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THE STANDARD FOR LIGHTING MANAGEMENT QUALITY SINCE 1953

CERTIFIED LIGHTING AUDITOR (CLA) TRAINING MANUAL

2025 EDITION

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CHAPTER 1: INTRODUCTION TO LIGHTING

THE LIGHT

Light is radiant energy which can be sensed or seen by the human eye. When light strikes an object, it is reflected back to our eyes, and that's how we see. Therefore, to see requires two things—an eye and light.

We rely on light to do everything. Wherever and whenever the sun doesn't shine, we use electric lighting systems to be able to see. We use lighting.

Lighting has an art and science to it. The science of lighting looks at how much light different people need to be able to do different things. For example, it would take more light to read a label with fine print on an apple than to simply pick it up and eat it. An old man would need more light to read the label than a young man.

The art of lighting looks at how people respond to where we put the light. We can light an object from above and create a shadow, from behind and create a silhouette, etc. By adjusting the lighting in a room, we can affect what kind of room people think it is, how comfortable they feel in it, and set a mood.

Good lighting can tell a story on a theater stage, draw attention to merchandise in a store, provide security, and allow people to perform necessary tasks accurately, efficiently and safely.

To provide lighting, architects, designers and engineers design lighting systems, manufacturers make them, sales professionals and electrical distributors sell them, electricians install them, and building owners and managers buy them.

Afterwards, lighting management companies maintain them and may upgrade them so that they work even better than first designed. That's where you fit in as an upcoming Apprentice Lighting Technician.

Lighting systems require ongoing maintenance based on rated life,

FIGURE 1-1

FIGURE 1-2
Courtesy of Universal Lighting Technologies, Inc.

FIGURE 1-3
Courtesy of Ledalite Architectural Products.

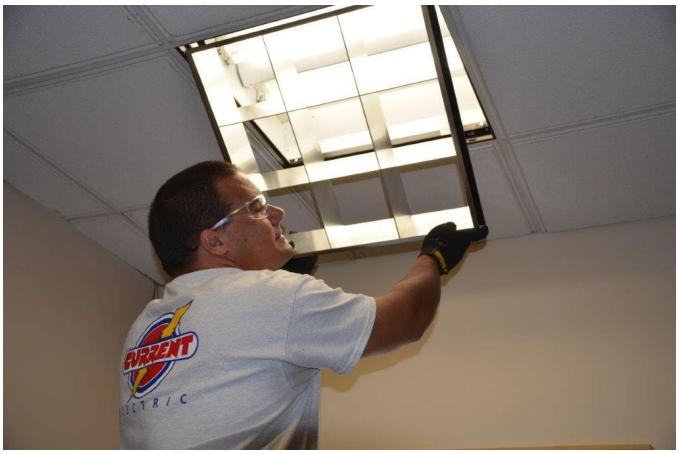
hours of operation and environment. Building owners pay a lot of money to have their lighting systems designed, engineered and installed. Ongoing and proper lighting maintenance is critical to ensure that problems are fixed, allowing the system to perform as good or better than originally designed. That's where you fit in.

Lighting management is a profession as old as the light bulb. Lighting management companies are comprised of professionals who clean, maintain, troubleshoot, diagnose and repair problems on all types of lighting systems, ensuring they perform as designed. In addition, lighting professionals audit, engineer, specify and install the correct lighting technology for the application. The correct technology may include new and emerging lighting products, a direct replacement of the existing products, or a combination of the two. The focus of the lighting project is determined by combining the customers' needs and wants with the expertise of a lighting professional and is typically designed to reduce energy and operational costs while improving performance. There's an art and science to lighting management.

The intended result is lighting that helps people do things accurately and safely for the lowest ongoing cost.

The first step to understanding lighting management is to

FIGURE 1-4
Courtesy of Current Electric Co.



understand lighting. To understand lighting, we must know the types of lighting, how lighting works, and the language used when discussing it.

THE LIGHTING SYSTEM

To become an Apprentice Lighting Technician, you must understand how a lighting system functions so you can keep it performing at its best.

While there are thousands of variations on the basic lighting system, most lighting systems can be broken down into four basic parts:

Light Source: The light source produces the light. The light source may be referred to as a light bulb or tube, but in the lighting industry, we use the term "lamp." A lamp is defined as "the complete light source package, including the inner parts as well the outer bulb or tube."

Ballast: Some light sources need a device called a ballast to start up and run the lamp. A ballast is defined as "an auxiliary piece of equipment required to start and to properly control the flow of current to gas discharge light sources such as fluorescent and high-intensity discharge (HID) lamps." Typically, magnetic ballasts

FIGURE 1-5
Lamps. Courtesy of GE Lighting.

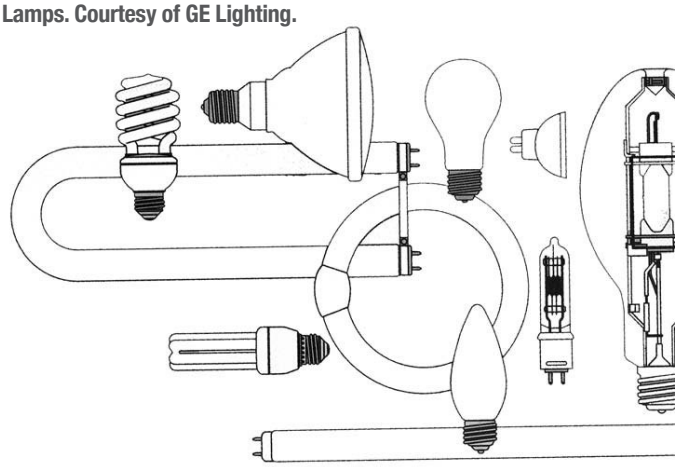


FIGURE 1-6
Ballasts. Courtesy of Universal Lighting Technologies, Inc.

(also called electromagnetic ballasts) contain copper windings on an iron core, while electronic ballasts are smaller and more efficient and contain electronic components.

Luminaire: The light fixture is referred to as a luminaire by lighting professionals. A luminaire is defined as: "the complete lighting unit, including the lamp, reflector, socket, wiring, diffuser and housing." The luminaire houses the lamp and ballast (when required), provides a connection point for supply voltage and directs the light by means of reflection known as optics.

FIGURE 1-7
Luminaire. Courtesy of Lightolier.

Control: An extended and essential part of the lighting system is the control, which may be as simple as a wall switch or dimmer, or as sophisticated as a computerized system allowing you to control a defined area or an entire building's lighting system from a PC or even your smart phone. The control can either modify the power flowing down the circuit to the lighting system so that the lights dim, or can open or close the circuit to turn the lighting system on or off.

The lighting system is connected to a lighting circuit. A lighting circuit is wiring that provides power to electric lights. Multiple luminaires can be connected to a circuit, depending on the load-

FIGURE 1-8
Lighting control. Courtesy of Lutron Electronics.

carrying capacity of the circuit (measured in amps) and the size of the lighting load (measured in watts).

REMEMBER
The control allows electric power to flow to the luminaire, the ballast starts and operates the lamp, the lamp produces light, and the luminaire controls the direction and intensity of the light emitted by the lamp.

THE ELECTRICAL SYSTEM

Electricity is a form of energy created by the movement of electrons. Directing these electrons through a circuit, we can energize electrical systems.

Lighting systems are electrical systems, like electric motors and fans. Electrical systems convert electrical input into work output. In the case of a lighting system, this work is the delivery of illumination. Because they are electrical systems, they require electric power to operate. This power is fed to the lighting system through the building's electrical system, which is made up of electrical circuits.

The electrical systems' wire is called a conductor because it conducts electricity along a defined path. Copper is a good conductor and is therefore used for electric wiring. Materials such as wood, plastic or glass are not good conductors. Poor conductors are called insulators.

Conductors are used to create circuits. In an electric circuit, electric power starts at a generator (power provider), flows into the building's electrical distribution equipment and through the electrical devices attached to the circuit (such as lighting systems), and returns to the generator.

Lighting systems have their own circuits that connect to the building power lines. Each circuit can supply multiple luminaires depending on the lighting load (wattage), wire size, the load-carrying capacity of the circuit, and circuit breaker size.

REMEMBER
Luminaires are connected to lighting circuits, which allow electric power to flow from the generator to the lighting system, through the lighting system, and back. A circuit is created using conductors, insulated material such as copper that allows easy, orderly, directional flow of electricity. The rate of flow is called current, the result of voltage and resistance. A given circuit can support a number of luminaires.

TYPES OF LIGHTING SYSTEMS

There are four common types of lighting systems that you will work on as an Apprentice Lighting Technician: incandescent, fluorescent, high-intensity discharge (HID) and light-emitting diode (LED). While these lighting types will be covered in greater detail in subsequent chapters, the following should start to familiarize them.

Incandescent: The common light bulb. Incandescent lamps produce light through a process called "incandescence," in which electricity is passed through a filament which is heated until it glows. Not only is light produced, but a lot of heat.

FIGURE 1-9
Incandescent. Courtesy of GE Lighting.

Another type of incandescent lamp is *halogen*, which is found in luminaires ranging from torchieres used in houses to track lighting to car headlights. Halogen lamps produce a brighter, whiter light than incandescent lamps, and last longer.

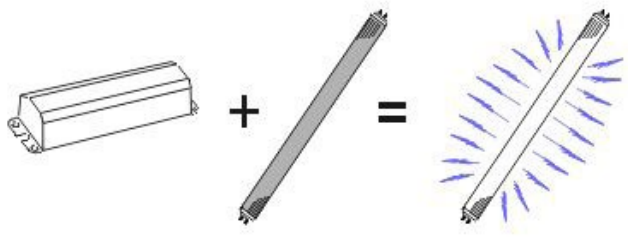
FIGURE 1-10
Halogen. Courtesy of GE Lighting.

Incandescent and halogen lamps do not require a ballast.

Fluorescent: The common white tube you have seen in ceiling luminaires in offices and retail stores. Fluorescent lamps produce light using a process called "fluorescence," in which electricity is passed through a gas until it emits energy that in turn is converted into visible light by a phosphor coating on the lamp envelope.

Fluorescent lamps need a ballast.

FIGURE 1-11
All fluorescent lamps need a ballast to operate. Courtesy of Philips Lighting.



High-Intensity Discharge (HID): HID lamps produce light similarly to fluorescent lamps, but at much higher pressures, producing a lot more light in the process. You have seen HID lamps in streetlight poles, parking lots and nighttime sporting events.

HID lamps need a ballast.

Light Emitting Diode (LED): LED lamps are actually an organic chip mounted to a circuit board that is energized by a driver (similar to a fluorescent ballast), producing an intense and highly directional light source. LED lamps are becoming a common source for downlights, track lighting and display lighting.

LED lamps need a driver.

REMEMBER

There are four major families of lighting—incandescent (including halogen), fluorescent, HID and LED. Fluorescent and HID lamps need a ballast to operate, and LED lamps need a driver. There are many types of lamps (ballasts and drivers) within each family.

HOW LIGHTING SYSTEMS ARE MEASURED

We can learn a lot about any lighting system we come across by understanding common lighting words, some of which are shown below. They tell us the basics of what we need to know about the lighting system.

How long does the lamp last? Lamp life is expressed as a number of operating hours as rated by its manufacturer. You can find a given lamp's rated life in the manufacturer's catalog.

Lamp life is very important in lighting maintenance because a big part of lighting maintenance is about replacing lamps. How long a lamp is predicted to last by its maker is called its *rated life*, and is measured in hours. There are three other things that are important for you to know about lamp life at this point.

Table 1-1.

LIGHTING SYSTEM MEASUREMENTS	Unit	Abbrev.
How long does the lamp last?	Life (hours)	hrs
How much light does it produce?	Light output (lumens)	lm or L
How much electricity does the system require?	Wattage (watts)	W
How efficient is it compared to others?	Efficacy	lm/W
What's the color of the light?	Color appearance	K
How accurate do colors look in the light?	Color rendering	CRI

First, lamp life is based on correct and proper installation. High line voltage, connecting the lamp to the wrong type of ballast, and other problems can shorten lamp life.

Second, fluorescent, HID and LED rated lamp life is an average. For fluorescent and HID lamps, that means at 100% of rated life, 50% of a large group of lamps can be expected to have failed. For LED lamps that life is typically determined when the systems have experienced a 30% depreciation in lumen output. The rate of failure is shown on the lamp's *mortality curve* (see Figure 1-12).

For example, given 100 fluorescent or HID lamps with a rated life of 20,000 hours, then at 20,000 hours only 50 of the lamps are expected to have failed, not all of them. If we look at the mortality curve for this lamp, we see that at 70% of their rated life, only 7% have failed. After 70-80% of lamp life, the rate of failure accelerates dramatically.

Third, rated lamp life is based on hours per start. Fluorescent lamps,

FOOTCANDLES AND CANDLEPOWER

Two important measurements of light are frequently confused—footcandles and candlepower.

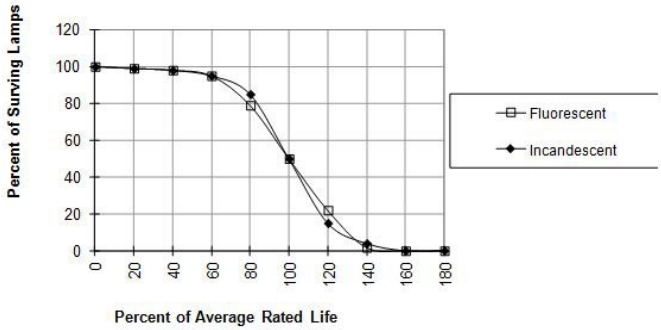
Footcandles, expressed as lumens per square foot, measure the light that falls on a surface (illuminance). A footcandle minimum, for example, may be written into lighting specifications based on the Illuminating Engineering Society of North America's (IESNA) recommended light level for a particular room or task.

Candlepower measures the intensity of a light source in a specific direction. Candlepower measurements are expressed in candelas and are independent of any object or surface that is being lighted.

for example, are typically rated at 3 hours per start and HID lamps are typically rated at 10 hours per start. If a fluorescent lamp's service life is rated at 3 hours per start, this is the lamp life if it is turned on for 3 hours, then off for 15-20 minutes, then on again for 3 hours, etc. The reason for qualifying rated life this way is that most of the wear and tear that happens to a fluorescent or HID lamp happens on start-up. Therefore, a fluorescent lamp rated at 20,000 hours at 3 hours per start is rated at 26,000 hours at 10 hours per start. If the lamp is left on and never turned off, it can last as long as 30,000 hours or longer.

How much light does it produce? In review, controls provide electric power to lighting systems, ballasts start and run lamps, lamps produce light, and luminaires control the direction and intensity

FIGURE 1-12
Typical mortality curve for fluorescent lamps. Large groups of lamps tend to follow this curve. Courtesy of the Lighting Design Lab.



of the light. The goal of all of this is to produce useable light.

The light produced by lamps is called lumen output and is measured in lumens. If you look at a lamp catalog, you will see that a given lamp produces a quantity of lumens. A typical T8 fluorescent lamp, for example, produces 2900 lumens. Fluorescent, HID and LED lamps are operated on ballasts or drivers, which affect the lumen output.

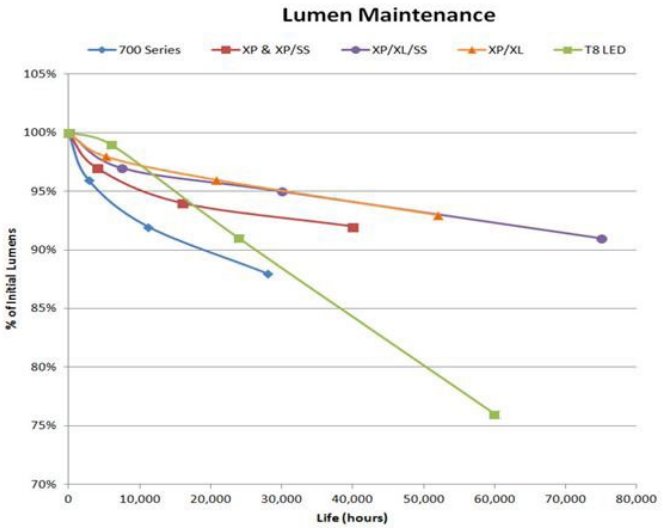
The important thing about lumen output is that the amount of lumens produced by a lamp goes down over time. This is called lumen depreciation (see Figure 1-13). The amount of lumen depreciation a given lamp experiences over time is called lumen maintenance. As the lamp ages, it produces less light.

How much electricity does the system require? Lighting systems depend on electricity to be able to work. The amount of electric power required is expressed as its rated wattage.

In reviewing a lamp and ballast manufacturer catalog, you will again notice that the lamp wattage is not the system wattage for fluorescent, HID and LED systems. This is because these lamp types need a ballast or driver to work. The ballast manufacturer shows the total wattage for the ballast plus the lamps that it operates.

You can have two 32W lamps, drawing a total of 64W, but when connected to a ballast, the system draws a combined 58W for both lamps and the ballast. This is a direct result of the ballast factor (BF), which will be explained later.

FIGURE 1-13
Lamp lumen depreciation curves for common lamp types. Courtesy of OSRAM SYLVANIA.



Why is this important? Because lighting costs money. First, it costs money to buy and install a lighting system. Then it costs money to run it and maintain it. One of the biggest costs of a lighting system is the electric bill from the local power company.

Wattage tells us how much electric power the lighting system requires to operate. Energy is power (W) x time (hours). So a lighting system drawing 114W of power that runs 8000 hours a year consumes 114W x 8000 hours ÷ 1000 = 912 kilowatt-hours (kWh) of energy. The local power company charges a dollar amount per kWh. If the kWh charge is $0.10/kWh, then our 114W lighting system costs $91.20 per year to run.

How efficient is it compared to others? Because lighting systems present an ongoing energy cost, building owners and managers have begun choosing lighting systems that have a lower operating energy cost. This is important for building owners, as reducing costs will increase profit. It's also important for the country, as using less energy can reduce air pollution and fuel consumption at the power companies' power plants.

Efficiency is important. It is important when designing a new lighting system and it is an important reason why building owners and managers are upgrading their existing lighting systems with new, energy-efficient, longer-life systems.

Once we know how much lumen output we want from the lighting system, we can specify a system that will produce the appropriate level of output for the lowest amount of energy use. That's a simple way of comparing lighting systems.

Another way is to look at the lighting system's efficacy. Energy-efficient lighting systems produce more lumen output per unit of electrical input. Efficacy is the expression of the number of units of lumen output per unit of electrical (watt) input; it is defined as lumens ÷ watts, or lumens/watt (lm/W or LPW).

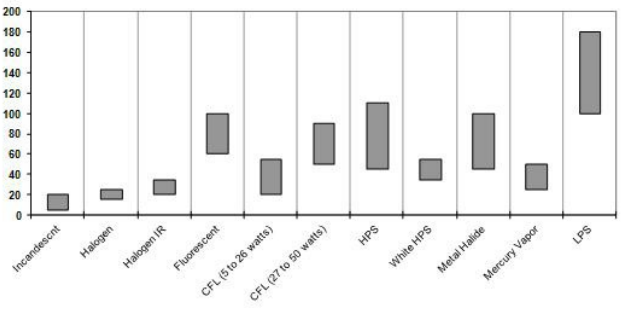
Lighting System A produces 8500 lumens and draws 150W.

Lighting System B produces 12000 lumens and draws 200W. Which one is more efficient?

Lighting System A's efficacy is 8500 ÷ 150 = 57 lm/W. Lighting System B's efficacy is 12000 ÷ 200 = 60 lm/W. Lighting System B therefore has a higher efficacy.

What's the color of the light? If you shine a flashlight through a glass prism, you'll see a rainbow come out the other end. This is because light is made up of colors, and all colors combine to create white light.

FIGURE 1-14
Lamp-ballast system efficacies. Courtesy of the Lighting Design Lab.



Lamps produce light that has a color appearance, which affects the color of objects when the light strikes them, and affects the color appearance of the lamp itself.

The "color of the light" is expressed as the lamp's color temperature and measured in degrees Kelvin (K). A low color temperature means the lamp is "warm" in appearance (reddish-white), a medium color temperature means the lamp is "neutral" in appearance (white), and a high color temperature means the lamp is "cool" in appearance (bluish-white). A typical household incandescent light bulb is a very warm light (2700K). Daylight is a very cool light (6500K).

The right color temperature is often a matter of preference. At home, people tend to prefer warmer light sources, while at the office, cool or neutral light sources are preferred.

How accurate do colors look in the light? When light hits an apple, the apple reflects light back into our eyes, and that's how we see it. But what makes an apple red? The apple's skin is chemically disposed to absorb all colors of the light spectrum except for red. Red is reflected back to our eyes, and we see the apple as red.

Electric lighting systems, however, are not like the sun. The light produced usually isn't perfectly balanced in all colors. Under some types of lighting, in fact, an apple can even look gray. When choosing a lamp, how are we supposed to know that it will render colors accurately—that is, how we would expect them to look?

The answer is color rendering, expressed as a lamp's Color Rendering Index (CRI) rating. The CRI scale starts at 0 and goes up to 100. A high CRI rating means the lamp can render colors very well. A low CRI rating means it doesn't. An incandescent lamp has a CRI rating of 100. Fluorescent lamps have CRI ratings from the 60s

FIGURE 1-15
Typical color temperature ratings for common lamp types. Courtesy of OSRAM SYLVANIA.

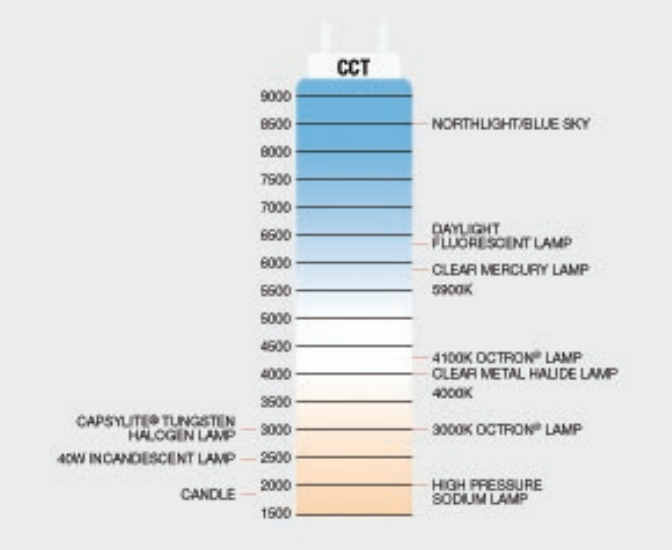
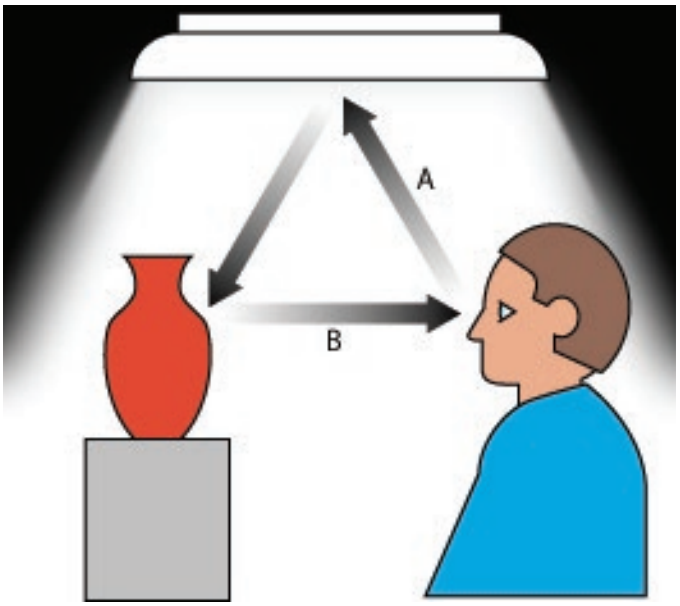


FIGURE 1-16
How we see. Light is emitted by a light source. The light strikes an object and reflects some of it. The reflected light stimulates the eye, which produces vision. Courtesy of OSRAM SYLVANIA.

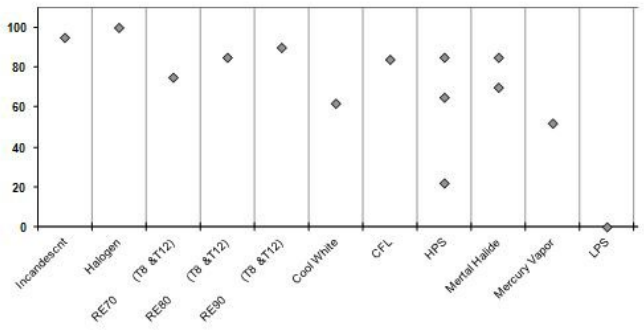


to the 90s, depending on the lamp. Only compare CRI between two lamps of the same color temperature.

LET'S LEARN ABOUT LAMPS AND BALLASTS

In following chapters, you will learn about the four major families of lighting and the devices used to control them. Using the information in this chapter, you will begin to understand, identify and compare different lamps and ballasts. There are two other important things you should keep in mind.

FIGURE 1-17
Typical CRI values for common lamp types. Courtesy of the Lighting Design Lab.



REMEMBER

When we examine a lighting system, we must know the lamp's rated service life, how much light the lamp or lamp-ballast system produces, how much electric power the system requires to produce light, how efficient it is compared to other lighting systems, what the color appearance of the lamp is, and how accurately it renders colors.

Lighting families are always in competition to provide a better product with higher quality and efficacy. Incandescent lamps, for example, were the light source of choice for exit signs until light-emitting diodes (LEDs) came along. Magnetic ballasts dominated fluorescent lighting until the demand for more energy-efficient lighting systems caused electronic ballasts to gain a leading market share in just 10 years. Each type of lamp and ballast is constantly evolving to meet market needs and stay competitive.

That being said, the most important thing to remember is, in a lighting system, there is no "one size fits all" solution and there is no such thing as a perfect lamp or ballast for every application. The best lighting always starts and ends with the customer's needs.

Take the Introduction to Lighting Quiz, turn the page, and get set to become an expert on lamps and ballasts.

INTRODUCTION TO LIGHTING QUIZ

Check your understanding of this chapter's material by completing these multiple-choice questions. The answers are on Page 84.

1. Light output is measured in …?
a) Footcandles
b) Lumens
c) Watts
d) Electrons

2. Rated lamp life is the time when …?
a) Lamps reach 20,000 hours of operation
b) 1/2 of a large group of lamps are expected to have failed
c) All lamps are expected to fail
d) It's the best time to group relamp

3. The Color Rendering Index is a scale that describes how accurate colors look when struck by the light from a given lamp. How is the scale defined?
a) 0-100, with 0 being worst and 100 being best
b) 0-75, with 0 being worst and 75 being best
c) 0-100, with 100 being worst and 0 being best
d) 0-75, with 75 being worst and 0 being best

4. Which of the following is NOT a typical function of a lighting system?
a) Ballast starts and operates the lamp
b) Lamp produces light
c) Ballast records energy consumption on an LCD display
d) Luminaire controls the direction and intensity of the light coming out of the lamp

5. Voltage is the "push" of electricity, which reaches resistance, and the resulting rate of flow of electric power down the line is called …?
a) A conductor
b) An insulator
c) The circuit
d) The current

6. Which of the following is NOT one of the major families of lighting?
a) Incandescent/Halogen
b) Electroluminescent
c) High-intensity discharge
d) Fluorescent

7. The amount of electric power a lighting system draws is measured in …?
a) Watts
b) Ohms
c) Amps
d) Volts

8. A lighting system's efficacy is measured in …?
a) Lumens/Watt
b) Amps/Volt
c) Lumens/kWh
d) $/kWh

9. Which is NOT one of the most important questions we typically need to ask to be able to understand and compare one lamp to another?
a) How long does the lamp last?
b) How much light does it produce?
c) How much electricity does it require?
d) What is its noise rating?

10. ____ describes the gradual decline in a lamp's light output as it ages.
a) Light efficacy
b) Lamp consolidation
c) Lumen depreciation
d) Hours per start degradation

11. A lamp with a very low color temperature is considered …?
a) Warm light source (reddish)
b) Neutral light source (white)
c) Cool light source (bluish)
d) Energy-efficient

12. A lamp's color rendering ability describes how well it can relatively …?
a) Prevent color shifting over time
b) Raise color temperature over time
c) Show colors accurately
d) Produce light per unit of consumed energy

13. If a lamp is rated at 20,000 hours at three hours per start, this is the lamp life if the lamp is …?
a) Turned off and on quickly every three hours
b) Left on for three hours and off for 15-20 minutes
c) On for three hours and off for three hours
d) None of the above

CHAPTER 2: INCANDESCENT LIGHTING

INTRODUCTION

The first working model of an incandescent lamp was developed by Thomas Edison in 1879. Today, its ancestors continue to light millions of homes and many spaces in hospitals, schools, churches, restaurants, apartment complexes, offices and factories.

By reading this chapter, you will gain an understanding of the two major types of incandescent lighting—incandescent and tungsten halogen lamps.

By the time you're done reading this section, you will be able to identify common incandescent and halogen lamps and read a lamp label and catalog.

FIGURE 2-1
Incandescent lamps. Courtesy of GE Lighting.

INCANDESCENT LAMPS

Incandescent lamps are simple compared to fluorescent and HID lighting systems. They feature familiar Edison bases so they can screw directly into sockets. They don't need a ballast.

However, the standard light bulb common in the home is only a partial view of incandescent lamps, of which there is a wide variety of types, shapes, styles, wattages and colors.

All incandescent lamps produce light using a method called "incandescence," in which a solid material is heated until it glows. An incandescent lamp is essentially a glass bulb over screw-in base, which connects the lamp to the power supply. Inside the bulb is a coil of fine wire, the "squiggle" often seen in drawings of light bulbs. Electricity is passed through the filament, which heats until it becomes white hot and produces light.

Incandescence makes the lamp a point source—the light is emitted from a point rather than the phosphor-coated bulb wall, as is the case with fluorescent lamps. This means incandescent lamps can be too bright to look at directly but can create "sparkle" in a space, which can be desirable for applications such as restaurants, and the light beam can be easily aimed and focused using reflectors and lenses.

Incandescent Lamp Types

Incandescent lamps are available in a wide variety of wattages, configurations, shapes and colors for a broad range of applications. The basic incandescent lamp is called a general service or standard lamp, with the most common lamp shape being A lamps—the household light bulb. Additional types include:

REMEMBER
When replacing incandescent lamps that have been operating, always let them cool down before attempting replacement, as the bulb will be very hot.

Reflectorized Lamps: The lamp may feature an integral reflector that aims the light forward in one direction. Without the reflector, the lamp would emit light in all directions. Popular reflector designations include BR (bulge reflector), PAR (parabolic aluminized reflector) and ER (elliptical reflector). A layer of glass in front of the lamp distributes the light output in a controlled beam pattern. There is a range of beam patterns from narrow spot to wide flood.

Infrared Lamps: These lamps are designed to produce heating instead of light.

Long-Life Lamps: These lamps are designed to provide 1,500-3,000 hours of service life, up to 2-4 times longer than standard incandescent lamps.

Rough Service: Rough service lamps are designed for construction sites, factories, elevators and other applications where shock, vibration or the weather can damage the filament or the bulb. These lamps are shock-, vibration-, shatter- and weather-resistant.

Clear Vs. Frosted: The lamp bulb may be frosted or clear. Clear incandescent lamps are point sources while frosted lamps diffuse the light emitted from the lamp.

FIGURE 2-2
Common incandescent lamp shapes. Courtesy of GE Lighting.

