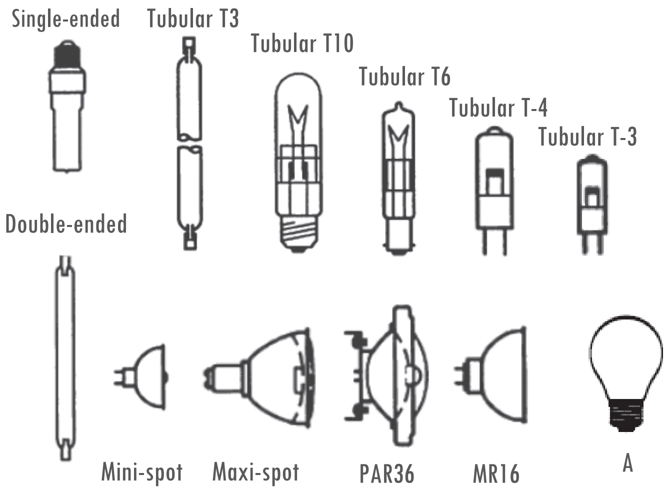
- CRI for incandescent bulbs is typically 97.
- The lamp charts throughout are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

Tungsten Halogen Lamps

Construction

- The quartz tungsten halogen lamp is another type of incandescent lamp.
- The conventional incandescent lamp loses filament material by evaporation which is deposited on the bulb wall, leading to bulb blackening and reduced lamp efficacy during the life of the lamp.
- When a halogen element is added to the filling gas under certain design conditions, a chemical reaction occurs, as a result of which evaporated tungsten is re-deposited on the filament, preventing any deposits on the bulb wall.
- The bulb of the tungsten halogen lamp is normally made of quartz glass to withstand the lamp's high-temperature operating conditions.
- The fixture often incorporates a reflector for better heat dissipation and beam control.

Shapes and Designation



Shape Code

Tubular T3	Line voltage tungsten halogen lamp - double-ended
Tubular T10	Line voltage tungsten halogen lamp - single-ended
Tubular T6	Line voltage tungsten halogen lamp - single-ended
Tubular T-4	Line voltage tungsten halogen lamp - without reflector
Tubular T-3	Low voltage tungsten halogen lamp - without reflector
Maxi-spot	Low voltage tungsten halogen lamp - with reflector

Mini-spot	Low voltage tungsten halogen lamp - with reflector
PAR 36	Low voltage tungsten halogen lamp - PAR36 reflector
MR16	Low voltage tungsten halogen lamp - MR16 reflector
A	A-Line – Universal use for home lighting

Low Voltage Tungsten Halogen

- Operates at low voltage - mainly 12 V.
- Each fixture includes a transformer - supplying the low voltage to the lamp and is compact in size.
- These are more efficient than standard incandescent bulbs; around 40 % more efficient for a similar output.
- These have longer life than standard incandescent; up to 4,000 hours.
- These are used mainly for display lighting.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp (Deg K)	LLD
A-Line								
29 A 19	29	1,000			380	13.1	2,900	
43 A 19	43	1,000			750	17.4	2,900	
53 A 19	53	1,000			1,050	19.7	2,900	
72 A 19	72	1,000			1,490	20.7	2,900	
Tubular								
25 T 4	25	2,000			255	10.2	2,900	
60 T 4	60	2,000			830	13.8	2,900	
75 T 10	75	2,000			1,100	14.7	2,900	
100 T3	100	2,000			1,600	16	2,950	
230 T 10	230	2,000			4,200	18.3	2,900	
500 T 4	500	2,000			10,450	21	2,950	
1500 T 3	1,500	2,000			33,000	22	2,950	
Single-Ended Quartz								
Q 75 CL	75	2,000	1,400	18.7				
Q 100 CL	100	750	1,800	18.0			3,000	
Q 150 CL/DC	150	1,000	2,800	18.7	2,688	17.9	2,850	0.96
Q 250 CL/DC	250	2,000	5,000	20.0	4,850	19.4	2,950	0.97
Q 400 CL/MC	400	2,000	8,250	20.6			2,950	
Q 500 CL/DC	500	2,000	10,450	20.9			2,950	
Double-Ended Quartz								
Q 200 T3/CL	200	1,500	3,460	17.3			2,850	0.96
Q 300 T3/CL	300	2,000	5,950	19.8			2,950	0.96
Q 400 T4/CL	400	2,000	7,750	19.4			2,950	0.96
Q 500 T3/CL	550	2,000	11,100	22.2	10,767	21.5	3,000	0.96
Q 1000 T6/CL	1,00	2,000	23,400	23.4			3,050	0.96
Q 1500 T3/CL	1,500	2,000	35,800	23.9	34,726	23.2	3,050	0.96
Low Voltage MR Types								
20MR16FL	20W	4,000	700	CBCP				
50MR16FL	50W	4,000	2,000	CBCP				
65MR16FL	65W	4,000	2,100	CBCP				

Notes :

- CRI for tungsten halogen lamps is slightly better than other incandescent lamps.
- CBCP = Centre Beam Candle Power, used instead of lumens with the low voltage reflector lamps.
- The lamp charts throughout are intended for comparison purposes only; please refer to the most recent

lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

Halogen PAR Lamps

General Description

- Halogen PAR lamps are lamps with a Parabolic Aluminum Reflector (PAR) which use a halogen capsule instead of a simple filament.
- The halogen capsule includes a tungsten filament and halogen gas.

PAR Lamp Families

- PAR lamps have evolved into four families, listed below, from lowest to highest efficiency:
    - Standard PAR lamps
    - Energy saving PAR lamps
    - Halogen PAR lamps
    - Infra Red (IR) halogen PAR lamps
- All PAR lamps have an aluminum or silver coating reflector on part of the bulb's surface.
- PAR lamps are used for directional lighting, i.e., highlighting or spot lighting.
- The most common size is the PAR38.
- Other sizes include PAR30, PAR20 and PAR16.
- Beam spreads are described as narrow spot (NS), spot (SP) and flood (FL).

Standard PAR Lamps:

- Use a tungsten filament but no halogen gas, i.e., no halogen capsule.
- Lamp watts: 75 W, 100 W, 150 W.
- Life: 2,000 hours.

Halogen PAR Lamps:

- Halogen PAR lamps use a halogen capsule instead of a tungsten filament.
- Lamp watts: 45 W, 65 W, 90 W.
- Life: 2,000 hours.

PAR 38 Lamp Replacements

	Standard PAR	Energy Saving PAR	Halogen PAR	IR Halogen PAR
	75	55, 65	45	-
Lamp rated power (watt)	100	80, 85	-	-
	150	120	90	60
Life (hrs)	2,000	2,000	2,000	2,000
Energy	-	20 % less	40 % less	60 % less
Lumen	-	same	same	Same
Color	-	same	Whiter	Whiter
GE Brand	PAR	Watt-Miser PAR	Halogen Performance Plus PAR	Halogen IR-PAR
Phillips Brand	PAR	Econ-O-PAR	Masterline	-
Sylvania Brand	PAR	Super Saver	Capsylite	-

Notes:

- Replacements provide about the same light beam candlepower around the center of the beam.
- The standard PAR is used as a basis for the comparisons shown in the table.

Applications

Highlighting merchandise in stores and window displays:

- Downlights
- Accent lighting
- Outdoor lighting

Advantages

Halogen PAR lamps have many advantages over standard and energy saving PAR lamps:

- Energy savings in the order of 40 % - 60 %.
- Whiter light.
- Constant light output throughout lamp life without lamp darkening.

Limitations

Halogen PAR lamps are more expensive than standard and energy saving PAR.

Assessment

- Halogen PAR lamps provide energy savings which outweigh the lamp price difference in less than a year.
- Halogen PAR lamps provide better quality light.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp (Deg K)	LLD
				PAR Quartz				
Q90 PAR38	90	2,000	1,740	19.3				0.96
Q150 PAR38	140	4,000	2,000	13.3	1,900	12.7	2,900	
Q250 PAR38	250	6,000	3,220	12.9			2,900	
Q500 PAR56	500	4,000	7,000	14.0			2,950	
Q1000 PAR38	1,000	4,000	19,400	19.4			3,000	

Note:
The lamp charts throughout are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers availability.

IR Halogen Lamps

- IR halogen lamps use a visually transparent infrared (IR) coating film on the capsule or bulb's surface that reflects heat back to the filament, making the lamp more efficient.

- Available in A-shape bulbs and PAR.
- These lamps are the most efficient incandescent lamps.
- Lamp lumens: 720 lm, 970 lm, 1,120 lm, 2,200 lm and more.
- Life: 3,000 to 6,000 hours.
- Excellent replacement for standard incandescent lamps.

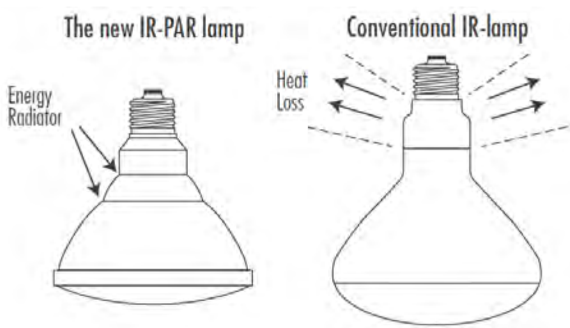
The following table compares standard incandescent, halogen and halogen IR lamps.

Lamp Type	Lamp Designation	Lamp Watts	Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt
PAR					
Standard incandescent PAR	150 PAR 38	150	2,000	1,700	11.3
Halogen PAR lamp	120 PAR 38	120	1,900	1,900	15.8
Halogen IR PAR lamp	90 PAR 38	90	4,000	2,030	22.5
A-Line					
Standard incandescent	100 A 19	100	750	1,600	16.0
Halogen	72 A 19	72	1,000	1,490	20.7
IR Halogen	70 A 19	70	3,000	1,600	22.9

Infrared Heat Lamps

General Description

Infrared heat lamps, also known as IR lamps, or simply heat lamps, are specially-designed incandescent lamps which produce mostly heat and little light.



- The Energy Radiator reflects the heat forward.
- Higher heat loss than the conventional (Soft Glass) IR lamp.
- Skirted PAR lamp base for increased support.

Types

- There are two basic types:
  - PAR type - i.e., parabolic aluminum reflector lamps.
  - R type - i.e., reflector type lamps.
- PAR type lamps are newer and more efficient. They include the following sizes:
  - 175 W PAR 38.
  - 100 W PAR 38.
- R type lamps are older and have been used more extensively. They include the following sizes:
  - 250 W R40.
  - 175 W R40.
  - 150 W R40.
- The 250 W R40 lamp is presently the most widely-used heat lamp in the market.
- Most infrared heat lamps have a red front glass, but lamps with clear white glass are also available.

PAR Lamps Can Replace R Lamps

- PAR lamps can replace higher wattage R lamps with an equivalent heat output.
- Typical replacements:
  - 175 W PAR can replace 250 W R lamp.
  - 100 W PAR can replace 175 W and 150 W R lamps.
- The parameters used to compare the two types of lamps are listed in the following table.

Technical Data

Lamp Type	Input Power (W)	Heat Output (W)	Heat Lamp Efficiency (%)	0° to 30° Heat Output (W)	Expected lifetime (hours)
175 W PAR	175	115	65.7	74	5,000
100 W PAR	100	65	65.0	42	5,000
250 W R	250	144	57.6	78	5,000
175 W R	175	95	54.3	46	5,000
150 W R	150				5,000

- Heat output is the useful heat available i.e., heat produced in an angle of 90° around the lamp axis in the front hemisphere.
- Heat lamp efficiency is defined as the ratio of the heat output over the nominal input wattage.
- Heat output in the 0° to 30° zone is the heat output near the centre axis of the lamp.

175 W PAR Lamps Can Replace 250 W R Lamps

- Replacement results in 30 % energy savings (75 W).
- Heat output is reduced by 29 W.

100 W PAR Lamps Can Replace 175 W R Lamps

- Replacement results in 43 % energy savings (75 W).
- Heat output is reduced by 30 W.

Applications

- Farm animal heating.
- Restaurants also use them for keeping food warm.

Assessment

PAR heat lamps offer a more efficient and overall better alternative to R type heat lamps.

b. Lamp Ballasts

Ballast – General Information

Definition

A ballast is a device used with a gas discharge lamp to provide the necessary starting and operating electrical conditions.

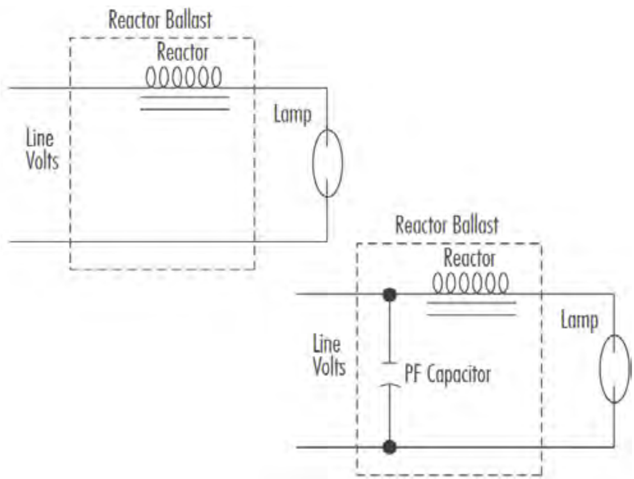
Function

- The ballast supplies the right voltage to start and operate the lamp.
- The ballast limits current to a gas discharge lamp during operation - the resistance of a gas discharge lamp becomes negligible once the arc has been struck.
- The ballast prevents any voltage or current fluctuations caused by the arc discharge from reflecting into the line circuit.
- The ballast compensates for the low power factor characteristic of the arc discharge.

Ballast Construction

- A simple standard ballast is a core and coil assembly.
- The core is made of laminated transformer steel.
- The coil consists of copper or aluminum wire which is wound around the core.
- The core-coil assembly is impregnated with a non-conductor to provide electrical insulation and aid in heat dissipation.
- Capacitors may be included in the ballast circuit to assist in providing sufficient voltage, start the lamp, and/or correct the power factor.
- Some ballasts are housed inside the lighting fixture.

Simple Ballast Illustrations



Ballast Losses

- A ballast, as an electric circuit, has electric energy losses.
- Ballast losses are obtained from catalogs of ballast manufacturers.
- Energy efficient ballasts have lower losses.

Types

- Basic types of ballasts based on ballast construction and efficiency are:
    - Energy efficient ballasts (core-coil magnetic).
    - Electronic ballasts (solid-state).
    - Standard magnetic ballast (core-coil design).
- Ballasts are also classified by the type and function of their electric circuit.
- Each ballast is designed to be used with a specific type and size (wattage) of lamp.
- The lamp type and size compatible with the ballast are listed on the ballast label.

Standards

- Ballasts should meet ANSI (American National Standards Institute) specifications for proper lamp performance. The Canadian standard for ballast efficiency is CAN/CSA-C654-M91 Fluorescent Lamp Ballast Efficacy Measurements.
- The CBMA (Certified Ballast Manufacturers Association) label indicates that the ballast has been tested and meets ANSI specifications.

- The UL (Underwriters Laboratories) label indicates that the ballast has been tested and meets UL safety criteria (US standard) as well as the Canadian CAN/CSA-C654-M91 criteria.
- The CSA (Canadian Standards Association) label indicates that the ballast has been tested and meets CSA safety criteria.
- Under the North American Free Trade Agreement, both UL and CSA can certify electrical products for sale in both countries.