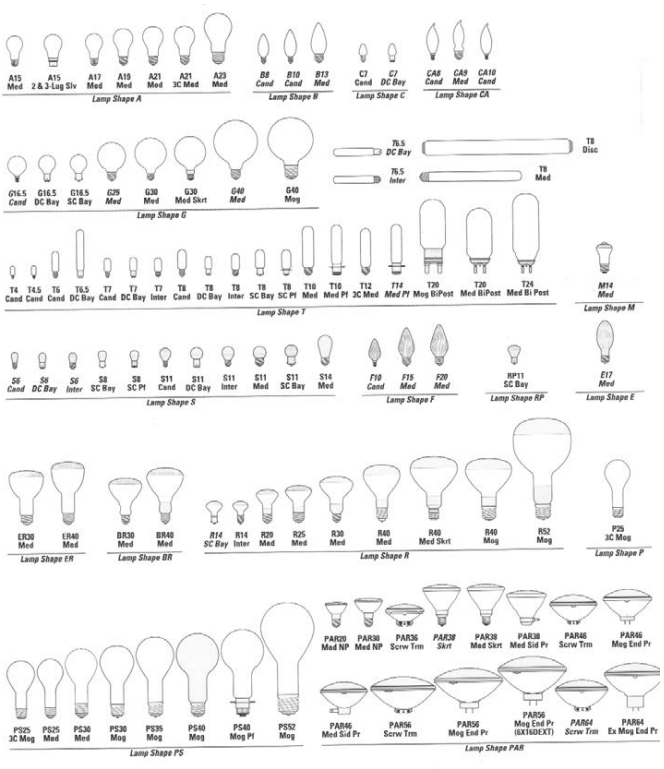
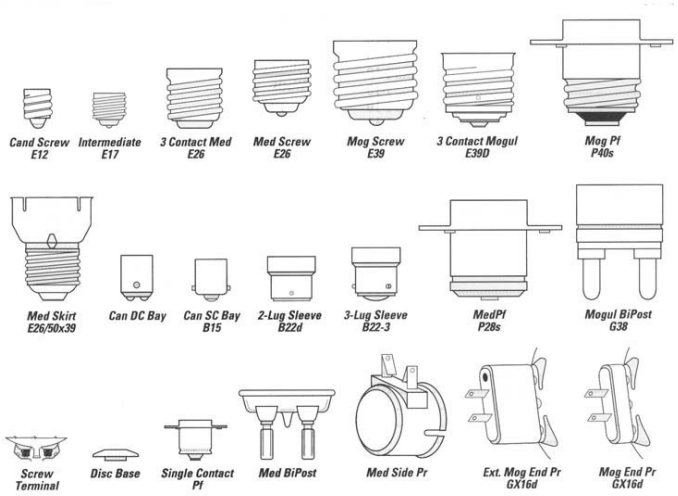


FIGURE 2-3
Common incandescent lamp bases. Courtesy of GE Lighting.



There are many other types of incandescent lamps, such as blacklights, energy-saving lamps, daylight or full-spectrum lamps, bug lights, plant lights, colored lamps, appliance and indicator lights, signal lamps, and night lights.

Now that we know the basic types of incandescent lamps, we can ask the questions posed in Chapter 1, to help us understand how they perform. How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? What's the color of the light? How accurate do colors look in the light? The answers for several major lamp types are shown below:

Advantages and Disadvantages

Advantages of incandescent lamps include:

- Lowest initial cost—lowest cost to purchase.
- Simple to install—simply screw into socket until an electrical contact with the power supply is established.
- Excellent color rendering (100 CRI); people are used to seeing things under incandescent light.
- Point source creates sparkle in a space and is easy to control, direct and focus using reflectors and lenses.

REMEMBER

Two fundamental types of incandescent lamps include bulbs in different shapes and reflectorized lamps, which include an integral reflector and lens to aim and focus the light beam in a desired direction.

- Instant starting and re-starting.
- Wide range of styles, light outputs, shapes, wattages.
- Easy to dim.
- Light output not affected over wide range of ambient temperature, hot or cold areas.
- No ballast is required.

Disadvantages of incandescent lamps include:

- Incandescent lamps are highly inefficient, making them more expensive than other types of lighting when the electric bill comes in the mail. When looking at a light source, there are two types of costs. One is the cost of purchase (low in the case of incandescent), and the other is the cost of ownership, including lamp replacement, maintenance and energy costs (high in the case of incandescent). A typical incandescent lamp converts only 10-15% of its electrical input into light output; the rest is converted almost entirely into heat.
- Short service life. Standard incandescent lamps are rated to last only 750-1,000 hours. Long-life lamps last 2,000-3,000 hours. A compact fluorescent lamp, designed to replace incandescent lamps, is rated to last 10,000 hours. Incandescent lamps must be replaced more frequently, creating replacement costs.
- Incandescent lamps are sensitive to shock and vibration, which can disable the filament. Rough service lamps are available for applications where the lamps are prone to shock and vibration.
- Incandescent lamps are also sensitive to variation in the voltage coming off the line. Operating a 240V lamp on 226V (-6%), for example, reduces wattage by 10% and light output by 20%, while increasing lamp life by 30%. Operating the same lamp on 254V (+6%) increases wattage by 10% and light output by 22%, but decreases lamp life by 30%.

Incandescent Lighting Questions

TYPE	HOW LONG DOES THE LAMP LAST? (HOURS)	HOW MUCH LIGHT DOES IT PRODUCE? (INITIAL LUMENS)	HOW MUCH ELECTRICITY DOES IT NEED? (WATTS)	HOW EFFICIENT IS IT COMPARED TO OTHERS? (LUMENS/ WATT)	WHAT'S THE COLOR OF THE LIGHT? (COLOR TEMPERATURE)	HOW ACCURATE DO COLORS LOOK IN THE LIGHT? (COLOR RENDERING INDEX)
90PAR38	2000	1350	90W	15	about 3100K	100 CRI
90PAR38 (130V)	4000	1000	79W	11.1	about 2900K	100 CRI
60PAR38/IR	3000	1110	60W	18.5	about 3100K	100 CRI
60PAR38/IR (130V)	6000	850	53W	16	about 2900K	100 CRI
35MR16/IR-24º	5000	800	37W w/transformer	21.6	about 3100K	100 CRI

- As a point source, incandescent lamps can cause stronger shadowing. This may be beneficial in some applications and detrimental in others.

Lamp Identification

The lamp manufacturers use different codes to describe their lamps. However, most incandescent lamps use similar elements: lamp wattage + lamp shape + bulb size in 8ths of an inch. Here's an example: 65BR30.

65 = lamp wattage.

BR = shape; this lamp has an integral reflector to aim the light in a controlled beam. Additional shapes include A, R, PAR, T, G and others.

30 = lamp diameter in 8ths of an inch; this lamp is 30 ÷ 8 = 3 3/4 inches in diameter.

After that, you may see a variety of codes that the manufacturers use and explain in their catalogs. These codes may address beam pattern (example: FL = flood, SP = spot, etc.), color (example: W = soft white, A = amber, etc.), service life (example: LL, DL = long-life, double-life), and number of lamps that come in a package (example: 24PK = 24 lamps per package).

Reading the Lamp Catalog

Incandescent lamps are typically grouped in ascending order of wattage (10, 20, 30, etc.). Each product listing answers most of our basic questions about the light source: How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? The listing provides other information, such as the lamp's ordering code so that people can buy them. The order codes differ between manufacturers, but cross-references are usually shown in the catalogs by brand name.

Below is a partial cross-reference between the three largest lamp manufacturers from the Osram Sylvania catalog:

Cross Reference of Manufacturers from the Osram Sylvania Catalog

GE	OSRAM/SYLVANIA	PHILIPS
Bug-Light	House Garden – Bug-Lite	Bug-A-Way
Double Life	Long Life	Longer Life
Daylight	Reveal	Natural
Energy Saver Soft White	Soft White Miser	Energy Saving
Excel-Line	Extended Service	Extended Service
Rough Service	Ruff-in-Tuff	Rough Service
Soft Pink	Soft Pink	Pink Softone Pastels
Spot-Gro	House Garden – Plant Light	Agro-Lite

Sample Catalog Listings

NOMINAL WATTAGE	BULB	BASE	PRODUCT #	ORDERING ABBREV.	VOLTS	AVG. RATED LIFE (HRS)	INITIAL LUMENS	DESCRIPTION	MOL
60	A-19	Med	11715	60A/BLACKLIGHT/RP	120	1000	--	Blacklight	4-7/16
60	A-19	Med	16794-0	60A/CL/LL 12/2	120	1500	900	Clear Long Life	4-7/16
60	A-19	Med	22384	60A/GD 24PK	120	3000	635	Light IF-Garage Door, Vibration Resistant	4.43

NOMINAL WATTAGE	Wattage of the lamp.
BULB	Describes the shape of the bulb (letter) and the diameter of the bulb in 8ths of an inch (number).
PRODUCT NUMBER	Also called an "order code" or "ordering code," this number allows you to identify a single, specific lamp when you want to buy one.
ORDERING ABBREVIATION	This is the lamp's code, which reveals some of its primary characteristics.
VOLTS	The line voltage the lamp is designed for.
AVG. RATED LIFE (HRS)	Indicates median life expectancy—the point at which 50% of a large group of lamps is expected to fail.
LUMENS	This is the amount of light produced by the lamp.
DESCRIPTION	Description of the lamp.
MOL	Maximum overall length of the lamp.
OTHER	Other information may include LCL, which is the distance between the center of the filament and the Light Center Length reference plane, in inches; color temperature (K); beam spread (reflectorized lamps); case or package quantity; approximate center beam candlepower; and class (B, vacuum, or C, gas-filled) and filament (designation describes the shape and mount structure of the filament).

Although there are some differences in the way the information is arranged and labeled, the catalog's categories contain the same basic information. Below are sample catalog listings showing lamps from different manufacturers:

HALOGEN LAMPS

Incandescent lamps produce light when electric current is passed through a tungsten filament, which heats until it glows. Tungsten is the filament material of choice because it has a very high melting point.

In a halogen lamp, the filament is housed in a clear quartz or high-temperature glass capsule, which is filled with halogen gas. This design enables the filament to operate at even higher temperatures. As a result, halogen lamps can produce more light output, more efficiently, from a smaller size, than a standard incandescent lamp.

The light that halogen lamps produce is a crisp, white light with less heat output, particularly with concentrated beams of light. They last up to five times longer than standard incandescent lamps and experience less lumen depreciation. And because the light source is smaller, its light output is easier to control using reflectors. Like incandescent lamps, halogen lamps can include an integral reflector and lens that directs the light output in a controlled beam, from narrow spot to wide flood.

Due to these characteristics, halogen lamps are popular for use in track, display, downlighting and other lighting designs in retail stores, supermarkets, automobile headlights, lobbies, restaurants, hotels, homes and other applications.

Note that while most incandescent lamps have Edison screw-in bases, halogen lamps can feature screw-in bases as well as recessed single-contact, double-contact and bi-pin bases.

Lamp Types

Basic halogen types include linear (also called double-ended), single-ended, capsule (single-ended but with no outer bulb), PAR (capsule in a reflectorized lamp), and low-voltage reflectorized lamp.

> **REMEMBER**
> Halogen lamps produce a cool, white light from a very compact source, and are often reflectorized to focus the light in a desired direction and beam pattern.

Linear halogen lamps feature a slim tubular design and with a recessed single-contact base at each end. Some linear halogen lamps may be IR lamps, which are more efficient than standard halogen lamps.

Single-ended and low-voltage reflectorized lamps (MR16, MR11, etc.) feature bi-pin bases. Halogen lamps are typically line-voltage lamps, using the voltage coming off the power line (120V, etc.). Low-voltage lamps use a transformer to step down the voltage to a lower voltage (12V, etc.).

FIGURE 2-4
Common halogen lamp shapes. Courtesy of Philips Lighting Company.

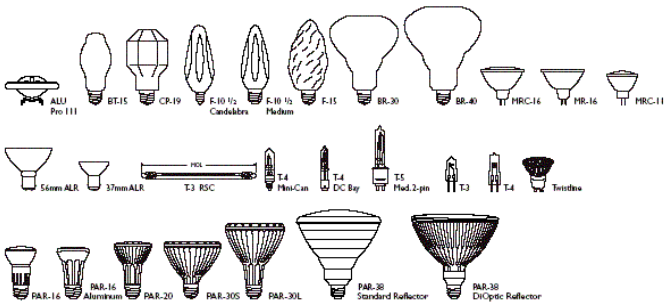
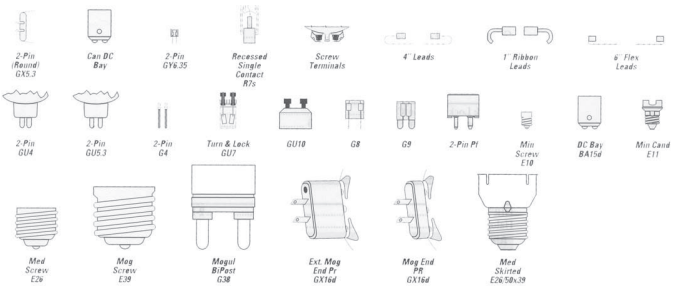


FIGURE 2-5
Common halogen lamp bases. Courtesy of GE Lighting.



PAR lamps are reflectorized lamps that feature a screw-in base.

Now that we know the basic types of halogen lamps, we can ask the questions posed in Chapter 1, to help us understand how they perform. How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? What's the color of the light? How accurate do colors look in the light? The answers for several major lamp types are shown on the next page.

Advantages and Disadvantages

Advantages of halogen lamps include:

- Excellent beam control.
- Crisp, white light output.
- Little lumen depreciation as the lamp ages.
- Low cost to purchase.
- Compact size.
- High efficiency.
- High color rendering ability.

> **REMEMBER**
> Halogen lamps may be line-voltage or low-voltage. Line-voltage lamps use power coming directly off the power line. Low-voltage lamps use a transformer to step down the line voltage to a desired low voltage needed to operate the lamp.

Halogen Lighting Questions

TYPE	HOW LONG DOES THE LAMP LAST? (HOURS)	HOW MUCH LIGHT DOES IT PRODUCE? (INITIAL LUMENS)	HOW MUCH ELECTRICITY DOES IT NEED? (WATTS)	HOW EFFICIENT IS IT COMPARED TO OTHERS? (LUMENS/WATT)	WHAT'S THE COLOR OF THE LIGHT? (COLOR TEMPERATURE)	HOW ACCURATE DO COLORS LOOK IN THE LIGHT? (COLOR RENDERING INDEX)
90PAR38	2000	1350	90W	15	about 3100K	100 CRI
90PAR38 (130V)	4000	1000	79W	11.1	about 2900K	100 CRI
60PAR38/IR	3000	1110	60W	18.5	about 3100K	100 CRI
60PAR38/IR (130V)	6000	850	53W	16	about 2900K	100 CRI
35MR16/ IR-24º	5000	800	37W w/transformer	21.6	about 3100K	100 CRI

- No ballast is required.

Disadvantages of halogen lamps include:

- High temperature, shorter life and lower efficiency compared to fluorescent lamps.
- Low-voltage lamps require a transformer.

Lamp Identification

The lamp manufacturers use different codes to describe their lamps. However, most halogen lamps use similar elements: lamp wattage + lamp shape + bulb size in 8ths of an inch/lamp designation/beam spread + beam angle. Here's an example: 75PAR30S/HAL/SP10.

75 = lamp wattage.

PAR = lamp shape; this lamp is a reflectorized lamp.

30 = lamp diameter in 8ths of an inch. This lamp is 30 ÷ 8 = 3-2/3 inches in diameter.

S = short neck lamp design (as opposed to L = long neck design).

HAL = lamp designation.

SP = spotlight (as opposed to FL = flood, etc.).

10 = beam angle.

You may also see codes for brand name, finish and other manufacturer-specific information.

Reading the Lamp Catalog

Halogen lamps are typically grouped in ascending order of wattage (10W, 20W, 30W), etc.). Each product listing answers most of our basic questions about the light source: How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? What is the color of the light? The listing provides other information, such as the lamp's ordering code so that people can buy them. The order codes differ between manufacturers, but cross-references are usually shown in the catalogs by brand name. Below is a partial cross-reference between the three largest lamp manufacturers from the GE catalog:

Although there are some differences in the way the information is arranged and labeled, the catalog's categories contain the same basic information. The Sample Catalog table on the next page has sample catalog listings showing lamps from different manufacturers.

YOU KNOW THE BASICS

Congratulations. If you score well on the Incandescent Lighting Quiz, consider yourself on the way to becoming a lighting management expert. Now you're ready to take on the second major type of lighting—fluorescent.

Cross Reference of Lamp Manufacturers from the GE Catalog

GE	OSRAM/SYLVANIA	PHILIPS
HIR PAR	Capsylite PAR IR	Masterline IRC
Halogen Plus PAR	Capsylite PAR	Masterline 2500
ConstantColor Precise	Tru-Aim Titan	Continuum Color
Precise IR	Tru-Aim IR	Masterline ES IRC
Standard MR16	Tru-Aim	Continuum
Halogen A-Line	Capsylite A-Line (Midbreak)	Halogena

Sample Catalog Listings

NOMINAL WATTAGE	BULB	BASE	PRODUCT #	ORDERING ABBREV.	VOLTS	AVG. RATED LIFE (HRS)	INITIAL LUMENS	DESCRIPTION	MOL
60	A-19	Med	11715	60A/BLACKLIGHT/RP	120	1000		Blacklight	4-7/16
60	A-19	Med	16794-0	60A/CL/LL 12/2	120	1500	900	Clear Long Life	4-7/16
60	A-19	Med	22384	60A/GD 24PK	120	3000	635	Light IF-Garage Door, Vibration Resistant	4.43

NOMINAL WATTAGE	Wattage of the lamp.
BULB	Describes the shape of the bulb (letter) and the diameter of the bulb in 8ths of an inch (number).
PRODUCT NUMBER	Also called an “order code” or “ordering code,” this number allows you to identify a single, specific lamp when you want to buy one.
ORDERING ABBREVIATION	This is the lamp’s code, which reveals some of its primary characteristics.
VOLTS	The line voltage the lamp is designed for.
AVG. RATED LIFE (HRS)	Indicates median life expectancy—the point at which 50% of a large group of lamps is expected to fail.
LUMENS	This is the amount of light produced by the lamp.
DESCRIPTION	Description of the lamp.
MOL	Maximum overall length of the lamp.
OTHER	Other information may include LCL, which is the distance between the center of the filament and the Light Center Length reference plane, in inches; color temperature (K); beam spread (reflectorized lamps); case or package quantity; approximate center beam candlepower; and class (B, vacuum, or C, gas-filled) and filament (designation describes the shape and mount structure of the filament).

INCANDESCENT LIGHTING QUIZ

Check your understanding of this chapter's material by completing these multiple-choice questions. The answers are on Page 84.

1. A reflector fitted onto an incandescent lamp is used to …?
a) Increase color rendering ability
b) Push light in a direction
c) Make the lamp last longer
d) Decrease heat produced by the lamp

2. In incandescent lamp typically converts _____% of its electrical input into light output.
a) 10-15%
b) 20-25%
c) 30-35%
d) 50%

3. Incandescent lamps are rated to provide only ___ hours of service life, so when we want an incandescent lamp but we want it to last longer, we can choose a long-life incandescent lamp, which provides ___ hours of service life
a) 2000 ; 4000
b) 1000 ; 4000
c) 750-1000 ; 1500-3000
d) 800-2000 ; 2000-4500

4. Rough service lamps are resistant to …?
a) Color shift
b) Line voltage variations
c) Shock and vibration
d) Wide range of ambient temperatures

5. Clear incandescent lamps are a …?
a) Point source
b) Linear source

6. Which of the following is NOT an advantage of incandescent lamps?
a) No ballast required
b) Lowest initial cost
c) High energy efficiency compared to fluorescent
d) Easy to dim

7. If we have an incandescent lamp with the designation 65BR30, what is its wattage?
a) 30W
b) 65W
c) R class
d) 3-2/3

8. MOL stands for …?
a) Maximum overall light
b) Maximum overall length
c) Minimum overall light
d) Minimum overall length

9. Which of the following is NOT an advantage of halogen lamps?
a) Uses a line-voltage ballast
b) High efficiency
c) Crisp, white light
d) Compact size

10. A PAR lamp is an example of which, most specifically, of the following?
a) Rough service lamp
b) Capsule lamp
c) Double-ended linear lamp
d) Reflectorized lamp

11. Which of the following is NOT a halogen lamp base?
a) Single-pin
b) Bi-pin
c) Double-contact
d) Screw-in

12. If we see 75PAR30/HAL/SP10 as a lamp designation, which of the following statements do we know to be true about the lamp?
a) 30W
b) 10W
c) 3 3/4 inches in diameter
d) 9-3/8 inches in diameter

CHAPTER 3: FLUORESCENT LIGHTING

INTRODUCTION

Fluorescent lamps (sometimes called fluorescent tubes) and ballasts are the most common lighting system you'll be working with. Fluorescent is the most popular indoor lighting system for commercial applications, commonly seen in offices, schools and other applications.

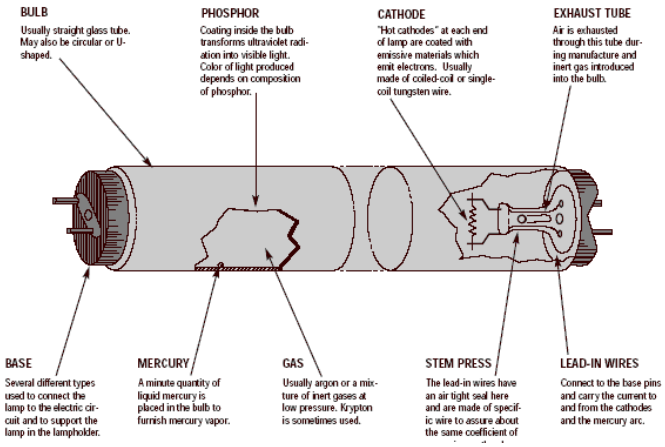
FLUORESCENT LAMPS

Fluorescent lamps were first commercially introduced at the World's Fair in 1939 and have since become the most popular type of lighting for indoor commercial spaces such as office buildings.

By the time you're done reading this section, you will be able to identify common fluorescent lamps and read a lamp label and catalog.

FIGURE 3-1
Fluorescent lamps. Courtesy of Philips Lighting Company.

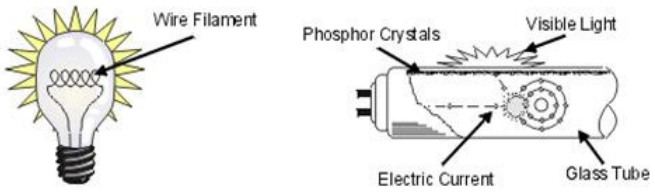
FIGURE 3-2
Fluorescent lamp composition. Courtesy of OSRAM SYLVANIA, Inc.



How They Work

The ballast provides voltage that causes an arc of electricity to jump between the electrodes at each end of the lamp. Electric current is now flowing through the lamp. This excites mercury vapor inside the glass tube and causes it to emit mostly ultraviolet energy. The ultraviolet energy is converted into visible light by the phosphor coating on the inside of the glass tube.

FIGURE 3-3
Fluorescent lamps are much more efficient than incandescent lamps in using energy to create light. Rather than using a wire filament, fluorescent lamps produce light by the passage of electric current flowing through a vapor of mercury atoms at low pressure. Such action produces ultraviolet radiation, which is converted to visible light by the phosphor powder on the glass wall of the lamp. Courtesy of Philips Lighting.



Connecting to the Power Supply

All lamps have a base that allows them to connect to the power supply. Incandescent light bulbs, for example, have a screw-in base—the lamp screws into the socket, an electrical connection is established, and when power is supplied, the lamp can produce light. Most fluorescent lamps don't have a screw-in base. They use one, two or four metal pins, or a *recessed double-contact base*, which allows the lamp to be properly fitted into the sockets in a luminaire. Lamps that feature one pin at each end of the lamp are called single-pin lamps. Lamps that feature two pins are called bi-pin lamps. Most fluorescent lamps found in commercial applications such as office buildings are bi-pin lamps.

FIGURE 3-4
Common fluorescent lamp shapes. Courtesy of GE Lighting.

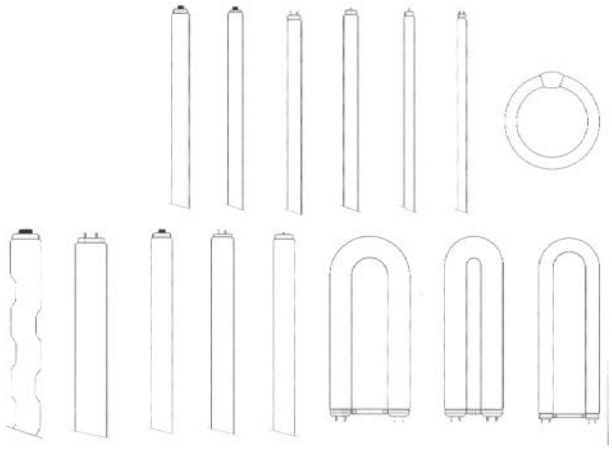
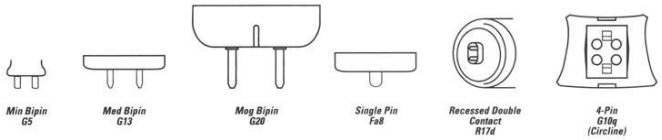


FIGURE 3-5
Common fluorescent lamp bases. Courtesy of GE Lighting.



REMEMBER
All lamps have a base, which connects the lamp to the power supply. Most fluorescent lamps have one or two pins in the base that, when fitted properly in the luminaire socket, establish an electrical connection.

Types of Fluorescent Lamps

Since there are so many fluorescent lamps available, there are a number of different ways to describe them.

Size: You may hear fluorescent lamps described as "large-sized fluorescent" and "compact fluorescent" (CFLs). Large-sized fluorescent lamps are all lamps except for CFLs, which are smaller fluorescent lamps often used to replace incandescent light bulbs to save energy.

The CFL can be plug-in (separate from the ballast, plugs into a socket using pins) or self-ballasted.

When the CFL is plug-in, it does not have an integral ballast and features 2 or 4 pins on its base for plugging into the socket. Be sure to match the CFL to the right socket for proper operation. Also note that 2-pin lamps run on magnetic ballasts and cannot be dimmed, while 4-pin lamps run on electronic ballasts and can be dimmed if the ballast has that capability.

When the CFL is self-ballasted, the lamp and ballast come together

FIGURE 3-6
Common compact fluorescent lamp shapes (plug-in lamps). 2-pin plug-in lamps are generally for magnetic ballast operation, while 4-pin plug-in lamps are generally for electronic ballast operation and can be dimmable. Courtesy of GE Lighting.

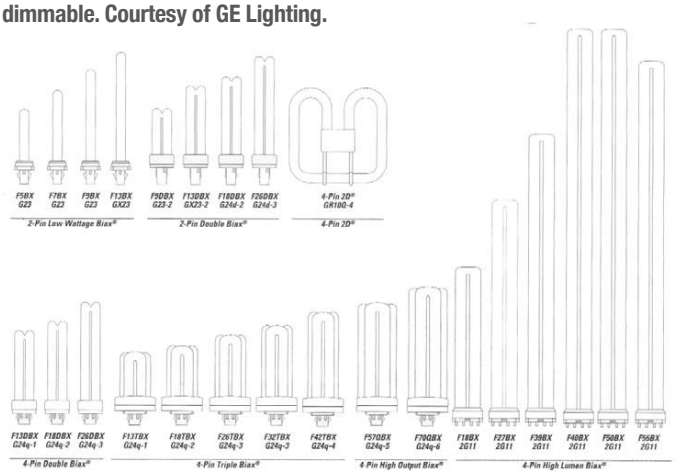


FIGURE 3-7
Common lamp shapes for self-ballasted compact fluorescent lamps. Courtesy of GE Lighting.

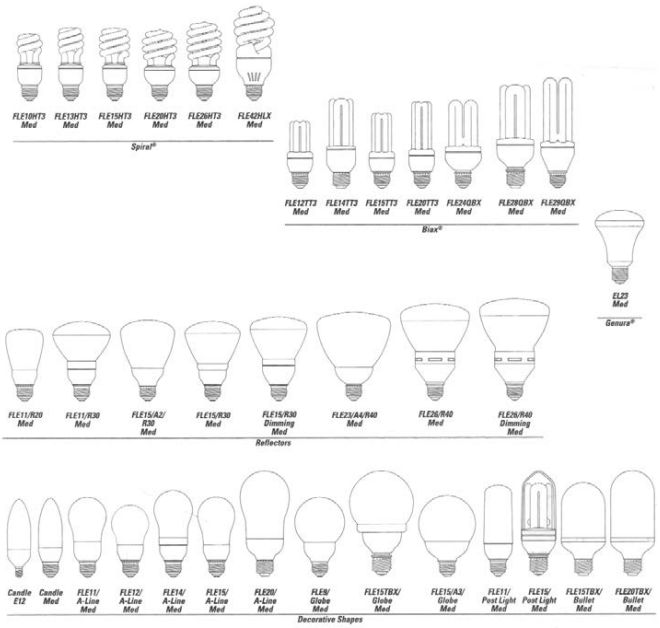
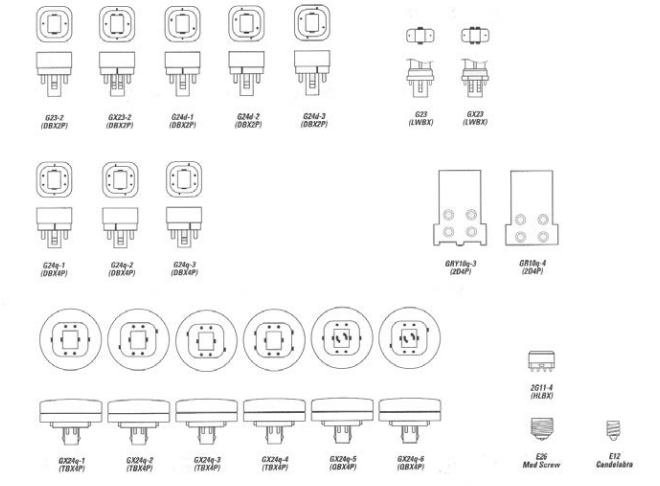


FIGURE 3-8
Common compact fluorescent plug-in lamp bases. Courtesy of GE Lighting.



in a single unit with a screw-in base for direct replacement of incandescent lamps. Self-ballasted CFLs may also feature an integrated glass globe or a reflector to diffuse (soften) or direct the lamp's light output.

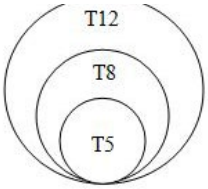
Diameter: One way to describe fluorescent lamps is by their diameter. Common lamp types include T12, T8 and T5, although the full range is T2 to T17. The T means the lamp is shaped like a tube. The number tells the width of the lamp in 8ths of an inch. So a T8 lamp is a tubular lamp that is 8 ÷ 8 = 1 inch in diameter. A T12 lamp is 12 ÷ 8 = 1.5 inches in diameter. This sounds like a simple

difference, but T12, T8 and T5 lamps represent entirely different families of lamps.

REMEMBER

T8 and T12 lamps are not interchangeable in the same luminaires unless you also change the ballast. T5 lamps are in metric sizes (centimeters) and T8 and T12 are in Imperial sizes (inches). This means T5 lamps and ballasts can't replace T8 and T12 lamps and ballasts in existing luminaires.

FIGURE 3-9.
Fluorescent lamps are often identified as a T followed by a number, such as T5, T8 or T12. The "T" means the lamp is shaped like a tube; the number is the lamp diameter in 8ths of an inch. To a T8 lamp is 8 ÷ 8 = 1 inch in diameter. Courtesy of Philips Lighting Company.



Shape: Fluorescent lamps can also be described by their shape. Most lamps you will see on the job are linear, meaning they are shaped like a straight line. Some lamps are U-shaped, also called "U-bend lamps," and others are circular, also called "circline lamps."

Lamp Starting Method: Fluorescent lamps can be classified according to the starting method the ballast uses to power them. Fluorescent lamps may be preheat, instant start or rapid start. Preheat lamps take a few seconds to warm up before they light. Most preheat lamps are CFLs that have bi-pin bases. Instant start lamps light immediately. Instant start lamps may be T8 or T12 lamps and feature single-pin bases. Instant start lamps may be 8-ft. lamps nicknamed "Slimline" lamps. Rapid start lamps light in about one second, feature bi-pin bases, and may be T5, T8 or T12 lamps.

Note that T8 lamps may be instant start or rapid start, and that some rapid start T8 lamps can be used on instant start ballasts.

Light Output: Some lamps are called HO or VHO lamps. This means the lamp produces a higher amount of light ("high output" or "very high output") than a standard lamp of the same type. A T5 lamp, for example, produces about 3000 lumens, while a T5HO lamp produces about 5000 lumens. T5HO lamps have bi-pin bases. High-output T8 lamps are either "Super T8" or HO lamps, both of them rapid start lamps. Super T8 lamps have bi-pin bases and T8HO lamps have recessed double-contact bases. High-output T12 lamps are HO or VHO lamps. Both types are rapid start lamps with recessed double-contact bases.