Thermal Protection

- The NEC (US National Electrical Code) and the Canadian Electrical Code require that all indoor ballasts must be thermally protected.
- This is accomplished by a thermal switch in the ballast which turns power off above a maximum temperature (1050°C approximately).
- Ballasts meeting this standard for protection are designated Class P.
- A cycling ballast, which turns power off and on, indicates an overheating problem.

Sound Ratings

- All core-coil ballasts produce a sound commonly described as a “hum”.
- Manufacturers give the ballasts a sound rating from A to F.
- An A ballast produces the least hum, and should be used in quiet areas (offices and homes).

- An F ballast produces the most audible hum, and may be used in places where noise is acceptable (factories, outdoors).

Ballast Life

- Most ballasts are designed for about 50,000 hours under standard conditions.
- If ballast and lamp heat is not dissipated properly, ballast life is reduced.
- An 8-10˚C increase over rated temperature on the case will cut ballast life in half.
- Ballasts are rated typically for 75˚C. 90˚C ballasts are a special design called "Extreme Temp". Some manufacturers list 8˚C instead of 10˚C.
- Similarly, a 100˚C decrease will approximately double ballast life.

Ballast Factor

The ballast factor defines the light output produced by a given fixture in lumens in comparison with the light output by a reference ballast in the laboratory. This factor must not be neglected when designing the lighting system. A ballast with a low ballast factor may generate energy savings but will produce less light.

Ballast Consumption

Ballast consumption is the electric power consumed by the ballast to start and operate lamps. It is equivalent to ballast losses.

Lamp Consumption

Lamp consumption is the actual electric power consumed by the lamp only.

Fixture Consumption

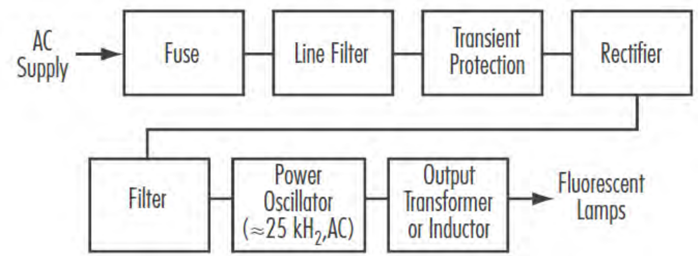
Total consumption of a fixture is the sum of tube consumption and ballast consumption.

Ballast Luminous Efficiency

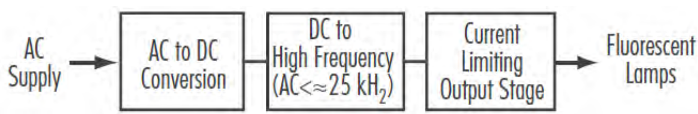
Ballast luminous efficiency (BLE) is the total fluorescent arc power divided by the ballast input power. BLE allows efficiency comparisons to be made across ballasts regardless of the ballast type or the number of lamps the ballast operates.

Electronic Ballasts for Gas Discharge Lamps

Typical Circuit Component Diagram



Functional Block Diagram



Notes

- Some ballasts have fewer components.
- Some ballasts have components to reduce total harmonic distortion, improve power factor and provide thermal protection.

General Description

- A rapid start ballast starts one or more gas discharge lamps by first heating the electrodes of the lamps to the proper electron emission temperature before initiating the arc.
- An instant start ballast does not preheat the electrodes but initiates the arc by a higher starting voltage.
- A modified start ballast starts the lamp in the same way as the rapid start ballast. It then reduces or cuts off the electrode heating voltage after the lamp arc has stabilized.
- Both types of ballast stabilize the arc by limiting the current to proper levels.
- Older technology (i.e., electromagnetic) ballasts are made of laminated cores wound with copper or aluminum wires; some have capacitors to control voltage and/or to correct power factor.
- Electromagnetic ballasts operate the lamps at line frequency, 60 Hz.
- Electronic ballasts for fluorescent lamps have electronic or solid-state components.
- Electronic ballasts operate the lamps at a high current frequency, typically from 25-50 kHz.
- Electronic ballasts are available in rapid start, instant start and 'program start' modes.

- Operation of rapid start lamps by instant start or modified start ballasts can potentially shorten lamp life if combined with other control technologies such as occupancy sensors. Refer to the ballast and lamp manufacturers' data.
- In comparison with the electromagnetic ballast, the electronic ballast weighs less, operates at lower temperatures and at a lower noise level, and is more energy efficient, but costs more.
- It is essential to match the electrical characteristics of both lamps and ballasts.

Technical Data

- Models are available for one-lamp, two-lamp, three-lamp or four-lamp fixtures.
- Available in 120 volts, 277 volts and 347 volts. Some ballasts are now available for universal voltage, i.e., 120 V to 277 V, and less common voltages such as 240 V.
- Some electronic ballasts are dimmable.
- The efficacy of electronic ballasts is 21 % to 43 % better than electromagnetic ballasts.
- Total harmonic distortion (THD) indicates the strength of electromagnetic noise generated.
- Lower ballast temperature means lower electrical losses and a smaller cooling load.

Power Factor

- Power factor can be calculated by two methods:
    - Wattage (W), voltage (V) and current (I).
    - Wattage (W) and reactive power (VAR).

- If calculated correctly – the results should be the same using both methods.

Rated Average Life

Ballasts are designed to operate for about 50,000 hours.

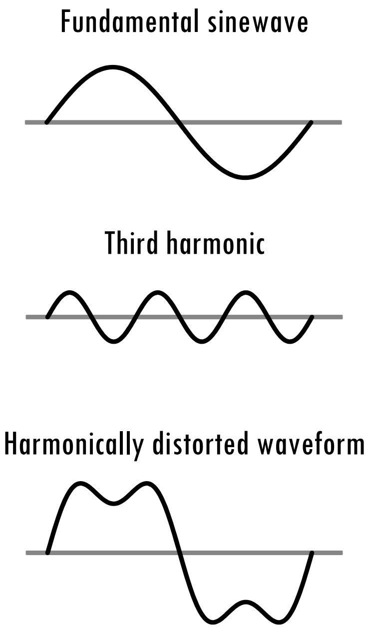
Assessment

- Lower ballast operating temperature reduces air-conditioning load.
- The early models had lower reliability than the present ballasts.
- When used with light sensors, dimmable electronic ballasts can reduce the lighting load by providing just the required light level, if other light sources exist.
- Similarly, an energy management and control system uses dimmable ballasts to partially shed the lighting load.

Total Harmonic Distortion

- Harmonics are frequencies that are integral multiples of the fundamental frequency.
- For a 60 Hz fundamental frequency, the second harmonic is 120 Hz, and the third is 180 Hz.
- Harmonics can be present in voltage and/or current.
- Harmonics occur whenever the wave shape is distorted from a pure sine wave.
- Electric utilities supply voltage and current very close to the sinusoidal wave form.

- If the user's load is nonlinear, drawing short pulses of current within each sine wave cycle, the sinusoidal current wave shape will be distorted and a harmonic current will be present.
- The figure below shows a distorted waveform resulting from a fundamental sine wave and the third harmonic.



- The characteristics of the nonlinear load determine the form of the distortion, the magnitude of each harmonic and the corresponding harmonic current.

- Total current is a combination of the fundamental frequency and a contribution from each of the harmonics.
- THD in the current is the root mean square (rms) of all the harmonic currents as a percentage of the fundamental current, and is defined as follows:

$$\text{THD} = \frac{\sqrt{\text{sum of squares of rms magnitudes of all harmonics}^{*}} \times 100\%}{\text{rms magnitude of fundamental}}$$

$*$ Does not include fundamental

- IEEE Standard 519-1981 refers to the Distortion Factor (DF) which equals the THD. However, THD is the preferred term in this guide as it is more descriptive.
- Most electromagnetic ballasts have THD between 18 % and 35 %.
- Electronic ballasts generate less than 32 % THD. Most of them are below 20 %. Some are below 10 %.
- Due to higher efficiency, the T8 electronic ballast system typically draws 30 % less current than the conventional electromagnetic ballast system.

Electromagnetic Interference or Radio Frequency Interference

- EMI/RFI may cause interference with communication equipment, such as a radio, TV, or computer.
- Fluorescent lamps energized by electromagnetic or electronic ballasts radiate EMI directly into the air.
- EMI from the lamps may feed back to the line conductors via the ballasts.

- EMI at the electronic ballast fundamental frequency and its harmonics propagate from the ballast's electronic circuits to the line conductors. This EMI may interfere with other electrical equipment on the same distribution network.
- EMI may radiate from the line conductor into the air.
- EMI may be radiated from the high frequency electronic components of the electronic ballast.
- In the US, electronic ballasts must comply with Federal Communications Commission Part 18, Subpart C, Class A for industrial and commercial applications, or Class B for residential applications.
- In Canada, all radio frequency lighting devices must comply with limits specified in the Interference Causing Equipment Standard ICES-005. This standard is issued by Industry Canada.

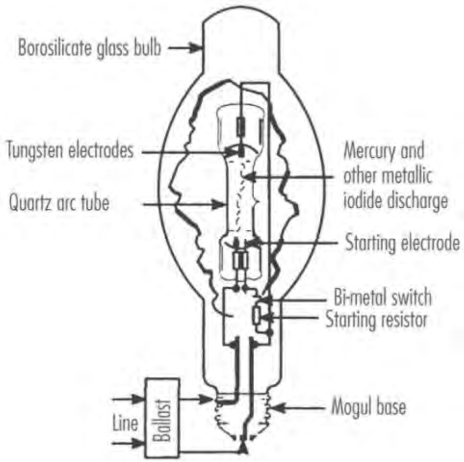
c.Gas Discharge Lamps

Metal Halide Lamps

Construction

- The metal halide (MH) lamps are generally similar in construction to the MV lamps.
- They operate on the same principle as all HID lamps.
- The main difference is that the arc tube contains metallic salts (scandium and sodium) in addition to the mercury vapour and argon gas.
- Like all HID sources, MH lamps consist of an arc tube enclosed in an outer bulb.

Typical Construction and Circuit of an MH Lamp



Operation

- Warm-up time is about 4 minutes.
- Restrike time (time required to start up after a momentary power interruption) is about 10-12 minutes standard - 4-7 min. for pulse start.
- MH lamps generally cannot be burnt in any position. Horizontal-burning lamps have the arc tube bowed upward, to follow the natural curve of the arc stream in the horizontal burning position.

Available Wattage

Sizes range from 40 to 1,500 watts.

Rated Average Life

6,000 hours (70 W) to 20,000 hours (400 W).

Color

- MH lamps are available in both clear and phosphor-coated versions.
- Clear lamps produce a slightly bluish-white color and have a CRI far superior to MV lamps.
- Phosphor-coated lamps produce a warmer-looking white light and an improved CRI.
- MH lamps exhibit some color variation from lamp to lamp and normally change color throughout their life.

Efficacy

- Efficacies range from 50 to 115 lumens per watt.
- MH lamps are more efficient than MV and fluorescent lamps, but less efficient than HPS and low pressure sodium (LPS) lamps.
- CRI - 65-90.

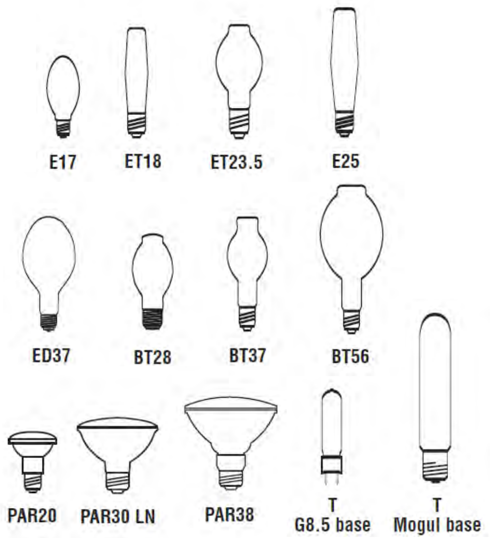
Applications

- Similar to MV lamps.
- MH lamps are effective replacements for MV lamps.
- Large wattages are used for floodlighting, street lighting, large industrial areas and sports arenas.
- Smaller wattages are used in merchandising areas, assembly spaces, schools, and public buildings.
- Clear lamps are used for color TV broadcasting, color photography, and industrial/commercial lighting.
- Phosphor-coated lamps are used for industrial/commercial indoor lighting and area lighting.

Brands

Major manufacturers carry a variety of metal halide lamps.

Shapes



BT	Bulged-tubular
E	Elliptical
ED	Elliptical with dimple in the crown
ET	Ellipsoidal Tubular
PAR	Parabolic
T	Tubular

Numbers indicate maximum diameter in eighths of an inch.

MH Lamps Safety

- Fixtures with MH lamps should be fully enclosed.
- MH and MV lamps operate under high pressure and very high temperatures and there is a possibility that the arc tube may rupture.
- When this happens, the outer bulb surrounding the arc tube may break, and particles of extremely hot quartz (from the arc tube) and glass fragments (from the outer bulb) create a risk of personal injury or fire.
- Sylvania, General Electric and Philips have issued warnings to the users of their MH lamps.
    - Sylvania's warning:
        - All MH lamps should be used in enclosed fixtures.
        - Enclosures must be made of suitable material, such as tempered glass.
    - General Electric's warning:
        - Enclosed fixtures should be used with lamps in horizontal or more than 15 % off-vertical position.
        - 175 W, 250 W, 1500 W MH lamps, regardless of position, should be used in enclosed fixtures.
        - 325 W, 400 W, 950 W, 1000 W MH lamps, in vertical position, or less than 15 % off-vertical position, can be used in open fixtures.
        - For continuously operating systems, turn the lamps off once a week for at least 15 minutes.
        - MH lamps near the end of their life may not start.

        - Relamp fixtures at or before end of rated life.
    - Philips warning:
        - MH lamps should be used in enclosed fixtures.

Direct Replacement of MV Lamps

- Some MH lamps are designed as direct replacements for MV lamps and use the existing MV lamp fixtures and ballasts.
- In comparison with the MV lamps, the efficacy may be improved by 70 %+, but the rated average life is generally shorter.
- An energy conservation retrofit.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp (Deg K)	CRI
Tubular Single-Ended								
MC 20	20	15,000	1,700	85.0	1,250	62.5	3,000	82
MC 35	35	15,000	3,300	94.3	2,640	75.4	4,200	82
MC 70	70	15,000	6,300	90.0	5,600	80.0	3,000	87
MC 100	100	15,000	9,500	95.0	7,600	76.0	3,000	85
MC 150	150	15,000	14,500	96.7	11,600	77.3	4,200	95
PAR								
PAR30 20	20	12,000	900	45.0			3,000	82
PAR20 24	24	12,000	1,220	50.8			2,800	82
PAR38 39	39	12,000	2,000	51.3			3,000	87
PAR38 70	70	12,000	3,600	51.4			3,000	95
PAR38 100	100	15,000	6,500	65.0			3,000	88
PAR38 150	150	15,000	9,100	60.7			3,000	88
Pulse Start								
M 70	70	12,000	5,600	56.0	3,000	42.9	4,000	65
M 100	100	12,000	8,500	85.0	4,675	46.8	4,000	65
M 150	150	12,000	14,000	93.3			4,400	65
M 175	175	12,000	14,400	82.	10,000	57.1	4,500	65
M 250	250	15,000	21,000	84	15,400	61.6	3,800	65
M 400	400	15,000	36,000	90	25,500	63.8	4,000	65
M 750	750	20,000	78,000	104	67,000	89.3	4,000	65
M 1000	1,000	20,000	110,000	110	96,000	96	3,800	65
High Output								
MS 400	400	20,000	42,000	105	26,000	65	4,000	65
MS 1000	1,000	20,000	115,000	115	92,000	92	4,000	65
Operable on Mercury Vapor Ballast								
M 325	325	20,000	28,000	86.1	18,200	56	4,000	65
M 400	400	15,000	34,000	85	20,400	51	4,000	
M 1000	1,000	12,000	107,000	107	85,600	85.6	3,800	

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer’s catalogs or websites for up-to-date information on lamp part numbers and availability.

Ceramic Metal Halide Lamps

General Description

- In order to counter the poor color consistency of metal halide lamps over life, lamp manufacturers have combined the ceramic arc tube from HPS lamps with the gas mix and metals used in Metal Halide lamps to produce Ceramic Metal Halide (CMH) lamps.
- These lamps offer significant advantages over typical Metal Halide lamps and are available in PAR packages to fit smaller recessed and track-mounted luminaires.
- These sources and luminaires offer significant savings compared to incandescent lamps typically used in retail (stores) and display lighting.

Comparison

120 W Halogen PAR 38 Flood:

25°, 3,000 hrs, 7,700 MBCP, 1,800 lm, 95 CRI

39 W CMH PAR 30 Flood (55W with electronic ballast):

30°, 9,000 hrs, 7,400 MBCP, 2,300 lm, 85 CRI

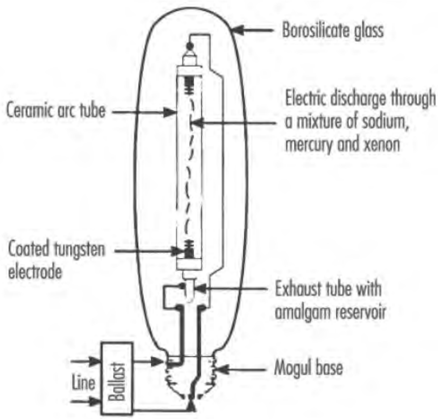
High-pressure Sodium Lamps

Construction

- High pressure sodium (HPS) lamps are HID lamps that ionize sodium vapour.
- Like all HID sources, HPS lamps consist of an arc tube enclosed in an outer bulb.

- The arc tube contains xenon (starting gas), sodium and mercury.
- The mercury is in the form of an amalgam with the sodium.
- HPS lamps do not have starting electrodes because of the arc tube's small diameter.
- The arc tube is made of a ceramic that can withstand high temperatures (1,300°C) and resist the corrosive effects of hot sodium.

Typical Construction and Circuit of an HPS Lamp



Operation

- The ballast provides a high-voltage pulse (2,500 V) for one microsecond for lamp start.
- This high-voltage spike establishes a xenon arc between the main electrodes.
- Mercury and sodium then vaporize rapidly and maintain the arc.

- Warm-up time is three to four minutes.
- Restrike time is about one minute—shortest restrike time of all HID sources.

Sizes

- HPS lamp sizes range from 35 to 1,000 watts.

Rated Average Life

- 10,000 to 80,000 hours.

Color

- The light color of HPS lamps is usually described as golden-white.
- HPS lamps are available in either clear or diffuse-coated versions.
- Improved color lamps operating under increased pressure have better color rendering properties at the expense of lamp life and luminous efficiency.

Efficacy

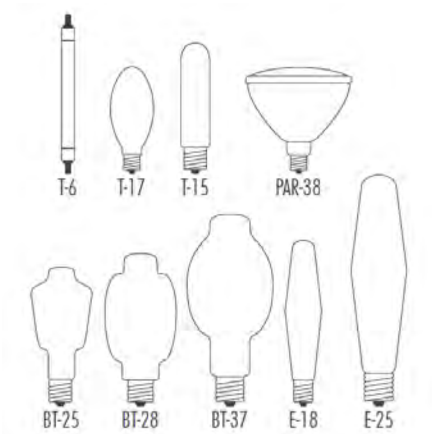
- HPS lamps are the most efficient source of golden-white light.
- HPS lamps are more efficient than MH lamps, but less efficient than Low Pressure Sodium (LPS) lamps.
- Efficacies range approximately from 50 to 150 lumens per watt.
- High power lamps have a higher efficacy than less powerful ones.

Applications

- All applications where color is less important.

- Clear lamps are used in roadway lighting, floodlighting, industrial lighting, area lighting, and airport lighting.
- Coated lamps are used in area and floodlighting, security lighting, industrial and commercial indoor lighting, and parking lots.

Shapes



Shape Codes

B	Bullet
BT	Bulged-tubular
E	Elliptical
PAR	Parabolic aluminized reflector
T	Tubular

Number indicates maximum diameter, in eighths of an inch.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp (Deg K)	CRI	LLD
Clear									
S 35	35	16,000	2,250	40.9	2,050	37.3	1,900	22	0.84
S 50	50	24,000	4,000	57.1	3,600	51.4	1,900	21	0.81
S 70	70	24,000	6,300	66.3	5,350	56.3	1,900	22	0.83
S 100	100	24,000	9,500	73.1	8,000	61.5	2,100	22	0.79
S 150	150	24,000	15,800	83.2	13,400	70.5	2,100	22	0.84
S 200	200	24,000	22,000	88.0	19,800	79.2	2,100	22	0.84
S 250	250	24,000	29,000	95.1	26,100	85.6	2,100	22	0.84
S 400	400	24,000	50,000	105.3	45,000	94.7	2,100	22	0.86
S 1000	1,000	24,000	130,000	118.7	124,000	113.2	2,100	22	0.84
Diffuse-Coated									
S 35/D	35	16,000	2,100	38.2	1,935	35.2	1,900	22	0.84
S 50/D	50	24,000	3,700	52.9	3,420	48.9	1,900	22	0.81
S 70/D	70	24,000	5,800	61.1	4,900	51.6	1,900	22	0.83
S 100/D	100	24,000	8,800	67.7	7,500	57.7	2,100	22	0.83
S 150/D	150	24,000	14,500	76.3	12,300	64.7	2,100	22	0.83
S 250/D	250	24,000	26,000	85.2	23,400	76.7	2,100	22	0.84
S 400/D	400	24,000	47,500	100.0	40,000	84.2	2,100	22	0.80
Color Improved Clear									
150	150	7,500	13,900	71.6	12,240	64.4	2,400	65	0.87
200	200	7,500	19,000	76.0	17,100	68.4	2,400	65	0.87
250	250	10,000	25,500	82.0	22,500	73.8	2,400	65	0.87
Color-Improved Diffuse-Coated									
150	150	10,000	13,000	68.4			2,300	70	0.89
250	250	10,000	23,000	76.0			2,300	70	0.89
400	400	10,000	39,500	82.0			2,300	70	0.89
Long-Life Clear									
70	70	40,000	6,050	63.7	4,950	52.1	1,900	22	
100	100	40,000	9,500	73.1	7,600	58.5	2,100	22	
150	150	40,000	15,700	82.6	12,100	63.7	2,100	22	
200	200	40,000	21,500	86.0	18,000	72.1	2,100	22	
250	250	40,000	27,500	90.2	23,200	76.1	2,100	22	
400	400	40,000	47,500	100.0	40,000	84.2	2,100	22	
1000	1000	40,000	127,000	116.0	115,000	105.0	2,100	22	
Extra Long-Life									
100	100	80,000	9,800	98.0			2,100	22	
150	150	80,000	15,200	101.3			2,100	22	

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

Direct Replacement of MV Lamps

- Some HPS lamps are designed as direct replacements for MV lamps and use the existing MV lamp fixtures and ballasts.
- In comparison with the MV lamps, the efficacy may be improved by 70 %+, but the rated average life is generally shorter.
- Often used in energy conservation retrofits.
- For lamp information, refer to the table below:

Lamp Designation	Lamp Watts	Total Watts Including Ballast 1 Lamp	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp (Deg K)	CRI	LLD
HPS Operable on Mercury Vapour Ballast										
Clear										
150	150	180	12,000	13,000	72.2	11,700	65.0	1,800		0.85
215	215	250	12,000	20,000	80.0	18,000	72.0	2,060		0.85
360	360	405	16,000	38,000	93.8	34,960	86.3	2,060		0.86
880	880	930	12,000	102,000	109.7	91,800	98.7	2,100		0.67
Phosphor-Coated										
150	150	180	12,000	12,000	66.7	10,800	60.0	1,800		0.85
330	330	380	16,000	30,000	78.9	27,000	71.1	2,000	30	0.73
360	360	405	16,000	36,000	88.9	32,400	80.0	2,060		0.88

Notes:

- HPS Lamps can be operated in any position without affecting lumen output.
- Life and mean lumen ratings for HID lamps are based on 10 hours per start.
- The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

Low Pressure Sodium Lamps

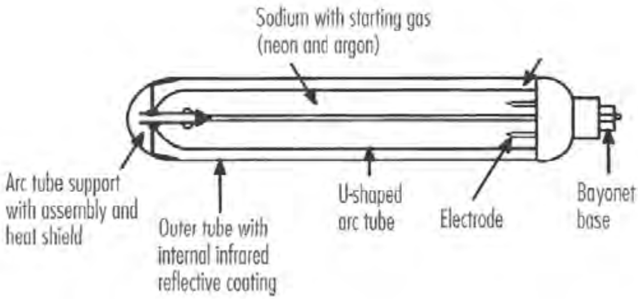
Construction

- Low pressure sodium (LPS or SOX) lamps are HID lamps, operated at low pressure, in which the arc is carried by ionized sodium vapour.
- LPS lamps are more closely related to fluorescent than HID lamps, since they have a low-pressure, low-intensity discharge source and a linear lamp shape.
- An LPS lamp consists of a U-shaped arc tube enclosed in a clear tubular outer bulb.
- An indium oxide coating on the inside of the outer bulb reflects most of the infrared radiation back to the arc tube.
- The arc tube is enclosed in a vacuum to minimize heat loss.
- The lamp is designed to fully utilize its generated heat.
- The arc tube can maintain an operating temperature of about 2,600°C, resulting in an extremely high luminous efficacy.

Operation

- At start-up, the current is carried by the starting gas (neon and argon) producing a red glow.
- As the lamp warms up, sodium is vaporized and the discharge begins to exhibit the characteristic yellow color of an LPS lamp.
- Warm-up time is about nine minutes.
- Restrike time is less than one minute.

Typical Construction



Sizes

LPS lamp sizes range from 18 to 180 watts.

Rated Average Life

- SOX 18 - 14,000 hours
- Others - 18,000 hours

Color

- The light of an LPS lamp has a yellow color (monochromatic).
- The color rendition is very low—it turns every color to either yellow or muddy brown.
- The CRI value does not apply to this lamp.

Efficacy

- The LPS lamp has the highest efficacy of all light sources.
- Lamp efficacies range from 100 to 200 lumens per watt.

- High power lamps have a higher efficacy than less powerful ones.
- The LPS lamp has the highest efficacy because it emits monochromatic yellow light close to the peak of the eye sensitivity curve.

Applications

- The LPS lamp is generally not used in new construction, but it may be found in existing sites.
- All applications where color rendering is not important, such as roadway lighting, security lighting, area floodlighting, and warehouses.

Lamp Designation	Lamp Watts	Total Watts Including Ballast 1 Lamp	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens Per Watt	Color Temp Deg K	LLD
SOX 18	18	32	14,000	1,800	56.3	53.7	1,740	1.03
SOX 35	35	60	18,000	4,800	80.0	76.2	1,740	1.03
SOX 55	55	80	18,000	8,000	100.0	95.2	1,740	1.03
SOX 90	90	125	18,000	13,500	108.0	103.1	1,740	1.03
SOX 135	135	170	18,000	22,500	132.4	126.4	1,740	1.03
SOX 180	180	215	18,000	33,000	153.5	146.7	1,740	1.03

Notes:

- The wattage and lumen for LPS lamps will increase by approximately 7 % to 5 % respectively, by the end of lamp life.
- Due to the monochromatic nature of LPS lamps, CRI is not applicable.

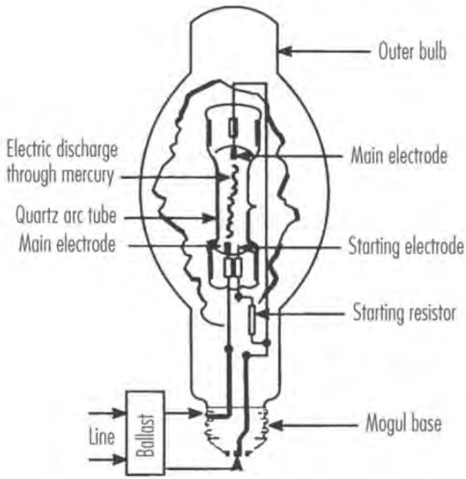
Mercury Vapor (MV) Lamps

Note:
Use of MV Lamps should be discouraged. They are no more efficient than fluorescent lights in indoor applications; in outdoor applications they should be replaced with one of the other gas discharge lamps. The disposal of mercury vapour lamps requires special methods because of the mercury inside the lamp. Local disposal authorities should be contacted for approved disposal methods.

Construction

- The MV lamp is the oldest HID source.
- An MV lamp, like all HID lamps, consists of an arc tube enclosed in an outer bulb (a bulb in a bulb).
- The arc tube contains the mercury vapour, a starting gas (argon) and the electrodes.
- The outer bulb contains an inert gas (nitrogen) to prevent oxidation of internal parts and to maintain the operating temperature. It also provides an inner surface for an optional phosphor coating.
- Light is produced by current passing through the mercury vapour at relatively high pressure.

Typical Construction and Circuit of an MV Lamp



Operation

- When the lamp is turned on, a voltage is applied to initiate an arc between a starting electrode and the nearby main electrode, which vaporizes the mercury.
- The "warm-up" time until the lamp develops full light output is five to seven minutes. The "restrike" time (time required to start up after a momentary power interruption) is about 10 minutes.
- During operation, when the electric arc is formed, the mercury vapour emits light and ultraviolet (UV) radiation.
- UV radiation can be converted to light by a phosphor coating on the inside of the outer bulb.
- MV lamps, like all HID lamps, require ballasts.

Sizes

- Standard MV, 40 to 1,000 watts.
- Self-ballasted MV, 160 to 1,250 watts.

Rated Average Life

- 24,000 hours for most MV lamps.

Color

- There are two types of MV lamps, clear and phosphor-coated.
- Clear MV lamps have a bluish-white color and poor color rendering.
- Phosphor-coated MV lamps have a better color appearance and color rendering.

Efficacy

With efficacies ranging from 30 to 80 lumens per watt, MV lamps are the least efficient of all the HID lamps. They are still more efficient than incandescent lamps but less efficient than fluorescent lamps.

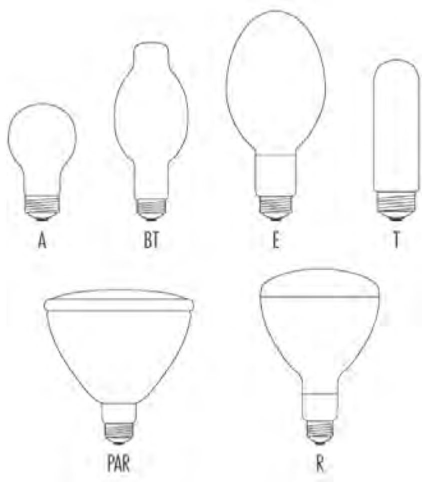
Applications

- MV lamps are no longer specified for new construction or retrofit due to poor efficacy.
- Interior industrial applications.
- Street lighting, security lighting, floodlighting.
- Retail shops, indoor shopping malls, restaurants, cafeterias, air/bus terminals, lobbies, foyers, gymnasiums, banks, barns.