Review: If somebody says, "That's a linear rapid start T8HO lamp," we know a lot about the lamp in just a few words: The lamp is shaped like a straight tube, works only with a compatible rapid start ballast, will light in less than a second, is one inch in diameter, has

Fluroescent Lamps

TYPE	WHAT IS THE LAMP'S DIAMETER?	WHAT SHAPES ARE AVAILABLE?	WHAT STARTING METHODS USED BY THE BALLAST ARE AVAILABLE	WHATKIND OF BASES ARE AVAILABLE?	WHAT LENGTHS ARE AVAILABLE?	WHAT HIGH LIGHT OUTPUT VERSIONS ARE AVAILABLE?
Compact Fluorescent	1/4 - 5/8- inch	Linear, U-shaped, circular, square ("2D")	Rapid start, instant start	Bi-pin	--	--
T5	5/8-inch	Linear, U-shaped, circular	Rapid start, instant start	Bi-pin	2-5 ft.	--
T5HO	5/8-inch	Linear, U-shaped, circular	Rapid start, instant start	Bi-pin, single-pin	2-5 ft.	HO
T8	1 inch	Linear, U-shaped, circular	Rapid start, instant start	Bi-pin, single-pin	2-6 ft. & 8 ft. (also some 12-in., 15-in. and 18-in.)	Super T8, HO
T12	1.5 inches	Linear, U-shaped, circular	Preheat, rapid start	Bi-pin, 4-pin	2-8 ft.	HO, VHO

TYPE	STARTING AID	BASE*	NO. OF LAMPS	CIRCUIT
Preheat	Ballast & starter	Bi-pin	1-2	Parallel
Instant Start	Ballast (usually larger)	Single-Pin (sometimes bi-pin)	1-2	Lead-lag: Parallel, Series sequence: Series
Rapid Start	Ballast	Bi-Pin, Recessed double-contact (HO and VHO) 1-4	Magnetic: Series, Electronic: Parallel or series	--

a recessed double-contact base, and produces more light than a standard T8 lamp.

If somebody says, "That's a preheat lamp," we know that it is probably a plug-in CFL with a bi-pin base.

Now that we know the basic types of fluorescent lamps, we can ask the questions posed in Chapter 1, to help us understand how they perform. How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? What's the color of the light? How accurate do colors look in the light? The answers for several major lamp types are shown below:

Looking at the table, we see, for example, that a T5HO lamp produces a lot of light but is not as efficacious (efficient) as T5 or T8 lamps. It is offered in a range of color temperatures, from neutral (white) to cool (bluish-white), and offers good color rendering.

Advantages and Disadvantages
There is clearly an immense variety of fluorescent lamps available, developed over time to meet every lighting need for which fluorescent lamps offer distinct advantages.

These advantages include:
- High energy efficiency, which presents a lower ongoing energy cost to the building owner
- Long service life
- Low surface brightness, making most lamps comfortable to look at directly.
- Fully dimmable
- Choice of color rendering abilities, with excellent color rendering available.
- Wide choice of color temperatures
- Broad variety of shapes, lengths and sizes
- Fast starting (with the exception of preheat lamps)

Fluorescent lamps do have some disadvantages compared to incandescent and HID, however.

These disadvantages include
- Higher initial cost than other sources such as incandescent
- Cost of adding a ballast to the system, compared to incandescent
- Sensitivity to temperature (extreme cold, but particularly heat)
- Shorter lamp life with high frequency of starts (low hours per start) on some ballasts

Reading the Lamp Label: Large-Sized Fluorescents
Fluorescent lamps are designated by a series of letters and numbers. There are rules, but many exceptions to the rules, as each manufacturer likes to do things a little differently to help brand their products.

Preheat and Rapid Start: Preheat and <40W rapid start lamps use a single code, although you will likely find minor variations depending on the manufacturer. Here's an example, consider a fluorescent lamp with this designation: F34T12/CW/RS/ES/ECO. What can we learn about it?

F = fluorescent. You may sometimes see a letter after the F, which is an abbreviation of the first letter of the lamp's brand name. Example: F032T8 = fluorescent Octron-brand 32W T8 lamp from Osram Sylvania.

34 = wattage. This lamp draws 34W of electric power.

T = lamp shape; the lamp is tubular. You may also see other letters, such as B, that indicate U-shaped lamps, or C, that indicate circular lamps.

12 = lamp diameter in eighths of an inch; 12 ÷ 8 = 1.5 inches in diameter.

CW = color of the light. This particular lamp is a cool white lamp. Manufacturers may use different designations here. Osram Sylvania's designation of 830, for example, indicates that the lamp has a CRI rating in the 80s and a color temperature of 3000K. GE Lighting's

Fluorescent Lighting Questions

TYPE	HOW LONG DOES THE LAMP LAST? (HOURS)	HOW MUCH LIGHT DOES IT PRODUCE? (INITIAL LUMENS)	HOW MUCH ELECTRICITY DOES IT NEED? (WATTS)	HOW EFFICIENT IS IT COMPARED TO OTHERS? (LUMENS/ WATT)	WHAT'S THE COLOR OF THE LIGHT? (COLOR TEMPERATURE)	HOW ACCURATE DO COLORS LOOK IN THE LIGHT? (COLOR RENDERING INDEX)
Compact Fluorescent	10-20,000	250 – 9000	5 - 120	Low-mid 70s	2700K, 3000K, 3500K	82-86 CRI
T5	20,000	2900	28	100+	3000K, 3500K, 4100K	82-85 CRI
T5HO	20,000	5000	54	93	3000K, 3500K, 4100K, 5000K, 6500K	82-85 CRI
T8	24,000	2900-3100	32	91-97	3000K, 3500K, 4100K, 5000K, 6500K	78-86 CRI
T12	20,000	2650-2900	34	80	3000K, 3500K, 4100K, 4200K, 6500K	53-85 CRI

designation of SPX30 means the lamp has a color temperature of 3000K. Philips Lighting's designation of TL830 means the lamp has a color temperature of 3000K.

RS = Optional letters that indicate the starting method used by the ballast. This lamp is a rapid start lamp. An instant start lamp may be designated IS.

ES = Optional letters that indicate whether this lamp is an energy-saving T12 lamp. ES is the generic designation; you may see EW (Econ-o-Watt), SS (SuperSaver) or WM (Watt-Miser).

ECO = Optional letters that indicate that the lamp complies the EPA's TCLP test and therefore can be disposed as municipal garbage instead of hazardous or universal waste. GE and Osram Sylvania use ECO; Philips uses ALTO.

Instant Start Lamps: These lamps have a somewhat different code. Here's an example: F96T12/CW/ES.

F = fluorescent

96 = the lamp's length in inches

T = the lamp is tubular

12 = the lamp's diameter in eighths of an inch

CW = series of letters and numbers that designate the color of the light (color temperature).

ES = the lamp is an energy-saving version of the standard model.

Reading the Lamp Label: Compact Fluorescent Lamps
In review, CFLs are small fluorescent lamps that are available as plug-in lamps (with bi-pin or 4-pin bases) or self-ballasted (with integral ballast and screw-in base for easy replacement of incandescent light bulbs).

The generic designation code for this type of lamp is made up of five parts: CF + shape + wattage/base/color quality. Let's look at an example: CFT9W/G23/35.

CF = compact fluorescent.

T = twin parallel tubes (can also be Q = four tubes in a quad configuration, TR = triple tube, M = combination, such as a spiral, or S = square shaped).

W = lamp wattage; this lamp is a 9W lamp.

G23 = simple bi-pin base; there are many types of bases designed for different types of luminaires. A self-ballasted base may have a code such as MED, indicating a medium screw-in base.

35 = color of the light; this lamp has a color temperature of 3500K. Manufacturers may use different designations, such as 835, which means the lamp has a CRI rating of 82 and a color temperature of 3500K.

Additional codes, depending on the manufacturer, can include:

E or EL = the integral ballast is an electronic ballast; electronic ballasts are lighter and more efficient than magnetic ballasts.

RS = the lamp is a rapid start lamp.

REMEMBER
There are many diameters of fluorescent lamps, from T2 to T17, but the most common are T8 and T12, with T5 being the most recent introduction and growing in popularity. The T means the lamp is tubular. Divide the number by 8 and you get the lamp's diameter in inches. So a T8 lamp is 1 inch in diameter.

Reading the Lamp Catalog
Lamp manufacturers publish catalogs that list the characteristics of their lamps along with order codes so that people can buy them. Manufacturers usually group their lamps in ascending order of wattage (10, 20, 30, etc.) and by product lines (incandescent, tungsten halogen, fluorescent and HID).

Although there are some differences in the way the information is arranged and labeled, the listed categories contain the same basic information. The ordering codes and brand names generally differ between manufacturers, but cross-references are often provided in the catalogs for lamps that are roughly comparable in performance characteristics. Here are a few examples of a brand cross-reference table from the GE catalog:

All catalogs contain data that answer our basic questions: How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? What's the color of the light? How accurate do colors look in the light? Below are sample catalog listings showing lamps from different manufacturers:

Cross Reference of Lamp Manufacturers from the GE Catalog

GE	OSRAM/SYLVANIA	PHILIPS
Chroma 50	Design 50	Colortone 50
Ecolux	Ecologic	Alto
Mod-U-Line	Curvalume	U-Bent
Specification Series (SP)	Designer Series (D)	SPEC Series
Watt-Miser	SuperSaver	Econ-o-Watt
T8	Octron	TL70/TL80
/1500	VHO	VHO
XL	XP	Advantage

Sample Catalog Listings

NOMINAL WATTAGE	NOMINAL LENGTH (IN)	BASE	PRODUCT #	ORDERING ABBREV.	PKG. QTY.	AVG.RATED LIFE (HRS)	CCT (K)	CRI	APPROX. LUMENS INITIAL	APPROX. LUMENS MEAN
17	24	Med Bipin	38215-0	F17T8/TL865/PLUS/ALTO	25	24,000	6500K	86	1300	1235
25	36	Med Bipin (G13)	45753	F25T8/SPX30/ECO	24	20,000	3000K	86	2150	2040
32	48	Med Bipin	27163	F032/835XP/ECO	30	24,000	3500K	85	3000	2850

NOMINAL WATTAGE	Wattage of the lamp.
Nominal Length	This is the length of the lamp from socket to socket in the luminaire. Since T5 lamps are metric, the nominal length shown will be the nearest familiar length. For U-shaped lamps, the length is measured from the base to the bend. For circular lamps, the length is the outside diameter. Some manufacturers add a column for Maximum Overall Length (MOL), which is the total length of the lamp, including the base.
Base	The type of base.
Product Number	Also called an "order code" or "ordering code," this number allows you to identify a single, specific lamp when you want to buy one.
Ordering Abbreviation	This is the lamp's code, which reveals some of its primary characteristics.
Pkg. Qty.	Also called "case quantity," this is the number of lamps packed in a case.
Avg. Rated Life (hrs)	Indicates median life expectancy—the point at which 50% of a large group of lamps is expected to have failed.
CCT (K)	Correlated color temperature. This is the lamp's color temperature, indicating the color of the light.
CRI	Color Rendering Index rating. This indicates how "natural" colors look under the light produced by the lamp on a 0-100 scale, with 100 being the best.
Approx. Lumens – Initial	This is the amount of light produced by the lamp on a "reference ballast" after a "burn-in" time of 100 hours.
Approx. Lumens – Mean	This is the amount of light produced by the lamp at 40% of rated life, which is considered the mean. Mean lumens are typically less than initial lumens because the lamp produces less light as it ages, a phenomenon called lumen depreciation.

FLUORESCENT BALLASTS

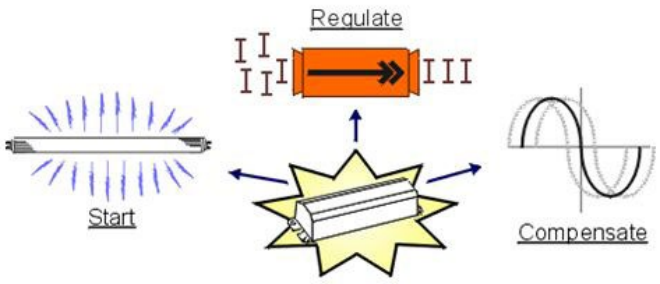
In review, a ballast is an electrical device used to start and operate fluorescent and high-intensity discharge (HID) lamps. They provide the correct voltage to start the lamp, and then regulate the current to make sure the lamp works correctly while it's on. By regulating the current flowing through the lamp, the ballast acts as a stabilizer against fluctuations in the voltage coming down the power line. That's how the ballast got its name. In the days when ships were powered by wind and sail, "ballast" was heavy material that kept the ship steady during stormy weather that made the waters choppy.

Every fluorescent lamp needs a ballast. Together, they form a lighting system or lamp-ballast system. To understand how fluorescent lighting systems work, you not only must understand the lamp, but the ballast. It's especially important for maintaining lighting systems, so that you can match the right lamp to the ballast.

Ballast's Effect on Lamp Performance

The light output and wattage of fluorescent lamps, published by manufacturers in their catalogs, is based on their operation on a "reference ballast," a laboratory device. When used on actual ballasts in the field, the lamp and ballast become a system and perform differently than what the lamp ratings would tell us.

FIGURE 3-10
The ballast delivers the proper voltage to start the lamp, regulates the current flowing through it after startup, and compensates for variations in line voltage. Courtesy of Philips Lighting.



For example, consider an electronic ballast that operates two F32T8 lamps. If we take the two lamps x 32W each that gives us 64W. Each lamp produces 2900 lumens, so again two lamps x 2900 = 5800 lumens of light output.

When these two lamps are operated on a given ballast, however, the total system draws only 59W, not 64W. And because the ballast has a ballast factor of 0.90, the actual light output of the total system is 5800 x 0.90, about 5200 lumens. The ballast factor should be thought of as a multiplier.

When the ballast is considered as an essential companion to the lamp, it's important to start thinking about fluorescent lighting as a system.

Ballast Types

Ballasts are most often classified as electronic or magnetic.

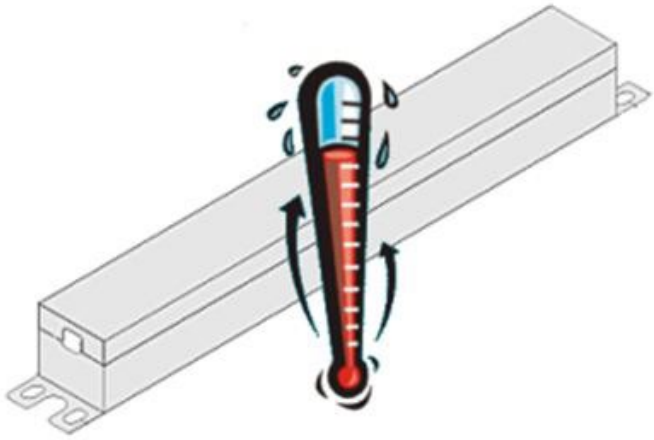
Magnetic Ballasts: Magnetic ballasts, also called "core and coil" ballasts, are the traditional ballast. They are called magnetic because electromagnetic components (the steel core and copper coils) do the job of 1) transforming the incoming line voltage to the right voltage to start the lamp, and 2) regulating the current to ensure smooth lamp operation. These components are surrounded by asphalt, which helps conduct heat away from the core and coils, and then packed in a metal case, also called a can.

FIGURE 3-11
Magnetic ballasts for fluorescent lamps. Courtesy of Universal Lighting Technologies, Inc.

Magnetic ballasts typically often contain two other components that are important to know about. The first is a capacitor, which makes the ballast more efficient and designates it as a high power factor ballast. The second is an internal thermal switch which designates the ballast as a Class P ballast. The Class P switch disconnects the ballast from the power line if it starts to get too hot while it's running, which prevents a fire hazard and also extends the life of the ballast. Excessive heat, in fact, is the number one reason why ballasts fail. Magnetic ballasts can last about 12-15 years.

A single ballast can operate 1, 2, 3 or 4 fluorescent lamps. Magnetic ballasts for typical indoor applications operate 1 or 2 lamps. Magnetic ballasts are available to operate rapid start, instant start and preheat lamps. They can also operate CFL, T8, T12 and other lamp types. Each specific ballast is designed for a certain number of lamps and certain lamp type, and are not interchangeable with ballasts operating other lamp types. That means given an existing building, if you change the type of lamp—say, from T12 to a T8—you have to change the ballast.

FIGURE 3-12
Heat is the number one cause of early ballast failure. Courtesy of Philips Lighting.



Electronic Ballasts: Electronic ballasts are the most energy-efficient ballasts available for rapid start and instant start luminaires. They may include a mixture of core and coils with electronic components, or all electronic components.

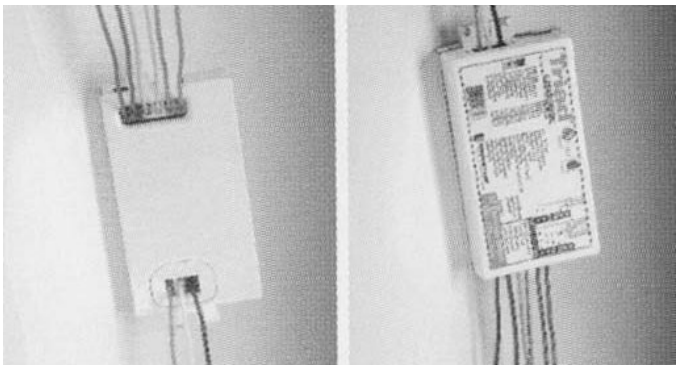
Besides operating fluorescents more efficiently, electronic ballasts are also quieter (virtually no buzz or hum coming out of the ballast), reduce flickering in lamps, and produce less heat, which can prolong ballast life to up to 25 years.

A single ballast can operate 1, 2, 3 or 4 fluorescent lamps. Electronic ballasts are available to operate rapid start and instant lamps. They can operate CFL, T5, T8, T12 and other lamp types. Only electronic ballasts can be used with T5 and T5HO lamps, and they are the most popular ballast for T8 lamps. While ballasts are generally not interchangeable, the trend in ballast manufacturing is to consolidate ballast models so that a single ballast could operate multiple lamp types, wattages and number of lamps on different line voltages. The ballast label and listing in the manufacturer's catalog will tell you what the ballast can and can't do.

Another trend in electronic ballasts is the increasing popularity of dimming ballasts. Dimming ballasts dim the lamps from 100% light output down to as low as 1% of light output, depending on the lamp and ballast. Dimming has several applications that are considered beneficial, from a single workstation or room to an entire building. All the lights in a building, for example, can be programmed on a PC to be dimmed at different times of the day to save energy. Workers can dim their own light levels to exactly where they want them. A room can be dimmed for A/V presentations. And the dimming ballast can be connected to a photosensor, which continually measures the light level in a room

FIGURE 3-13
Electronic ballasts for fluorescent lamps. Courtesy of Universal Lighting Technologies, Inc.

FIGURE 3-14
Compact fluorescent electronic ballast. Courtesy of Universal Lighting Technologies, Inc.



with access to daylight. As the amount of daylight goes up and down based on the position of the sun, the photosensor signals the dimming ballast to lower or raise the light levels so that the overall light level stays in a consistent range, thereby saving energy.

Looking at these two types of ballasts, magnetic and electronic, and understanding that ballasts and lamps work together as a system, we can ask several of our lighting performance questions again and get more precise answers:

REMEMBER
Based on their construction, there are two basic types of ballasts, electromagnetic (magnetic) and electronic. Electronic ballasts have grown in popularity since the early 1990s due to their higher energy efficiency. They are also lighter, quieter and minimize lamp flicker.

Starting Methods

Ballasts are also often categorized according to starting method or circuit. The ballast may be preheat, rapid start, instant start or program start.

Preheat Ballasts: Preheat lamps take a few seconds to warm up and start, using an added device called a starter or manual switch. Preheat ballasts are magnetic ballasts designed to operate mostly <20W CFLs with bi-pin bases.

Instant Start: Instant start ballasts provide a high starting voltage that starts the lamps immediately. Instant start ballasts can be magnetic or electronic ballasts. Most instant start magnetic ballasts are designed to operate 1 or 2 T12 lamps with single-pin bases. Instant start electronic ballasts are designed to operate 1, 2, 3 or 4 T8 lamps with bi-pin bases or T12 lamps with single-pin bases.

Rapid Start: Rapid start ballasts apply a lower starting voltage but use another method to ensure rapid starting, usually in about one second. Rapid start ballasts can be magnetic or electronic ballasts designed to operate 1, 2, 3 or 4 T5, T8 or T12 lamps.

Program Start: Another type of rapid start ballast is the programmed rapid start ballast. Programmed-start operation minimizes stress on the lamp cathodes during start-up (remember

Fluorescent Performance Questions

LAMP	BALLAST	HOW MUCH LIGHT DOES IT PRODUCE? (INITIAL LUMENS)	HOW MUCH ELECTRICITY DOES IT NEED? (WATTS)	HOW EFFICIENT IS IT COMPARED TO OTHERS? (LUMENS/WATT)
Compact Fluorescent	Magnetic	N/A	N/A	N/A
32W Compact Fluorescent	Electronic	2400	35	69 lm/W
28W T5	Electronic	2900	32	91 lm/W
54W T5HO	Electronic	5000	60	83 lm/W
32W T8	Electronic	2700	30	90 lm/W
34W T12	Magnetic	2330	35	67 lm/W

that each time the lamp starts, there is wear and tear on the cathodes, wearing them out until the lamp fails). This maximizes lamp life. Programmed start ballasts are ideally suited to any application where longer lamp life is beneficial, particularly spaces where the lamps are turned on and off very often during the day.

REMEMBER
Before installing a fluorescent lamp, make sure that it is rated for the ballast—the lamp and ballast must be compatible for the lamp to operate properly. Matching the wrong lamp and ballast can also damage the lamp and ballast.

Wiring Configuration

The ballast and lamps can be wired together in several different ways, which impacts how the lamps perform. There are three types of wiring configurations: series-sequence, parallel and series-parallel.

Series-Sequence: Series-sequence ballasts operate two lamps in series. This means that the circuit connects the ballast to the first lamp to the second lamp and back. When one lamp fails, the other will also fail to light or light only dimly. Rapid start, programmed rapid start and instant start magnetic ballasts are typically wired in series.

Parallel: Parallel ballasts operate two, three or four lamps in parallel. This means that the circuit connects the ballast to each lamp independently, which in turn means if one lamp fails, the others on the circuit will continue to light normally. Instant start electronic ballasts are typically wired in parallel. A majority of T8 lamps are operated by instant start ballasts. Some instant start magnetic ballasts are called lead-lag ballasts and also operate in parallel.

Series-Parallel: Some four-lamp ballast designs are available that are series-parallel. The ballast isolates one two-lamp "leg" from the other two-lamp leg. The two lamps within each leg are operated in series. The legs themselves are operated in parallel. What this means is that one lamp fails, its companion in its leg may also fail to light, but the other two-lamp leg will continue to operate normally.

Special Application Ballasts

A wide range of ballasts have been developed for special applications, such as wet and cold locations. Below is a sample of these special-application ballasts:

Trigger Start Ballasts: These ballasts act similarly to rapid start ballasts and are designed to operate preheat lamps, eliminating the need for a separate starter.

Cold Weather Ballasts: These ballasts provide a higher starting voltage to start fluorescent lamps in cold applications such as freezers and outdoor spaces, as fluorescent lamps typically experience starting problems in cold temperatures. The lamps can also be jacketed to prevent problems operating. (Cold weather ballasts should not be used for normal temperature conditions, as the higher starting voltage can shorten lamp life.)

Reading the Ballast Label

Like fluorescent lamps, ballasts are given codes by manufacturers, who each do their codes differently and explain them in their catalogs. Most product codes, however, have a combination of this information: product family, input voltage, starting method, number of lamps the ballast operates, the lamp type and wattage (or length), the wiring configuration (series, parallel, etc.), case or can description or size, and ballast factor.

The ballast label, affixed onto the face of the ballast itself, also provides basic information you need to make sure you're matching the right ballast to the right lamp, and choosing the right ballast for the application.

Refer to the generic label on this page to follow a short guided tour of a typical ballast label.

Ballast Label

120 VOLTS (3)	60 HERTZ (4)		
LAMP TYPE (5)	LAMP WATTS (5)	LINE CURRENT (6)	MIN START TEMP (7)
(2) F40T12	40W	0.73 Amps	50ºF
(2) F40T12	34W	0.63 Amps	60ºF
(2) F40T10	40W	0.73 Amps	50ºF
(2) F40T12/U	40W	0.73 Amps	50ºF
(2) FB40T12/ES	34W	0.63 Amps	60ºF
(2) F30T12*	30W	0.61 Amps	50ºF
*CSA APPROVED ONLY			

EXAMPLE BALLAST CORPORATION (1)

BRAND NAME (1)

BALLAST CODE(2)

CERTICATIONS (8)

Class P(9), Type H
Type 1 Outdoor (10)
High Power Factor (11)
Sound Rated A (12)
No PCBs (13)

BALLAST WIRING DIAGRAM (14)

The ballast label will tell you:

(1) *Manufacturer and brand name*.

(2) *The catalog number* for the manufacturer who supplied the ballast. So if you need to order more, you can easily look the ballast up in the catalog.

(3) *Line voltage*. The voltage rating tells you what value the supply voltage should be—e.g., 120, 277 (the most common) or other voltage. The ballast must match the circuit. Universal-voltage ballasts cover the voltage range of 120-277V.

(4) *Hertz.* This figure tells you the input frequency.

(5) *Ballast/lamp compatibility.* Instructions will specify what general types of fluorescent lamps can be operated by this ballast. If you install T8 lamps on this sample ballast, the lamps will not perform properly or may not light at all.

(6) *Amps*. This value lets you know how much current the ballast draws as part of the total lighting system.

(7) *Minimum starting temperature*. Cold temperatures affect lamp performance. This ballast would not work well in a cold area such as a walk-in freezer. In that situation, you'd need a "cold weather" ballast.

(8) *Certifications.* Several logo symbols are stamped on the label, telling you what organizations have certified the ballast to operate properly and safely. These organizations include American National Standards Institute (ANSI), the Electrical Testing Laboratories (ETL) and the Underwriters Laboratories (UL), or its Canadian counterpart, the Canadian Standards Association (CSA). These organizations certify that the ballast performs according to industry standards and that it is safe if used correctly. The designation (E) tells you that the ballast complies with energy laws that require that most ballasts meet a minimum standard of energy efficiency.

(9) *Class P designation*. This tells you that the ballast has thermal protection.

(10) *Type.* Ballasts are rated as Type 1 or Type 2 for outdoor use. Type 1 are non-weatherproof ballasts that can be used in outdoor luminaires or in luminaires for wet or damp areas according to UL requirements. The ballast must be used within a metal enclosure. Type 2 ballasts are similar except they can be used in a non-metallic enclosure.

(11) *Power factor*—high or low (normal). Power factor is the relative efficiency of the use of electricity. High power factor ballasts draw less current.

(12) *Sound rating*. The label shows the sound rating of the ballast. In ballasts with electromagnetic components, the action in the core and coil component causes a slight hum. Ballasts are typically rated Type A, B, C or D, with Type A being most quiet.

(13) *PCBs*. PCBs are a substance banned from use in ballasts in 1979 due to their possible harmful effects on the environment and human health. The label will indicate whether the ballast houses a capacitor with PCB-containing fluid. All ballasts containing a capacitor and manufactured after 1979 should say, "No PCBs." If the ballast doesn't say this, it must be treated in accordance to state and federal guidelines for its disposal. And if the PCB-containing ballast is leaking fluid, do not expose your skin to the fluid; immediately follow special safety procedures in this situation.

(14) *Wiring diagram.* The diagram shows how the ballast should be wired to the sockets to properly operate the lamps.

Reading the Ballast Catalog

The ballast manufacturers provide catalogs that list the characteristics and ordering codes for their ballasts. The catalog usually categorizes ballasts by family: preheat, rapid start, instant start. Within these families, the ballasts are listed in ascending lamp wattage (25, 50, 75, etc.) or lamp length (24", 36", 48", etc.).

As with the lamp manufacturer's catalogs, some differences exist in the way the data is arranged or labeled. The significant difference is the catalog number. Again, each manufacturer has its own designation system. Cross-reference guides are provided by the manufacturers to assure interchangeability.

INDUCTION LIGHTING

An induction lighting system is a gas discharge lamp which produces light by electromagnetic field(s) instead of using electrodes or filaments. Induction is also known as electrodeless vacuum, electrodeless fluorescent, electrodeless lamp or E-lamp. Induction comes from the same family as the fluorescent due to its operation. The Induction lighting system is made of three parts: electronic ballast (also known as a generator), induction lamp, and internal or external inductor.

Nikola Tesla is credited with the principle of the invention for induction back in 1890. It wasn't until the late 1960 that other companies, like GE, started experimenting with induction. In the 1990s, there was a growth in the development of induction and at the same time available on the market. Induction popularity grew around 2005 for a direct replacement of HID lighting.

Induction lighting systems have become very popular for their energy savings of up to 65% when replacing an HID light source.

How Induction Works

The electronic ballast sends high-frequency energy through the wires, which are wrapped around the lamp's coil (coupler). This couples the energy and creates an electromagnet also know as inductor. The powerful electromagnetic field travels through the glass, exciting the mercury atoms within the glass vessel. The mercury atoms are provided by an amalgam (a solid form of mercury). The excited mercury atoms produce ultraviolet energy. The ultraviolet energy is then converted into visible light by the phosphor coating on the inside of the glass vessel.

Sample Ballast Catalog Listings

TYPE	LAMPS	METHOD	CATALOG #	VOLTAGE	BALLAST FACTOR	(W)	(A)	POWER FACTOR	THD (%THD)	MIN. START TEMP F/C	DIAGRAM	DIM.
F32T8	2	IS	ICN-2P32-SC	120	0.88	59	.49	>.98	<10	0/-18	X	X
				277	0.88	59	.22	>.98	<10		X	X
	2	IS	B-232-S-IS-277	277	0.87	58	0.22	>.99	<10	0/-18	X	X
	2	PS	EEB-232-L-PS-277	277	0.71	47	0.17	>.99	<10	0/-18	X	X

Lamp Type	This shows the lamp type operated by the ballast, including the wattage.
No. Lamps	The number of lamps the ballast can operate. You may see 1/2, which means the ballast can operate 1 or 2 lamps.
Starting Method	The method the ballast uses to start the lamps. IS = instant start, PS = programmed rapid start, RS = rapid start. You may also see DIM, which means the ballast is a dimming ballast.
Catalog Number	The manufacturer's catalog number.
Line Voltage	The input voltage the ballast is designed for. A growing number of ballasts are universal-voltage ballasts, which operate on multiple line voltages.
Ballast Factor	Measure of light output from a commercial ballast compared to a reference ballast (which the lamp rating is based on). The first ballast has a ballast factor of 0.87, so a lamp that produces 2900 lumens would produce 2900 x 0.87 = 2523 lumens when operated on this ballast. The manufacturer may publish a code here to indicate the ballast has a high, normal or low factor.
Input Power (W)	The input power to the entire lighting system, including the ballast operating the two lamps.
Line Current (A)	The line current the ballast draws.
Power Factor	Power factor is the relative efficiency of the use of electricity. High power factor ballasts draw less current.
THD (%)	Total harmonic distortion.
Min. F/C Start Temp	The lowest ambient temperature, in Fahrenheit/Celsius, at which the ballast can reliably start the lamps.
Wiring Diagram	References the wiring diagram for the ballast connected to the lamps.
Dim.	References the dimensions.

FIGURE 3-15
Induction lighting system. Image courtesy of Fulham Co., Inc.

Lamp Types

Induction has two types of lamps which are distinguished by the form of ignition. All induction lamps have an inductor, which is also referred to as the coil or the ferrite inductor. The first type is an external inductor lamp type which has the inductor on the outside of the lamp, normally at the two opposite ends. Two coils also work as a mounting base and heat sink. The coils are glued to the glass vessel and are tightened down with an aluminum heat sink.

The second type is the internal inductor which is also referred to as a power coupler. The coupler is still your basic coil, which acts as an antenna in the center of the induction lamp creating the magnetic field. This type of induction lamp allows for the power coupler to be removed from the glass vessel.

All induction lamps have an amalgam tip, where the solid amalgam pellet is located. During production, an exhaust tube is used and sealed to provide the pressure within the glass vessel. The exhaust tube is located opposite to the amalgam tip.

FIGURE 3-16
External inductor induction lamp. Image courtesy of Fulham Co., Inc.