MV vs Other High Intensity Discharge Lamps

- Replacement of MV lamps with metal halide or HPS lamps may improve efficacy by more than 70 %.
- Refer to chapters on MH lamps and HPS lamps.
- MV lamps are rarely used in new lighting systems.

Shapes



Shape Code

A	Arbitrary
BT	Bulged-tubular
E	Elliptical
PAR	Parabolic aluminized reflector
R	Reflector
T	Tubular

Lamp Designation	Lamp Watts	Total Watts Including Ballast 1 lamp	(2 lamps)	Rated Lamp Life (hrs)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp Deg K	CRI	LLD
Clear											
H43 75	75	95	(190)	24,000	2,800	29.5	2,430	25.6	7,000	22	0.73
H38 100	100	125	(250)	24,000	4,100	32.8	3,380	27.0	7,000	22	0.78
H42 125	125	155	(310)	24,000	5,700	36.8	5,020	32.4	7,000	22	0.88
H39 175	175	210	(410)	24,000	7,900	37.6	7,400	35.2	6,800	22	0.88
H37 250	250	290	(580)	24,000	12,000	41.4	10,800	37.2	5,900	22	0.81
H33 400	400	450	(880)	24,000	20,500	45.6	18,700	41.6	5,900	22	0.84
H35 700	700	775	(1,550)	24,000	41,000	52.9	37,300	48.1	5,900	22	0.81
H36 1000	1,000	1,100	(2,200)	24,000	57,500	52.3	50,600	46.0	5,900	22	0.78
Phosphor Coated											
H46 50/DX	50	63	(125)	16,000	1,565	25.0	1,260	20.0	4,000	43	0.61
H43 75/DX	75	95	(190)	16,000	2,800	29.5	2,250	23.7	4,000	43	0.72
H38 100/DX	100	125	(250)	24,000	4,200	33.6	3,530	28.2	4,000	43	0.70
H42 123/DX	125	155	(310)	24,000	6,350	41.0	5,270	34.0	4,000	43	0.76
H39 175/DX	175	210	(410)	24,000	8,600	41.0	7,650	36.4	4,000	43	0.70
H37 250/DX	250	290	(580)	24,000	13,000	44.8	11,000	37.9	4,000	43	0.62
H33 400/DX	400	450	(880)	24,000	23,000	51.1	18,400	40.9	4,000	43	0.70
H35 700/DX	700	775	(1,550)	24,000	44,500	57.4	34,500	44.5	4,000	43	0.64
H36 1000/DX	1,000	1,100	(2,200)	24,000	63,000	57.3	47,500	43.2	4,000	43	0.65
Self-Ballasted (for replacement of incandescent)											
H160		160		12,000	2,300	14.4	1,600	10.0			
H250		250		12,000	5,000	20.0	3,750	15.0			
H450		450		16,000	9,500	21.1	7,125	15.8			
H750		750		16,000	14,000	18.7	10,500	14.0			

Notes:

- Mounting for position-oriented lamps is indicated as HOR (horizontal) or VER (vertical) only.
- When the position is not specified, the lumen output value given applies to vertical mounting. Slightly reduced values will result if the lamp is mounted in other positions.
- Life and mean lumen ratings for HID lamps are based on 10 hours per start.
- Indicates MV lamp (H for Hg - the chemical symbol for mercury).
- These lamps are being phased out.

HID Lamps Ballast

Probe Start Ballasts

The standard core and coil HID ballast or probe start ballast consists of a series of electrical coils on a core of steel laminations. The coils are impregnated with a varnish to provide electrical insulation, reduce noise and dissipate heat. Some ballasts for interior use are housed in metal cans and potted with insulating materials.

Pulse Start Ballasts

- Pulse start HID Ballasts incorporate a different starting technique which reduces ballast losses and increases lamp performance.
- Pulse start retrofits can be a good measure for existing metal halide installations in schools, and industrial and commercial projects.
- A 320 W metal halide pulse start system can replace a 400 W system.
- The pulse start lamp gives less lamp lumen depreciation, better color consistency over lamp life, and faster hot restrike.

Electronic HID Ballasts

Designed primarily for the low wattage Ceramic Metal Halide lamps, electronic HID ballasts are gradually expanding to higher lamp wattages.

Advantages:

- Significantly smaller size and lower weight than core and coil systems.
- More efficient, up to 20 % savings over conventional ballasts.
- Square wave output increases lamp life.
- Automatic end-of-life detection; shuts lamp down instead of trying to restart.

d. Fluorescent Lamps

Fluorescent Lamps General

A difference exists between metric and imperial dimensions of fluorescent lamps. Typical fluorescent tubes are T-5, T-8 and T-12 according to the imperial system. The number refers to tube's diameter which is expressed in eighths of an inch. For example, a T-5 tube has a diameter of 5/8 of an inch. In the metric system, tubes diameters are expressed in millimeters. A T-16 fluorescent tube has a diameter of 16 mm and is equivalent to a T-5 tube in the imperial system. T-26 fluorescent tube has a diameter of 26 mm and is equivalent to a T-8 tube in the imperial system.

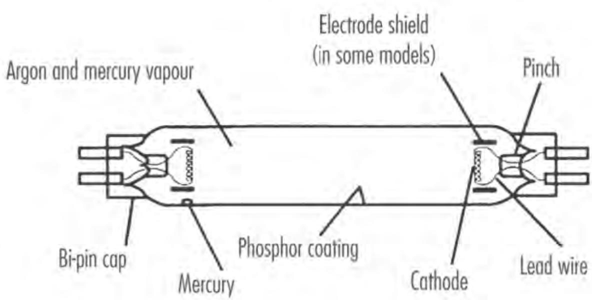
Fluorescent tubes presented in this guide are referred to using imperial dimensions and nomenclature.

Efficiency of T-8 lamps is constantly increasing and highly efficient T-5 lamps are now available on the market. These products are a good option for replacing inefficient T-12 lamps. The use of T-12s is constantly decreasing. The US Department of Energy's regulation, which took effect in July

2012, will eventually lead to the phase-out of the majority of the 4-foot and 8-foot T-12 lamps. The goal of Natural Resources Canada is to amend its regulation on general service fluorescent lamps (GSFL) lamps in order to harmonize with the US regulation.

Construction

- For typical construction of a fluorescent lamp, see the figure below.
- A fluorescent lamp is a low-pressure mercury electric discharge lamp.
- A fluorescent lamp consists of a glass tube filled with a mixture of argon gas and mercury vapour at low pressure.
- When current flows through the ionized gas between the electrodes, it emits ultraviolet (UV) radiation from the mercury arc.
- The UV radiation is converted to visible light by a fluorescent coating on the inside of the tube.
- The lamp is connected to the power source through a ballast, which provides the necessary starting voltage and operating current.



Preheat Lamps

- Preheat lamps are not widely used today.
- The cathodes of the lamp are preheated electrically for a few seconds before a high voltage is applied to start the lamp.
- The preheating is accomplished by the use of an automatic switch, called a "starter", which applies current to the cathodes for sufficient time to heat them.
- The preheat lamps have a bi-pin (double-pin) base at each end.
- Preheat lamps operate normally in a preheat circuit (preheat ballast, starter, lamp and lamp holders).
- Preheat lamps can also be used in rapid start circuits.

Instant Start Lamps

- The instant start lamp requires a high starting voltage, which is supplied by the ballast.
- Since there is no preheating of the cathodes, there is no need for a starter.
- Electrode heating is provided by the arc once it has been established.
- The instant start lamps have a single-pin base at each end of the bulb.
- A few instant start lamps have bi-pin bases, with the pins connected together inside the base.
- Instant start lamps operate normally only in an instant start circuit (instant start ballast, lamp and lamp holders).

Rapid Start Lamps

- The ballast quickly heats the cathodes causing sufficient ionization in the lamp for the arc to strike.
- The cathodes may or may not be continuously heated after lamp starting, depending on ballast design.
- Rapid start lamps start almost instantly (in one or two seconds).
- No starter is required - eliminating the time delay of preheat systems.
- Less voltage is required for starting than with instant start lamps, thus using smaller, more efficient ballasts.
- The rapid start lamps have a bi-pin (double-pin) base at each end.
- Rapid start lamps can also be used for dimming and flashing applications (such as advertising).
- Rapid start lamps operate normally only in a rapid start circuit (rapid start ballast, lamp, and lamp holders).
- Rapid start lamps are the most widely used fluorescent lamps.

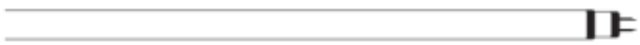
Types of Rapid Start Lamps

- Linear fluorescent lamps – new types, both T8 and T5 sizes.
- Linear fluorescents (430 mA for F40) - old types, primarily T12 size.
- Energy saving fluorescents, primarily T12 size.
- U-shaped fluorescents, in both T8 and T12 sizes.
- Circular lamps, in T9 and T5 sizes.
- High output lamps, available in T12, T8 and T5 sizes.

- Very high output lamps (1500 mA), primarily T12 size.
- Lamp diameters range from 5/8″ to 2.5″.

Shapes

Bi-Pin



T-5 miniature bi-pin (5/8" diameter)

T-8 medium bi-pin (1" diameter)

T-12 medium bi-pin (1-1/2" diameter)

Circular

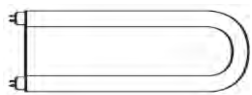
4-pin T-5 (5/8" diameter)

High Output and Very High Output

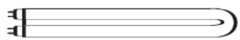
T-8 recessed double contact (1" diameter)

T-12 recessed double contact (1-1/2" diameter)

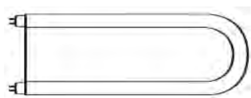
U-Shape



U-Shaped T-12 with 6" leg spacing



U-Shaped T-8 with 1-5/8" leg spacing



U-Shaped T-8 with 6" leg spacing

Lamp Designations

Bi-pin lamps *(preheat, instant start, rapid start)*

Identified by wattage, bulb diameter and color.

Example: F40TI2/CW/ES

F	:	Fluorescent lamp
40	:	Wattage (34 W for ES types)
T	:	Tubular bulb shape
12	:	Maximum tube diameter - in eighths of an inch (12/8 = 1.5″)
CW	:	Cool white color

Example: F32 T8/41K

F	:	Fluorescent lamp
32	:	Wattage (32 W)
T	:	Tubular bulb shape
8	:	Maximum tube diameter - in eighths of an inch (8 x 1/8 = 1″)
41K	:	4,100 K, Cool white color

Single-pin lamps *(instant start)*

Identified by length and color rather than wattage because they can operate at more than one wattage.

Example: F96T12/WW

F	:	Fluorescent lamp
96	:	Lamp length in inches
T	:	Tubular bulb shape
12	:	Maximum tube diameter - in eighths of an inch
WW	:	Warm white color

Lamp Lengths

Some typical lamp lengths are:

- F20 lamp - 24″ (2′)
- F30 lamp - 36″ (3′)
- F32 T8 lamp - 48″ (4′) – becoming the industry standard lamp
- F40 lamp - 48″ (4′)
- F96 lamp - 96″ (8′)

Color Codes

(e.g., 841 = 80 % CRI and 4100 Kelvin)

		CRI	Color Temp (Deg K)
C50	Chroma. 50	90+	5,000
C75	Chroma 75	90+	7,500
CW	Cool White	62	4,200
CWX	Cool White Deluxe	87	4,100
D	Daylight	76	6,500
LW	Lite White	48	4,150
N	Natural	86	3,600
SP	Spectrum Series	70+	Varies
SPX	Spectrum Series	80+	Varies
WW	Warm White	52	3,000
WWX	Warm White Deluxe	74	2,950
741	T8 Cool Lamp Color	70+	4,100
735	T8 Neutral Lamp Color	70+	3,500
730	T8 Warm Lamp Color	70+	3,000
841	T5 & T8 Cool Lamp Color	85+	4,100
835	T5 & T8 Neutral Lamp Color	85+	3,500
830	T5 & T8 Warm Lamp Color	85+	3,000

Deluxe means better CRI, but with older style T12 lamps and also lower efficacy.

Lamp Type Code

The lamp type code follows the color code.

Lamp type codes are listed below.

IS	Instant Start
RS	Rapid Start
HO	High Output
VHO	Very High Output
U	U-shaped
WM	WattMiser (General Electric)
SS	Super Saver
EW	Econowatt (Philips)

Characteristics

General	- A fluorescent luminare consists of: a ballast, usually shared by two lamps, a fixture, and a lens or louvers
Lamp Configuration	- Linear, U-shape, circular or compact
Lamp Watts	- 7 W to 215 W
Ballast Watts	- Varies according to type, electromagnetic or electronic, and Ballast Factor
Rated Average Life	- 20,000 hours for typical F32T8 lamps
	- 24,000 hour T8 lamps are available
	- 20-24 times the life of a typical incandescent
Luminous Efficacy	- 40 to 100 lumens per watt

Lamp Lumen Depreciation Factor (LLD)	- 70 % to 90 %
Colour Temperature	- 2,700 K to 7,500 K
	- Wide range of color temperatures
Color Rendering Index	- 62 to 94
Warm-up Time	- Instant
	- Sensitive to extremes of temperature
	- Slower than incandescent
Restrike Time	- Immediate
Lamp Cost	- Low
	- Energy-saving and energy-efficient lamps more expensive
Main Applications	- Offices, commercial

Lamp Designation	Lamp Watts	Including Ballast 1 Lamp	(2 Lamps)	Rated Lamp Life (hrs.)	Initial Lumens	Initial Lumens Per Watt	Color Temp (Deg K)	CRI
Energy Saving, Rapid Start, Bi-Pin Base F40T12/…./RS/….EW, SS or WM								
CW	34	47	(72)	20,000	2,775	59.0	4,100	62
CWX	34	47	(72)	20,000	1,925	41.0	4,100	87
WW	34	47	(72)	20,000	2,825	60.1	3,000	52
D	34	47	(72)	20,000	2,350	50.0	6,500	75
LW	34	47	(72)	20,000	2,925	62.2	4,160	48
30U	34	47	(72)	20,000	2,925	62.2	3,000	85
35U	34	47	(72)	20,000	2,925	62.2	3,500	85
41U	34	47	(72)	20,000	2,925	62.2	4,100	85
50U	34	47	(72)	20,000	2,925	62.2	5,000	85
SPEC30	34	47	(72)	20,000	2,925	62.2	3,000	70
SPEC35	34	47	(72)	20,000	2,925	62.2	3,500	73
SPEC41	34	47	(72)	20,000	2,925	62.2	4,100	70

Notes:

- Refer to lamp manufacturers for colors other than shown here.
- Rated Average Life for fluorescent lamps is based on three hours per start.
- Mean Lumens for fluorescent lamps are listed at 40 % of lamp life.