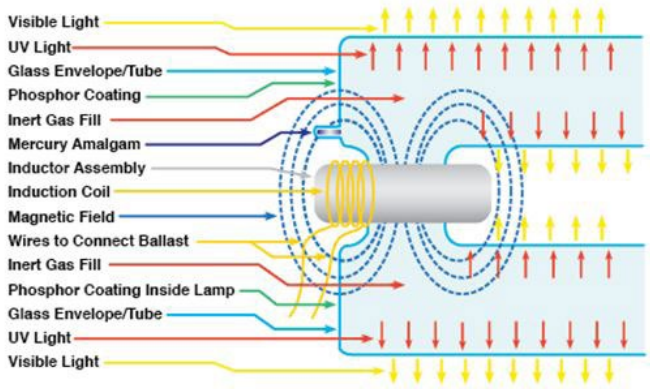
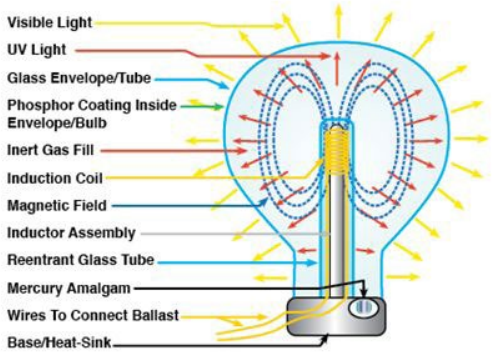


FIGURE 3-17
Internal inductor induction lamp. Image courtesy of Fulham Co., Inc.



Lamp Shapes

Induction lamps come in various shapes and sizes. There are a few similarities within some manufactures on the lamp shape, but the sizes vary and are not a one-to-one replacement. The most common shapes are the bulb, tubular (rectangular, racetrack), and circular (round, donut) induction. The lamp glass vessel still consists of the glass, pressurized vessel, inert gas, amalgam pellet and phosphor coating on the inner glass tube. A majority of lamps come with a plug-and-play connection for the dedicated electronic ballast. The lamp wires do not have a polarity when connecting it to the induction ballast.

Bulb Induction Lamps

Induction bulb lamps operate with an internal inductor. The internal inductor also provides the mounting base and heat sinking for the lamp. The lamp wattages for this type run from 35W to 250W, depending on the manufacture. The advantage of this system is the shape of the lamp is common to the HID lamp replicating the light distribution much easier when doing a retrofit.

Tubular Induction lamps

The tubular induction lamp is formed in a rectangular shape that varies in length from 8 to 42 inches. The tube diameter also varies per wattage. The tubular lamp operates with the external inductor, two at each end. The tubular induction lamp is designed in a rectangular shape that varies in length from 8 to 42 inches.

Circular Induction Lamps

Circular induction lamps are designed with a donut or round shape with two external coils for optimal heat sink and mounting options. The circular induction lamp starts from 6 inches diameter to 19 inches. It is normally use for high-bay applications and shoebox luminaires.

FIGURE 3-18
Induction lamps. Image courtesy of Fulham Co., Inc.

Screwbase Induction Lamps

Screwbase induction lamps are available in a medium and a mogul base. These induction lamps should not be matched or connected with HID magnetic transformers. This will result in a failure or electrical issues within the wiring circuit. Screwbase lamps are available in circular and bulb induction, which normally operate by the standard induction ballast for the non-screwbase lamp.

FIGURE 3-19
Screwbase induction lamps. Image courtesy of Fulham Co., Inc.

Reading The Lamp Label and Lamp Specification

Manufacturer lamp codes vary by manufactures and by induction lamp family. For more information, consult the manufacturer's catalogs or spec sheet.

There are common codes for the lamp types and shapes, for example a letter follow by a number. The letter tells us the lamp shape: T = Tubular, C = Circular, B = Bulb, G = Globe. The number tells you the rated wattage of the lamp: 55 = 55W, 100 = 100W. Some manufactures will indicate the lamp Kelvin temperature on the lamp.

On the next page are sample specifications for a circular induction lamp.

Electronic Induction Ballast

The induction electronic ballast is also referred to the induction generator. The majority of the current induction electronic

Sample Specifications for a Circular Induction Lamp

Lamp Type	
Circular/Tubular	External Inductor Type
Hybrid Fluorescent	All
Primary Ignition	Low Frequency Inductor Coil
Operating Temperature Range (Thermal Management)	
Induction Lamp Core Mounting Base	100°C - 130°C
Amalgam Lamp Tip Temperature Range	55°C - 125°C
Lamp Coil	160°C - 200°C
Circular/Tubular	Convection or Conduction
Lamp Operation	
Color Temperature Fluctuation	<10%
LPW Fluctuation	<10%
Lamp Kelvin Temperature Options	
Kelvin Temperature (Standard)	5000K
Limited Stock (call Fulham for availability)	3500K, 4000K
Special Factory Order (call Fulham)	2700K, 3000K, 6000K, 6500K
Kelvin Color Temperature Tolerance	±300K
Cold Start and Operation Systems	
Operating Temperature (Closed Fixture)	-40°C Freezer Operation Only (Call Fulham for Assistance)
EMI	
Meets International Standard L Level FCC Non-Consumer units Compliant FCC 47-CFR Part 18	
Vibration Tests	
"The HighHorse Induction lamp is designed to tolerate shock and vibration that would be expected in typical applications such as post top, bridge, roadway underpass or tunnel lighting. HighHorse Induction lamps have been tested under the following conditions with no damage: -Shock - Lamps subjected to three (3) one-half wave shocks of 10 ms duration at 20 g. -Vibration parameters adapted from ANSI C136.31-2001, American National Standard for Roadway Lighting Equipment - Luminaire Vibration, Section 5, luminaire vibration test."	

Start Freq.	**Amplitude**	**End Freq.**	**Amplitude**
5Hz	1.5 G	7.07107Hz	3.5 G
10Hz	3.5 G	30Hz	3.5 G
Sweep between 5 Hz and 30 Hz at 0.861654 Min/sweep (Linear), Duration: 100,000 cycles at 100%, Total test time: 1:36:30, Care should be taken when mounting ballast to minimize vibration			

UV	
UV (bare lamp-less with lens)	5uw/cm2

ballasts typically operate at around 250KHz. Depending on the manufacturer, there are a few that will operate at 13.6MHz and at 2.65MHz. The induction electronic ballast have the following characteristics: input frequency of 50/60Hz, high power factor, low total harmonic distortion, high system efficiency, dedicated voltage, or universal voltage (120V-277V).

Below are sample system electrical specifications for an induction generator:

Induction electronic ballasts can be remote-mounted up to 50 ft. for specific lamp types. The remote mount option varies per induction manufacturer. For more information, consult the manufacturer's catalog.

Induction ballasts come in several shapes and sizes. The ballast case design is typically per application use. The most common one is the standard aluminum profile ballast similar to your fluorescent electronic ballast.

Connecting To the Electronic Ballast

The induction electronic ballast normally comes with a connector on the output leads which plug in with the induction lamp connector. Some manufactures do not use a plug-and-play connectors which might require wire nuts or some sort of connector. The minimum wire specification requirements for induction are as follows: 90C, 600V, 18AWG and stranded wire type is recommended.

FIGURE 3-20
Induction electronic ballasts. Image courtesy of Fulham Co., Inc.

Induction System Specification

Induction lighting is sold as a system: lamp and ballast. The standard information for a lighting system should be provided by the manufacturer: input power, input current, rated initial lumens, efficacy, lumen maintenance, CRI, correlated color temperature and rated life.

Induction Lamp Dimensions

Dimensions vary per lamp type and manufacturer. Detailed dimension should be available per the manufacturer.

Amalgam Content

The mercury in the induction lamp is in solid form as opposed to all other technologies using mercury, in which it is liquid. If the lamp is broken, this liquid mercury can find its way into and contaminate the water supply. It can also evaporate, creating low level contamination of the atmosphere. With induction, the mercury is compounded with other metals to create a solid form called amalgam. This is solid pellet that can easily be removed and easily disposed of and recycled with little or no risk of contamination of the surrounding area. Since the induction lamp life is 100,000 hours, much longer than other lamp technology, the amount of mercury usage with induction is far less than other common lamps.

Amalgam content should be provided by manufacture stating the amalgam pure weight content in milligrams.

Advantages

- Long lifespan due to the lack of electrodes—rated lamp life of 100,000 hours.

Sample Electrical Specifications for an Induction Generator

INPUT VOLTAGE	120-277V	**EMI/RFI COMPLIANCE**	FCC Part 18-A	CERTIFICATIONS
VOLTAGE FLUCTUATION TOLERANCE	±10%	**SOUND RATING**	Class A	
INPUT FREQUENCY	50/60 Hz	**TYPE**	1 Outdoor	
OUTPUT FREQUENCY	<250K Hz	**SURGE PROTECTOR ****	Yes (Reference Hi-Pot Test Footnote)	
THD	<10%	**MAX. REMOTE DISTANCE *****	7 ft. (84") (Reference Wiring Footnote)	
POWER FACTOR	> 0.95	**WIRING**	Plug-n-Play Connectors	
CONSTANT WATTAGE OUTPUT	<5%	**WIRE RATING**	150°C 600V (Lamp Wire Shielded)	
CASE TEMP.	<65°C	**ELECTROSTATIC DISCHARGE (ESD)**	IEC 61000-4-2:Class 4	
OPERATING TEMP. OPEN FIXTURE	0°C to 50°C	**ELECTRICAL FAST TRANSIENT/BURST (EFT)**	IEC 61000-4-4:Class 4	
OPERATING TEMP. CLOSED FIXTURE	-20°C to 50°C	**SURGE IMMUNITY**	IEC 61000-4-5:Class 4	

Circular Lamp System Specifications

System Model Number	Watts	Input current (Amp) 120V ~	Input Power (W)	Rated Initial Lumens (LM)	Efficacy (LM/W)*	Lumen Maintenance (60Khrs)	CRI	Color Temp. (Kelvin)	Average Lamp Life (Hours)
HH-ILS-CP40-5K HH-ILS-CDS40-5K	40	0.35 - 0.15	42	2800 - 3000	70 - 75	70%-75%	> 80	2700K - 6500K (5K Standard Color)	100,000
HH-ILS-CP70-5K HH-ILS-CDS70-5K	70	0.62 - 0.27	74	4900 - 5250	70 - 75				
HH-ILS-CP80-5K HH-ILS-CDS80-5K HH-ILS-CDC80-5K	80	0.70 - 0.30	84	5600 - 6000	70 - 75				
HH-ILS-CP100-5K HH-ILS-CDS100-5K HH-ILS-CDC100-5K	100	0.88 - 0.38	105	7500 - 8000	75 - 80				
HH-ILS-CP120-5K HH-ILS-CDS120-5K HH-ILS-CDC120-5K	120	1.05 - 0.45	126	9000 - 9600	75 - 80				
HH-ILS-CP150-5K HH-ILS-CDC150-5K	150	1.32 - 0.57	158	12000 - 12750	80 - 85				
HH-ILS-CP200-5K HH-ILS-CDS200-5K HH-ILS-CDC200-5K	200	1.75 - 0.76	210	16000 - 17000	80 - 85				
HH-ILS-CP250-5K HH-ILS-CDS250-5K HH-ILS-CDC250-5K	250	2.19 - 0.96	263	21250 - 22500	85 - 90				
HH-ILS-CDS300-5K HH-ILS-CDC300-5K	300	2.63 - 1.14	315	25500 - 27000	85 - 90				
HH-ILS-CDS400-5K HH-ILS-CDC400-5K	400	3.50 - 1.52	420	34000 - 36000	85 - 90				

FIGURE 3-21
Dimensions for a circular induction lamp. Image courtesy of Fulham Co., Inc.

CIRCULAR LAMP MODEL #	L (in)	H(in)	ØX (in)	INPUT WIRE L (in)
HH-IL-C40W5K	6.49	2.78	6.04	15±1”
HH-IL-C70W5K	7.89	3.04	7.22	15±1”
HH-IL-C80W5K	7.89	3.04	7.22	15±1”
HH-IL-C100W5K	9.46	3.04	8.57	15±1”
HH-IL-C120W5K	10.75	3.04	9.82	15±1”
HH-IL-C150W5K	12.58	3.04	11.62	15±1”
HH-IL-C200W5K	14.97	3.04	13.92	15±1”
HH-IL-C250W5K	15.76	3.02	15.28	15±1”
HH-IL-C300W5K	18.20	3.02	17.28	15±1”
HH-IL-C400W5K	18.61	3.00	17.80	15±1”

- High system efficiency from 60 to 90 lumens per watt.
- High power factor due to the low loss of the high-frequency electronic ballasts, which are typically between 95% and 98% efficient.
- Low lumen depreciation (>70% at 60,000 hours).
- Wide range of color temperature options—2700K to 6500K.
- Instant ON and hot restrike; lamp life not affected by switching.
- No flickering.

Circular Induction Lamp Amalgam Content

Lamp Type	C40W	C70W	C80W	C100W	C120	C150W	C200W
Amalgam Type	B	B	B	B	B	B	C
Weight/ PC (mg)	40	40	40	40	40	40	40
PCS	2	3	3	3	4	5	6
Total Weight (mg)	80	120	120	120	160	200	240
Content of Hg in %	3.5	3.5	3.5	3.5	3.5	3.5	3
Pure Hg Weight (mg)	2.8	4.2	4.2	4.2	5.6	7	7.2

- The long life and superior lumen maintenance of induction significantly reduces maintenance costs and provides a significant reduction in the total cost of ownership.
- CRI >80.
- S/P Ratio of >1.80.
- Enhanced visual performance, improving security and safety.
- Very low mercury content.
- Remote mounting up to 50 ft. for some lamp types.
- Suitable for cold-temperature applications.
- Fixed-output or dimming option available.

Disadvantages

- Hazardous materials mean induction lamps must be recycled separately. The mercury pellet must be removed from the lamp and recycled before disposing of the lamp itself.
- Large lamps compared to HID.
- Not a direct retrofit in many applications.

REMEMBER
The induction lamp amalgam temperature is the most important test point for the lamp.

Induction Temperature Chart

TEST POINT	TEMP. TEST POINTS	RATED TEMP.	MAX TEMP.
1	BALLAST: TC	< 65°C (149°F)	65°C (149°F)
2	BALLAST: SIDE 1	< 65°C (149°F)	65°C (149°F)
3	BALLAST: SIDE 2	< 65°C (149°F)	65°C (149°F)
4	BALLAST PLATE/ MOUNTING LOCATION	N/A	N/A
5	BALLAST AMBIENT	N/A	N/A
6	LAMP BASE (HEAT SINK)	< 130°C (266°F)	130°C (266°F)
7	LAMP COIL	< 160°C (320°F)	200°C (392°F)
8	LAMP AMALGAM TIP	55°C (131°F) - 125°C (257°F)	125°C (257°F)
9	LAMP AMBIENT	< 80°C (176°F)	< 100vC (212°F)
10	COIL WIRE RATING	< 140°C (284°F)	150°C (302°F)
11	N/A	N/A	N/A
12	LAMP TUBE ON INSIDE CENTER	< 140°C (284°F)	180°C (356°F)
13	WIRE CONNECTOR	< 105°C (221°F)	105°C (221°F)
TEMPERATURE MEASUREMENTS ARE RECOMMENDED TO BE AT THE RATED TEMPERATURE INSTEAD OF THE MAXIMUM TEMPERATURE FOR BEST PERFORMANCE.			
MAXIMUM LAMP AND BALLAST TEMPERATURES CAN NOT BE EXCEEDED AT THE MAXIMUM OPERATING AMBIENT TEMPERATURE OF THE FIXTURE.			
CONTACT FULHAM FOR THE INDUCTION TEMPERATURE TEST PROCEDURE.			

Intended Use

Induction is intended as an alternative for HID light sources that can be found in outdoor and indoor lighting. Due to the 100,000-hour rated life, the induction system is suitable for hard-to-reach places and areas with limited access. Typical applications include airport, tunnel, swimming pools and stairways. Induction is commonly used in parking lots, garage lighting, area lighting, roadway lighting, decorative lighting, gas stations, warehouses and large retail stores.

Retrofit and Replacements

Induction lighting systems are commonly used for retrofitting in order to save energy. A 400W HID lamp source can be replaced with a 200W induction system. This provides a savings of 50% over the original source. There are some applications that cannot be retrofitted with induction due to the size of the luminaire, light distribution or thermal considerations.

When performing a retrofit, certain aspects of the lighting system should be kept in mind in order to achieve the long life of the system:

- Induction system must be grounded.
- Retrofit installation must meet state and local electrical codes.
- Maximum manufacturer ballast case temperature rating cannot be exceeded.
- Induction lamp temperatures should not exceed the maximum specified by the manufacturer.
- Optics for induction systems and luminaries must meet application requirements.
- The induction lamp amalgam temperature must be maintained within the manufacturer's specifications.

For replacement, the manufacturer of the induction system should be contacted. Normally, induction systems are not interchangeable between manufactures, and the manufacturers should always be consulted before matching different induction lamps and induction ballasts.

YOU KNOW THE BASICS

Congratulations. If you score well on the Fluorescent Lighting Quiz, consider yourself on the way to becoming a lighting management expert. Now you're ready to take on the third major type of lighting—high-intensity discharge.

FLUORESCENT LIGHTING QUIZ

Check your understanding of this chapter's material by completing these multiple-choice questions. The answers are on Page 84.

1. The best way to describe an energy-efficient lamp is one that …?
a) Produces less light and saves energy
b) Last longer
c) Provides better color rendition
d) Produces more light per unit of consumed energy

2. In a fluorescent lamp, UV energy produced inside the lamp impacts the inside of the glass bulb and is converted into visible light. What substance on the bulb converts UV energy into visible light?
a) Fluorescence
b) Halogen gas
c) Phosphor
d) Mercury

3. Which of the following is not a fluorescent lamp type?
a) Preheat
b) Metal halide
c) Rapid start
d) Instant start

4. What do rapid start lamps need to operate?
a) A ballast
b) A starter
c) An ignitor
d) A key

5. Which of the following is not an advantage of a fluorescent lamp?
a) Flexibility
b) High efficiency compared to incandescent
c) Fast starting
d) Lamps can last beyond 90,000 hours.

6. On a parallel circuit, if one lamp goes out, the other lamp will …?
a) Fail to light
b) Continue to operate normally
c) Light only dimly
d) Experience severe end blackening

7. What is the diameter of a T8 lamp?
a) 0.5 inches
b) 5/8 inches
c) 1 inch
d) 1.5 inches

8. An instant start F96T12 lamp is how many inches long?
a) 9
b) 12
c) 96
d) 48

9. In a lamp code, "T" means the lamp is …?
a) Circular
b) Tall
c) Tubular
d) Tested by Underwriters Laboratories, Inc. (UL)

10. Which of the following is NOT a fluorescent lamp base?
a) Bi-pin
b) Recessed double-contact
c) Single-pin
d) 8-pin

11. 11. Which of the following is NOT a fluorescent lamp shape?
a) Circular
b) Star-shaped
c) Linear
d) U-shaped

12. If somebody says, "That's a T5HO lamp," what would we know about its light output?
a) Produces more light than a T5
b) Produces less light than a T5
c) Light output degrades rapidly compared to T5
d) It produces the same amount of light as a T8 lamp

13. Some compact fluorescent lamps have bi-pin or 4-pin bases, and others have screw-in bases. Which of the following do we know to be true about CFLs with screw-in bases?
a) They have a warm color temperature
b) They are shatter-proof
c) They are preheat lamps
d) They are self-ballasted

14. A ballast is required for all lighting systems except …?
a) Fluorescent
b) Metal halide
c) Incandescent and halogen
d) CFLs

15. Which of the following does a ballast do?
a) Start the lamp
b) Control the current
c) (a) and (b)
d) None of the above

16. Which of the following is not a fluorescent ballast type?
a) Preheat
b) Rapid start
c) Instant start
d) High pressure sodium

17. Trigger start ballasts, which operate like rapid start ballasts, were designed to operate …?
a) Rapid start lamps
b) Instant start lamps
c) Preheat lamps
d) Slimline lamps

18. A Class P ballasts is one which contains …?
a) A beeper to call you when there's a problem
b) A thermal protection device that shuts down the ballast if it overheats
c) A device that allows the ballast to start lamps at cold temperatures
d) None of the above

19. Electronic ballasts offer which benefit?
a) Less flicker
b) Greater efficiency
c) Quieter operation
d) All of the above

20. If a lamp produces 3000 lumens and the ballast has a ballast factor of 0.90, what is the lamp's light output when operated by the ballast?
a) 3000
b) 2700
c) 2500
d) 3236

21. The most common failure in an induction luminaire is …?
a) Generator / driver
b) Vessel/Lamp
c) Socket
d) Igniter

22. What is the primary cause of shortened generator life in an induction luminaire?
a) Occupancy sensors
b) Frequency of starts
c) Heat
d) High kWh rates

23. Typically, induction luminaires use what type of socket?
a) Medium bi-pin
b) Mogul
c) Edison
d) None

24. Where might induction luminaries be appropriate?
a) Tight spaces
b) Hard-to-access locations
c) Stadium lighting
d) Accent lighting

CHAPTER 4: HIGH-INTENSITY DISCHARGE LIGHTING

INTRODUCTION

High-intensity discharge (HID) lighting systems are typically used to light large areas. HID lamps are compact light sources that can produce very high light output. They are point sources, so it is relatively easy to control and direct the light output. Due to these characteristics, HID luminaires can be mounted high above a large area, lighting it with a minimum number of luminaires. HID lighting systems are also very rugged, able to start and operate in a wide range of ambient temperatures, making them suitable for outdoor use in applications such as parking lots, sports stadiums and roadways.

FIGURE 4-1
Courtesy of OSRAM SYLVANIA.

HID lamps are like fluorescent lamps in that a ballast provides a starting voltage that establishes an arc between two electrodes in the arc tube. These compact arc tubes are pressurized, delivering more light and generating considerable heat.

There are four major families of HID lighting systems, named for the primary elements in the arc tube that are used to turn electrical input into light output. These are high pressure sodium (HPS), metal halide (MH), mercury vapor (MV) and, by some definitions, low-pressure sodium (LPS). Each has its own advantages and disadvantages.

HID lighting is commonly used in a broad spectrum of applications, including sports arenas, roadways, factories, warehouses, signage, landscapes, security and other applications.

In this chapter, we will describe these families, then review HID ballasts.

REMEMBER

HID lamps are compact light sources that can produce very high light output, making them ideal to light a large area with only a few luminaires. The major HID families are named for the elements used in their arc tubes to turn power into light. HID lamps may often look like large incandescent lamps, including a screw-in base, but function more similarly to fluorescent lamps.

HID LAMPS

In this section, we will describe the major HID families, how to identify common lamp types, and how to read a lamp catalog.

High-Pressure Sodium Lamps

High-pressure sodium (HPS) lamps are basically constructed of a rugged arc tube inside a quartz bulb, capped by a base. The arc tube contains mercury and sodium. As a result, HPS lamps are highly efficient and long-lasting, but typically produce a somewhat orangish light. They are a good choice for applications where we want high efficiency and long service life but do not consider color of light and how accurate colors appear to be very important. The bulb may be clear or phosphor-coated. Some HPS lamps include an integral reflector to direct and aim the lamp's light output. Typical applications include parking lots, warehouses and street lights.

HPS lamps not only need a ballast, but a starter (ignitor) to start the lamp. These ignitors deliver very high voltages.

HPS lamp bases are most often of mogul design, although 35W lamps feature a medium base and wattages up to 150W are available with a medium base. Double-ended lamps are also available.

FIGURE 4-2
High pressure sodium lamp composition. Courtesy of OSRAM SYLVANIA, Inc.

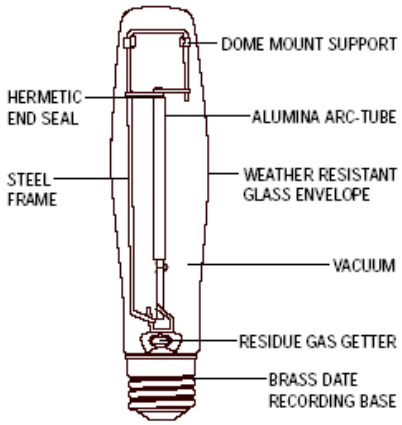
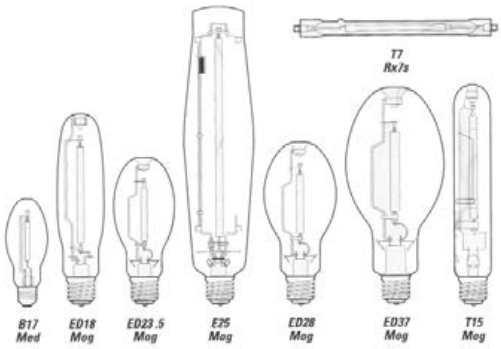


FIGURE 4-3
Common high pressure sodium lamp shapes. Courtesy of GE Lighting.



Metal Halide Lamps

Metal halide (MH) lamps contain mercury and various metals in their arc tubes. As a result, they are somewhat less efficient than HPS lamps but produce a clean, white light while rendering colors more accurately. The lamp bulb may be clear or phosphor-coated; phosphor-coated lamps have even better color quality. These characteristics have made MH lamps popular for sports arenas, factories, car dealership lots, gas station canopies, and other applications. While MH lamps offer the best color qualities of all HID lamps, standard models tend to shift in color appearance as they age, from white to slightly pink or bluish. Some MH lamps include an integral reflector to direct and aim the lamp's light output.

Standard MH lamps are called probe-start or switch-start lamps. Pulse-start lamps are now becoming more popular because they offer higher light output and better lumen maintenance.

Ceramic metal halide lamps are also becoming popular for applications where color quality is important. Ceramic metal halide lamps offer higher efficiency, color rendering, and greater color stability than standard metal halide lamps. They have long been used in low wattages (35-150W) and are now available in larger sizes (250-400W).

Like all HID lamps, MH lamps need a ballast and low-wattage (and all pulse-start) lamps also need a starter (ignitor).

MH lamp bases are most often of screw-shell design, although medium bases are available for lamps operating on 175 or fewer watts, and mogul bases are featured on most high-wattage lamps.

FIGURE 4-4
Metal halide lamp composition. Courtesy of OSRAM SYLVANIA, Inc.

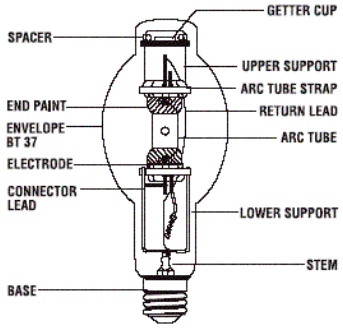


FIGURE 4-5
Common metal halide lamp shapes. Courtesy of GE Lighting.

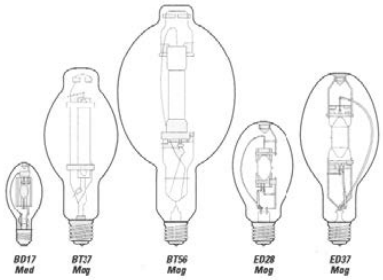
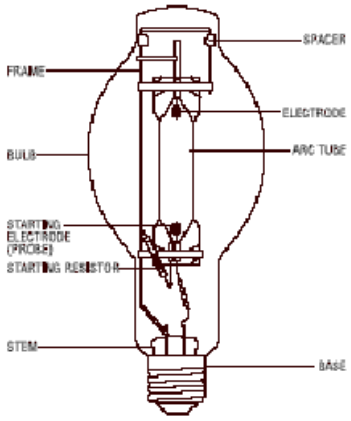


FIGURE 4-6
Ceramic metal halide lamps offer higher efficiency, color rendering, and greater color stability than standard metal halide lamps. Courtesy of OSRAM SYLVANIA, Inc.

Mercury Vapor Lamps

The mercury vapor (MV) lamp's arc tube contains mercury and argon gas. As a result, MV lamps are less efficient than HPS and MH lamps, produce a bluish-white light, and do not render colors as accurately as HPS lamps. The lamp may be clear or phosphor-coated. The lamp has a long service life. MV lamps were once the standard in HID lighting, replacing incandescent, but have since lost much of their popularity to HPS and MH lamps.

FIGURE 4-7
Mercury vapor lamp composition. Courtesy of OSRAM SYLVANIA, Inc.



Low-Pressure Sodium Lamps

Low-pressure sodium (LPS) lamps use sodium and neon and argon gas in their arc tubes. As a result, LPS is the most efficient HID lamp and experiences very little lumen depreciation, but produces light concentrated in one color—yellow—while rendering colors very poorly. In fact, anything lit by an LPS lamp that is not yellow—cars, people, houses—appears black or a flat gray. As a result, this lamp's application is limited to area lighting applications where efficiency is important but color quality is not.

FIGURE 4-8
Common mercury vapor lamp shapes. Courtesy of GE Lighting.

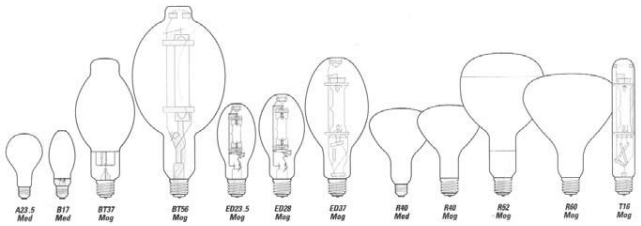


FIGURE 4-9
Common low-pressure sodium lamp shapes. Courtesy of GE Lighting.

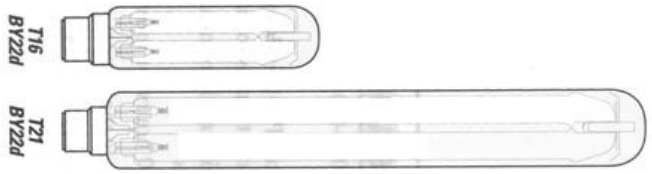
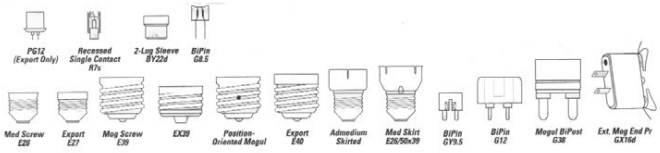


FIGURE 4-10
Common HID lamp bases. Courtesy of GE Lighting.



Now that we are familiar with the four major families, we can ask the questions posed in Chapter 1:

Advantages and Disadvantages

Advantages of HID lighting include:

- Compact light sources.
- High light output per watt.
- Low operating costs.
- Low maintenance costs.
- Long life.
- Ability to operate over wide range of temperatures.

REMEMBER

If you're looking for efficiency, HID lamps are ranked: LPS, HPS, MH and MV. If you're looking for color quality, HID lamps are ranked: MH, MV, HPS and LPS. HPS and MH lamps are most popular. All HID lamps need a ballast.

- Choice of color temperature.
- Options for good color rendering.
- Small metal halide designs to replace halogen lamps.

Disadvantages of HID lighting include:

- Limited color capabilities with HPS and MV lamps.
- Most clear lamps can produce shadowing.
- MH lamps can fail "non-passively," requiring special measures.
- Probe-start MH lamps can experience color shift over the life of the lamp.
- Most lamps are not economical or practical for low ceiling heights.
- During dimming, color shift may occur at below 50-60% of light output (below 50% is not recommended by the lamp manufacturers).
- A period of time is required to achieve full light output when starting and restarting.
- Color-improved HPS lamps tend to experience color shift as they age.
- Lamps must be properly shielded to prevent UV leakage.

Starting

HID lamps need ballasts to start. HPS, all pulse-start MH lamps, and all low-wattage MH lamps also need a starter (or ignitor).

One of the disadvantages of HID lamps is that they do not immediately reach full light output, requiring a warm-up time. The amount of time it takes to reach full light output depends on the lamp type, but ranges from 2 to 10 minutes. Standard HPS lamps start almost immediately and achieve full light output in 3-5 minutes. Probe-start MH lamps reach full light output in 2-10 minutes. Pulse start lamps reach full light output in 2 minutes. MV lamps take 5-7 minutes and LPS lamps take 7-10 minutes.