Lamp Designation	Lamp Watts	Including Ballast 1 Lamp	(2 Lamps)	Rated Lamp Life (hrs.)	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp Deg K	CRI	LLD
Instant Start, 200 milliamp, Single Pin Base											
F72T8/CW	38	55	(100)	7,500	3,100	56.4	2,700	49.1	4,300	62	0.83
F96T8/CW	50	70	(130)	7,500	4,200	60.0	3,860	55.1	4,300	62	0.89
Instant Start, 430 milliamp, Single Pin Base											
F48T12/CW	39	65	(104)	9,000	3,000	46.2	2,760	42.5	4,300	62	0.82
F48T12/LW	30	55	(84)	9,000	2,675	48.6	2,460	44.7	4,100	49	0.82
F72T12/CW	55	80	(150)	12,000	4,600	57.5	4,320	52.9	4,300	62	0.89
F96T12/CW	75	97	(172)	12,000	6,300	64.9	5,800	59.8	4,300	49	0.89
F96T12/LW	60	82	(142)	12,000	6,000	73.2	5,430	66.2	4,100	49	0.89
Rapid Start, 430 milliamp, Bi-Pin Base											
F30T12/CW/RS	30	46	(76)	18,000	2,300	50.0	2,010	43.7	4,300	62	0.81
F40T12/..../RS											
cool white	40	53	(93)	20,000	3,150	59.4	2,715	51.2	4,300	62	0.84
cool white deluxe	40	53	(93)	20,000	2,200	41.5	1,800	34.0	4,200	87	0.84
warm white	40	53	(93)	20,000	3,200	60.4	2,715	51.2	3,000	52	0.84
warm white deluxe	40	53	(93)	20,000	2,150	40.6	1,765	33.3	3,100	73	0.84
daylight	40	53	(93)	20,000	2,600	49.1	2,245	42.4	6,500	75	0.84
lite white	35	48	(83)	20,000	3,050	63.5			4,160	48	0.84
lite white deluxe	34	47	(72)	20,000	3,050	64.9			4,100	67	0.84
Rapid Start T-8, Bi-pin Base											
F032/730	32	30	(59)	20,000	2,800	93.0	2,520	84.0	3,000	75	0.90
F032/830	32	30	(59)	20,000	2,950	98.0	2,714	90.0	3,000	82	0.92
F032/830 6		30	(59)	24,000	2,900	96.6	2,755	91.8	3,000	85	0.95
F032/830/XP		30	(59)	24,000	3,000	100	2,850	95.0	3,000	85	0.95
High Output Rapid Start, 800 milliamp, Recessed Double Contact Base											
F48T12/CW/HO	60	85	(146)	12,000	4,300	50.6	3,740	44.0	4,300	62	0.82
F72T12/CW/HO	85	106	(200)	12,000	6,650	62.7	5,785	54.6	4,300	62	0.82
F96T12/CW/HO	110	140	(252)	12,000	9,200	65.7	8,005	57.2	4,300	62	0.82
F96T12/LW/HO	95	119	(231)	12,000	9,100	76.5	7,915	66.5	4,160	48	0.82
F96T12/LWX/HO	95	119	(231)	12,000	9,100	76.5			4,100	67	0.82
Very High Output Rapid Start, 1500 milliamp, Recessed Double Contact Base											
F48T12/CW/VHO	110	146	(252)	10,000	6,250	42.8	4,750	32.5	4,300	62	0.69

F72T12/CW/VHO	165	213	(326)	10,000	9,900	46.5	7,920	37.2	4,300	62	0.72
F96T12/CW/VHO	215	260	(450)	10,000	14,500	55.8	11,600	44.6	4,300	62	0.72

Notes:

- Some lamps listed here are no longer commercially available, notably the full output F40/CW lamp; they are included here for comparison only.
- The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

Fluorescent Fixture Reflectors

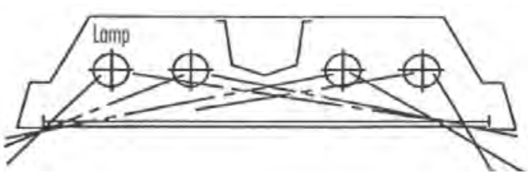
General Description

Fluorescent fixture reflectors are sheets of aluminum placed inside fluorescent fixtures, which divert light directed toward the ceiling down toward the work area.

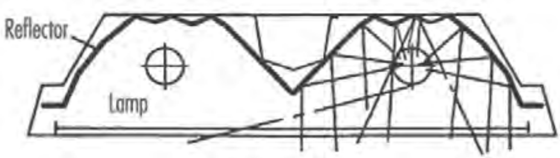
Illustration

Illustration of a recessed reflector for a 2´ x 4´ fixture, with removal of two lamps:

Before installation of the reflector



After installation of the reflector



Physical Data

- There are three basic types of reflectors:
    - Anodized aluminum or steel reflectors - in which the surface is painted with a highly reflective electrostatic or powder-epoxy finish.
    - Anodized aluminum reflectors - in which the aluminum surface is treated (polished) electrochemically.
    - Silver film reflectors - in which a thin film of silver is laminated to an aluminum substrate.
- The reflector finish can be high gloss paint, specular (mirror-like), semi-specular, or diffuse (matt).
- The reflector shape is specially designed to optimize light distribution (custom-designed by the supplier).
- Reflectors are made in the following sizes:
    - Single reflectors - 4´ or 8´ long, one-lamp use.
    - Double reflectors - 4´ or 8´ long, two-lamp use.
    - Recessed reflectors - for 2´ x 2´ or 2´ x 4´ fixtures.

Technical Data

- The average total reflectivity for anodized aluminum reflectors is about 90 % to 91 %.
- The average total reflectivity for silver film reflectors is about 94 % to 97 %.
- Life expectancy of a silver film reflector is about 15 years.
- Life expectancy of an anodized aluminum reflector is about 20 years.

Applications

- Reflectors are used for lighting energy conservation.
- Reflectors are used for fixture retrofitting or in new energy efficient fixtures.
- A typical application is the installation of a recessed reflector in a 2´ x 4´ fixture, with removal of two of the four tubes.
- In most instances, it is necessary to re-centre the two remaining lamps in the fixture to avoid dark spots.
- The reflector creates the image of a lamp in the place of the removed lamp; this allows delamping without creating dark spots.
- The light output of a retrofitted fixture with half the lamps removed typically decreases by about 35 %, depending on reflector material and design.
- Cleaning and relamping at the same time increases light output by 5 % to 20 %.

Costs

Costs depend on the type, size and design of the reflector.

Advantages

- Reduces lighting power consumption.
- Improves luminous efficacy in the work area.
- Reduces cooling load, in the case of delamping.
- Extends ballast and lamp life by decreasing operating temperature.
- Fewer lamps and fixtures are required.
- Reduces maintenance costs.

Disadvantages

- May have a long payback period.
- Not cost-effective if fixtures of different size and type are involved.
- May create a ‘cave effect’ in some situations, causing walls to appear dark at the top because the light is focused downwards.

Assessment

- Has clear benefits from a lighting efficiency point of view.
- Should be compared to other lighting conservation measures.

Low Watt T-8 Lamps

Lamp manufacturers now offer reduced output or low-wattage T-8 lamps for increased savings on retrofit projects, or for new construction.

Standard F32 T-8 Lamps:	30,000 hrs, 82 CRI, 2,925 initial lumens, 91 initial lm/W
Low-Wattage F28 T-8 Lamps:	34,000 hrs, 82 CRI, 2,675 initial lumens, 96 initial lm/W
Low-Wattage F32 T-8 25W Lamps:	40,000 hrs, 85 CRI, 2,500 initial lumens, 100 initial lm/W

- These lamps have some limitations, for example, they cannot be dimmed, and do not operate in cool temperatures (<60°F).

- Some operate on programmed start ballasts and all operate on instant start ballasts.

Premium T-8 Lamps

Lamp manufacturers now offer premium grade T-8 lamps for special applications where exceptional color, longer life and improved lumen output are required.

Standard F32 T-8:	30,000 hrs, 82 CRI, 2,925 initial lumens, 91 initial lm/W
Premium F32 T-8:	36,000 hrs, 86 CRI, 3,100 initial lumens, 103.3 initial lm/W

T-5 and T5-HO Lamps

- Lamp manufacturers now offer T-5 fluorescent lamps in both standard and High Output (HO) versions.
- The smaller diameter tube yields a more compact lumen package, which is easier to control.
- T-5 fluorescent lamps are available in various lengths and wattages from 14 W to 80 W, and in a circline version in 22 W, 40 W, and 55 W.
- T-5 lamps are nominal length lamps, which means that they cannot be retrofit into fixtures using standard T-12 or T-8 lamps. Therefore, they are generally used for re-design or new construction projects.
- T-5 fluorescent lamps require the use of electronic ballasts and unique sockets.

- T-5 lamps can be used in indirect applications in which light source is concealed. The visible light emitted by the source is diffusely reflected by surrounding surfaces.
- T5-HO is an increasingly popular fluorescent lamp; primarily used in normal to high bay applications, big box retail, warehouse and distribution centres, industrial applications, and gymnasiums. T5-HO are also dimmable and operate on instant start ballasts.
- T5 and T5-HO have a maximum light output at higher ambient temperatures.

Standard T-5 Lamps:	14 W, 24″ (nom), 24,000 hrs, 82 CRI, 1,350 initial lumens 21 W, 36″ (nom), 24,000 hrs, 82 CRI, 2, 100 initial lumens 28 W, 48″ (nom), 24,000 hrs, 82 CRI, 2,900 initial lumens 35 W, 60″ (nom), 24,000 hrs, 82 CRI, 3,650 initial lumens
High Output T-5 Lamps:	24 W, 24″ (nom), 24,000 hrs, 85 CRI, 1,950 initial lumens 39 W, 36″ (nom), 24,000 hrs, 85 CRI, 3,500 initial lumens 54 W, 48″ (nom), 24,000 hrs, 85 CRI, 5,000 initial lumens
Low-Wattage T5-HO Lamps :	47 W, 48″ (nom), 30,000 hrs, 84 CRI, 4,800 initial lumen, 49 W, 48″ (nom), 25,000 hrs, 85 CRI, 5,000 initial lumen, 51 W, 48″ (nom), 30,000 hrs, 85 CRI, 5,000 initial lumen,

Fluorescent Lamps Ballast

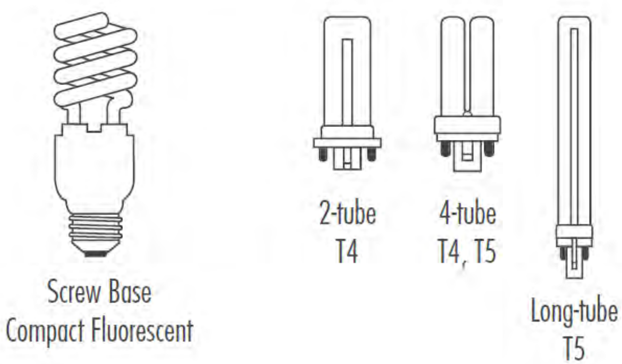
- Note that electro-magnetic fluorescent ballasts are gradually being removed from the market place by energy regulations. They are being replaced by electronic ballasts.
- Ballast specification is based on: number of lamps, lamp type (F32T8/841 or other) and line voltage.
- Example: two-lamp F32T8/841 120V electronic ballast.
- Desired level output is the main factor guiding ballast factor selection.
- Electronic ballasts can be divided according to their starting methods: rapid start, instant start and programmed start. Starting method should be selected according to the type of application.
- An instant start ballast uses a high voltage (~600 V) instead of preheating the electrodes. This is the most efficient type of ballast, but material is blasted from the electrodes at every start since no heating occurs. This is why this type of ballast should be used in applications with long duty cycles and should be avoided in applications in which lamps are frequently turned on and off.
- A rapid start ballast heats the cathodes and applies voltage to the lamp simultaneously. Cathode heating is maintained during lamp operation. This makes the rapid start ballast less efficient than the instant start ballast, but this type of ballast should be selected for dimming operations.

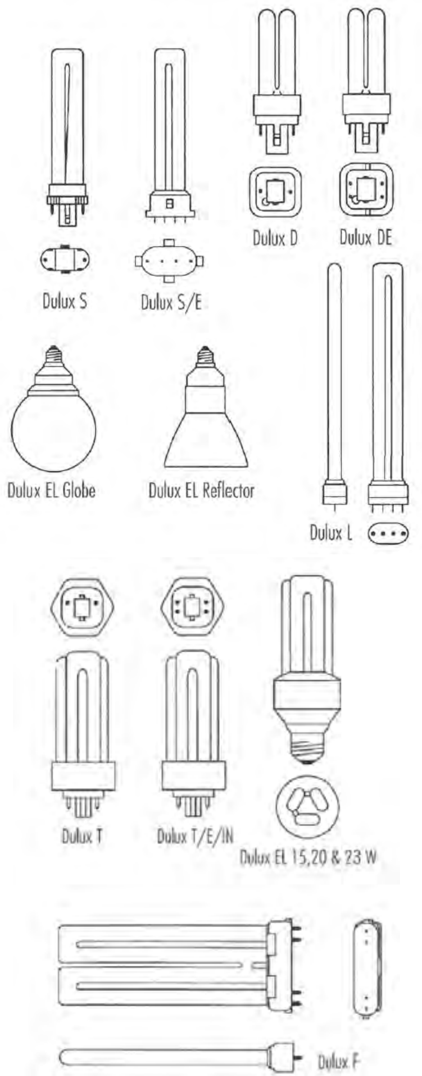
- With a programmed start ballast, the cathode is first preheated and voltage is then applied to the lamp. This type of ballast will offer more start from lamps so they should be considered for applications with a frequent power cycle.

Compact Fluorescent Lamps

Compact fluorescent lamps are small-size fluorescent lamps.

- There are two general types of lamps:
  - Self-ballasted or screw based lamps, for direct replacement of incandescent lamps.
  - Pin-based lamps for compact fluorescent light fixtures.
- They are also available in a large variety of sizes and wattages, and in twin-tube, quad-tube, long tube, twisted, reflectorized, and fully enclosed versions.




Dulux D
Dulux DE
Dulux S
Dulux S/E
Dulux EL Globe
Dulux EL Reflector
Dulux L
Dulux T
Dulux T/E/IN
Dulux EL 15,20 & 23 W
Dulux F

Shapes

Lamp	Lamp Watts	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp Deg K	CRI	Life (hrs.)	Base	Incandescent Equivalent
2-tube or Bi-tube										
CFT5W	5	230	46	198	40	2,700	82	10,000	G23	15 W
						4,100	82	10,000	G23	15 W
CFT7W	7	400	57	344	49	2,700	82	10,000	G23	25 W
						3,500	82	10,000	G23	25 W
						4,100	82	10,000	G23	25 W
						5,000	82	10,000	G23	25 W
CFT9W	9	580	64	499	55	2,700	82	10,000	G23	40 W
						3,500	82	10,000	G23	40 W
						4,100	82	10,000	G23	40 W
						5,000	82	10,000	G23	40 W
CFT13W	13	800	62	688	53	2,700	82	10,000	GX23	60 W
						3,500	82	10,000	GX23	60 W
						4,100	82	10,000	GX23	60 W
						5,000	82	10,000	GX23	60 W
4-tube or Quad-tube										
CFQ9W	9	525	58	452	50	2,700	82	10,000	G23-2	40 W
						3,500	82	10,000	G23-2	40 W
CFQ13W	13	780	60	671	52	2,700	82	10,000	GX23-2	60 W
						3,500	82	10,000	GX23-2	60 W
						4,100	82	10,000	GX23-2	60 W
CFQ18W	18	1,150	64	989	55	2,700	82	10,000	G24D-2	75 W
						3,500	82	10,000	G24D-2	75 W
						4,100	82	10,000	G24D-2	75 W
CFQ26W	26	1,710	66	1,470	57	2,700	82	10,000	G24D-3	100 W
						3,500	82	10,000	G24D-3	100 W
						4,100	82	10,000	G24D-3	100 W
Long-tube or High Output										
FT18W	18	1,250		1,075		3,000	82	12,000	2G11	75 W
						3,500	82	12,000	2G11	75 W
						4,100	82	12,000	2G11	75 W

FT24W	24	1,800	1,548	3,000	82	12,000	2G11	100 W
				3,500	82	12,000	2G11	100 W
				4,100	82	12,000	2G11	100 W
FT36W	36	2,900	2,494	3,000	82	12,000	2G11	150 W
				3,500	82	12,000	2G11	150 W
				4,100	82	12,000	2G11	150 W
FT40W	40	3,150	2,709	3,000	82	20,000	2G11	150 W
				4,100	82	20,000	2G11	150 W
				5,000	82	20,000	2G11	150 W
FT55W	55	4,800	4,128	3,000	82	12,000	2G11	200 W
				4,100	82	12,000	2G11	200 W
				5,400	82	12,000	2G11	200 W
FT80W	80	6,000	5,160	3,000	82	12,000	2G11	300 W
				3,500	82	12,000	2G11	300 W
				4,100	82	12,000	2G11	300 W

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

Self-ballasted Types

Lamp	Watts	Initial Lumens	Initial Lumens Per Watt	Mean Lumens	Mean Lumens Per Watt	Color Temp Deg K	CRI	Life (hrs.)	Incandescent Equivalent
CF7EL	7	375	54	300	43	2,700	82	8,000	25 W
						3,000	82	8,000	25 W
CF11EL	11	600	55	480	44	3,000	82	10,000	40 W
CF13EL	13	800	62	640	49	2,700	82	10,000	40 W
						3,000	82	10,000	40 W
						3,500	82	10,000	40 W
						4,100	82	10,000	40 W
						5,000	82	10,000	40 W
						6,500	82	10,000	40 W
CF19EL	19	1,200	63	960	15	2,700	82	8,000	75 W
						3,000	82	10,000	75 W
						5,000	82	10,000	75 W
						6,500	82	10,000	75 W
CF20EL	20	1,280	64	1,024	51	3,000	82	12,000	75 W
CF23EL	23	1,600	70	1,280	56	2,700	82	10,000	100 W
						3,000	82	10,000	100 W
						3,500	82	10,000	100 W
						4,100	82	10,000	100 W
						5,000	82	10,000	100 W
						6,500	82	10,000	100 W
CF27EL	27	1,750	65	1,400	52	3,000	82	10,000	100 W
CF30EL	30	2,000	67	1,600	53	2,700	82	10,000	120 W
						3,000	82	10,000	120 W
CF40EL	40	2,600	65	2,080	52	2,700	82	8,000	150 W
						3,000	82	6,000	150 W
CF65EL	65	4,200	65	3,360	52	4,100	82	8,000	250 W

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

General Remarks

- The self-ballasted (screw base) lamps are available with incandescent-like features (small size, shape, dimming, 3-way, etc.).
- Compact fluorescent lamps are about four times more efficient than standard incandescent lamps.
- Efficacy or lamp efficiency increases with lamp size and wattage. The smaller size, lower wattage lamps are generally less efficient than the larger size and higher wattage lamps.
- Compact fluorescents have an average life that is 10 times longer than that of standard incandescent lamps, and have a lower maintenance costs.
- They have a high color rendering index, generally >82, but lower than that of incandescent lamps.
- They need a ballast to operate, as do all fluorescent lamps.
- Lamps of different manufacturers are interchangeable.
- Most compact fluorescent lamps are available with a variety of color temperature values, similar to T5 and T8 fluorescent lamps (3,000 K, 3,500 K, 4,100 K).
- There is an Energy Star program for compact fluorescent lamps in North America.

Compact Fluorescent Fixtures

- Many manufacturers produce fixtures for compact fluorescent lamps which include a specially designed ballast and socket (lamp holder). These are available in recessed, outdoor and decorative versions.
- Lamp manufacturers produce retrofit adapters which include the ballast and lamp socket, and have a base to screw directly into a standard incandescent socket (see Self-Ballasted Types, above).
- Recessed compact fluorescent fixtures should have a properly designed reflector, otherwise light will be trapped inside the fixtures and be wasted.

Two-tube Compact Fluorescent Lamps

- Can be used as replacements for small incandescent lamps.
- Compact fluorescent lamp sizes 5 W, 7 W, 9 W and 13 W can replace incandescent lamp sizes 25 W, 40 W, 50 W and 60 W respectively.
- Compact fluorescent lamps of different wattage rating use slightly different bases and sockets to eliminate the possibility of plugging a lamp into a fixture with the wrong ballast for that lamp. For example, it is not possible to plug a 13 W lamp into the socket of a fixture with a ballast rated for a 26 W lamp.

Applications

- Lobby areas, hallways and corridors, any area where there are long hours of use.
- Recessed downlight fixtures.
- Wall and ceiling-mounted fixtures.

- Directional signs.
- Security lighting fixtures.
- Desk and task lighting fixtures.
- Display lighting (museums, stores).
- To replace light bulbs in fixtures which are not readily accessible.

Four-tube Compact Fluorescent Lamps

- Made by combining two two-tube compact fluorescent lamps.
- Also known as double twin-tubes, quad or cluster lamps.
- Same length as two-tube compacts, but double the light output (lumens).
- Four-tube compact fluorescent lamp sizes 9 W, 13 W, 22 W and 28 W can replace incandescent lamp sizes 40 W, 60 W, 75 W and 100 W respectively.

Applications

- Similar to the applications of the two-tube compact fluorescent lamp (see above).
- The four-tube compact fluorescent lamps replace relatively higher wattage incandescent lamps than the two-tube compacts.

Long Tube Compact Fluorescent Lamps

- Longer than the two-tube and four-tube compact fluorescent lamps.
- Can replace standard fluorescent lamps.

- Long tube compact fluorescent lamp sizes 18 W, 24 W and 36 W have the same light output as standard fluorescents F20, F30 and F40 respectively, but are only one third of the length.
- Longer compact fluorescent lamps also feature a longer lamp life, up to 20,000 hrs.

e. Light Emitting Diode

Physics

- A Light-Emitting Diode (LED) is made of two semiconductor materials. The first material is positively doped while the second one is negatively doped.
- When current flows at the junction of these two semiconductor materials, light is emitted on a certain wavelength (color).
- The term Solid State Lighting (SSL) refers to technology in which light is emitted by electroluminescence.

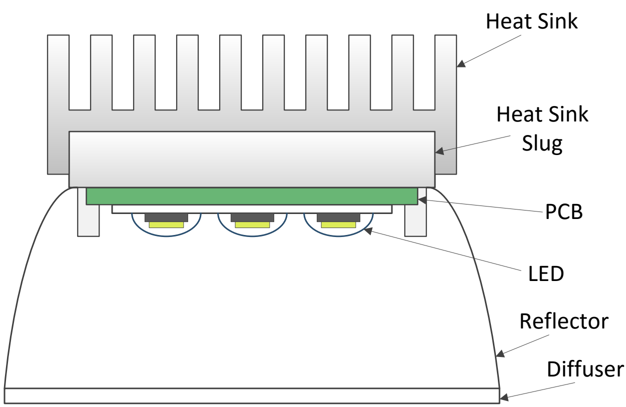
Construction

- LED active materials are incorporated into a housing made of plastic or ceramic.
- LED thermal dissipation is a critical aspect of LED luminaire design. Like any other electronic device, LED properties strongly depend on temperature.

- Like any other light source, part of the energy input to the LED is converted to visible light, but unlike gas discharge or incandescent lamps, LED lamps generate few IR and UV radiation. The portion of input power that is not converted to visible light must therefore be removed by conduction and convection. Since LED properties depend on temperature, thermal dissipation is a critical aspect of LED luminaire design.

Typical Construction of High Power LED Luminaire

- The main components of a led luminaire are the LED, the circuit board (including driver), optical parts (lens, reflector, and diffuser) and the heat sink. The following pictures shows the typical components found in a high power LED luminaire.



- A fan can be part of the design to enhance heat dissipation.

A driver is required to avoid overheating of the LED. It reacts to change in LED temperature and provides a constant power to the LED as its electrical properties change with temperature. A driver for LED can be seen as equivalent to a ballast for discharge lamps.

Characteristics of LED Lamps

Color rendering index	- As low as 50 : poor - Up to 95+ : excellent
Color temperature	- As low as 2,500 K : warm - As high as 8,000 K : cold
Luminous efficacy	- 40 to 150 lumens per watt
Lamp life (hours)	- 10,000 to 100,000
Lamp watts	- 1 to 1,500 W
Warm-up time	- Instant
Restrike time	- Instant
Lamp cost	- High - Low operating cost

Applications

- Interior commercial lighting.
- Interior industrial lighting.
- Street lighting.
- Refrigerated display.

- Outdoor lighting.
- Architectural lighting.
- Residential lighting.
- TV broadcasting.

Advantages of LED

- Long lifetimes lower maintenance costs by reducing re-lamping frequency.
- High energy efficiency and luminous efficacy.
- Will not fade colors, thereby avoiding inventory spoilage.
- Instant start and instant restrike.
- Dimmable.
- Contains no mercury.
- Emits virtually no UV/IR light in the beam.
- Better compatibility with dimmers than fluorescent lamps.
- Better CRI than CFL lamps (residential sector).

LED Lamps types

This section presents typical LED products and applications in which they are used in commercial, industrial and residential sectors. Typical energy saving values that are presented should be considered conservative, considering that LED systems efficacy is constantly improving.

LED Troffers

- LED troffers can be used in a wide variety of applications. They are especially well suited for surface mount or suspended installations in commercial applications.
- They are available in different shapes and can be used for new construction or replacement applications.
- Dimmable with 0~10V DC control.
- Specifications of some LED troffers products are given in the following table.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Lumens	Lumens Per Watt	Color Temp (Deg K)	CRI
2X2RT-38-35	38	50,000	3,500	92.1	3,500	82
2X2RT-38-40	38	50,000	3,500	92.1	4,000	82
2X2RT-38-50	38	50,000	3,500	92.1	5,000	82
2X4RT-48-35	48	50,000	4,400	91.7	3,500	82
2X4RT-48-40	48	50,000	4,400	91.7	4,000	82
2X4RT-48-50	48	50,000	4,400	91.7	5,000	82
2X2LT-53-30	53	50,000	3,600	68	3,000	82
2X2LT-53-35	53	50,000	3,500	66	3,500	82
2X2LT-53-40	53	50,000	3,800	72	4,000	82

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

LED Retrofit Tubes

- LED tubes can be used for replacement of fluorescent lamps. They represent a good retrofit option for T8 and T12 tubes. They require less power and have a longer life than fluorescent lamps.

- Use of LED retrofit tubes can generate savings up to 10 % when compared to 28 watts T8 tubes, and up to 40 % when compared to T12 systems.
- LED retrofit tubes should be chosen with caution. Multiple products are offered on the market. Some of them may be of good quality but consist of cheaper tubes, for which reliability may be a problem.
- Compatibility between different LED tubes is also an issue. Dimensions and characteristics should be verified to make sure the product will fit in the fixture.

- The following table gives some examples of LED retrofit tubes.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Lumens	Lumens Per Watt	Color Temp (Deg K)	CRI
LED11T8	11	60,000	1,070	97.3	3,500	85
LED11T8	11	60,000	1,100	100	4,100	87
LED11T8	11	60,000	1,100	100	5,000	83
LED22T8	22	60,000	2,130	96.8	3,500	85
LED22T8	22	60,000	2,200	100	4,100	87
LED22T8	22	60,000	2,300	105	5,000	83

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

LED Strip Lights

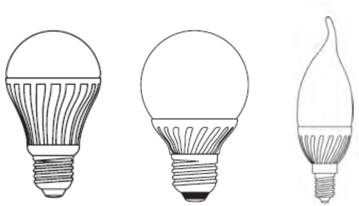
- This type of LED is a good option for refrigeration and freezer display in commercial sector.
- It consumes less energy than fluorescent lamps.
- Moreover, heat dissipation is reduced in refrigerated space. This minimizes interactive effects and generates savings on cooling requirements.
- Replacing T12 fluorescent with LED Strips can reduce lighting energy requirements by 70 %. Considering interactive effects on cooling systems, savings can reach 95 % of initial lamps consumption.

LED High Bay

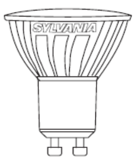
- This type of lamp can replace HID and T5 fluorescent luminaires for interior applications.
- Industrial facilities, warehouse and gymnasium are some examples of areas where LED high bay can be used.
- LED high bay can be considered for both new construction and replacement applications.
- They can generate important energy savings but initial cost of this type of lamps is still expensive. Their use is not yet widespread but with expected improvements on LED technology efficiency and cost reduction, the use of this type of luminaire becomes increasingly relevant.
- Depending on what they are compared with, LED high bay can generate between 20 % and 60 % energy savings.

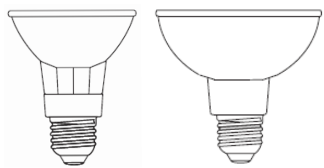
LED Screw-in Replacement Lamps

- This type of LED lamps can be used for replacement of incandescent, CFL and halogen lamps.
- They come in a variety of shapes and color temperature. Picture below shows some examples of available shapes for LED replacement lamps.



A-shaped





MR16 PAR

The following table gives some example of equivalence between led screw-in replacement lamps and incandescent lamps.

Lamp Designation	Lamp Watts	Rated Lamp Life (hrs)	Lumens	Lumens Per Watt	Color Temp (Deg K)	CRI	Incandescent Equivalent
16 PAR 38	16	40,000	920	58	2,700	82	90 W
16 PAR 38	16	25,000	950	59	3,000	82	90 W
16 PAR 38	16	40,000	990	62	4,000	82	90 W
16 PAR 38	16	40,000	1,020	64	5,000	82	90 W
20 PAR 38	20	40,000	1,150	58	2,700	82	90 W
20 PAR 38	20	25,000	1,200	60	3,000	82	90 W
20 PAR 38	20	40,000	1,250	63	4,000	82	90 W
20 PAR 38	20	40,000	1,300	65	5,000	82	90 W
13 PAR 30	13	40,000	680	52	2,700	82	75 W
13 PAR 30	13	25,000	700	54	3,000	82	75 W
13 PAR 30	13	40,000	730	56	4,000	82	75 W
13 PAR 30	13	40,000	760	58	5,000	82	75 W
15 PAR 30	15	40,000	770	51	2,700	82	75 W
15 PAR 30	15	25,000	800	53	3,000	82	75 W
8 PAR 20	8	40,000	380	48	3,000	82	35 W
8 PAR 20	8	40,000	365	46	2,700	82	35 W
4 A 19	4	25,000	250	63	2,700	82	25 W
4 A 19	4	25,000	260	65	3,000	82	25 W
5 A 19	5	25,000	260	52	3,000	82	25 W
6 A 19	6	25,000	450	75	2,700	82	40 W
6 A 19	6	25,000	450	75	2,700	82	40 W
6 A 19	6	25,000	470	78	3,000	82	40 W
6 A 19	6	25,000	490	82	4,000	82	40 W
6 A 19	6	25,000	510	85	5,000	82	40 W
8 A 19	8	25,000	450	56	2,700	82	40 W
8 A 19	8	25,000	450	56	3,000	82	40 W
10 A 19	10	25,000	800	80	2,700	82	60 W
10 A 19	10	25,000	830	83	3,000	82	60 W

Note:
The lamp charts throughout this publication are intended for comparison purposes only; please refer to the most recent lamp manufacturer's catalogs or websites for up-to-date information on lamp part numbers and availability.

f. Other Existing Light Sources

Induction Lighting

- An induction coil is powered by a high frequency generator. The induced current causes acceleration of charged particles inside the lamp bulb. The metal vapour atoms are excited and ionized causing the release of ultra-violet energy. The UV energy causes the phosphor coating on the lamp wall to glow, creating white light.
- These products are seeing gradual implementation, especially in roadway lighting where long lamp life is beneficial.
- They have limited directionality. They are not as good as LEDs for applications where directional light is required. On the other hand they perform well at producing multi-directional light.
- These products are proprietary and are therefore not interchangeable.
- They require special sockets and electronic control equipment.
- Extremely long lamp life, typically 100,000 hours.
- A wide variety of induction lamps are offered on the market. Various wattages and light outputs are available to suit a variety of applications.