HID lamps can experience a momentary power interruption or

TYPE	HOW LONG DOES THE LAMP LAST? (HOURS)	HOW MUCH LIGHT DOES IT PRODUCE? (INITIAL LUMENS)	HOW MUCH ELECTRICITY DOES IT NEED? (WATTS)	HOW EFFICIENT IS IT COMPARED TO OTHERS? (LUMENS/WATT)	WHAT'S THE COLOR OF THE LIGHT? (COLOR TEMPERATURE)	HOW ACCURATE DO COLORS LOOK IN THE LIGHT? (COLOR RENDERING INDEX)
HPS	16,000-24,000 +	2200-130,000	35-1000	80-130	2100K	20-85+ CRI
MH	9000-30,000	2000-110,000	20-1000	80-130	3200-5200K	60-96+ CRI
MV	20,000+	1500-58,000	40-1000	40-50	5700K	15-50 CRI
LPS	20,000	1800-30,000	18-180	110-120	1800K	-44-0 CRI

sudden voltage drop from the power coming off the line, causing the lamp to "extinguish." Even though the lamp is still hot, it will not restart immediately because the arc tube must cool down first. HID lamps, depending on the lamp type, take up to 20 minutes to hot re-strike. HPS lamps take about a minute to re-strike, then achieve full light output in 3-4 minutes. Probe-start MH lamps take about 12-20 minutes to re-strike and restart the warm-up process. Pulse-start MH lamps take about 3-4 minutes to re-strike and restart the warm-up process. MV lamps take 3-6 minutes.

For applications where instant starting is required, special HPS and MH lamp designs are available which start and restart the lamps immediately. The HPS design starts immediately because it has two arc tubes.

Lamp Identification

Manufacturer lamp codes vary by manufacturer and by HID lamp family. For more information, consult the manufacturers' catalogs.

There are common codes for lamp bulb shapes, however, a letter followed by a number. The letter tells us the bulb shape: E or ED = ellipsoidal shape, BT = bulbous tubular, R = reflector, PAR = parabolic aluminized reflector. The number tells us the lamp's width in 8ths of an inch. A BT56 lamp, therefore, has a tubular shape mixed with a bulbous shape, and is 56 ÷ 8 = 7 inches in diameter.

FIGURE 4-11
HID lamps take a few minutes to warm-up and reach full light output. After being shut off, the lamps must cool down, then warm-up again. Courtesy of Philips Lighting.

LIGHT SOURCE	WARM-UP TIME	RESTRIKE TIME
Mercury Vapor	5-7 minutes	3-6 minutes
Metal Halide (probe-start)	3-4 minutes	10-20 minutes
Metal Halide (pulse-tart)	2 minutes	3-4 minutes
High Pressure Sodium	3-4 minutes	1/2-1 minute
Low Pressure Sodium	7-10 minutes	3-12 seconds

REMEMBER
It is possible for the arc tube in an MH lamp to rupture upon lamp failure and leak UV radiation that can cause skin burn and eye inflammation. Special MH lamp and ballast designs include safety features to protect occupants. The National Electrical Code now includes a provision that requires all metal halide luminaires to either be shielded or have a safety-design lamp if the luminaire is open.

Reading the Lamp Catalog

Lamp manufacturers publish catalogs that list the characteristics of their lamps along with order codes so that people can buy them. Manufacturers usually group their lamps in ascending order of wattage (10, 20, etc.) and by product lines (HPS, MH, etc.).

Although there are some differences in the way the information is arranged and labeled, the listed categories contain the same basic information. The ordering codes and brand names generally differ between manufacturers, but cross-references are often provided in the catalogs for lamps that are roughly comparable in performance characteristics. Here are a few examples of a brand cross-reference table from the Osram Sylvania catalog:

FIGURE 4-12
HID lamps, as a rule, are identified with an ANSI Lamp Code, as shown below. This Code is most helpful when locating a replacement lamp, or when selecting the correct ballast. Courtesy of Philips Lighting.

ANSI Code (Prefix)	Lamp Type	Examples
H	Mercury Vapor	H33, H37
M	Metal Halide	M47
S	High Pressure Sodium	S55
L	Low Pressure Sodium	L70

Brand Cross Reference Table from Osram Sylvania Catalog

GE	OSRAM/SYLVANIA	PHILIPS
Metalarc	Multi-Vapor	Metal Halide
Metalarc Ceramic	ConstantColor CMH	Master Color
Super Metalarc	High Output Mult-Vapor	Protected Metal Halide
Mercury Safeline	Saf-T-Gard Mercury	Safety Lifeguard Mercury Vapor
Lumalux	Lucalox	Ceramalux HPS
SOX Low Pressure Sodium	SOX Low Pressure Sodium	SOX Low Pressure Sodium

All catalogs contain data that answer our basic questions: How long does the lamp last? How much light does it produce? How much electricity does it need? How efficient is it compared to others? What's the color of the light? How accurate do colors look in the light? Below are sample catalog listings showing lamps from different manufacturers:

HID BALLASTS

Like fluorescent lighting systems, HID lighting systems require a ballast to start the lamps and regulate the current. Most HID ballasts are magnetic ballasts. Electronic ballasts are available, but their use is presently limited. Generally, one ballast operates one lamp. Lamps and ballasts must be compatible for the system to work correctly. If you change the lamp type, you typically have to

Sample Catalog Listings

LAMP WATTS	BULB	BASE	PRODUCT #	ORDERING ABBREV.	ANSI CODE/ BALLAST REF.	PKG. QTY.	DESCRIPTION	MOL (IN)	RATED AVG. LIFE (HRS)	APPROX. LUMENS		CRI	CCT (K)
										INITIAL	MEAN		
METAL HALIDE													
400	ED37	Mogul	34415-0	MH400/U	M59/S	6	G, S, Clear	11.5	20,000	36000	24000	65	4000
400	BT28	E39 POM Mogul	64443	MS400/ HOR/BT28	M59/E	6	Clear; horizontal operating position +15º	8.30	20,000	40000	26000	65	4200
400	BT37	Mogul	26218	MVR400/ HOR/MOG	M59	6	Clear bulb; horizontal operating position	11.5	20,000	28000	22500	65	4200
HIGH-PRESSURE SODIUM													
400	ED18	E39 Mogul	85379	LU400/H/ ECO	551	12	TCLP Compliant	9.75	24,000+	51,000	45,000	22	2100
400	ED18	E39 Mogul	26431	LU400/CP	551	4	Clear consumer pack	9.75	24,000+	51,000	45,000	22	2100
400	ED37	E39 Mogul	76998	LU400/D/H/ ECO	551	6	TCLP Compliant, Diffuse	11.31	24,000+	47,500	42,750	22	2100

Lamp Watts	Rated wattage for the lamp.
Bulb	This is the bulb shape designation followed by the maximum diameter (expressed in 8ths of an inch).
Base	The type of base.
Product Number	Also called an “order code” or “ordering code,” this number allows you to identify a single, specific lamp when you want to buy one.
Ordering Abbreviation	This is the lamp’s code, which reveals some of its primary characteristics.
ANSI Ballast Type	Standardized ballast designation for ballast type used to operate the lamp.
Pkg. Qty.	Also called “case quantity,” this is the number of lamps packed in a case.
Description	This can include information such as the lamp’s designated operating position (universal, base-up, down, etc.) and the lamp finish (clear or coated).
MOL	Maximum overall length of the lamp in inches.
Avg. Rated Life (hrs)	Indicates median life expectancy—the point at which 50% of a large group of lamps is expected to have failed.
Approx. Lumens – Initial	This is the amount of light produced by the lamp on a reference ballast after a “burn-in” time of 100 hours.
Approx. Lumens – Mean	This is the amount of light produced by the lamp at 40% of rated life, which is considered the mean. Mean lumens are typically less than initial lumens because the lamp produces less light as it ages, a phenomenon called lumen depreciation.
CRI	Color Rendering Index rating. This indicates how “natural” colors look under the light produced by the lamp on a 0-100 scale, with 100 being the best.
CCT (K)	Correlated color temperature. This is the lamp’s color temperature, indicating the color of the light.

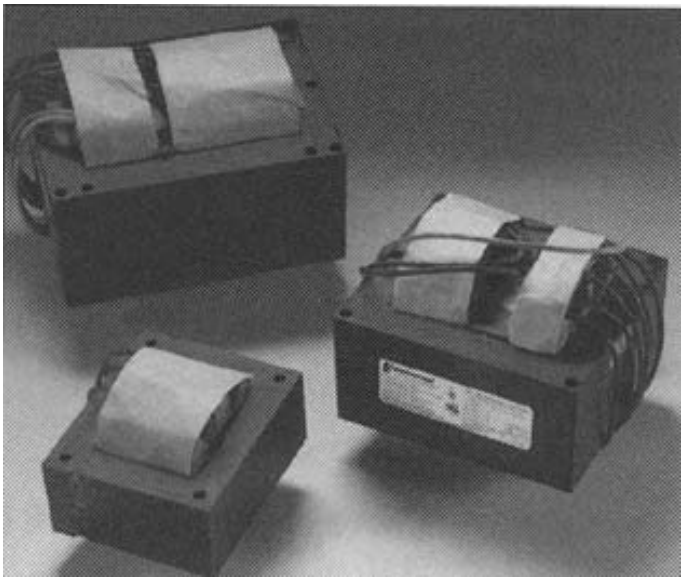
change the ballast. The most significant reason why ballasts fail before they should is high ambient temperatures.

Types

Basic types of magnetic HID ballasts include core-and-coil ballasts, the most common type, plus potted core-and-coil, encased and potted, indoor enclosed, outdoor weatherproof and post line ballasts. We will also briefly review electronic HID ballasts.

Core-and-Coil: This is the basic electromagnetic ballast. It can

FIGURE 4-13
HID ballasts. Courtesy of Universal Lighting Technologies, Inc.



be used by itself or as part of an assembly in five other ballast configurations, shown below.

Potted Core-and-Coil: This is a basic ballast encased and potted in a high-temperature resin to minimize ballast noise and conduct heat away from the ballast's operating components. The potted core-and-coil is typically used in indoor applications where audible noise is an important consideration.

Encased and Potted: This ballast, also designed for indoor use, has a core-and-coil that is encased and potted in cans that look similar to fluorescent ballast cases. The insulating materials minimize noise. These ballasts are also called F-can ballasts.

Indoor Enclosed: These ballasts are used in indoor applications where the ballast must be installed separately from the luminaire. In some factories, for example, luminaires mounted high above the floor can experience heat rise to a level that ballast life is greatly shortened. To keep the ballast away from these high temperatures, the ballast is mounted on a wall instead of in the luminaire. These ballasts can also be used when the luminaire is hard to reach or the weight of the ballast poses problems.

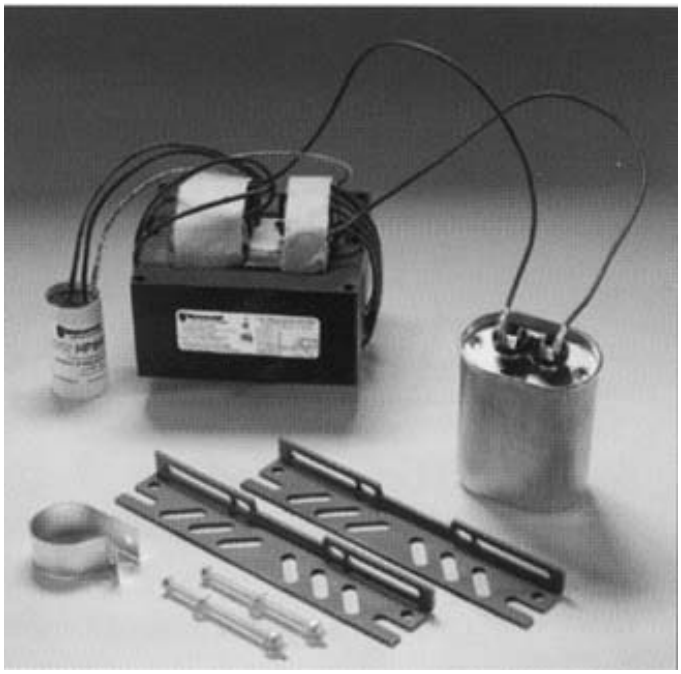
Outdoor Weatherproof: These ballasts are designed to operate separately from the luminaire under all weather conditions. They are vulnerable to flood situations, however. The core-and-coil ballast with a capacitor (and starter where required) is mounted to a base; the entire assembly is then protected by an aluminum cover. Some are filled with resin.

Post Line: These ballasts are designed for lantern-type outdoor luminaires mounted on slender poles, which require a ballast that can fit in the poles. Elongated core and coils are encased and potted in a high-temperature resin. The capacitor and starter (where required) are included within the can.

Electronic Ballasts: Electronic ballasts perform the same functions as magnetic ballasts, but are more efficient and compact, produce minimal heat, can be dimmable, and can improve lamp performance. Some luminaires, such as downlights and track lights using low-wattage HID lamps in indoor applications such as office and retail spaces, are manufactured with electronic HID ballasts.

Now that you know the basic types of ballasts, we can ask our questions from Chapter 1 again, recognizing that lamp performance changes once we add a ballast and create a lighting system:

FIGURE 4-14
HID ballast replacement kit. Courtesy of Universal Lighting Technologies, Inc.



How to Read a Ballast Catalog

The ballast manufacturers provide catalogs that list the characteristics and ordering codes for their ballasts. The HID section is generally categorized by lamp family (HPS, MH, etc.). Within each family, the ballasts are listed in ascending lamp wattage (25, 50, 75, etc.).

Lighting Questions

LAMP	BALLAST	HOW LONG DOES THE LAMP LAST? (HOURS)	HOW MUCH LIGHT DOES IT PRODUCE? (DESIGN LUMENS)	HOW MUCH ELECTRICITY DOES IT NEED? (WATTS)	HOW EFFICIENT IS IT COMPARED TO OTHERS? (LUMENS/WATT)	WHAT'S THE COLOR OF THE LIGHT? (COLOR TEMPERATURE)	HOW ACCURATE DO COLORS LOOK IN THE LIGHT? (COLOR RENDERING INDEX)
HPS	Magnetic	10,000-24,000	2200-130,000	35-1000W	80-130	2100K	20-85+ CRI
HPS	Electronic	10,000-24,000	2400-143,000	35-1000W	90-140	2100K	20-85+ CRI
MH	Magnetic	3,000-30,000	2000-110,000	32-1500W	80-130	3200-5200K	60-96+ CRI
MH	Electronic	3,000-30,000	2300-126,000	32-450W	92-150	3200-5200K	60-96+ CRI
MV	Magnetic	10,000-24,000	1500-58,000	40-1000W	40-50	5700K	15-50 CRI
LPS	Magnetic	16,000-18,000	1800-30,000	18-180W	110-120	1800K	-44-0 CRI

Each manufacturer has its own designation system for identifying its ballasts, with explanations of these systems in their catalogs, but also publishes generic American National Standards Institute (ANSI) designations that match various ballast types (H33, H36, H37, M98, M102, M130, etc.). The lamp manufacturers also publish the ANSI designations so that you will know that ballast types work with each of their lamp models. The manufacturers typically publish a cross-reference guide as well so that you know what ballasts are comparable and interchangeable. A sample partial cross-reference guide, from Universal Lighting Technologies, is shown below:

Below is a sample catalog listing with products from two of the major manufacturers:

YOU KNOW THE BASICS

Congratulations. If you score well on the HID Lighting Quiz, consider yourself on the way to becoming a lighting management expert. Now you're ready to take on a relatively new light source that is rapidly gaining acceptance in lighting—LED.

REMEMBER

HID ballasts start and operate lamps similarly to fluorescent ballasts and like fluorescent ballasts, the biggest reason for shortened life is excessive heat that breaks down the windings. The ballast must be properly matched to the lamp for the lighting system to work properly. Unlike fluorescent ballasts, one ballast can operate only one lamp. The ballast can be mounted at a distance from the luminaire in areas where there is typically a lot of heat present around the luminaire.

Brand Cross Reference Table from Universal LIghting Technologies

ADVANCE / PHILIPS	MAGNETEK	HID DESCRIPTION	# OF LAMPS	LAMP TYPE	ANSI DESIGNATION
71A4021	1030-25-500C	Mercury 240V CWA	1	400W	H33
71A5037	1133-256	Metal Halide 277V HX-NPF	1	35/39W	M130
71A5280	11310-277-500C	Metal Halide 120/277V HX-HPF	1	70W	M85

Sample Ballast Catalog Listing

INPUT VOLTS	CATALOG #	CIRCUIT TYPE	WATTS INPUT	MAX INPUT CURRENT	NOM. OPEN CIRCUIT VOLTAGE	FUSE RATING (AMPS)	WIRING DIAGRAM	DIMENSIONS FIG.	A	B	TOTAL WEIGHT (LBS.)
400W METAL HALIDE LAMP, ANSI CODE M59 OR H33											
120/ 208/ 240/ 277	71A6091-A	CWA	458	4.0/ 2.3/ 2.0/ 1.7	300	10/7/5/5	A	2	2.2	4.0	11.5
35/39-50W METAL HALIDE LAMP											
120/ 208/ 240/ 277	M35MLTC3M	HX-HPF	50	0.82/ 0.48/ 0.42/ 0.36	230	2/1/1/1	4	PC1	0.8	2.0	1.7

Input Volts	The input voltage in which the ballast is designed.
Catalog #	The manufacturers catalog number
Circuit Type	HID balalsts are classified by which type fo circuit they employ – Reactior (R), High Reactance Autotransformer (HX), Constant Wattage Autotransformer (CWA), Regulated Lag (Reg Lag), or Electronic. The most common type is CWA.
Watts Input	The input power to operate the ballast including the lamp
Max Input Current	The highest current draw to be expected for a given ballast
Fuse Rating	Typically 2.5 to 3 times higher than the highest amp rating of the ballast.
Wiring Diagram	References the wiring diagram for the ballast connected to the lamps
Total Weight	Weight of transformer, capacitor and related components
Other Characteristics	Information regarding non-standard feathers of a given ballast

HID LIGHTING QUIZ

Check your understanding of this chapter's material by completing these multiple-choice questions. The answers are on Page 85.

1. What do HPS, all pulse-start MH lamps, low-wattage MH lamps need to start?
a) A key
b) Parallel circuit
c) Starter or ignitor
d) Two ballasts

2. Which of the following lamp types does not belong in the HID family?
a) Metal halide
b) High-pressure sodium
c) Halogen
d) Mercury Vapor

3. Which of the following is NOT a typical application for HID lamps?
a) Offices
b) Parking lots
c) Factories
d) Street lights

4. Which of the following HID lamps has the best color rendering ability?
a) Standard HPS
b) MV
c) LPS
d) MH

5. Which of the following HID lamps is the most efficient?
a) HPS
b) MV
c) MH
d) LPS

6. If you light an object using an LPS lamp, what color will the object appear?
a) Gray, black or yellow
b) Reddish-yellow
c) Bluish-white
d) Bright white

7. If you replace an HID lamp with another HID lamp type, which of the following are you most likely to have to replace as well …?
a) The luminaire
b) The pole if it's mounted on one
c) The ballast
d) The nearest circuit breaker

8. Which of the following is NOT a ballast used to operate HID lamps?
a) F-can
b) Core-and-coil
c) Preheat CFL
d) Post line

9. Which of the following is every ballast's biggest enemy?
a) Noise
b) Heat
c) Dirt
d) Line voltage

10. If an HID lamp bulb is phosphor-coated, the lamp generally has better ____ than clear lamp bulbs.
a) Color qualities
b) Efficiencies
c) Service life
d) Voltage ratings

11. Due to their high light output and compact sizes, HID lamps are ideal for lighting ____ spaces.
a) Small
b) Restricted
c) Large
d) Office

12. If a pulse-start MH lamp experiences a momentary power interruption, when the power returns, it takes 3-4 ____ to re-strike and begin the warm-up process because the arc tube must ____ before the lamp can restart.
a) Seconds ; heat sufficiently
b) Minutes ; heat sufficiently
c) Seconds; cool down
d) Minutes ; cool down

13. A BT56 lamp is _____ in shape.
a) Tubular
b) Bulbous tubular
c) Reflector
d) Ellipsoidal

14. A BT56 lamp is _____ in diameter.
a) 56 inches
b) 5.6 inches
c) 8 inches
d) 7 inches

CHAPTER 5: LIGHTING AUDITS

INTRODUCTION

A good lighting audit encompasses much more than just simply counting lights. A good lighting audit starts with a good lighting auditor. A lighting auditor needs to possess many skills; the role calls for an individual with the mind of an engineer, the heart of a salesperson, the wit of a politician and the ear of a friend.

With the right auditor in place, next, a good audit requires excellent processes, proper tools and the appropriate support. Michelangelo could not have painted the ceiling of the Sistine Chapel without good paint brushes and access to the building. Similarly, a lighting auditor needs to have the tools to do their job and the support from the customer to conduct a good audit.

WHAT IS AN AUDIT?

An audit is a ***comprehensive and diagnostic site evaluation*** undertaken with the intention of creating an ***investment-grade engineering study*** of existing building systems, from establishing the current ***baseline*** to proposing an ***actionable solution***.

Anything less is not an audit. All these components are critical.

Comprensive and Diagnostic Site Evaluation
A 'comprehensive and diagnostic site evaluation' is probably first to mind when imagining an audit; however, it's important to really consider what this means. The term 'comprehensive' suggests something inclusive and of large scope. In the good sense of the word, an audit should be 'intrusive'; it needs to be probing and leave no stone unturned.

The term 'diagnostic' adds an important distinction to this component of the definition. 'Diagnostic' implies that the audit isn't just observational in nature, it is interactive. A 'diagnosis' is a scientific determination, meaning that active testing and probing is undertaken with the intention of drawing a conclusion. The auditor's role is to open fixtures, switch breakers, ask questions, and politely challenge "known" conclusions.

Investment Grade
Traditionally, the term 'investment-grade' is used to describe a level of audit that would satisfy a financial institution making a loan on a lighting project or create a level of confidence in the audit such that an Energy Services Company (ESCO) might finance the lighting project out of the projected energy savings. This is still true.

However, it is important to recognize that any time a customer chooses to purchase a lighting project, they are investing in the outcome. The customer, like everyone, has limited resources. If a customer spends $100,000 on a lighting retrofit, that means that they have $100,000 less to invest in marketing, process improvements, hiring additional employees or opening a new location. This fact is not lost on the customer, in fact, lighting projects are often evaluated on their rate of return vs. the rate of return for other investments. Given this environment, shouldn't all audits have the level of diligence to be considered 'investment-grade?'

Engineering Study
The term 'engineering study' is included to point out that the audit is based on scientific and mathematical principles. While some of the inputs such as the hours of operation are good faith estimates, they must be based on the best and most accurate data possible. Science and math are dispassionate and quantitative; they are based on data. The audit has no place for exaggeration or sales puffery. While the sales process often necessarily pulls at emotions or non-quantitative inputs, the audit process and the audit document must be impartial and data-driven.

Baseline
The 'baseline' is mission-critical. There's no path forward without knowledge of where the building systems are today. The baseline includes macro concepts such as existing energy usage that will be the foundation of important items such return on investment (ROI) calculations. However, it also includes all the micro level details that drive every individual project decision such as capturing ceiling heights to know what lifts to order.

Actionable Solution
Finally, the audit must unearth all the data needed to create an 'actionable solution'. The whole point of the audit process is to solve a problem for the customer and to sell the project for your company. The auditor must always keep this in mind. The auditor must maintain an inner dialog throughout the audit process, always asking if there is enough accurate data to act on.

WHAT IS *NOT* AN AUDIT?

It's just as important to know what isn't an audit as it is important to know what is an audit. Often, you will be confronted with the 'opportunity' to engage in processes that do not rise to the level and quality of a true audit. More confusingly, the people who will ask you to undertake these processes will often refer to them as audits and, even worse, believe that they are audits. These are not bad people, more often than not, they are trying to help and trying to save you time.

The reality is that, as an audit professional, you will need to politely educate people on the benefits a real audit provides. You will need to be vigilant about using the term 'audit' properly and gently leading others to do the same.

The other reality is that, while these other processes are not audits, they do add value and, sometimes, they are necessary. For example, the customer may not be sold on the time and expense involved with a full-scale audit. A quick walk-through is an excellent chance to sell the value of an audit along with the other value your company can offer. It is a chance to learn about the customer, their facility and the range of potential solutions. So, there is not necessarily anything wrong with these processes, it's just that they aren't a substitute for an audit.

Here's a list of terms and processes often confused with an audit:

Survey: The term 'survey' is often used interchangeably with the term 'audit'. However, the word 'survey' is defined as the 'broad treatment of a subject'. When used in the lighting world, think of a survey as a lightweight audit. The survey usually entails less than a day on site with minimal intrusion. A survey can be valuable to

have a more pin-pointed discussion with the customer but, ultimately, a survey doesn't contain the level of detail of an audit nor is it actionable like an audit. If you have done a survey, you will still need to do an audit before you can start the project.

Walk-through: Think of a 'walk-through' as a lightweight survey, or two steps removed from an audit. Usually, a walk-through entails a whirlwind tour of the facility conducted over an hour or two. There is no intrusiveness involved and, normally, the goal is to see the types of fixtures at the site and get a rough gauge of fixture quantities. It can be helpful for planning a future audit and determining customer interest.

Sales "audit": This is not an audit at all; depending on who conducted the 'sales audit', its value can range from nothing to the level of a walk-through. Usually, it refers to an "audit" performed by the sales staff, but it may also refer to a walk-through done by the audit team while the sales team is on site trying to sell the project.

Third party "audits": Occasionally, the customer will give you an audit that has been done by a competitor. It's okay to accept the document if the customer offers it, but it is not acceptable to ask for it. These "audits" can be really valuable, but the only way of determining their value is to do your own full audit. If the third-party audit is good, it can be a way of verifying your own findings and it may provide clues on how to propose and sell the project. However, it is important to be wary of the data. Often, there is no way of knowing who did the audit, when the audit was performed and the level of care that was exercised in performing the audit.

The customer's "audit": The customer has hired you and your company because you have expertise in lighting. Blindly using the customer's data without undertaking your own investigation sends a terrible message. There are sophisticated customers out there who can provide excellent data, but you won't know if you have that customer until you do your own audit. In addition, the auditor's eyes see the project from a perspective that most people will overlook. The value that these "audits" have is in helping you see how your customer perceives the project.

Drawing 'take-offs': It's a fact: the drawings were wrong the day they were issued. Ten, twenty and thirty years later, the building has undergone additions, renovations, major retrofits and may even have different tenants. There is little chance that the drawings have been kept up to date through the years and almost no chance that they are 100% accurate even if they have. The drawings are quite valuable in supporting the audit, but they are not a substitute for the audit itself.

Lump counts: Anything that is an aggregated count without a room-by-room breakout cannot be used as an audit. Room-by-room data is critical for calculating energy usage, projecting return on investment (ROI) numbers and maintaining code compliance.

Stale data: Any data over one or two years old is suspect. Commercial buildings have a habit of changing a lot more frequently than most people think. Any data gathered before a known renovation, retrofit or tenant change is similarly suspect. This information may provide clues and answer some questions you have during your own audit, but it is not a replacement for a new audit.

WHY DO WE PERFORM AUDITS?

Nearly 100% of the time, a lighting audit is undertaken to sell a lighting and/or controls project. If you work for a company that sells or installs lighting and controls, this is the reason for conducting an audit. Quite simply, an audit is a sales tool—albeit an impartial sales tool based on science and mathematics.

It is really easy to forget the real purpose of an audit in the day-to-day grind of gathering and processing data. In defining an audit, we learned that the audit must be 'actionable' and this is why—it is a means to earning business.

There are exceptions to this rule, but they are exceedingly rare. Occasionally, a company may be asked to conduct an audit for the purposes of putting a project out to bid where the company conducting the audit is excluded from competing in the bid process. Rarely, a client may request an audit to verify energy savings or sustainability achievements.

Looking towards the future, some jurisdictions have been considering a requirement for periodic energy audits (including lighting) in commercial buildings within their jurisdictions. If this idea gains traction, this may be a growth area for the audit industry.

For now, the audit exists to sell lighting and controls projects.

COMPONENTS OF A SUCCESSFUL AUDIT

Now that we have defined what an audit is and isn't, it is important to know the pieces and parts that come together to make a good audit. There are four critical components—people, processes, tools and data points.

People

While all four components—people, processes, tools and data points—are critical, none are more important than the person conducting the audit. So, what kind of person makes a good auditor?

At a bare minimum, an auditor needs to be detail oriented and thorough. The auditor needs to be able to investigate and document dozens of data points in each room or space. An auditor needs to be able to read a map or drawings and successfully navigate a building to capture every space included in the scope of work.

Unfortunately—and often— that's all that many organizations consider when selecting an auditor. The prevailing notion with groups like this is, "how difficult can it be? It's just counting lights, right?" The reality, of course, is that counting lights is just one of many important roles that a good auditor undertakes. Viewing your audit role more expansively is a really great way to add more value to your company and to the industry. If you happen to be with an organization that views the audit role in more simplistic terms, taking on a more expansive view of the audit role will cement your place and your value within your organization.

If it's not just about counting lights, then what other traits must a good auditor possess?

First, let's expand on the detail-oriented nature of an auditor and lighting knowledge. A good auditor has the mind of an engineer. Engineers are detail-oriented, of course but, in addition, they are

always looking towards a solution.

Most likely, as an auditor, your role will not include specifying the new lighting solution; however, you must have an eye for it while you're auditing. Are the potential solutions even feasible given the existing state of the building? If so, how difficult will they be? What extra data can you collect on site to make a particular solution possible? What questions can you ask the customer to find the best solution for them? Are you seeing the potential for a solution that hasn't been considered?

And, how about the 'just counting lights' part? Knowledge of lighting and lighting systems is another engineering exercise. Consider this—the industry has famous, award-winning lighting designers who are honored for their roles every year at tradeshow banquets. They are an important part of our industry, but they only need to know the current commercially available lighting products. You, as an auditor, will be confronted with over 140 years of various legacy lighting technologies that you need to be able to identify and evaluate. The depth and breadth of a good auditor's lighting knowledge is vast and, more importantly, technical.

Next, a good auditor has the heart of a salesperson. A good salesperson listens to the customer's needs and recommends a solution to solve their problems. A good salesperson sometimes sees problems that a customer didn't know they had and solves them, too. A good salesperson educates the customer and arms them with the knowledge they need to make good decisions. Customers buy from salespeople they like, so a salesperson's job is to do all of this and still be likeable.

Your role as an auditor is to be an ambassador for your company and, in a more general sense, an ambassador for the industry. Keep this in mind with everyone you encounter because you have no idea who will be influential in the decision-making process.

For example, it's often not a coincidence that you were paired with a local maintenance tech at a particular facility at the onset of a project. That local tech may sit on the company's sustainability committee and be the national purchasing manager's go-to person for technical matters. If so, they will influence the decision.

Similarly, you will be the on-site technical lead for your company. The salesperson has a perspective based on their relationship with, most likely, a corporate purchaser or corporate manager who doesn't reside at the site. You will have a lot to contribute to the salesperson's understanding of how to sell this project and what the local needs are.

Often, as an auditor, you will be the first person the customer comes into contact with and you may be the face of the project for much of the presales phase. In any case, you will be performing a sales role. You are there to solve the customer's problems and to educate them; your efforts in doing so should be in lock-step with the messaging that the salesperson has undertaken to date.

While the salesperson has had to be general due to their lack of site knowledge, you can be much more specific with what you are learning on site. For example, the salesperson may have discussed the benefits of dimming with the customer and now, seeing firsthand that the site is overlit, you can point that out and reemphasize the benefits of the energy savings that would result from task tuning through dimming.

Maybe more importantly, your knowledge of the site could expand the scope of the project for your company while benefiting the customer. Perhaps the salesperson hasn't mentioned controls and you see that the lighting is on 24/7 at the facility. Bringing this up with the customer and following up with the salesperson could result in more revenue for your company and additional energy savings for the client.

A good auditor has the sense of a veteran project manager. They can anticipate challenges to executing the project and have the same desire to mitigate potential risks to project margins and project deadlines. A lot of this is gained with experience. Having a project manager as a mentor while learning the ropes can be a big help.

You will be called on for other skills as you interface with the customer. You will need the wit of a politician and, often, the ear of a friend. For example, gaining access to a facility may be difficult if your gatekeeper has had a bad day or has an authoritarian personality. You need to understand where they are coming from and craft your position in a way that resonates with this person while still being genuine. And, as far-fetched as it may seem, you must operate with the awareness that this person could influence the sale.

It's a lot of skills to juggle but mastering these traits will lead to a successful audit and make you very valuable to your company. In a nutshell, the role of an auditor should be seen as a profession, not as a job. Approaching the role from this perspective puts you on a path of continuous improvement and will lead you to success in the auditor's role.

Processes

Preparing for the Audit: You will not have a successful audit if you don't prepare for it in advance. There is a lot of necessary information and resources that takes time to gather and all the stakeholders must be aligned on the goals of the audit. The outcome of the preparation process will be an audit plan.

Pre-Audit Checklist: It is critical to have a written checklist of everything that will be needed before the audit begins. Every stakeholder inside your company must have access to the checklist and it needs to be clear who owns each checklist item. This includes both upstream stakeholders (groups like sales and business development) and downstream stakeholders (groups like design and project management). Ultimately, the audit team will be responsible to make sure every section of the checklist is completed by the responsible party before moving forward with an audit.

At a minimum, these are items that should be on the checklist:

1. ***Customer commitment:*** It is the sales team's responsibility to prove that the customer is committed to the process. Audits cost a lot of money to execute and committing resources to one project means the resources can't be allocated to another project. Does the customer have a budget allocated for the project? When will the funds be available? When do they want to start? Is there a timeline for the project? Do they have a sustainability program or a sustainability goal? These are all clues that the customer is serious.

2. ***Customer goals:*** This will be led by the sales team, but may include other people who have supported the sales team in initial conversations with the customer. Does the customer have a an ROI number they need to achieve or do they want to see specific energy savings? Knowing the end goal of the project is important for determining how to approach the audit. For example, there may not be a need to audit for controls if the customer isn't interested in controls. If the customer's goal isn't technically possible, there is no need to audit at all.

3. ***Competitive view:*** This will be led by the sales team. Will there be competition on this project? Has someone already proposed a solution? Is the project open for bid? Does your company offer a unique solution you need to audit for?

4. ***Architectural drawings/reflected ceiling plans (RCPs):*** This will be the combined responsibility of the sales team and the audit team. Drawings are critical for digital audit programs and desirable in any audit to have a 'sense of place' when conducting and presenting the audit. For networked control audits, they are a must.

5. ***Energy/utility information:*** This may be known by the sales team but it may need to be guided by and followed up on by the audit team. Ideally, 12 months of the most recent utility bills should be gathered and analyzed. A full 12 months is necessary to average out the seasonal highs and lows that are not represented on one bill. However, one bill is better than nothing. This data will provide the kWh rate and utility numbers for researching rebates. In addition, the bills will be a reality check for future energy calculations. They may even be a reality check for doing the audit! If the customer wants a 2-year ROI and their rate is $0.06 kWh with no rebate potential, it probably isn't possible. Why waste the audit resources if you can't sell the project?

6. ***Site information:*** This will be the combined responsibility of the sales team and the audit team. Where is the building? Where does the audit start and stop within the building? Why? What is the square footage of the building? What are the basics from the customer's perspective—hours of operation, lighting technology, controls, line voltage? This will give the auditor a baseline and an estimate of the time it will take to audit the facility. Of course, all provided data will be investigated and vetted.

7. ***Contact information:*** This will be the responsibility of the sales team. The audit team needs to know who to contact and who they will be working for. The end-use customer may let you in the door, but you may be working for the landlord or another contractor. The audit team needs all of these contacts. Examples include the corporate decision-maker, site contact, secondary site contact, contractor, agent, ESCO or distributer.

8. ***Scope of work:*** This will be the combined responsibility of the sales team, audit team and design team. What building systems will be audited and what are the likely solutions? The audit plan will be impacted by these decisions.

9. ***Special training, certifications and background checks:*** This will be the combined responsibility of the sales team and the audit team. Some sites require special training, certifications or background checks just to be on site. How long will these processes take? Who will pay for them? Where will the auditors need to go to get them?

10. ***Personal protective equipment (PPE):*** This will be the combined responsibility of the sales team and the audit team. The auditors should have the basics such as a hard hat, safety glasses, steel-toe shoes, ear protection and a safety vest. However, they have to know to bring them. Other items, such as metatarsal shoes, will likely be purchased on a case-by-case basis and it takes time to find them. At a minimum, showing up without these items looks unprofessional and causes unnecessary delays. At worst, it could result in losing the customer or major expenses such as return trips.

11. ***Research on the customer:*** This will be the responsibility of the audit team, the sales team and anyone else who knows something about the customer. You should know a little bit about the history of the company and the nature of the site you're visiting. People like when you take an interest in them and they like to talk about what they do. It helps build rapport with the site contacts and will result in a better audit. More importantly, the lighting needs of the customer will vary based on the business they are in.

Audit 'Navigation'/Audit Flow: The way you move through each facility has a direct impact on how thorough your audit will be and, also, on how you perceive and present the space. Obviously, it is important to avoid missing areas. It is equally important, however, to present the audit in a logical order than resonates with the customer and downstream teams. For example, you wouldn't present a high-rise building in floors that were out of numerical order.

You can begin planning even before you get to the site. If your pre-audit checklist has been completed, you will have some kind of architectural drawings or, at least, something such as fire escape plans. Google Earth can help as well. While Google can't see inside of buildings, it can help identify buildings on multi-building sites and it will show the property so you can plan the exterior audit.

Create a plan, subject to change, for when you get on site. It is important to break the building down into recognizable chunks either by geography (walls, floors, areas) or usage (accounting department, annealing, warehouse). If you're deploying a team to the site, it is critical that every auditor knows which sections they will audit and that they are familiar with the boundaries. This will avoid missing areas or double-counting areas. This plan is simply for determining who counts what areas.

Now, you must determine how to organize the audit document. The audit will serve as a 'roadmap' to all the downstream stakeholders, so it must be organized in a logical fashion with easily recognizable and identifiable names. The customer will almost always be the priority in terms of naming conventions and audit flow; however, many stakeholders must be served:

- ***"End-use" customer (paying for the project):*** This is usually a corporate decision-maker residing in a different office, perhaps hundreds of miles away. However, it could be a landlord or a general contractor subcontracting the lighting project. What

are their needs? Do they have cost centers that need to be separated in the audit? For example, they may be allocating the respective project costs to each department getting a lighting upgrade. Do they have a lingo or nomenclature that they associate with spaces or processes? If so, it's important to use the lingo so they understand each area of the audit.

- ***"End-use" customer (using the lights):*** This is the local group directly benefiting from the lighting upgrade. It may be the same "end-use" group above, but probably not. First and foremost, the audit and resulting lighting needs to serve the needs of this group. The audit needs to identify what can be improved and how this group can benefit as they will often have a vote on the project. Similarly, they will have a lingo associated with the space and it needs to be incorporated into the audit so they can envision the project. Finally, this is often the group in charge of maintenance, so any changes with maintenance need to be called out.

- ***Sales team:*** How do they plan to sell the project? Will it be in phases? If so, the audit should be divided up along those lines. Will they be selling a technology that won't be available for a year? The breakdown should account for this as well. Most importantly, the sales team needs to understand how it was broken down so they can sell the project and so the project management team can execute on it.

- ***Specification, design and installation teams:*** These teams need to be able to find their way quickly. The specification and design teams will need to be able to cross-reference the line items to the drawings. The installation team will need to know where to distribute materials and where to deploy staff.

With the audit stakeholders in mind, now a decision can be made on how to breakout the audit. This will also influence your audit plan, for example, you probably don't want two auditors in the same breakout area. The following are some common ways of breaking out the audit:

- Individual buildings: This works best with a campus-type setting, particularly when the buildings are small to medium in size. Often, on a business campus, the buildings fall into cost-centers or along departmental division lines as well.

- Individual floors: This works best with mid- to high-rise buildings; however, any building with multiple floors can be broken out this way. Even if the primary breakout is done along different lines, a secondary breakout can occur across floors.

- Multi-location customer: These sites have to be treated as individual projects and audited individually; no two locations are the same even for cookie-cutter retail facilities. Prioritization may be given to rebate opportunity, kWh rates or code compliance. Be careful about front-loading low hanging fruit as the project gets more difficult to justify later in the program. It is better to strike a balance if you can.

- Cost centers: Communication with the customer ahead of the audit is critical for saving time and delivering what they need on the first round of proposals. Customers who adhere to cost centers for these kinds of projects almost always want the audit and ensuing proposal broken out by cost center. For example, it is very difficult to break the 7th floor out into the accounting, marketing and human resources cost centers months after you conducted the audit; however, it is really easy if you plan it ahead of time.

- Project phases: You may audit an entire project at one time but, if it will be broken up into four phases, it's important to audit and present the project along the phase schedule. Eventually, your team will need to know what material to order and where to install it, so having the audit breakout is critical.

- Customer preference: The customer is king. If they want to see the audit a certain way, it needs to be presented that way. The good news in this scenario is that you know you have customer engagement and buy-in up front.

- Combination: There can be multiple levels of breakouts and there probably should be. For example, the primary breakout may be by building with a secondary breakout by floors.

If you have a good audit plan, there shouldn't be a need for a lot of changes once you get to the site. However, if the need for changes arises, stop and take your time. Be deliberative and think through the implications of the changes. An extra ten minutes of thought now may save days of time and return trips later.

A good auditor practices good audit technique and stays consistent throughout an audit. Doing so creates a roadmap and minimizes the chances of missing spaces or double-counting spaces:

- Audit from the top floor of the building to bottom floor of the building, in order.

- Audit vertical conveyances (stairs, elevators) in their entirety as you first encounter them.

- Start every floor in the same corner.

- Audit in the same direction/path on every floor.

- Audit the outer core first, the inner core next and the areas in-between last.

- Audit one side of a hallway at a time; don't zig-zag.

- If you have drawings, mark off each space as you go to make sure nothing is missed.

On the last point, the building is likely to have changed since the drawings were issued. Take the time to note changes to the layout. Mark up the drawings with the changes. If you don't have drawings, often you can capture an image of a fire escape plan and make your changes there.

It is easy to see the roadmap emerge from this process and it will be evident to downstream teams and to the customer. This methodology works in lock-step with the audit breakout process listed above as the spaces can be attributed along the way.

Adhering to the process will be challenging at times. You will need to be remain firm, yet with a yielding flexibility to maintain a friendly

relationship with the staff. Don't be railroaded into changing the plan unless it becomes functionally impossible to do so. You control the audit, not your escort. If the escort is giving you problems, explain the audit process to them along with the benefits of adhering to the process. Most of the time, they will accommodate you when they realize the importance of the audit order and making sure you don't miss spaces.

If you can't move through the building in order, you can still organize the audit this way later. However, you will need to be extremely careful about capturing every space. The likelihood of missing entire areas is much greater when you skip around. It becomes even more critical to mark off each section and room on the drawings to make sure nothing gets missed.

Lastly, take your time. A few minutes invested at this stage pays dividends later. If you're directionally challenged, take the time to orient yourself and walk through the space in advance to get familiar with it. Make sure to allot enough time for unexpected issues and unforeseeable events.

Scope of Work

Lastly, before you get started on your audit, it is important to have a very good grasp on the scope of work (SOW). It's important to know what the scope of work is, but it's even more critical to understand why the SOW is what it is. The answers to these questions will determine the course of your actions throughout the audit process.

- **What is included in the SOW and why?:** The 'what' component is usually geographical, for example, you may be told to audit the warehouse but not the adjacent offices. That's fine, but you need to know why. Knowing that the offices just had a retrofit explains it. Other times, the 'what' component might be based on something more unusual, for example, you may be told to audit only HID wallpacks under 175 watts. This was an actual audit SOW and the reason was a lucrative rebate opportunity that zeroed in on low wattage HID wallpacks.

- **What is not included in the SOW and why?:** This is where a good auditor can add value and tack a lot of revenue on to a project by simply asking "why". Keep your sales hat on! Sometimes the warehouse out back is not included because the manager of that cost center was unaware of an available budget for upgrades. A quick conversation can expand the SOW. Ask yourself, if something changed, would the customer want to add this item to the SOW?

- **Are there rebates and/or incentives that will influence the SOW?:** If the local utility is heavily incentivizing new fixtures and doesn't offer any incentive for lamp and driver retrofits, then the new fixture option has to be considered. The data points you capture in your audit will change accordingly. Suddenly, ceiling types, plenum heights and fixture mounts must now be a part of the audit scope so it's possible to properly specify new fixtures.

- **What are the project goals?:** What's important to your customer? Typical goals include quick ROI, cutting-edge technology, proof of concept, consistency across the customer's property portfolio and, even, satisfying egos. The audit SOW will be entirely different for a project that prioritizes low ROI vs. an audit SOW that prioritizes cutting-edge technology.

- **What do the downstream teams need to do their job?:** If networked controls will be a part of the SOW, there will be an entire additional team that needs very different and specific data points. The relationships of one space to another become very important, so mapping is critical. Indeed, non-lighting technologies such as thermostats may suddenly be part of your data gathering efforts. Lighting design, rebate and project management teams also have very real and legitimate needs for specific data and need to be considered in the audit process.

- **What must be audited, even if it is outside of the SOW?:** Even if an item is not included in the SOW, it often has to be audited to calculate energy loads or to satisfy code. For example, local code will almost always prescribe a targeted lighting power density (LPD) for a given space. It's fine if the CFL recessed cans are out of scope, but they still need to be audited and considered in the LPD calculations for the room. It might even be a chance to add them to the SOW if the prescribed LPD values can't be achieved leaving them as is.

- **What is the project timeline?:** Audits have a shelf-life. If the purpose of the project is to sell a technology that will be ready in two and a half years, it's probably a good idea to hold off on the audit for a while. Likewise, if you are facing a rebate that expires in two months, the SOW may be centered around getting an audit and design approved quickly to schedule a pre-inspection walk by the utility to secure incentive monies.

Audit Tools

A good audit requires good tools. Investing $150 in a laser measure sounds expensive. However, a mismeasurement from a $15 laser measure or, worse, a visual guess on ceiling height can result in ordering the wrong lift for the job. This, in turn, can lead to project delays waiting on the proper lift which may or may not be immediately available. That can lead to a crew stranded with no work and, more alarming, to an unhappy customer. Suddenly, the $150 laser measure looks pretty inexpensive compared to $4,000 in added project costs and the relationship disaster with the customer.

Each auditor should be issued a core set of tools that includes the following items:

- **Digital tablet (Equipped with a Comprehensive Audit App):** Audits should be performed digitally to avoid transcription time and transcription errors. Also, the data-rich audit programs commercially available result in better, more accurate audits. Look for an audit app that has comprehensive data fields encompassing all the data points that must be collected, yet an app that is flexible and customizable. In addition, the app must allow inputs/outputs from multimedia sources such as photos, video, voice recordings, map uploads, etc. The tablet that hosts the app must be capable of running the chosen audit program. The physical size of the tablet can be left up to individual preference. Whatever tablet you choose must be issued with a case designed to protect the device from hard falls and harsh environments. Equipment drops and falls are inevitable in the audit world.

- **Pen/Paper/Clipboard:** If audits are to be done the old-

fashioned way, the auditor needs to be armed with a few spare pens and a good clipboard.

- **Camera:** The camera is critical to the audit because photos and video can capture and convey so much information. The digital audit program you choose is likely to have both functionalities built-in, with the advantage of being able to automatically link the photos and video to specific data in the audit. Even so, a stand-alone camera has a better zoom and better resolution, so it can capture things like labels on high-bay fixtures that the tablet's camera can't get close to. Thus, there is a need for both. Look for a camera with a minimum of 25X optical zoom and 12 megapixels. A compact point-and-shoot with these features may be as small as a deck of cards and very reasonably priced.

- **Light meter:** While you can get a light meter app on your phone, it is not calibratable or certifiable. Both features are important for liability purposes if there is a disagreement about light levels at a later point. But, note, the certification must be kept up to date. Compact all-in-one units are easiest to carry and can be accurate if used properly. Units with a remote lumisphere on a cord are more difficult to carry and deploy in the audit setting, though they remove many of the issues surrounding bad readings.

- **Tally counters:** Tally counters are critical for maintaining good counts and allow you to conduct a few counts on a single pass if you have more than one tally counter. Avoid the inexpensive, plastic tally counters as they are unreliable and don't last. A good tally counter will have a solid, positive snap that allows you to feel the count in noisy environments where you can't hear the click.

- **Laser measure:** This is critical for measuring large distances and for measuring ceiling heights where you can't run a tape measure. You get what you pay for, however. Avoid the inexpensive units as they don't measure reliably. Also, be aware that laser measures are almost useless in sunlight, so you will need a backup plan outdoors during the day.

- **Tape measure:** The tape measure is good for outdoors and for smaller distances that are critical, for example, measuring the diameter of recessed cans.

- **Inspection mirror:** Ladders slow you down and may not always be available. A 4-foot inspection mirror can keep you moving in a lot of situations where you need a quick peek, for example, counting fixtures in a cove.

- **Ballast discriminator:** This tool measures the cycle rate of fluorescent lamps to indicate if the ballast is magnetic or electronic—typically, the difference between T12 and T8. The need for this tool is diminishing; however, it is really handy to have when you encounter a mix of the two technologies.

- **Flashlight:** A flashlight is needed more often for navigation purposes than for inspection. While the tablet often has a flashlight, it's nicer to have a dedicated tool for the job and, also, one that is brighter.

- **Basic hand tools:** This includes pliers and a multi-bit screwdriver with security bits. Be careful about getting weighed down with too many tools; however. These two tools will get you into most fixtures.

- **Extra batteries:** Anything that runs on batteries will die at some point during the audit. It's senseless to lose an hour tracking down AA batteries that you could have easily had with you had you planned for it. Similarly, if a tablet is your primary tool, it's important to have a back-up power bank handy so you don't have to stop to recharge. Obviously, everything with batteries should be charged overnight and ready to go the next day.

- **A carrying system for the tools:** You must have a way to carry and organize the tools; it's too much for pants pockets. Backpacks, waist-packs and photographer's vests are all popular methods of organizing the tools. Find the one that you feel most comfortable with.

- **Personal protective equipment (PPE):** The basic kit should include a hard hat, steel-toe shoes, safety vest, ear protection and safety glasses. Other PPE may be required, but can be purchased on a case-by-case basis. A professional auditor asks if PPE is required in advance and shows up to the site wearing it. It inspires confidence in the customer and it avoids wasting time to retrieve it.

- **Proper attire:** The proper clothing depends on the site and the customer. You wouldn't wear jeans to audit the White House and you wouldn't wear a suit to audit a coal mine. Outdoor audit attire will be dictated by weather and probably involves a hat. Generally, dress as nicely as the staff at the facility and wear comfortable shoes. Minimize jewelry and don't wear loose fitting clothes that could expose you to risk around machinery.

Audit Data Points

The point of the audit is to capture the data needed to sell the project. The mission of the auditor is to have an audit plan in place that allows the team to capture the necessary data in one trip to the site.

In reality, there is an endless stream of data that can be captured at any site, so it is also necessary to strike a balance between the bare minimum and the ultimate in perfection. The 'perfect audit' delivers enough data to be confident in the solution and to allow iterative changes in the sales process. However, it stops short of the kind of perfection that would take weeks and weeks to execute and cost hundreds of thousands of dollars in labor, measurements and testing.

The data points below are not exhaustive nor are they all mandatory on every audit. The scope of work and the audit plan will dictate which are necessary and, as technology evolves, more data points may be added to the list. However, a good audit will address most and, possibly, all of the items on the list. Bear in mind, that many of these data points apply to every line item in your audit, so you will be capturing this data again and again as you move through the building.

- **Addresses and locations:** Just like you needed the address to know where to show up for the audit, downstream teams will need to know where the building is to execute their roles. For example, the rebate team needs to know where the buildings

are to calculate the incentives. Everyone will need to know which building is attributable to which data set.

- **Utility bills:** Ideally, you will already have the bills as a part of your pre-audit checklist exercise. If you don't, now is the time to ask for them while you are on site—if you don't get them now, you probably never will. Remember, you need 12 months of bills to average out seasonal peaks and valleys and you will need bills for every meter on site. Still, take whatever utility bills you can get at this point; one bill is better than none. The bills will now be a part of the audit data set so they can be passed along to downstream teams as part of the package.

- **kWh rate:** The auditor will determine the kWh rate from the bills above and enter it as part of the audit record. This can be done later to maximize time efficiency in the field; however, the auditor must ensure that they have everything needed to perform the calculations before leaving the site. The kWh rate should be an average of the 12 months of the bills or as close as possible given the number of provided bills. If the customer refuses to provide bills, general averages can be looked up online searching for "commercial kWh rates Boca Raton, Florida", for example. In this case, it's important to record the weblink for where the information was obtained.

- **Architectural drawings/reflected ceiling plans (RCPs):** Like the utility bills, you should already have drawings and RCPs as a part of the pre-audit checklist process. If you don't, you can politely push for them while you are on site; it will be your last chance to get them. If the customer won't provide them, there's usually something you can find such as fire escape plans or a furniture plan. The idea is to have something to scale with the existing layout. Whatever you get, it will now be part of the audit record for all downstream teams and, if you have a digital audit program, it can be uploaded and marked up digitally with notes and changes as you audit the site.

- **Hours of operation:** This is mission-critical. There are only three components of energy usage—the kWh rate, wattage (load) and hours of operation. Of the three, the hours of operation is the only one that isn't "a number on a page". The kWh rate can be calculated from utility bills and the wattage of fixtures is known and published. The hours of operation could be anything. So how do you determine what they are?

  - **Are there posted hours of operation?:** This usually only applies to retail facilities, but it is a great starting point. If the store is open ten hours a day, you know the minimum burn hours for the sales floor are at least ten hours per day. However, it is very likely higher due to the staff coming in before the store opens and staying after it closes. Be careful, though, not all spaces will burn 10+ hours per day, for example, the broom closet.

  - **Interviews:** You will want to conduct informal interviews with your site contacts and the building occupants to learn more about the hours of operation. Start with the maintenance staff and your site contact, then ask people you see as you conduct the audit. But, be aware that these people often have a stake in what they are telling you. Often you will hear what the facility should operate like, not how it actually operates. Thus, you will need to balance these interviews with other inputs.

  - **Observations:** First and foremost among these other inputs is your personal observations. Are lights burning 24/7 in closets or electrical rooms? Do occupants turn off the lights when they leave their offices? What is employee moral like; i.e. do they care about saving the company money? Drive by the facility after dinner; are the lights on after hours? Does the cleaning crew turn off lights as they finish cleaning each area?

  - **Are there lighting controls?:** If so, that demonstrates a company commitment to energy savings. Are they working? Have they been overridden or defeated by the staff? At the very least, if there are controls, you will now have separate hours of operation for controlled areas vs. non-controlled areas.

  - **Is there a building management system (BMS) or networked lighting controls system?:** This may be the only way to find a 'number on a page'. If you can get access to the schedule and verify that the system is operational, you could have the exact hours of operation in hand.

  - **Does the customer have an energy or sustainability program in place?:** This is a clue that occupants may be more aware of the benefits of turning off lights and energy savings.

  - **Is there emergency lighting?:** If you have emergency lights burning 24/7, they need to be called out and calculated with a 24/7 operation.

  - **Utility bills:** Utility bills are your reality check. Lighting is typically about 30-40% of the energy load in most buildings (with notable exceptions). If your calculations show a kWh consumption higher than 40% of the utility bill, it's a red flag.

  - **Hours breakout by space:** Ultimately, you will be breaking out the hours of operation by spaces. For example, a broom closet will likely have different hours of operation than the warehouse at your customer's site. It's extremely important to model the hours of operation for each space vs. having one overall hours of operation figure for the entire building. This is the only way to accurately calculate a project ROI and energy savings.

- **General area:** As you start to get into the room-by-room data collection in the audit, it's important to call out general areas to start to focus attention on the 'sense of place' in the audit. This will help downstream teams in conceptualizing the space and planning the project execution. Examples of the general space can be a whole building, a floor or a cost-center—something to start to point in the direction of where you are in the building. Make sure to understand how the customer wants the audit to be broken out (see previous section) and get with your site contact to make sure you are using their nomenclature to identify the areas.

- **Building/area/room names:** As you audit, you must identify

where each room is located and describe the room with a meaningful and identifiable name. The room name will be supported by the hierarchy of where it is located—the audit will identify the building name, then an area name within that building and, lastly, the room name for every defined room. The 'room' name is the final defined space that all the attribute data below will be describing. If possible, it is best to use the customer's nomenclature to describe the space. 'Annealing Station' is better than calling the space 'Manufacturing Space #4' because it happens to be the fourth manufacturing space you audited. Better yet, if the spaces have labels, always refer to that identifier even if you tack on the customer's nickname for it. Marking an office as "F12534" is unmistakable if there's a label on the door. It can be "F12534 Jane's Office" if everyone knows it as 'Jane's Office'. The important point is that the name you use needs to create a roadmap for all downstream teams.

- **Lamp/ballast/fixture type:** The technical specifications for existing lighting are covered in previous chapters and a good auditor needs to know these technical details for every existing system. From the standpoint of capturing data for the audit, however, these are the attributes that need to be captured for every fixture in every space:
  - **Lighting technology:** Is the fixture LED, HID, incandescent or fluorescent? If it is HID, is it high pressure sodium or metal halide? If it is fluorescent, is it T12, T8 or T5? This knowledge will inform your choices for solutions as well as creating a baseline for energy savings.
  - **Form factor:** What size and shape is the light source? If it is fluorescent, is it a 2-foot lamp or a 4-foot lamp? If it is incandescent, is it an A19 lamp or a G20 lamp? If it is a plug-in CFL, is it a 2-pin lamp or 4-pin lamp? The size of the lamp will dictate solution options, especially if you're retrofitting the fixture.
  - **Wattage:** What is the wattage of the lamp?
  - **Number of lamps:** How many lamps are in each fixture? Obviously, this impacts energy usage and retrofit options.
  - **Ballast/driver type:** If the fixture has a ballast, what kind is it? If it's fluorescent, is it instant-start or programmed-start? Is it a low ballast factor ballast or a normal ballast factor ballast? This will impact energy usage and, potentially, limit certain retrofits.
  - **Switching/wiring configuration:** Are the fixtures switched in a standard, inboard-outboard or checkerboard configuration? Are they tandem wired? This will determine the energy usage of the fixture, the number of ballasts on board and the potential solutions for the space.
  - **Fixture type:** What kind of fixture is it? Is it a troffer, strip fixture, highbay or area light? If it's a troffer, is it a 2x2 or 2x4? Is it a standard troffer or a deep troffer? Is the troffer plenum rated? This data is critical for retrofit applications and, also, extremely important for replacement fixtures because all the pieces and parts must fit together.
  - **Fixture lens:** What kind of lens is on the fixture? This will impact retrofit/replacement options. For example, knowing that fixtures have a paracube lens will explain the light loss at the workplane when the designers model the space. Another example is a parabolic lens with three rows. This is a is tough application to retrofit from three lamps to two lamps—you either get a dark row of cells with a missing lamp over the center row or you must order a very specific retrofit kit that centers the two lamps over the two center dividers to illuminate all three rows.
  - **Fixture mount:** Is the fixture mounted from a pendant or a hook? Is it recessed in a T-Bar ceiling? The mounting type must be known when you're ordering the replacement fixture so the new fixture is compatible with the old mounts.
  - **Special features:** The most important special feature is emergency operation. This absolutely must be known to avoid cost overruns on the project and to remain code compliant with local authorities (see section below). Other special features may include tamper-proof fixtures or explosion-proof fixtures. All these categories have the potential to erode project margins and create liability if they are missed.
  - **Fixture color:** Fixture color may be important to match existing hardware or to meet a customer specification. It is not professional to mount a black fixture on a dark bronze pole nor can you show up with a Navy Blue fixture when your customer's specification is Colonial Blue. Many times, color will be a special-order feature that isn't returnable and has extremely long lead times. Thus, ordering the wrong color has huge implications for cost and project delays.
  - **A note on replacing existing LED with new LED technology:** This is a special category that is growing in importance as the first wave of LED installations are aging out and beginning to be replaced. Finding fixture wattages can be very difficult, even if you can find a fixture label. Often, the fixture code (catalog logic) is no longer listed online with the manufacturer as the product may have been retired ten or more years ago. You will need to do your due diligence to discover this information and it may involve reaching out to factory reps for old cutsheets. LED doesn't really die; it just fades away…. Lumen depreciation marks end-of-life for LED fixtures, so establishing that the old fixture's time has come relies on taking good light meter readings and projecting the difference between illuminance levels when new vs. now. The cutsheets will also help in this endeavor.
- **Lamp color temperature:** This metric may be reported once if the site only has one color temperature throughout. However, if there are two or more color temperatures present, it is important to know exactly where the lines of demarcation are so that the appropriate quantities of material can be ordered for each area. Often, color temperature is different based on fixture types, for example, a predominantly fluorescent site may be 4100k for fluorescent applications, but the incandescent cans may be 2700k. Sometimes, a building addition or major renovation in an area will have a different color temperature than

the rest of the building.

- **Lighting application:** It's helpful to downstream teams to understand how the lighting is being used. Often, the application will drive the choices for replacement lighting or, even, determine if the lighting will be replaced at all. There are three categories of uses: ambient lighting, task lighting and decorative lighting:
  - » **Ambient lighting**: Ambient lighting is lighting that illuminates an entire room or space; it is typically identifiable by both the all-encompassing scope of the light as well as the even distribution of light throughout the space. Troffers are a great example of ambient lighting.
  - » **Task lighting**: Task lighting almost always works in conjunction with ambient lighting. Typically, you will find ambient lighting providing low- to medium-level illumination in the space with task lighting fixtures providing higher illumination for specific tasks in a very defined area. Task lighting is identifiable by a limited scope of illumination—a desk, for example—and a higher level of illumination than adjacent areas. A strip fixture located above a workbench is an example of task lighting if the space is also illuminated by ambient highbay fixtures.
  - » **Decorative lighting**: Decorative lighting is sometimes called 'sparkle'. This kind of lighting exists for no other reason than to be 'jewelry' in the space or to highlight an architectural feature of the building. A fancy brass chandelier in the reception area is a great example because, most of the time, the primary light for the space is being delivered by other fixtures. Its purpose is to look grand and attract the eye, not primarily to illuminate the space. A wallwash fixture is also 'sparkle'; it really doesn't illuminate the space so much as it shows off the texture of, say, an exposed brick wall.
- **Pole fixtures**: Exterior lighting has some additional challenges, particularly pole lighting. The audit should include additional data for pole applications including pole height, pole width, pole type (metal, wood, concrete), pole shape (round, square, round tapered, square tapered), pole bolt pattern, base type, base height and mounting type. The auditor should examine the condition of the pole to prevent potential future liability. Is the pole rusty, particularly at the base? Has the pole been hit by a car; is it dented or leaning? Every data point should have a corresponding photo for each pole to document the data. A trick for keeping track of this is to number the poles on the drawings, then use your tally counter to keep the photos organized. Before encountering Pole #26, take a photo of the tally counter showing the number 26, then all subsequent photos belong to Pole #26.
- **Fixture quantity:** How many fixtures are in the room or space? Note, you can have several types of fixtures in each space and you will need a separate line item for each kind of fixture along with the quantities for that line item. This will roll up into the energy calculations but, also, it will become the basis for how many retrofits/replacement fixtures are ordered.
- **Hours of operation**: We discussed the hours of operation above and how to arrive at the various categories and specific hour-usages. Now is the time to attribute one of those categories to a specific line item. Typically, each room or space has the same usage across all light fixture types, but not always. If a space has emergency lighting, those fixtures will operate 24/7 and the others will have some other attribution. Another example might be a room where the troffers are on a sensor, but the recessed cans are not. Both systems will have different hours of operation.
- **Line voltage**: This is an extremely critical metric to capture; wrong answers or wrong assumptions can lead to very costly mistakes. This metric must be verified for every space; be on the lookout for building additions, expansions, or renovations where line voltages may change. Also, be aware that certain systems may be powered by different voltages, for example, troffers and highbays. Line voltage is a data point that must be independently verified by the auditor in the field and it is important that everyone downstream understands the methodology of how it was determined. There are several ways it can be ascertained:
  - » **Lighting panels**: This is a primary, definitive source. Check the panels and the circuit breakers for each area. Record the voltages and take photos of the panel, panel number, panel label, circuit breakers, circuit breaker voltages and the panel schedule.
  - » **Open fixtures/check ballasts**: This is a primary, definitive source. Open powered fixtures and record the voltage listed on the ballasts. Take photos as proof.
  - » **Take voltage readings:** This is a primary, definitive source. Typically, auditors won't have the training and equipment to safely capture voltage readings. However, some may and, sometimes, there is access to people who can. If it is possible, take advantage of this opportunity and capture photos of the voltage readings.
  - » **Ask your contact and/or the maintenance person**: This will provide clues, but should only support a definitive source above. There's nothing wrong with asking, but be aware that the answer may not be right. Hopefully, it aligns with what you've found as a definitive source. If not, you need to investigate further.
  - » **Check the architectural drawings/RCPs:** This will provide clues, but should only support a definitive source above. This is another reason to have the drawings. The drawings are probably accurate, but the architect's intentions may not have manifested themselves at the construction phase or the original equipment may have been replaced at some point, so be a little bit wary.
  - » **Check ballast labels on attic stock:** This will provide clues, but should only support a definitive source above. The voltage you find will probably be correct, however, the fixtures are in storage for a reason. They may have come from another facility with different voltages or, maybe, they were ordered in error to start with. Again, be wary and take

photos.