7 EMERGING AND/OR EFFICIENT TECHNOLOGIES

a. Controls

In the lighting industry, a significant amount of research and development is being carried out in the area of lighting controls to develop technologies required for better and more consistent dimming of light sources, such as low wattage metal halide, compact fluorescent and LED lamps. Control systems can be used to automatically adjust lighting output according to changes in time, occupancy and daylight. Self-powered wireless control devices make it possible to easily control individual lights or any group of lights.

Digital Addressable Lighting Interface (DALI) is a protocol that uses bi-directional exchange to allow flexible lighting controls. It is based on International Electrotechnical Commission (IEC) standards and major manufacturers offer DALI-compliant control devices for all kind of light sources.

Daylight harvesting is also a domain of active research. Manufacturers are constantly commercializing new products integrating most recent developments and generating higher energy savings.

When designing a lighting system, utilization of effective control features should be considered as a priority, since a well-designed control strategy, especially one using emerging control technologies, can generate considerable energy savings.

b. Cold-Cathode Fluorescent Lamps (CCFL)

Unlike ordinary fluorescent lamps, cold cathode fluorescent lamps (CCFL) are equipped with electrodes that can discharge electrons without being heated. CCFLs are made in a variety of size and colors. They are smaller in diameters and have longer lifetimes and better resistance to on-off cycles than ordinary fluorescent lamps. In addition, their temperature rise is very limited, which makes CCFLs ideal for backlighting in electronic devices such as LCD televisions and monitors. Since CCFLs are dimmable and can be turned on instantly, they offer several advantages when used in room-lighting applications.

c. Organic LED (OLED)

An organic light-emitting diode is a type of LED in which a layer of organic semiconductor placed between two electrodes emits light in response to an electric current. OLEDs are characterized by higher efficiency, lighter weight and better durability than conventional LEDs. In addition, the organic semiconductor is thinner than the crystalline layer in a LED. These characteristics make OLEDs ideal for digital displays in electronic devices. It is expected that, very soon, OLEDs could also be used in the usual applications that are being served by the conventional LED.

d. Plasma Lighting

Plasma lighting refers to light that is generated by the excitation of a plasma inside a closed bulb using radio frequency. Noble gases with additional materials such as metal halides, sodium and mercury are used inside plasma lamps. A waveguide generates an electrical field into the plasma. Free electrons excited by this electrical field collide with gas and metal atoms. These collisions bring atomic electrons to higher energy levels. Returning to their original states, these electrons emit light whose color depends on the materials used to fill the lamp. Efficiency and lifetimes of plasma lamps are comparable to those of LEDs.

e. Electron Stimulated Luminescence (ESL)

Electron-stimulated luminescence (ESL) uses a process called cathodoluminescence to generate light, which occurs when accelerated electrons emitted by a cathode hit a phosphor surface that emits light. ESL lamps do not use mercury. They consume 70 % less energy than incandescent lamps and have a lifetime of approximately 10,000 hours. However, this technology is not expected to emerge in the near future since it can be applied to the same sectors as LED which is now well established in the market.

f. Utilizing Natural Light

Natural Lighting

Using natural lighting involves using windows and other building openings to provide natural light as effective internal lighting during daytime. Making effective use of natural light must be considered as an important aspect when designing a building. Well-designed access to natural light can generate much energy savings and provide occupants with visual comfort.

Skylights

To increase the amount of light entering the interior space of a building, skylights can be used. These are a roof opening covered with glass, through which light can enter the building. Skylights are particularly useful for spaces that do not receive much natural light. Of course, they can be installed in any area where it is necessary to increase natural light and decrease the use of artificial lighting during daytime.

g. Other Emerging and Efficient Technologies

Since lighting accounts for a big portion of energy consumption in many buildings, much attention and effort has been devoted to developing technologies that allow better use of energy for lighting.

Many of the emerging technologies are for lighting controls. For example, lighting controls are increasingly being integrated into the building automation design; self-powered wireless controls offer high flexibility and require low investment and operating costs. Control systems offering detailed monitoring of space utilization can also help maximize savings. Since these new technologies can help save considerable investment and operation costs, particular attention should be paid to them when designing lighting systems.

8 ENERGY CONSERVATION AND ENERGY EFFICIENCY MEASURES

Energy conservation and energy efficiency measures can both reduce energy consumption. In practice, the use of these two terms may not always be in accordance with their definitions, but a fundamental difference exists between these two kinds of measures.

Energy efficiency measures are intended to decrease energy consumption by applying higher-efficiency technologies, while energy conservation measures are aimed at generating energy savings through behavioural changes, like turning lights off when they are not needed. Simply replacing an incandescent lamp with a CFL while maintaining the same lighting level is considered an energy efficiency measure. An energy conservation measure could involve keeping the original incandescent lamp and turning it off when no lighting is needed. The following subsections in this chapter present energy conservation and energy efficiency measures that apply to lighting systems.

a. Lighting Retrofitting

Components of a lighting system can be replaced with parts that have better energy efficiency but were not available or not cost effective when the luminaire was manufactured. Such a practice, called retrofitting, does not require installing new luminaires but only modifying existing ones. Replacing old T12 fluorescent tubes with new and more efficient T8 tubes would be a good example of light retrofitting; this measure does not require any change of luminaires. Replacing magnetic ballasts with electronic ones is another retrofit measure that can be applied to fluorescent tubes. Retrofitting measures applied to lighting fixtures often represent interesting options that can generate significant savings at relatively low costs.

b. Lighting Replacement

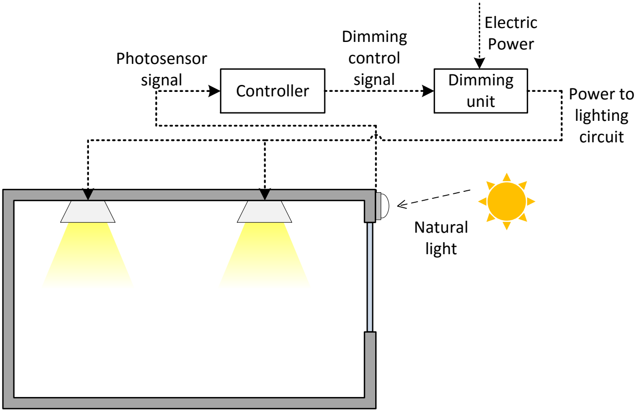
Sometimes, retrofitting is not a possible option or cannot generate sufficient energy savings. So, it can be decided to remove the existing lamps and replace them with a different technology. Unlike retrofitting, making replacements requires removing old fixtures and installing new fixtures that will accommodate new lamps. Replacing metal halide lamps with T5-HO fluorescent tubes in a warehouse with a high ceiling is a common example of lighting replacement. Lighting replacement can generate significant energy savings but will require more investment than retrofit measures.

c. Daylight-harvesting Fixtures

Daylight-harvesting fixtures can dim lamps in response to available daylight while maintaining a constant light level in a location. Artificial lighting intensity is always kept at a minimum level to make the maximum use of the natural light.

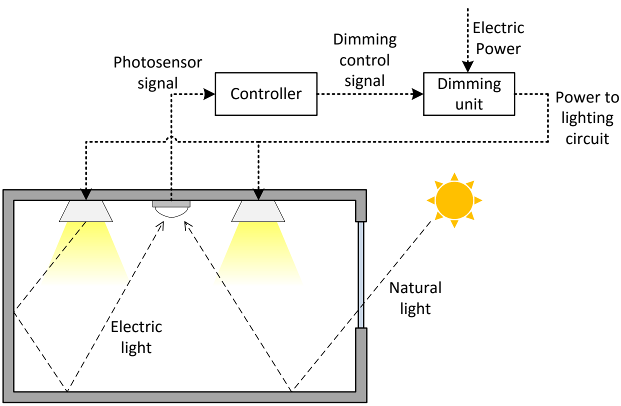
Daylight-harvesting systems use photosensors to detect the prevailing light level and automatically dims the lamps. Two types of systems exist. In an open-loop system, sensors can be positioned on the exterior wall or the roof of the building or a spot inside the building facing a window or a skylight to detect the amount of available daylight. Electric lighting is then adjusted based on the amount of available daylight.

Open-loop Daylight-harvesting System Illustration



In a closed-loop system, sensors are placed inside the space and detect the total amount of light from daylight and electric sources. Fixtures are dimmed to meet the required light level.

Closed-loop Daylight-harvesting System Illustration



To generate maximum savings, daylight-harvesting fixtures should be used in locations with sources of abundant natural light, such as clear windows and skylights.

For areas where availability of direct natural light is less important, fiber optics and solar tubes can be used to gather daylight and provide natural light to interior spaces. Those technologies can be used with the daylight harvesting systems described above to enhance energy savings by increasing use of natural light.

d. Avoiding Over-lighting

Over-lighting or over-illumination of a space occurs when light intensity is higher than what is required for the activity that takes place. Over-lighting must not be ignored when designing the lighting of a space. Providing the right light intensity can prevent unnecessary energy consumption and cost spending. The number of lamps installed, their spacing and their intensity must be chosen to match lighting levels prescribed for the right type of activity.

Access to natural light and its variation throughout the day is an important factor to consider when trying to eliminate over-lighting. In fact, artificial light intensity can be reduced depending on the amount of light entering the space. Daylight-harvesting, as described in the preceding subsection, can be an effective method to avoid over-lighting. If the type of activity being carried out in a space changes, light bulbs should be changed or appropriate controls should be implemented to adjust light intensity and avoid providing too much lighting to occupants. Implementing such measures can result in energy savings.

e. Exit Signs

Physical Data

- Most exit signs are approximately 12″ long, 8″ high and between 1″ and 4″ in depth.
- In the event of a power failure, a sign can be lit by either the emergency power supply system or by batteries.
- Cost varies due to construction features such as vandal-proofing, internal battery etc., and aesthetic features.
- Exit Signs can be internally lit (most common) or externally lit (rare).

Externally Lit

- An external light is aimed on the sign.
- Bulb replacement is easy.
- Sign is difficult to see in smoky conditions.
- Incandescent lamps are used.

Internally Lit

- Single or double-sided sign with light source inside the fixture.
- Some exit signs have an opening fitted with a diffractive lens at the bottom to help light the exit route.

Light Sources of Internally Lit Signs

There are four light sources for internally lit exit signs:

- Incandescent lamps.
- Compact fluorescent lamps.
- Low-voltage lamps: LED and miniature.
- Tritium gas.

LED Signs

- Made with LEDs in plastic tubes which form the letters.
- These signs use plastic as the medium to transmit the light.
- Require less depth than incandescent and compact fluorescent signs.
- More uniform illumination of letters.
- Manufacturers expect a 10 to 15 year lamp life.
- Consumes approximately 2 to 3 watts.

LED Lamp Retrofit

- Most incandescent signs can be retrofitted with LEDs. This is a popular practice since it generates more savings and LEDs have a longer life than compact fluorescent lights, which offer another retrofit option.
- LED replacement lamps should be chosen with caution and it should be kept in mind that replacements suggested by some manufacturers (for example a 6 W LED to replace 40 W incandescent bulb) may be overestimated and LED lamps may produce less lumen than the incandescent lamps. Light output of the replacement product should always be compared to the light output of the replaced product.
- Energy efficiency regulations encourage using LEDs to replace incandescent lamps in existing exit signs.
- LED lamps come in a wide variety of bases and can therefore fit various socket shapes and sizes, which makes replacing lamps very easy.

Tritium Gas Signs

- Radioactive tritium gas undergoes beta decay, releasing an electron which is incident on a phosphor-coated tube, shaped into the word EXIT.
- A modern tritium exit sign uses 25 curies (about 2.5 milligrams of tritium in the gaseous form).
- No external energy source is required.
- Lamp life is 10 to 20 years; it must then be replaced.
- Highest capital cost for lamp and fixture.

Incandescent Signs

Due to their high operation and maintenance costs, existing incandescent signs should be immediately replaced.

- Incandescent signs usually have two 15 to 25 watt bulbs.
- Most common type of exit sign in the past.
- Lighting of each letter is not uniform.
- Bulb life is generally 1 to 6 months.
- Consumes approximately 30 to 50 watts.

Code Requirements

- According to the Natural Resources Canada regulation, the maximum lighting power of internally lit exit signs is 5 watts per legend. A legend is defined as the word displayed on the sign, such as “EXIT” or “SORTIE”.
- According to The National Building Code of Canada, lighting for exit signs should be supplied by an electrical circuit separated from other circuits or circuit serving other emergency equipment. Moreover, letters on exit signs should be as follows:
    (a) Red letters on a contrasting background or white letters on a red background, at least 114 mm high with 19 mm stroke spelling EXIT or SORTIE when the sign is internally illuminated.

(b) White letters on a red background or red letters on a white background at least 150 mm in height with 19 mm stroke spelling EXIT or SORTIE when the sign is externally illuminated.

- The National Fire Protection Association of the United States requires the exit signs be illuminated by at least 5 foot candles (54 lux) and shall employ a contrast ratio of 0.5 or higher. This is not a requirement in Canada.

Note: Check local codes for requirements in your area.

Assessment

- LED signs consume less electricity and provide more uniform illumination, as well as being more aesthetically pleasing.
- Tritium gas signs do not consume electricity. The energy comes from the radioactive decay of tritium. They have a high initial cost but require very little maintenance.
- The energy efficiency of Exit Signs is now regulated in Canada and LED technology is the only one able to meet these performance levels.

9 LIGHTING COSTS AND SAVINGS ANALYSIS

Artificial lighting requires electricity. Therefore, lighting increases energy consumption. Reducing energy consumption of lighting can help reduce the total energy consumption of a building (kWh) and reduce the peak demand of electricity (kW). Monetary savings can be determined based on electricity tariffs, but energy consumption and peak demand reduction must be first accurately determined since they both have an impact on the electricity bill.

Operating hours and lighting requirements may differ from one location to another in the same building and this aspect must be considered. The same types of areas can be combined together to make the analysis easier.

The following example involving a school suggests a typical approach to determining lighting energy costs. Typical locations with lighting systems are given as follows:

- Classrooms – T-12
- Corridors – T-12
- Gymnasium – Mercury Vapor
- Cafeteria – Incandescent and T-12
- Exterior – Mercury Vapor

In this example, the analysis could be made of five types of location. For each one, the required information on the existing lighting system should be collected in order to determine its energy consumption. Based on the information about the specifications of the new systems, it is possible to evaluate the energy consumption reduction and calculate the energy savings. The table at the end of this section shows the type of information that should be considered for the classrooms mentioned above. More details on energy saving calculations are given below.

Energy savings calculations

In order to evaluate the impact of a lighting retrofit or replacement measure, electrical consumption and electrical demand savings must be taken into account.