- » **Check ballast labels on the parts shelf:** This will provide clues, but should only support a definitive source above. The voltage will probably be correct, but you never know if the wrong ballasts were ordered. Or, maybe, they arrived from a recently shuttered sister facility with different voltages. Be wary and take photos.
- » **Check ballast labels in the recycle bin:** This will provide clues, but should only support a definitive source above. Same as above, the voltages you find will probably be correct, but they may be in the recycle bin because someone finally had the courage to throw away bad inventory. Or, one of the staff members may have recycled ballasts from their basement renovation and the ballast voltages have nothing to do with the facility. Use it as a clue, but be wary and take photos.
- » **Photocells and shorting caps**: This will provide clues, but should only support a definitive source above. For exterior applications, photocells and shorting caps are often labeled with the line voltage. It's a really good clue, but not a failsafe as the wrong voltage may have been installed. This is a case where a good zoom camera can help identify the voltages. Also, as parking lots expand, the voltages often change. The camera can be a good resource if you see changes in pavement color or pavement material that suggest an expansion took place.

- **Existing controls**: If the space has existing lighting controls, this must be noted in the audit. The notation will need to indicate the type of control (sensor, timer, photocell) along with the technology (infrared, ultrasonic, dual-tech) and the mounting type (j-box, ceiling, wall, fixture). This will impact which controls get specified in the project for this space, if any. It also might dictate the replacement of existing controls if the new lighting system isn't compatible with the old controls. It should also be a reality check for your hours of operation—if you have existing controls, the hours of operation have to be less than they are for the equivalent space. For example, if your 'private office' category operates 3,500 hours/year, your 'private office—sensored' category must logically operate less than 3,500 hours/year.

- **Conditioned space**: Any space that is air-conditioned must be marked on the audit. Lighting creates heat in the space and the replacement lighting, using less energy, will create less heat. That means that the air-conditioning doesn't expend as much energy cooling the space; though, it will take more energy to heat the space in the winter. In most regions, the customer will realize HVAC savings if they have air-conditioning because air-conditioning uses more energy than heating throughout the year. This air-conditioning savings will be calculated in the ROI based on the spaces that are marked as conditioned.

- **Room size/room type**: Increasingly, many local and state codes are based on lighting power density (LPD). In these cases, building owners are beholden to meeting certain wattage thresholds per square foot based on the space type or building type. For example, a private office may be allowed 0.75 watts/square foot. In order for the specifiers and designers to be code compliant, they must know what kind of space they are working with and the square footage of the space. Specifiers and designers typically like to work at the room level vs. the building level because the LPD allowances are usually more generous. As a result, the audit should include the square footage of each space along with its usage type.

- **Ceiling height:** Typically, ceiling height and fixture height are the same. Ceiling height is important to note for each space for two reasons: (1) to accurately conduct a photometric analysis, and, (2) to make sure the installation team has the right equipment to install the solution. The design team needs to know the ceiling height because ceiling height directly relates to the illumination levels on the workplane; the same fixture installed at two different heights will produce different illumination levels on the workplane. The installation crew must know the ceiling height to have the right ladders on hand or to order the right lifts. Mistakes with illumination levels or lifts can result in margin erosion and project delays.

- **Fixture height:** If your fixtures are at a different height than the ceiling, it is important to note both the ceiling height and the fixture height for the same reasons as listed above; only this time, you're alerting downstream teams that there are two figures to consider (ceiling height and fixture height) vs. one figure (ceiling height). An example of where you would find fixtures at a different height than the ceiling is any pendant mounted fixtured.

- **Ceiling type**: Ceiling type is very important. The labor to install a troffer in a drop ceiling is much lower than the labor to install the same fixture in a gypsum ceiling, even without drywall work. If drywall work is required, the price variance can be even greater. Ceiling type will also dictate the range of solutions, for example, you wouldn't typically hang a troffer in an open ceiling without some kind of enclosure.

- **Estimates:** As an auditor, you need to politely assert yourself for access to every space and you need to exhaust all your resources in getting to those spaces. Logistically, you should assert yourself as you come to each space to avoid having to double-back to spaces later. However, you have to balance that with the need to get through the bulk of the audit in a timely manner. Also, if there is a chance that your requests will be received unenthusiastically, make sure you finish the rest of the audit first before trying to get access to ensure you have captured the bulk of the data. At some point, however, it is inevitable that you will have to estimate spaces. Keep that list to a minimum and always—without exception—mark any line item you did not get access to as an estimate. This is critical to protect your company from the liability of a wrong estimate. This is a time when the drawings are critical so you can see the size of the space. Hopefully, you will have RCPs to have an idea of what kind of fixtures are in the space and how many fixtures there are. Even without drawings, however, the estimate shouldn't be a guess. By now, you should know roughly how large the space is and what kind of fixtures you have encountered in areas around it. If the customer provides the estimate, note that clearly along with the name of the person who provided the estimate. If you provide the estimate, the

estimate should be a tiny bit high as it's easier to give money back than to ask for more later. Also, it will avoid project delays in getting more material.

- **Light meter readings:** Light meter readings are an important element of the lighting audit. It isn't necessary to capture readings in every space unless the scope of work calls for it. However, it's important to capture readings in all the various space types (warehouse, open office, private office) and under each fixture type (highbays, troffers, strip fixtures). A representative sampling of each is fine. You will also want to measure spaces that are important to the customer and, especially, any space that has presented problems in the past or that the customer is concerned with today. Here are some items to keep in mind:
  - » **Workplane:** As a default, always measure at the workplane which is 30 inches above the finished floor (AFF). This is a standard desk height. Occasionally, another surface will be critical, typically in some industrial process involving machinery or inspections. Exterior lighting is measured on the ground.
  - » **Awareness:** Be aware of where you are standing when you are measuring light levels. Don't create a shadow over the meter and stand far enough away that light or dark clothing doesn't impact the reading.
  - » **Target light levels:** Ask the customer if they have a standard for light levels in various spaces. If they do, make sure to report the standards in your audit. If not, the target will default to the IES standards for the various spaces/ industries.
  - » **Mapping**: If you can, map out the points where the meter readings were captured so they can be replicated after the project is installed.
  - » **Why capture the readings?:** The readings are important to protect your company from liability. If the customer thinks the light levels went down after the retrofit, you will be armed with the data to refute or confirm the claim. Also, it helps the design team with their photometric analysis. If you're charged with increasing or decreasing light levels, you must know where you're starting.
- **Photos:** You cannot take too many photos! Photos will fill in memory gaps and the inevitable data points you forgot to collect. They also make the building 'real' for downstream teams, helping them conceptualize the spaces and answering a lot of questions they will ultimately need to ask. There are a lot of points to consider with the photos:
  - » **Native photo equipment:** If you have a digital audit program, the program will probably take advantage of the camera that is native to the device you are working on. The good news is that tablet and phone cameras are excellent these days. The resolution of the cameras is more than enough and the dynamic range, or the way the camera manages contrast, is world-class. Also, most digital programs will automatically link the photo to the line item you're working on, which is a real time-saver. The bad news is that the native cameras don't have a very good zoom range and they cannot be overridden in semi-automatic modes that are important when capturing lighting. If you have access to a digital program, you will capture 90% of your images on the native camera using the standard wide-angle view. That's great, but you still need another camera.
  - » **Stand-alone photo equipment:** If you don't have access to a digital audit program, you will absolutely need a stand-alone camera. Even if you do have access to an audit program, the stand-alone camera will be invaluable to you. We reviewed camera specifications in a section above, but overall, you should have a 12+ megapixel camera with a minimum of a 25x zoom. This camera will be used to zoom in to read labels as high as 50 feet above the auditor and it can be pressed into semi-automatic modes to capture details in high contrast situations such as bright lighting with dark backgrounds. If there's a budget for a second stand-alone camera, the newer 180° and 360° cameras have a useful application as well, but they are not a substitute for the zoom capabilities needed in the primary stand-alone camera. A note for the future, look for changes in this space. The native cameras in phones and tablets are quickly improving. The need for the stand-alone camera is valid today, but this need may become obsolete in the coming years.
  - » **Photo attribution:** Regardless of how or where the photo is captured, it must be attributed to a specific line item in the audit, something most digital programs do automatically. Photos are absolutely useless otherwise. You will be taking hundreds and, possibly, thousands of photos per audit and there's no way of remembering where any of them were taken without formal attribution in the audit. A tip to help with attributing photos later on your stand-alone camera—always take a photo of the room nameplate first, then capture photos within the room. When you organize the photos later, you will know where the photos go.
  - » **What photos must be taken?:** At a bare minimum, the following photos are necessary for every audit:
    - – Photos of each lamp/ballast/fixture type on site. The photos should be captured in wide angle shots and zoomed shots. The fixture should be shown in operation, then opened and photographed in detail. Lamp etches, ballast labels and fixture labels should be a part of the photo set. Lamp bases need to be captured. Anything unusual or any damage should be captured. These photos are critical for energy calculations, retrofit/replacement options and design details.
    - – Photos of all lighting panels. The photos must include the panel in situ to show how much room is available around it, the panel name, the panel data plate, the panel schedule, the corresponding circuit breakers and the rated voltage of the circuit breakers. This is critical for controls proposals and to verify line voltage.

- Photos of anything unusual. Anything out of the ordinary and, especially, anything that would impact project costs or retrofit strategies needs to be photographed.
- Photos of each room type. This is important for the design team and assists with the photometric layouts.
- Photos that support any of the following callouts: hours of operation, line voltages, wattages and special equipment.

» **What photos are nice to have?:** As an audit professional, you will want to provide additional photos and documentation. There are a lot of opportunities to help the project along:

- Scenic photos of the building, campus, or signage. These can be used in sales proposals. If you're rolling up on the building at sunset and see a nice shot, why not help the salesperson with a memorable shot for their presentation deck?
- Photos of every room or space. This is a lot more helpful than it sounds. Inevitably, it'll help the team answer an unexpected question or fill in a detail that was missed. Often, the customer will raise a concern about a space after the audit and you'll be armed with the photos to help provide an answer.

» **What photos should you avoid capturing?**: Avoid taking any photos of people, proprietary processes or sensitive information. Also, don't take photos if you are prohibited from capturing images. Most site contacts will work to get an exception for facilities that prohibit photography if you explain the importance of the photos and agree to limit your photography to just lighting and controls.

» **Camera training:** An auditor doesn't need to be a professional photographer but, ultimately, an auditor can turn in a much better audit with some basic photographic knowledge and some orientation on the camera. These tips will only work on a stand-alone camera, which illustrates the value of having a separate camera.

- Fill flash. The problem with lighting is that it is very contrasty. The auditor needs to capture a detailed photo of the bright light fixture or, conversely, the dimly lit mount behind the light fixture. The problem is that the camera can't decipher which is more important and, usually, tries to 'average out' the exposure. This leaves the photo with no details in either area—the bright or dark areas. One strategy is to use 'fill flash'. This involves setting the camera to always use flash, regardless of whether or not the camera thinks it needs it. The flash will illuminate the dark background while the camera meter exposes for the bright light. This provides details in both the areas. Note, however, the fill flash will only work for surfaces within 12 feet of the camera.
- Meter lock. This brings us to the other strategy for contrasty situations. It is possible to lock the camera's meter on either the dark area or the bright area. In this case, the only details that will emerge in the photos are in the area you locked in on. However, the strategy works at any distance as opposed to the fill flash that requires the subject to be within 12 feet. If you need both the light and dark areas, just take two photos and lock the meter on the appropriate areas for each.
- Zoom. The optical zoom on a 25x camera (or better) is capable of reading fixture labels 50 feet away. It can also read lamp etches as well. This is something that even the best tablet or phone cameras are not capable of. However, it's important to understand when zoom is appropriate and when it isn't. Zoom is great for details, but wide-angle shots are great for showing the environment and application. You need both, but you need the standard wide-angle more often. This is why the native camera in a digital audit program will be used 90% of the time, but it's also why the stand-alone camera is critical, too. Without the zoom, the auditor is left to guess on highbay applications and most exterior lighting—expensive systems that often operate outside multi-tap ballast parameters.

- **Mapping:** Hopefully, you will be auditing in a digital program that supports map/drawing uploads and allows you to link each room or space to a spot on the map. Typically, this involves dropping a pin on the map and moving it to the appropriate space. Location data is important to create a 'sense of place' in an audit as it allows downstream users to envision the spatial relationships between the areas. Beyond the 'sense of place', it is mission-critical to know these spatial relationships when proposing networked controls systems. In a digital audit, every line item needs to be linked to the map; it takes very little time and it is incredibly valuable. If you're still auditing on paper or in Excel, mapping each line item will be very cumbersome and may not be worth the effort unless you are proposing networked controls or the scope of work demands it.
- **Notes:** The notes section is a free-form area to capture anything and everything that is unusual about a given space or area. You won't be filling this in for every line item on your audit; however, every line item that demands it should be completed. You should record anything unusual or interesting that will help facilitate the project or help sell the project including anything that will add time or cost to the project, any pre-existing damage, and anything that would suggest that an alternate solution may be viable.
- **Access issues**: Similar to the notes section, access issues only need to be noted where they arise. If you determine that there will be an access issue, make sure to note it in the audit, explain the barrier and identify the solutions to overcoming the barrier. Generally, you will encounter two kinds of access issues:

  » **Permissions-based access issues:** Is there a gatekeeper for the site or certain areas of the site? Is there a gatekeeping process? Will background checks be required

for the installation crew? Will the installation crews have to attend training? Will the crew only be able to work if a project manager is present on site? These processes and rules will cost your company time and money and there's no sense sending people for background checks if you know they won't pass. Worse, sending people to the site without these processes in place is a waste of resources. The auditor is in a unique position to know most of these barriers and needs to communicate them in the audit.

  - **Physical access issues:** Can the installation work only be performed after hours or on weekends? Will the work be scheduled during a plant-shutdown? Do you need a lift for a mezzanine that can only support a limited amount of weight? Often, the auditor is the first to know this information and needs to communicate it in the audit so that the appropriate project costs can be captured in the proposal as well as setting the company up to schedule the installation properly.

- **Special equipment:** Like above, special equipment only needs to be called out for the line items that require it. Special equipment—lifts, high-reach ladders, scaffolding, wire blankets—are costly adders to projects as most companies don't own this equipment and, instead, rent it. While necessary, the rentals can drive up the project costs by thousands of dollars per week and, maybe more importantly, often need to be scheduled weeks out to be available. It is the auditor's job to identify where this equipment will be needed and what equipment needs to be specified. This will determine the duration of the rental(s) and the rental costs and help avoid project delays and margin erosion. Typically, 'reach' is the metric most people think of when considering special equipment, but there are more considerations besides how high the equipment can go:
  - **Equipment size:** Can the equipment fit through the doorways (height and width) or aisles at the site?
  - **Equipment access:** Is there even a way to get the lift to the area you're working on? For example, a mezzanine may not have an access point, elevator, or crane to get the lift onto the mezzanine floor.
  - **Weight**: Is the surface you're working on rated to support the weight of the lift, for example, a mezzanine?
  - **Upscale floors:** Marble, wood or slate floors may necessitate a plywood path to preserve the floor. This will be time consuming and costly to administer.
  - **Obstructions**: Is there bird netting or equipment in the way of the lift? This will take time to work around.
- **Difficulty factor:** The audit should call out the difficulty factor of each challenging application—it's important to know how difficult the challenge will be. A good rule of thumb is to rate the difficulty on a scale of one to ten and add a lot of notes to explain the rating. The equipment should be captured in the data fields already, so the notes should focus on anticipated time and labor.
- **Emergency lighting:** Emergency lighting may be the most contentious and controversial subject in the lighting audit world! There's a good reason—missing it altogether or under reporting it has a huge financial impact on the bottom line and, worse, most of the material you will need to address the emergency lighting isn't sitting on a shelf somewhere; it has long lead times. On top of that, being out of compliance—even for a few days—carries with it enormous risks of liability if there is an emergency event during the time it is down along with heavy fines from local jurisdictions. The emergency system(s) must be identified by the auditor and called out appropriately.
  - Identification of the emergency system: First, the auditor needs to identify the emergency system in place. Options include:
    - Nothing: Rare, but it happens typically in smaller buildings.
    - Emergency generator: In this case, the fixtures operate on a dedicated emergency circuit and the generator will supply the appropriate voltage to the fixture during an emergency event. In other words, the emergency circuit employs the same ballast or driver to power the light fixture that is used in everyday operation. If this is the only system in place, this is the end of the reporting needed in the audit.
    - Emergency battery backup ballasts: If there isn't an emergency generator, then the emergency function is powered by a special battery powered ballast that is charged during non-emergency operation. When a power loss occurs, the battery ballast takes over and can power the fixture for a minimum of 90 minutes. These battery ballasts are the source of the controversy at the heart of the emergency fixture debate. They are extremely expensive and they are only rated to work with a very narrow range of applications—the retrofit or replacement will not be able to use the battery backup 99% of the time and, as a matter of good practice, they should be replaced anyway. If you find this system, you will need to find and report every emergency fixture in the building.
    - Both: It is extremely rare, but some buildings have both a generator system as well as emergency battery backup ballasts. Typically, you will find this situation in buildings that have had additions or major core-and-shell renovations. Thus, it is important to still keep a keen eye out even if you have confirmed that the site has an emergency generator.
  - **Audit counts and callouts for emergency battery backup ballasts:** the auditor only needs to proceed with counts and callouts if there are emergency battery backup ballasts in place.
    - Look for the red indicator light on the emergency fixture. All of them should have one. This light can be extraordinarily difficult to see as it is often placed behind lenses or industrial hoods. They are often burned

out, making them nearly impossible to see in the best applications. And, sometimes, the fixture doesn't have one even though it is supposed to. You will need to walk to every fixture and look. Amass the best count you can.

- Turn off the regular circuits. If you have permission and there aren't people in the space, you may try to turn off the regular lighting circuit(s) and count the remaining fixtures. This is helpful, but not usually practical. Also, there may be emergency fixtures that are not operational and, thus, escape the count.

- Estimates using RCPs and/or percentages. This is the only category where an estimate may be the only acceptable solution. First, attempt a physical, in-person count. Even if the count is suspect, it will provide a reality check. Next, consult the RCPs for the project and start counting using drawing take-offs. Remember, the counts still must be broken out by fixture type and by each area and accounted for accordingly in the audit. Finally, if the first two methods don't work, a straight percentage estimate may be in order. In this case, attribute 10% of the fixtures as emergency units (always rounding up) in areas you would expect to have emergency lighting (again, broken out by fixture type and room).

- Specialized lighting equipment: Typically, specialized lighting is not included in a general lighting audit. The best practice is to note that it exists and take some photos of it, but not include details in the audit unless there is a compelling reason to do otherwise. Examples of specialized lighting include:

  - **Theatrical, advertising or event lighting:** Any kind of lighting for theater, stages or television production is very specifically designed and specified by experts in that arena. Similarly, any kind of advertising or event lighting falls into the same category. Advertising and event lighting can usually be identified by dynamic, RGB color-changing themes. All of these categories—theatrical, advertising and event lighting—are also identifiable by operating systems such as DMX.

  - **Machine or process equipment lighting:** Any kind of lighting embedded into a machine or process equipment is usually off-limits. Examples of such equipment may include medical instruments, industrial saws and CNC equipment. The exception would be any equipment that has a standard fixture like a 4-foot vapor-tight unit—in other words, something commercially available in a regular hardware store. If these items are included in the scope of work, pay attention to color temperature as it is usually a very important component of the equipment. A great example is paint booths since paint color must be rendered accurately.

  - **Retail shelf lighting:** Many times, this lighting is pretty standard fare—4-foot fluorescent lamps and such. However, the issue is determining who owns it. You may be working for a retail chain, but the shelf lighting may belong to the cosmetics company that purchased the shelf space. Do some investigation and find out before committing to auditing it.

CONCLUSION

It is critical to be aware of what an audit is and why an audit is undertaken. Equally, it is critical to be able to identify various processes that masquerade as an audit and be aware of the value that can be realized from each.

With an understanding of what an audit is, it is critical to have the right people, processes, and tools in place in order to accurately capture and communicate the necessary data points for each project. Above all, the 'people' component is the most important; the auditor must steward the teams around them to ensure the success of the audit.

LIGHTING AUDITS QUIZ

Check your understanding of this chapter's material by completing these multiple-choice quiestions. The answers are on page ##.

1. The Color Rendering Index (CRI) is a scale that describes how accurate colors look when struck by the light from a given lamp. How is the scale defined?
a) 0-100, with 0 being the worst and 100 being the best
b) 0-75, with 0 being the worst and 75 being the best
c) 0-100, with 100 being the worst and 0 being the best
d) 0-75, with 75 being the worst and 0 being the best

2. The amount of electrical power a lighting system consumes is measured in:
a) Watts
b) Volts
c) Ohms
d) Amps

3. A lighting system's efficacy is measured in:
a) Lumens/Watts
b) Amps/Volts
c) Lumens/Volts
d) Watts/Amps

4. The Color Rendering Index measures a lamp's ability to:
a) Show colors accurately
b) Prevent color shifting over time
c) Raise color temperature over time
d) Enhance color temperature

5. The best way to describe an energy-efficient lamp is one that:
a) Produces more light per unit of consumed energy
b) Produces less light and saves energy
c) Lasts longer
d) Provides better color rendering

6. If a fluorescent lamp is rated at 20,000 hours at three hours per start, it means the lamp is:
a) Left on for three hours and off for 15-20 minutes
b) Turned off and on quickly every three hours
c) On for three hours and off for three hours
d) Left off three hours and on for 15-20 minutes

7. Which of the following is the unit of measurement of the amount of light delivered from a lamp or luminaire?
a) Lumens
b) Footcandles
c) Candlepower
d) Watts

8. Color temperature is measured:
a) In degrees Kelvin
b) In degrees Centigrade
c) On the color rendering index (CRI) scale
d) In degrees Fahrenheit

9. Under controlled conditions, what is the percentage of failures at the rated life of a fluorescent lamp?
a) 50%
b) 100%
c) 60%
d) 70%

10. Define lumens.
a) The overall light output of a luminance source
b) The radiant energy from a luminaire
c) The reflectance of a luminaire
d) The spectral power of a luminance source

11. Manufacturers are required to list "No PCBs" on ballast labels for ballasts manufactured after which year?
a) 1979
b) 1941
c) 1968
d) 1987

12. PPE stands for:
a) Personal protective equipment
b) Possible post engagement
c) Post power empowerment
d) Pre-potential energy

13. The Color Rendering Index (CRI) is an international system used to rate a lamp's ability to _____.
a) Render object color
b) Emit radiant energy
c) Emit light when heated
d) Produce light after 100 hours

14. The _____ of a lamp describes its actual color appearance.
a) Color temperature
b) CRI scale
c) Black-body radiator
d) Phosphor coating

15. Which of the following is not a lighting control?
a) Dimmer
b) Timer
c) Pendant
d) Photosensor

CHAPTER 6: DIGITAL VS. PAPER AUDITS

INTRODUCTION

With a firm grasp on the art and science of conducting quality building audits, we turn to the mechanics in which the actual data encountered in the facility is tabulated and recorded. No twenty first century discussion would be complete without discussing the impact of the digital audit. Digitization has revolutionized the way audits are conducted as well as the speed and precision afforded to the auditor, their teammates, and all project stakeholders.

Before digital data collection, the industry used pen and paper to record information gathered in the field. While this method sufficed through generations of project work, it led to many costly mistakes (due to misinterpretation of handwriting, and non-standard definitions and nomenclature).

DEFINITION OF A DIGITAL AUDIT

A digital audit is an audit where all required site diagnostic information, both quantitative and qualitative, is captured, stored, and transferred in an electronic format using a computerized device like a tablet computer or smartphone. With studies showing that approximately 50% of all project errors originate in the field, the digital audit has quickly become the foundational component of comprehensive project success.

Digital audits are typically accomplished by use of an audit-specific software program or "App" specifically designed to operate on a supported electronic device and designed for the unique purpose of facilitating lighting or energy audits.

Several critical attributes of a Digital Audit include:

- **Purpose-built:** Unlike general purpose document or form-based programs, a Digital Audit program is purpose-built for the unique data and media capture requirements of an investment-grade audit. These include logical, facility-oriented layout and workflow, incorporation of relevant data capture fields, picklists and toggle buttons, integration of multi-media components (including maps, floorplans, photos, video, audio and other media).
- **Operates disconnected from the internet during data capture:** In spite of the vast improvement and availability of wireless internet services (including WiFi, 4G, LTE, 5G,etc.), there is still no guarantee of a consistent signal in any given building. Due to building construction materials, distance to antennas, or interference with other electronic or mechanical devices, wireless signals are often unreliable. For this reason, Digital Audit programs need to operate independently or in an "off-line" mode that does not rely on a connection during the site audit.
- **Single data source and document flow:** One of the critical advantages of a Digital Audit process, is the unification of data layout and definition that brings all project collaborators (auditor, project developer/specifier, financial, sales and project management) together in a single, commonly understood workflow. Contrast this to the pre-digital days where every auditor may use their own definitions, notation, and tools to record data. This led to severe challenges in understanding, accuracy and could often compromise project success.
- **Not a spreadsheet:** As the lighting retrofit industry evolved away from paper-based methods, it was often tempting for auditors and project personnel to use computer spreadsheets (like Excel, Apple Numbers or Google Sheets) to collect, transfer and process site data. This is understandable as spreadsheet programs themselves are often included in business software bundles, are quite accessible and very pliable to an individual users.

  Unfortunately, spreadsheets introduce additional challenges into the Audit and Project Development process such as including none or limited data controls and validation, open up data definition to many authors, include no data chain of custody (who did what), entail limited security and provide no cross-project insight (all project data stored in separate computer files) to name a few.

DATA COLLECTION

With an audit defined as a "comprehensive and diagnostic site evaluation", data collection is a critical input that impacts the quality of the engineering study. Key advantages of the Digital Audit with respect to data collection include:

- **Data validation:** Digital audit software programs enforce data validation rules to ensure site information is not entered incorrectly or in an indecipherable way. Benefits include:
  - » **Consistent forma**t – Downstream teammates enjoy a consistent format, knowing where to find needed site data to complete their diagnosis and offer an optimal solution
  - » **Singular data source** – One place to find needed information and eliminate the confusion of multiple data sources, documents, definitions, and media.
  - » **Uniform nomenclature** – A common definition to identify, label and communicate technical data helps eliminate confusion and error, and make the difference between profitability and loss.
  - » **Unbreakable Process** – A continuous "unbreakable" process eliminates rogue data formats and unsanctioned data entry introduced by manual and one-off spreadsheet formats.
- **Accuracy:** It is a well-known expression among lighting professionals that "Every good lighting project begins with a quality audit". This directly relates to the accuracy of the data collected in the field, and the impact that eliminating the potential for errors has on project outcomes (e.g. specifying and receiving incorrect materials, wrong counts, shipping and re-stocking costs, the cost of idle labor due to incorrect materials). Digital Audits remove a great deal of the opportunity for error due to validation and other measures to ensure accuracy.
- **Time Efficiency:** Conducting professional audits is time-

consuming and thus expensive for a business to carry out. Eliminating unnecessary steps or preventing re-work goes a long way to boost both the efficiency (work completed) and effectiveness (achieving the objective) of the professional audit. Key drivers include:

  - » **Elimination of non-value add tasks** – such as double-entry of data (in the field and throughout project development and project management), re-orienting site visuals (blueprints, floorplans and photographs) .
  - » **Opportunity cost** – Leveraging saved time for the team's advantage such as selling more projects, staff improvement, quality of life and others.
  - » **Automated duplication** – Leveraging computing power to duplicate identical spaces (e.g. a school classroom) and thus eliminate the additional labor and time-consuming process of completing it manually.

- **Modern Digital Storage:** Twenty first century information technology has brought elevated safety, security and convenience to consumers and business professionals alike. It's never been easier (or faster) to store, protect and retrieve vital business information. Several factors include:
  - » **Cloud storage** – In years past, when most information was written on paper, a forgotten notebook, lost suitcase or misplaced binder would leave an auditor scrambling to re-locate their lost work, or worse, have them traveling back to the site to re-audit the same facility. Today's cloud storage solutions (part of major digital audit programs) offer a seamless and continuous way to ensure site data is never lost and always available to take the next step in the project development process.
  - » **Data across multiple locations** - The term "Cloud" refers to multiple computer servers, data centers and storage mechanisms working in unison to keep information secure and accessible to those with access. Sophisticated computers and networks automatically store the data across multiple data centers to ensure significant redundancy and thus minimizing (effectively eliminating) the possibility of data loss.
  - » **Always be careful** – As powerful as modern data storage has become, it is up to every professional auditor to ensure their data is safe before, during and after the audit. Even a device not connected to internet is subject to being lost (for example if you forget to upload, the device fails, or you lose the device before uploading).
- **Learning and confidence-building:** The digital audit has the added advantage of accelerating learning and guidance for beginner auditors, thus accelerating their path to productivity. Reasons include:
  - » **Digital preference** - Younger adults entering the field are accustomed to, prefer and actually learn faster if conducted in a digital manner.
  - » **Digital guidance** - Digital audit tools provide a template and pathway that illustrates the correct approach to completing an audit. In addition, many programs provide visual queues when required information is missing.

ADVANTAGES OF VISUAL REFERENCES

Prior to the advanced Digital Audit technology available today, limited visual reminders existed (outside a separately carried camera) to aid the project team in orienting their baseline assumptions and decided upon solutions once away from the audit site. The advent of smart phones (and their included camera apps) brought some relief and at least eliminated the need to carry a separate camera. This, however, pales in comparison to the advantages gained by a full arsenal of visual references now available to the auditor and project team.

- **Organized by location:** Past audits have had the challenge of re-orienting (as well as remembering) where photos were taken in the scope of the building or what data and descriptions referred to in terms of building location. Digital Audits integrate visual references with building areas, rooms, and specific fixtures to avoid confusion that may compromise the baseline assessment and quality of solution.
- **Avoiding return trips:** Having to return to the building due to missed or forgotten details introduces unfortunate time, cost, and opportunity cost (what you otherwise could be doing with that time and money). Even worse, if a return trip entails a significant distance, these costs are even more significant. Use of visual references such as maps, floorplans, photos and even a 360 photo (a controllable panoramic image surrounding the original point from which the shot was taken) serve as high-quality proxies for a return visit and are a critical function of the Digital Audit.
- **Sense of place:** The location and orientation of all building details are critical to conducting an accurate audit that will ensure a project remains cost-effective, on-time, and profitable. Use of visual references are a critical method for the auditor to communicate not just the "what" but the "where" when referring to audit details (including where equipment is located and how it is accessed). These visual "place" descriptors offer powerful communication for:
  - » **Controls layout** – Where sensors, gateways and controls will be oriented for the proper installation, commissioning, and operation of the upgraded system
  - » **Project material management** – Where materials can be unloaded, stored and distributed for use by the installation crew, ensuring they remain productive and the project receives the greatest optimization of labor time and money.
  - » **Equipment needs and locations** – Use of special equipment (such as lifts or scaffolding) is inevitable for many commercial and industrial projects. Planning and coordinating their rental, use and placement is a vital part of project development and management, and the auditors use of visual references (and mark-up) is an important input to project team-members.