Electrical consumption savings

Electrical consumption savings correspond to the amount of energy that is saved. It is the difference between energy consumption before and after the installation of a measure and it is expressed in kWh. To evaluate energy savings on a yearly basis, the following formula can be used:

$$\text{Energy savings}\left(\frac{kWh}{yr}\right) = \text{Consumption before}\left(\frac{kWh}{yr}\right) - \text{Consumption after}\left(\frac{kWh}{yr}\right)$$

Energy consumption takes account of the number of lamps, their power and their operation period. The following formula can be used to calculate energy consumption on a yearly basis:

$$\text{Consumption}\left(\frac{kWh}{yr}\right) = Number\ of\ lamps * Lamp\ power(kW) * Operating\ time\left(\frac{hrs}{yr}\right)$$

Demand savings

Electrical demand savings correspond to the reduction in power demand resulting from the installation of an energy saving measure. It is expressed in kW. Demand savings can be calculated with the following formula:

$$\text{Demand savings(kW)} = \text{Electrical demand before (kW)} - \text{Electrical demand after (kW)}$$

Electrical demand depends on the lighting system power as well as the diversity factor, which is the probability that a particular piece of equipment will be functioning during the facility's peak load.

$$\text{Electrical demand}(kW) = Number\ of\ lamps * Lamp\ power\left(\frac{kW}{lamp}\right) * Diversity\ factor$$

Initial Equipment Description

Information	Calculations	Value	Unit
Location (Name and/or Type)		classroom	-
Number of Similar Locations		10	-
Location Area		48	m^2
Total Area	(10 classrooms)*(48 m^2/classroom)	480	m^2
Light Name or Tag		2 F 40	-
Type of Lamp and Fixture		T-12	-
Number of Lamps per Fixture		2	-
Quantity of Similar Fixtures in the Room		10	-
Lamp Unitary Power		40	W
Fixture Unitary Power[2]	(40 W/lamp)*(2 lamps/fixture)	80	W
Power Factor		0.8	-
Diversity Factor[3]		100	%
Hours per Year Operated		2,000	hrs/yr
Year of Commissioning		2010	-
Lifespan of Lamp When New		12,000	hrs
Energy Consumption	(8,000 W)*(2,000 hrs/yr)/(1,000 W/kW)	16,000	kWh/yr
Peak Demand	(200 lamps)*(40 W/lamp)/(1,000 W/kW)	8	kW

New Equipment Description

Information	Calculations	Value	Unit
Light Name or Tag		2 F 32	-
New Lamp Type		T-8	-
Number of Lamps per Fixture		2	-
Quantity of New Fixture in the Room		8[4]	-
New Ballast Factor		1	-
New Lamp Unitary Power		32	kW
Power Factor		0.8	-
New Operating Hours		1,750[5]	hrs/yr
Lifespan of New Lamp		15,000	hrs
Total Power of the Fixture	(160 lamps)*(32 W/lamp)/(1,000 W/kW)	5.12	kW
New Consumption	(5,120 W)*(1,750 hrs/yr)/(1,000 W/kW)	8,960	kWh/yr
New Peak Demand	(160 lamps)*(32 W/lamp)/(1,000 W/kW)	5.12	kW

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[2] Including the ballast factor.

[3] The probability that a particular piece of equipment will be functioning during the facility's peak load.

[4] Reduced Number of fixture due to adequate quality of light.

[5] Installation of occupancy sensors

Energy Savings Calculations			
Information	**Calculations**	**Value**	**Unit**
Energy Savings	(16,000 kWh/yr)-(8,960 kWh/yr)	7,040	kWh/yr
Peak Demand Savings	(8 kW)-(5.12 kW)	2.88	kW
Electricity Tariff		0.12	$/kWh
Demand Charge		15	$/kW
Electricity Cost Savings	(7,040 kWh/yr)*(0.12 $/kWh)	844.80	$/yr
Peak Demand Cost Savings	(2.88 kW)*(15 $/kW)*(12 months)	518.40	$/yr
Total Cost Savings	(844.80 $/yr)+(518.40 $/yr)	1,363.20	$/yr
Cost of New Fixture		13	$
Total Investment	(8 fixtures/room)*(10 rooms)*(13 $/fixture)	1,040	$
Payback Period	(1,040 $)/(1,363.20 $/yr)*(12 months/yr)	9.2	months

10 CANADIAN CODES, STANDARDS AND REGULATIONS REFERENCES

Adherence to the appropriate codes and standards is best achieved by following the recommendations of a qualified lighting specialist. There are considerable revisions and changes which will continue to evolve both at the national and provincial/state level. For example, the Canadian Federal Energy Efficiency Act of 1992 provides for the establishment and enforcement of regulations concerning minimum energy performance levels for energy-using products. The act also enforces labeling of energy-using products as well as the collection of data on energy use. These regulations refer to many industry testing and performance standards, and are administered in Canada by Natural Resources Canada (NRCan, www.oee.nrcan.gc.ca). These regulations apply to regulated energy-using products imported into Canada or manufactured in Canada and shipped from one province to another. It is important to consult the acts and regulations which are enforced in your jurisdiction.

There is also the Energy Independence and Security Act of 2007, which has established higher standards for appliances and equipment including lighting products in the United States.

Code for Buildings

Similarly, it is important to remain current on local and regional requirements. There are often references to national codes or standards, but there may also be enhanced requirements. The following are some examples of national efforts with internet links to websites giving details about these standards.

- Commercial Buildings: ASHRAE/IESNA standard 90.1. This standard provides the minimum requirements for the energy-efficient design of most buildings. It includes space-by-space power density limits.
  www.ashrae.org/
- Guide to Canada's Energy Efficiency Regulations - Natural Resources Canada. This guide provides general information about the requirements of the Energy Efficiency Act, including lighting products.
  oee.nrcan.gc.ca/regulations/17311
- National Energy Code of Canada for Buildings (NECB) provides minimum requirements for the design and construction of energy-efficient buildings and covers the building envelope, systems and equipment for heating, ventilating and air-conditioning, service water heating, lighting, and the provisions of electrical power systems and motors. NECB provides limits in terms of maximum lighting power, and content referring to lighting is similar to ASHRAE 90.1 content.
  http://www.nationalcodes.nrc.gc.ca/eng/necb/

11 WORKSHEETS AND AUDIT

a. Audit Quick Guide

Before upgrading lighting systems, it is essential to conduct an audit. The objective of such an audit is to gather and compile all the information about the existing lighting systems. This will essentially provide a good knowledge about the components that are in place and how they are being used. The results of the audit can provide valuable information that will help determine the best course of action for maximizing energy and cost savings.

The information that is typically required to perform an audit can be divided into four categories:

- General information
- Financial information
- Occupant information
- Lighting information

General Information

General information covers everything about the location where the audit is performed. In the case of a building, division of space, the dimensions of all the areas, and the age of the building are the kinds of information to be collected. The type of activity that is performed in a room and the temperature at which it is maintained is also an aspect to consider because it can have an impact on interactive effects and on the savings generated by a measure. Floor plans or reflected ceiling plans showing fixture locations provide useful information and should be collected.

Financial Information

Any lighting measure needs to be financially justified before being implemented. Monetary savings are directly associated with the cost of electricity. It is, therefore, essential to acquire data about the local utility rate structure and the charges for energy (kWh) and demand (kW). These kinds of input are used to quantify the monetary savings and determine if the investment is justified or not.

Occupant Information

Occupants can provide information on hours of operation of lighting in various areas of a building. They can also provide relevant information about possible discomfort caused by inappropriate lighting levels.

Lighting Information

For each area covered by an audit, the following parameters should be identified:

- Hours of operation
- Types and sizes of fixtures
- Number of fixtures
- Number of lamps per fixture
- Number of lamps per ballast
- Types of lamp
- Types of ballast

Each situation is unique and the purpose of an audit can differ from one situation to another. Here are some examples of parameters that do not need to be systematically identified but could offer some relevant information, depending on the purpose of the audit :

- Fixture condition
- Availability of daylight
- Tasks performed in the space
- Area dimensions
- Height of the tasks
- Fixture mounting height

b. Audit Data Worksheet

PROJECT SUMMARY

Project:	Project Manager:
Site:	Project Engineer:
Report:	Lighting Specialist:
Total Area:	Lighting Designer:
Date or Report	Regional Office:
Rev.:	
Project No.:	
Building No.:	

COST AND SAVINGS ANALYSIS

Existing Electrical Use – (Base Year Electrical Data):

Annual Electrical Demand – Peak Average:	kW
Annual Electrical Consumption:	kWh
Annual Hours of Use (Average):	hours

Electricity Rates Information

	Blended Rates	Summer	Winter
Demand Charge ($/kW)			
Consumption Charge ($/kWh)			

AUDIT DATA

Initial Equipment Description

	Area 1	Area 2	Area 3	Area 4	Unit
Location					-
Type of Lamp					-
Lamps per Fixture					-
Type of Ballast					-
Ballast Factor					-
Number of Similar Fixtures					-
Lamp Power					W
Fixture Power					W
Power Factor					-
Diversity Factor[6]					%
Operation Time					hrs/yr
Year of Commissioning					-
Rated Life					hrs

6 The probability that a particular piece of equipment will be functioning during the facility's peak load.

c.Measure/Savings Worksheet

Current Equipment Description

	Area 1	Area 2	Area 3	Area 4	Unit
Location					
Type of Lamp					
Lamps per Fixture					
Number of Similar Fixtures					
Lamp Power					
Fixture Power					
Power Factor					
Diversity Factor[7]					
Operation Time					
Year of Commissioning					
Rated Lamp Life					
Energy Consumption					
Peak Demand					

New Equipment Description

	Area 1	Area 2	Area 3	Area 4	Unit
Location					
Type of Lamp					
Lamps per Fixture					
Number of Similar Fixtures					
Lamp Power					
Fixture Power					
Power Factor					
Diversity Factor[7]					
Operation Time					
Year of Commissioning					
Rated Lamp Life					
Energy Consumption					
Peak Demand					

Local Energy Savings

	Area 1	Area 2	Area 3	Area 4	Unit
Energy Savings					
Peak Demand Savings					

Lighting Energy Savings Summary

	Demand (kW)	Electricity Consumption (kWh)	Cost ($)
Total Current Usage			
Total Usage After Measure			
Savings			

7 The probability that a particular piece of equipment will be functioning during the facility's peak load.

12 EMISSION REDUCTION CREDITS

The Western Climate Initiative (WCI) was started in February 2007 by the governors of five US states (AZ, CA, NM, OR, and WA) to evaluate and implement ways to reduce greenhouse gases (GHG) emissions. In 2008, four Canadian provinces (BC, MB, ON and QC) joined the Western Climate Initiative (WCI). As of December 2011, the remaining WCI members were California and the four Canadian provinces. The participants of the WCI are committed to developing a multi-sector, market-based cap-and-trade program to reduce greenhouse gas emissions. Additional information on the WCI is available on its website:

http://www.wci-inc.org/

As part of the WCI, facilities emitting over 25,000 metric tons of equivalent CO2 are subject to the cap-and-trade program. In December 2011, California and Quebec both adopted regulations to establish cap-and-trade programs compatible with the requirements of the WCI. Additional information on Quebec's regulation is available on the website of Quebec's *Ministère du Développement durable, de l'Environnement et des Parcs* (Ministry of Sustainable Development, Environment and Parks):

http://www.mddefp.gouv.qc.ca/changements/carbone/Systeme-plafonnement-droits-GES-en.htm

Companies with GHG emission levels higher than the cap established by regulations will have to modernize by adopting clean technologies or buy emission allowances at government auctions or on the carbon market. As for companies with GHG emission levels below the emission cap, they can sell their excess carbon credits to other companies on the carbon market.

Businesses that are subject to the cap-and-trade program could reduce their GHG emissions by using many methods, such as process modification, energy efficiency and fuel switching. Lighting represents an area with plenty of opportunities for reducing energy consumption and meeting GHG reduction objectives as part of a cap-and-trade program.

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14 GLOSSARY OF TERMS

Ballast

A device used with a gas discharge lamp to provide the necessary starting and operating electrical conditions.

Candela (cd)

Fundamental unit from which all other lighting units are derived. Candlepower, the intensity of light in a specified direction, is measured in candelas. An ordinary wax candle has a candlepower of about one candela.

Candelas are used to compare intensities of different kinds of directional light sources. In a 75 W spotlight lamp the centre of the beam is 1,730 candelas and in a 75 W floodlight lamp it is 430 candelas, i.e., the centre of the spotlight's beam is four times as intense as the floodlight's.

Center Beam Candle Power (CBCP)

Center beam candle power (CBCP) is a term sometimes used for lamps using a reflector such as PAR lamps. This quantity refers to the luminous intensity at the center of the light beam. It is expressed in candelas.

Diffuser

A device commonly put on the bottom and/or sides of a luminaire to redirect or scatter the light from a source.

Diffusion

The scattering of light that falls on a surface.

Diversity Factor

The probability that a particular piece of equipment will be functioning during the facility's peak load.

Efficacy

The ratio of total lumens produced by the light source to the watts consumed by the source, expressed in lumens per watt.

Efficiency

The ratio of the total lumens emitted by the luminaire to those emitted by the lamp, expressed as a percentage.

Electromagnetic Spectrum

The total range of wavelengths of frequencies of electromagnetic radiation. The visible portion covers a wavelength from approximately 380 nm to 780 nm (1 nm = 10^{-9}m).

Electromagnetic Wave

A wave that travels through space and consists of a magnetic and an electric field.

Foot Candle (fc)

The practical working unit for the measurement of lighting level equal to one lumen falling uniformly on an area of one square foot.

General Service Fluorescent Lamp (GSFL)

A fluorescent tube with pins at one or both ends for installation.

Illuminance

Luminous flux density or lumens per unit area incident on a surface. The unit of illuminance is the lux (lx) where:

> 1 lx = 1 lm/m^2 (SI units) or the foot candle (fc) where 1 fc = 1 lm/ft^2 (imperial units). The relationship between lux and foot candle is 1 fc = 10.76 lx.

Illuminating Engineering Society of North America (IESNA)

The recognized technical authority in the illumination field in North America.

Interactive Effects

Interactive effects or cross effects occur when an installed energy efficiency measure has an impact on the energy consumption of other elements in the facility, such as heating and cooling.

Lamp

A generic term for an electric source of light. A lamp usually consists of a light-generating element (arc tube or filament), support hardware, enclosing envelope and base.

Lamp Lumen Depreciation (LLD)

Ratio between the anticipated mean lumen output of a lamp through its lifetime and its initial lumen output.

Light

Any radiation which makes things visible. It is radiant electromagnetic energy capable of exciting the retina of the eye and producing a visual sensation.

Lumen (lm)

The unit of luminous flux, i.e., the quantity of light emitted by a lamp.

Luminaire

A complete lighting unit consisting of a lamp(s) and parts designed to distribute the light, to position and protect the lamp(s) and to connect the lamp(s) to the power supply.

Luminance

The luminous intensity of a surface in a given direction per unit of projected area. The unit for luminance is NIT = candela/m^2 or foot-lambert = πcandela/ft^2. A surface emitting or reflecting light in a given direction at a rate of one candela per square meter of projected area has a luminance in that direction of 1 cd/m^2 or 1 NIT.

Luminous Exitance

The light leaving a surface at a point is measured in lumens per square foot.

Lux (lx)

A unit of illuminance or lighting level equal to one lumen uniformly falling on an area of one square meter.

Photometer (light meter)

An instrument for measuring photometric quantities such as illuminance (in foot candles or lux). The light sensitive cell, typically a selenium cell, must be cosine corrected and $V(\lambda)$ corrected.

Reflectance

The ratio of light emitted from a surface to the light falling on that surface.

Refraction

The bending of light rays as they pass through clear glass or plastic.

Specular Surfaces

Surfaces from which the reflection is predominantly regular, e.g., highly polished or mirror finished surfaces.

Transmittance

The ratio of light transmitted through a light-passing material (e.g. glass or ceramics) to the incident light falling on that material.

15 INDEX

Your feedback and comments will be sincerely appreciated.
Please write us at:

info@ceati.com

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- Environmental Performance
- Social Responsibility
- Security