KEY FUNCTIONS ASSOCIATED WITH A DIGITAL AUDITING PLATFORM

While there are several audit programs available for portions of the lighting audit and project development process, pay special attention to needed capabilities outlined in this guide to understand the full scope of needed functions. Several highlights follow:

- **Floorplans:** Ability to capture a visual floorplan of the building space being audited. These can be provided by the client in a digital (PDF or .JPG format), snaped via photograph of the emergency exit plan or hand sketched with the digital tools provided in the audit platform.
- **360 Camera:** A device that produces controllable panoramic image surrounding the original point from which the shot was taken. These can be wirelessly connected to your audit device and either hand-held or mounted in a tripod or selfie stick.
- **Copy Function:** Including areas (e.g. macro spaces like floors or warehouses), spaces (e.g. room), and fixtures. Advanced digital audit tools allow for copying once and copying multiple spaces at one time.
- **Tailored Audit Experiences:** To ensure maximum efficiency and productivity, advanced digital platforms allow the specific data types, layouts, field order, defaults, dropdown values and baseline fixture types to be pre-set in order to save the auditor time in the field. These capabilities are commonly used in multi-location or national account opportunities such as schools, retail banks, small box retail or quick serve restaurants.
- **Access to a marketplace:** A highly adopted and well-followed digital platform provides the added advantage of unifying a diverse company and labor force around a common process (much like an international business market adopts a common language). A digital audit platform is no different and enables many players and material providers to interact in a common manner (whether a company requires labor or materials or has them to offer).
- **Support of the platform:** A well-organized and stable digital audit provider will provide ample support for both the technology offered as well as its ability to accommodate multiple parties working together (see marketplace).
- **Full lifecycle:** Rarely are audits conducted without the ultimate objective to scope, specify, sell, and install a complete project. Likewise, technology designed to support only parts of this lifecycle are of limited value. A comprehensive digital platform will support an end-to-end project lifecycle from Audit, proposal, project management, close-out, as-built reporting, and complete system asset data.

DIGITAL VS. PAPER AUDITS QUIZ

Check your understanding of this chapter's material by completing these multiple-choice quiestions. The answers are on page ##.

1. Digital audits can significantly reduce the amount of time spent auditing. Which of the following is not an example of how digital audits save time?
a) Pre-built lamp/ballast/fixture combinations
b) Copy function
c) Obtaining kWh rates, utility bills and architectural drawings
d) Correlating photos and map points to audit data

2. Digital audit software does not allow for more than one auditor at a time on a project.
a) True
b) False

3. Which of the following are common issues with paper audits that will potentially result in a loss of time and money?
a) Transcription errors from the paper audit
b) Illegible handwriting
c) Inconsistent nomenclature
d) All of the above

4. Some audit programs may require an internet connection to operate; preventing the ability to conduct a digital audit if the device is not connected.
a) True
b) False

5. Which of the following can negatively impact the ability to conduct a digital audit?
a) Device battery life
b) Device speed
c) Device storage capacity
d) All of the above

6. What are the primary benefits of digital audits?
a) A single platform for all stakeholders
b) Enriched data collection, for example linked photos and map points
c) Credibility with customer
d) All of the above

7. What is the best way to make sure to document room details you may have missed to avoid a second trip to the building?
a) Take a blurry photo of the corner of the room and hope for the best
b) Take a photo of the room with an integrated 360-degree camera
c) Draw a stick figure version of the room layout on a napkin
d) Describe the room to someone over the phone and ask them to write it down for you

8. Which of the following is an advantage of using a digital floorplan?
a) The floorplan creates and identifies the perception of 'place' for stakeholder teams who might not be able to visit the site, for example, knowing where one room (with quickly linked assets) is in relationship to another is important to the controls designer.
b) The floorplan always incorporates a copy of the reflected ceiling plans (RCPs), so the installation crew can use it to existing trace circuits and identify the original lighting schedule.
c) The floorplan can be used by other stakeholder teams to create a process flow, for example, it allows a project foreman to deliver materials to appropriate rooms/areas/floors during installation.
d) A and C

9. A digital audit platform makes it easier to alert project managers of which conditions?
a) The need for special equipment such as scaffolding or lifts
b) Special conditions or potential installation difficulties that could increase labor rates for specific measures
c) Existing switches or controls
d) All of the above

10. Annotating photos captured during a digital audit is important because:
a) The auditor can call out potential design ideas or potential difficulties that can be addressed by downstream teams
b) The auditor can visually note power runs and distances to the project developer or designer
c) The auditor can note and identify things that would be difficult to explain in writing alone or a voice memo
d) All of the above

11. The best way to audit parking lot pole lights is to:
a) Guess the number and location of pole lights based on how bright the lot feels at night
b) Upload a Google Earth image to your digital audit program, then create the layout of poles using digital pins in the program layered over the Google Earth image
c) Count the poles while driving through the lot and mark them from memory later
d) Assume the poles are evenly spaced and use a calculator to estimate how many should be there

12. It is best if the digital audit software operates without the need for an internet connection because:
a) Internet connections cause interference to electrical equipment
b) Internet connections are sometimes unreliable inside various building spaces
c) It ensures occupants are not disturbed by internet media
d) Auditors may be tempted to stream movies if an internet connection were available

13. Digital audit applications store media assets (Pictures, videos, etc.) on the location where they were taken. This is important because:

a) It is a more efficient storage method and saves memory on the device
b) It makes the synchronization go faster
c) It saves time over the manual method of having to find and remember where photos were taken once you are back at the office
d) All of the above

14. It is a good idea to sync your device periodically during the audit (where connection is available) because:

a) It makes the application run faster
b) It's a good way to test the client's WiFi speed prior to finalizing the audit
c) It protects the data that has been collected so far in the event the device is lost or damaged
d) All of the above

15. Before selecting a device for conducting digital audits:

a) Be sure it is compatible with your cellular carrier's plans
b) Ensure it is compliant with the software company's specifications
c) Be sure it has quality speakers
d) None of the above

CHAPTER 7: LIGHTING AUDITS CASE STUDIES

AUDIT SCENARIO – HEALTHCARE

Your next-door neighbor, Phyllis, is the Director of Facilities for Heather Hospital Medical Group. 'Heather' has locations throughout the greater New Orleans area. Over a weekend cookout, Phyllis asks if your company would be interested in auditing the Dr. Jon M. Doe Medical Office Building (MOB), which was named after Heather Hospital's former chief medical officer.

The Doe Building was built in 1996 and it is located at one of Heather's six locations in southern Louisiana. The building is a five-story, 300,000 square foot brick structure and it serves as the headquarters for the Heather Hospital Medical Group. In addition, the Doe MOB houses primary care services including prenatal and pediatric wards and adult care.

During the audit planning meeting a week later, Phyllis shows you an energy efficiency incentive flyer she received from their electric utility. The brochure calls out a new lighting incentive program for parking garages, a measure not previously incentivized. Phyllis is excited about the opportunity and immediately expands the scope of the audit to include the parking garage across the street from the Doe Building.

Phyllis justifies the additional audit scope with the rebate money she will potentially receive along with monies from another project that came in under budget. The parking garage is three stories tall and has 342 parking spots. It is 122,500 square feet including the roof top parking area. The garage has a small office, two booths for parking attendants, a storage area, stairways and elevators.

With the added scope sorted out, Phyllis now gives you the floor plans for the Doe MOB Building and tells you that the stairwells and elevators are out of scope. In addition, she indicates that there are three floors dedicated to patient services which each consist of a reception area, offices, patient areas and some equipment rooms. She tells you that these three patient services floors are identical, so you will only be allowed to audit one floor to avoid disturbing the staff and patients. Phyliss says you can 'just do the math' for the other floors.

Phyllis states that these floors are currently using 3-lamp, 28-watt T5 fluorescent troffers, except for the equipment rooms which have 2-lamp, 28-watt T5 fluorescent strip fixtures. She says that these same fixtures are installed on the two headquarters floors as well; however, the layout is different for each of these two floors. Finally, she adds that they have an emergency back-up generator on the south side of the building.

You conclude your meeting with a brief discussion regarding the hours of operation and you schedule the audit for the following Tuesday.

1. Light quality, light levels, color temperature and CRI are important topics of concern for the administration both doctors/medical staff as well as the administrative staff.

a) True
b) False

2. In addition to addressing safety and security issues for patients and staff, appropriate lighting for the operation of security cameras is becoming increasingly important in the healthcare environment.

a) True
b) False

3. When auditing patient-facing areas, observations concerning the lighting environment are important because:

a) Appropriate lighting can facilitate a calm and soothing feeling, reducing patient apprehension.
b) Appropriate lighting can promote a professional appearance, inspiring confidence in patients and visitors.
c) Appropriate lighting will allow the doctor observe accurate colors and skin tones, plus eliminate interfering shadows during the patient exam.
d) All of the above

4. Waiting rooms should have a relaxing, residential ambiance, perhaps, including a warm color temperature, a dimming light source and table lamps to complete the appearance.

a) True
b) False

5. During the audit, it is important to determine if the building has a legacy control system.

a) True
b) False

6. Lighting design for the healthcare environment can be complicated because it must address the needs of which user(s)?

a) Doctors and the medical support staff.
b) Administrators and visitors.
c) Patients.
d) All of the above

7. What is the most important reason to identify and document fixture damage and broken lenses during the audit?

a) The existing condition of the lighting can illustrate a more urgent need to upgrade the current lighting, helping drive the sale.
b) Documenting damage at this stage protects your company from potential future liability for pre-existing damage and helps preserve project margins.
c) To call out the facilities staff for doing a bad job of maintaining the lighting.
d) Both A and B.

8. Which of the following statements is true about magnetically-mounted LED retrofit strip kits for existing troffers?
a) They are usually less expensive and quicker to install than traditional 'door' retrofits and, especially, new fixtures.
b) It's important to capture the inside dimensions and lens type of the existing troffer before specifying these kits.
c) All of these kits are DLC listed.
d) A and B

9. Patient exam rooms typically have multi-level lighting, often using multiple ballasts per fixture and/or tandem wiring to create various lighting scenes.
a) True
b) False

10. As a professional, when auditing a healthcare facility, you should observe the following behavior(s):
a) Do not stand or linger in any areas where you might be able overhear private conversations or, even, a place where there would be the mere perception that you could be in the position to overhear a private conversation
b) Do not take any photographs of an environment that may have patient names or patient records
c) A and B
d) None of the above

11. Situational awareness is especially important when performing an audit in a healthcare facility because:
a) Situational awareness will elevate your observations of the lighting.
b) The difference between life and death can come down to seconds; the staff has no patience for people under foot or in the way
c) Situational awareness will help you navigate the floorplan flawlessly.
d) Situational awareness will allow you to detect lighting schedules and daylight harvesting zones.

12. Lighting in a healthcare facility can impact:
a) The patient's experience and the caregiver's performance.
b) The insurance company's wiliness to cover certain procedures.
c) The healthcare facility's annual energy and maintenance budget.
d) A and C

13. Even though the stairwells are out-of-scope, why might you include the stairwells in this project anyway?
a) Stairwells typically operate 24/7, so lower wattage light sources and controls can help the overall project ROI.
b) Light sources with a longer life can reduce maintenance in awkward and expensive-to-reach spaces.
c) It's easy to capture now and avoids a trip back to the site if they include the stairs later.
d) All of the above

14. What is the most likely reason why you were told that the stairs are out of scope?
a) They are alarmed and used only for emergency egress.
b) The building is leased by the healthcare provider and the stairs are not part of their leased space, i.e. they are maintained by the landlord.
c) The lighting is always off in the stairwells, so it won't generate energy savings.
d) The stairwells already have LED lighting.

15. Lighting can play a role in Heather Hospital Medical Group's ability to compete in the marketplace because lighting can have a significant impact on appearance, branding and patients' perceptions.
a) True
b) False

16. What is an advantage(s) for including the parking garage in your proposal?
a) Lighting for parking garages doesn't have rules and standards associated with it like the medical building, so it will be an easy way to add more revenue to the project.
b) Most garage lighting operates 24/7 and operates at higher wattages, typically helping achieve a quicker ROI.
c) Combining a potentially good ROI for the garage with a potentially less attractive ROI for the Doe Building may achieve overall project ROI that is acceptable to the customer, facilitating the sale of both projects.
d) B and C

17. During the audit of the parking garage, you should capture:
a) Light level readings
b) Measurements such as ceiling heights, fixture heights and ceiling truss/coffer depths.
c) Traffic density and average car speeds.
d) A and B

18. During the audit of the parking garage, you should identify and address dark areas and/or shadows as these kinds of conditions can create a perception of an unsafe environment.
a) True
b) False

19. In the parking garage, capturing ceiling/fixture heights as well as truss/coffer depths is important to:
a) Properly light the ceiling of the garage, helping to alleviate the perception of darkness due to the 'cave effect'.
b) Calculate the proper length of safety chain that each fixture will require.
c) Ensure proper fixture clearance so the lighting fixtures and cars are not damaged.
d) A and C

20. When auditing the parking garage and the exterior of both buildings, it is not important to note any timer controls and/or photocells.
a) True
b) False

21. Which of the following are important to capture during the audit of the parking garage?
a) Fixtures spacing and fixtures in potential daylight harvesting zones.
b) Fixtures in the adaptation/transition zones at the garage entrances and exits.
c) Fixtures in circadian lighting zones.
d) A and B

22. Which of the following are important to capture during the audit of the parking garage?
a) Birds nesting on light fixtures.
b) Fixtures with step-dimming functionality.
c) Timer controls and/or photocells.
d) All of the above

23. What is the typical lamp nomenclature for the lamps in the office troffers?
a) T5HO/28W/840
b) T5/28W/840
c) T5/54W/840
d) T5HO/54W/840

24. The current light levels in the traffic lanes of the parking garage are about 4 foot-candles. Typically what is considered a reasonable light level for this application?
a) 1fc
b) 10fc
c) 25fc
d) 40fc

25. During the audit of the Doe Building, it would be a good idea to ask the POC if there is parking lot or street lighting that is powered by panels in the building.
a) True
b) False

26. What are some clues that adjacent parking lot lighting and/or street lighting may belong to the hospital?
a) The local utility sent the hospital that flyer about exterior lighting.
b) The light fixtures and poles are the same color and style of poles and fixtures already known to belong to the hospital in other lots or on other roads.
c) The lighting panel in the closest building has several unlabeled 480V circuits.
d) B and C

27. When auditing exterior lighting, you should document:
a) Pole dimensions.
b) Damaged/corroded poles and fixtures.
c) Ceiling heights.
d) A and B

28. Landscape lighting and signage should be excluded from scope automatically because these systems are typically specified, designed and maintained by specialists.
a) True
b) False

29. The Director of Facility's advice about counting one patient services floor and extrapolating the data to the other two identical floors is a good idea; no need to waste time counting the same thing three times when you can do the math.
a) True
b) False

30. It is a good practice to open and inspect the fixtures in the Doe Building even through the Director of Facilities told you that they are 2-lamp and 3-lamp T5 fluorescent fixtures.
a) True
b) False

31. Based on the information provided by the contact, which of the following is true:
a) The lighting in the building isn't likely to have emergency battery backup ballasts in the fixtures.
b) The building is likely to have emergency battery backup ballasts in the fixtures.
c) Even though you've been told there is an emergency generator, you should see if it's powering the lights and make sure that the fixtures do not have emergency battery backup ballasts in them.
d) Both A and C

32. Phyliss has been a great neighbor and you know from discussions over the years that the 'Heather' group has enormous cash reserves to pay for projects like this, so you can safely commit to conducting the audit at the cookout. There's no need to talk to your manager and the sales team at your company.
a) True
b) False

33. Even though this looks like a great opportunity, what are some reasons that you need to discuss it with your company before committing to the audit?
a) Your company may have already identified this as an opportunity and may be working with other people at 'Heather'; if so, sales will need to work delicately in both channels and figure out a plan for moving forward.
b) You're going to want to get credit for bringing this business to your company, so you need to let someone know as soon as possible in case one of your coworkers beats you to the opportunity.
c) There may be a history with this customer you are unaware of; for example, your company may have worked with 'Heather' in the past and not been paid.
d) Both A and C

34. Adding the parking garage to the scope seems like a great opportunity; however, what are some reasons you will want to talk with your manager and/or the sales staff before committing to the additional scope?

a) You want to let your co-workers know the value you bring to the table; i.e. you were able to expand the scope and potentially add additional revenue by listening to the customer and helping them with their needs.

b) The parking garage will add a significant amount of time to the audit; your company may have committed you to another opportunity with the time this will take or may need to prioritize another audit/ opportunity ahead of this one, at least in the short term.

c) The audit process and tools for parking garages are completely different, so you will need to determine when the tools are available for use.

d) Both A and B

35. When you get to the site, you find out that the manager of the facilities team has appointed himself to be your escort for the entire audit. He has strong opinions about lighting, for example, he has heard that induction lighting lasts over 100,000 hours and is basically maintenance-free. He has directed you to install induction lighting in the parking garage, preferably, 'full-spectrum' induction if it is available. What do you do?

a) Tell him that you'll note his suggestions in the audit and consider them in the final solutions package.

b) Tell him that he isn't the customer and that there are a lot of other considerations that are more important; for example, the utility is incentivizing LED, not induction.

c) Tell him to talk with Phyliss and the two of them can figure out an agreeable solution to present you with.

d) All of the above

AUDIT SCENARIO – AUTOMOTIVE DEALERSHIP

You are the 'go-to' auditor for automotive dealerships at your company. The Smith Group is a multi-state concern with 42 locations and sells most of the major brands. Smith has requested your services for a dealership situated on 20 acres in a midwestern city. This location represents an American brand and it is located along a state road just west of a major interstate. The site is close to a very large university.

Most of the dealership buildings were built in the early 1980's by a former competitor that filed for bankruptcy in 2008. Seizing an opportunity, Smith Group purchased the buildings and assets and has been operating profitably since. Smith also sells used cars from this outlet, as well as providing the maintenance, repair and collision services most other dealerships offer.

The two largest buildings are the showroom/service center up front and the collision center out back. Obviously, the showroom building is customer-facing with the sales floor, customer lounge, service center, offices and restrooms. The collision center has a small waiting room but is otherwise an employee-only area.

Since the acquisition in 2008, Smith has been one of the top performing dealerships for the American brand they sell. They are very proud of this accomplishment and they want to maintain their standing with this brand as well as their relationship with their customers and the overall community. More importantly, the owner of Smith Group lives in town and is very active and visible in community events, so this is even more personal to her.

Smith has had some significant issues with the lighting at this location. Routine maintenance has been hit-or-miss over the past couple of years with two back-to-back lighting service companies not making good on their service contracts after going out of business. Spot replacements have been an expensive, ongoing battle for the staff. The owner knows that poor lighting conditions are problematic and, intuitively, she feels that it is impacting sales.

The local demographic is heavily influenced by the university and includes educated professors and administrators, moderately affluent alumnae and budget-minded but bright students. This is a group that knows how to shop and Smith has many solid competitors in this marketplace. The owner thinks she can differentiate Smith Group by creating a visually stimulating environment and a fun shopping experience. She has also set a company-wide goal to be 'net zero' by 2035 and she thinks that this 'green' image will really resonate with the university demographic.

During the pre-audit walk-through with the owner, she proudly provides a tour of the dealership and educates you on the history of the location and the brand they sell. You visit all the buildings and tour the lot and, eventually, learn some of the pain points they have been experiencing as well as her goals for the project.

The owner wants to create a showroom that provides uniform lighting for the sales desks yet really highlights the cars. She has heard at dealership trade shows that some of the "new lighting out there" is better with color and sparkle in the showroom. Likewise, she has heard that the same thing is true outside on the lot. The owner just read an article in one of her trade journals that draws a concrete link between better lighting and increased sales. She's really excited, "it's all about selling cars," she says, "that, and maybe deterring the would-be car thieves". Apparently, one or two cars get stolen off the lot each year.

The owner is very detail-oriented—not even the exit signs have escaped her scrutiny. She complains that they are all different colors, some are white, some are silver, some have red letters, others have green letters. More bothersome, they are unevenly illuminated with a warm hot spot in the center if they are even lit at all.

One of the unique features of this dealership is the customer lounge. Customer surveys conducted by the car manufacturer indicated that the customer base was interested in two conflicting lounge experiences. One was a family-room type atmosphere where the customer could relax, watch TV and sit next to a fireplace while their children played. The other was a quiet work zone with cubicles where customers could read and work on their laptops.

Being one of their best dealerships, the car manufacturer approached Smith Group to pilot a dual lounge concept—installing both lounges to see which resonated the best with the customers. The manufacturer underwrote most of the cost of the renovation in exchange for control over the design and décor and the ability to gather data about its usage. Both lounges are up and running, separated by a refreshment center and kitchenette that serves complimentary beverages.

The pilot has been a huge success and the owner of Smith Group wants to use the same outside-the-box thinking for all other projects at her dealership. She has made it clear that that this project is to serve as inspiration for all future projects including yours.

1. What item(s) should you ask the owner to provide to prepare your audit plan?
a) 12 months of utility bills if possible; one month of bills minimum.
b) A complete set of floor plans.
c) The hours of operation.
d) All of the above

2. Why is it important if the collision center is on a separate electric meter?
a) The collision center may have a different kWh rate than the other buildings.
b) Multiple meters would make the dealership ineligible to shop for electricity on the open market.
c) Depending on how they negotiated the electrical rate, this building may or may not be eligible for rebates.
d) A and C

3. Why is it important if the collision center is on a separate electric meter?
a) Certain equipment other than lighting may be a very large consumer of electricity, driving up demand charges and triggering a demand ratchet.
b) Certain equipment other than lighting may be resulting in a power factor charge.
c) Certain equipment other than lighting may make the project in this building ineligible for lighting rebates.
d) A and B

4. The owner gives you an old blueprint from when the building was originally built. It does not show the lighting and none of the subsequent additions or renovations are documented in the drawing. The footprint and layout have changed drastically over the years. What should you do?
a) Ask if there are current architectural drawings and, if not, ask if there is something simple such as a fire escape plan that shows the current footprint and layout.
b) Do not use it because it is old and out of date.
c) If this is the best drawing available, make a copy and note all the changes during your audit.
d) A and C

5. As much as the owner likes the new lounges, she does not really like the lighting that was installed when the lounges were renovated. The owner thinks this project would be a good opportunity to change the lighting and to make it consistent with the lighting you will install in the rest of the building. What should you do?
a) Add the lounges to the scope of work.
b) Recommend discussing this scope of work with the car manufacturer since they paid for most of the project; the owner may need their buy-in to make the changes.
c) Advise the owner that it is acceptable to have different lighting in the lounges because these areas support different tasks and are designed to create a different ambiance than the showroom floor, service areas or, even, each other.
d) B and C

6. During your audit of the restrooms, you notice that the lights have been left on in every single restroom. What should you do?
a) Do not worry about the restrooms; they do not use much energy.
b) Recommend a dual technology occupancy sensor for each restroom.
c) Recommend an infrared wall switch sensor for the large, multi-stall restrooms.
d) A and C

7. Based on the owner's complaints, what type of existing exit signs does the Smith Group most likely have?
a) Compact Fluorescent
b) LED
c) Incandescent
d) None of the above

8. What are the typical burn hours for illuminated exit signs?
a) 5,096 – 14 hours per day, 7 days per week
b) 4,368 – 12 hours per day, 7 days per week
c) 8,760 – 24 hours per day, 7 days per week
d) None of the above

9. What is your recommended solution for the defective exit signs?
a) Relamp the existing exit signs with compact fluorescent lamps.
b) Relamp/retrofit the existing signs with LED exit sign replacement lamps or an LED kit.
c) Replace all existing exit signs with new LED exit signs.
d) None of the above

10. How would you approach the audit of the exterior lighting?
a) Perform most of the audit functions during the day, especially capturing photos of details that will be difficult to capture after dark.
b) After dark, to capture photos of the general appearance of the lot, concentrating on dark spots and shadows.
c) After dark, record light level readings.
d) All of the above

11. In general, an automotive dealership will be more interested in saving energy rather than considering lighting that would improve the aesthetics or appeal of the vehicles.
a) True
b) False

12. What is the most important goal for Smith Auto Group?
a) Upgrading to a more energy efficient lighting system and achieving 'net zero' so they can market their 'green' image to customers.
b) Saving money through maintenance avoidance by installing a new lighting system and finding a more reliable lighting service provider.
c) Selling cars.
d) A and B

13. While auditing the dealership lot, you see some fixtures with faded NEMA tags and a few others with yellow NEMA tags. The lamps inside are bulbous in shape and have a fat arc tube, but they're hard to see because they are so far away. What conclusions can you draw and what should you do?
a) The fixtures were most likely retrofitted from high pressure sodium to metal halide without changing the NEMA tags; add this to the list of questions to ask the owner.
b) Check the lighting schedule on the original blueprints to determine the identity of the lamps.
c) Capture zoomed-in photos of the lamps to and/or return after dark to determine the identity of the lamps for sure.
d) A and C

14. As you audit the service center, you notice the work areas on and around the vehicles seem dark and the light is not positioned over several bays. What should you do?
a) Document the exact position and spacing of the existing fixtures on a floorplan.
b) Rely on your experience to add or move fixtures; in any case, the solution will be brighter than the existing lighting and will alleviate this situation.
c) Capture light level readings where the work is being done; record the readings on the floorplan.
d) A and C

15. While auditing the service center, you should pay special attention to the service pits as this can often be a very challenging area to illuminate.
a) True
b) False

16. Service technicians' safety is the paramount concern in lighting service pit areas as technicians are in danger of perils such as falls, asphyxiation, fires, explosions and rough contact.
a) True
b) False

17. An appropriate fixture rating for the service pit area in the service center would might be Class I, Division 1. In general, what do the 'classes' and 'divisions' mean? (Reworded)
a) Classes refer to the likelihood of a hazard, divisions refer to the type of hazard.
b) Classes refer to the type of hazard, divisions refer to the likelihood of a hazard.
c) Classes refer to the severity of a hazard, divisions refer to the size of a hazard.
d) Classes refer to the size of a hazard, divisions refer to the severity of a hazard.

18. The showroom area has floor-to-ceiling windows, what information should you capture?
a) Dimensions of the windows, especially head height
b) Orientation of each bank of windows
c) The presence of items such as window film, shades and light shelves.
d) All of the above

19. Which of the following is true about side lighting applications?
a) Obstructions such as trees or nearby buildings can impact the quantity of light that can be used for side lighting.
b) The height and width of the windows impacts the size of the potential daylighting zone.
c) Side lighting includes all fenestration such as windows, doors and skylights.
d) A and B.

20. When auditing the showroom, what considerations need to be noted to ensure that the new lighting will properly showcase and highlight the vehicles?
a) The proposed light levels at a standard task height of 30 inches.
b) The ceiling height, fixture height and the color/texture of surfaces such as walls and floors.
c) The changing nature of the display layout, i.e. is it relatively static or is it very dynamic?
d) B and C

21. The sales and administrative offices are dim and, during the audit, you notice many of the occupants have brought in their own desk lamps. You capture light level readings and determine the offices have an average of 12 foot-candles. What would a reasonable light level be?
a) 15-20fc
b) 5-15fc
c) 20-50fc
d) 75-100fc

22. As you begin your audit of the collision center, you should meet with the collision center manager to learn about the repair process and the typical tasks performed in the space.
a) True
b) False

23. Smith Group has a relatively new, state-of-the-art, pre-manufactured painting system used to match factory colors or match the existing paint on the cars they repair. It is an extremely specialized and complex system and one the really differentiates their business from the competition. How should you audit this area?
a) Document the location of the painting system on your drawing; note the surrounding conditions and light levels.
b) Exclude any of the lighting installed on the equipment by the manufacturer of the painting system. This lighting may be an integral part of the overall calibration/operation of the equipment.
c) Perform your audit on all ambient and task lighting surrounding the equipment. Note the specialized environment in the audit.
d) All of the above

24. Due to unique safety requirements, a paint spray booth typically has an extremely high and non-negotiable energy consumption due to needs for air replacement, air circulation, climate control and heat recovery. This leads many facility managers to exclude paint booths from the lighting scope when there is often a potential to reduce lighting energy and improve lighting quality.
a) True
b) False

25. Lighting with a high CRI lighting source and one with a color temperature that closely resembles natural light is advantageous in a paint booth to:
a) Achieve a more accurate color match.
b) See color as it appears outdoors, where cars are typically seen.
c) Highlight dents, dings and imperfections on the car's surface.
d) A and B

26. Placement of light fixtures is not crucial in a paint spray booth.
a) True
b) False

27. Heat generated by lamps, ballasts and luminaires can be dangerous in a paint booth.
a) True
b) False

28. What unusual fixture type might you encounter in a paint spray booth?
a) Corner light fixture
b) Well light fixture
c) Wallwash fixture
d) Narrow spot fixture

29. In the collision center, the final steps are detailing, clean up and quality control. What details should you capture in this area?
a) Potential damp/wet conditions
b) Cleanliness of fixtures
c) Shadows and/or dark spots
d) All of the above

30. What are some of the special lighting applications you need to be looking for in a car dealership?
a) Customer lounges; vending machine area; restrooms; showroom
b) Showroom, service pit; paint booth; paint inspection area and car wash
c) Service pit; paint booth; F&I office; parts counter
d) Aftermarket sales area; sales offices; customer lounges; service pit

31. Besides the usual requests for drawings and utility bills, what else should you ask the owner for?
a) Zoning regulations.
b) A copy of the car manufacturer's architectural and lighting design requirements.
c) A copy of local lighting ordinances, especially regarding light trespass.
d) A certificate of insurance (COI).

32. Smith Group's logo is purple, so the owner wants to install purple area light fixtures on purple poles. However, the car manufacturer that Smith Group represents at this location has an iconic orange logo and their corporate identity is strongly associated with the color orange. How should you handle the request for purple fixtures?
a) Inform the owner that purple is an expensive, special-order color with long lead times. This will impact both the project ROI and project timeline.
b) Inform the owner that special-order colors are not returnable, so she will have to be especially careful selecting the exact shade of purple.
c) Ask the owner if the car manufacturer they represent has any special lighting requirements or restrictions that may prohibit her from choosing this option.
d) A and B

33. NEMA tags have a number displaying the wattage of the lamp. The actual number displayed on the NEMA tag is the lamp wattage.
a) True
b) False

34. If you see a NEMA tag on a light fixture, you should consider the possibility that it belongs to the utility and investigate further.
a) True
b) False

35. One of the benefits of upgrading from the existing HID lighting to LED lighting is that it will potentially help the dealership capture better images of car thieves on their security cameras.
a) True
b) False

36. The 'net-zero by 2035' sustainability goal may have a drastic impact on the audit and the ensuing project for which reasons:
a) Fixtures may be replaced/retrofitted that may otherwise never have been considered for replacement/retrofits outside the context of the sustainability goal, for example, replacing first-generation LED fixtures with slightly lower wattage current-generation LED fixtures.
b) Traditional metrics such as ROI may be less important or not important at all depending on the urgency/importance placed on achieving the sustainability goal.
c) The sustainability goal may have been pushed on to the Smith Group by the car manufacturer they represent; if so, measures to achieve this goal may be partially or wholly underwritten by this entity. As a result, Smith Group may not be quite as price-sensitive as a traditional customer.
d) All of the above

37. Why is it important to know the driving force behind the 'net-zero by 2035' sustainability goal?
a) To understand the urgency being placed on achieving the goal
b) To understand the external/societal benefits that this net-zero goal can achieve.
c) To understand who may be underwriting or contributing to the costs of the program.
d) A and C

38. Documenting the current fixture outages and asking more about the history of the fixture outages during the audit can help the sales process in which of the following ways?

a) The customer may be amenable to spending more money to get longer-lived lighting solutions to reduce the headache of on-going maintenance.

b) The customer may be open to purchasing a service agreement from your company in addition to the purchase of the lighting replacement/retrofit project.

c) Knowing the customer's awareness and pain surrounding the history of fixture outages makes it easier to draw a link between better lighting and a potential increase in car sales.

d) All of the above

AUDIT SCENARIO – WAREHOUSE

You have been assigned to audit the Acme warehouse, located at 8504 County Road 450S, Franklin, Indiana, inside an of industrial park surrounded by several large farms. The warehouse was built in 1988 and Acme purchased the building in 2017.

The warehouse is 200,000 square feet. There is a 15,000 square foot office area at the front corner of the building, with a small reception area, restrooms, a breakroom, a kitchenette and common areas. The balance of the square footage contains the warehouse which has a 20-foot ceiling. In addition to warehouse storage, the warehouse area also contains a propane cylinder storage area for Acme's forklifts as well as a breakroom, kitchen area and an office for the maintenance manager. All of these areas are located in the corner opposite from the main office.

Your point of contact (POC) is the maintenance manager. After a brief conversation with the POC, you book a flight and make a reservation to stay at a nearby bed and breakfast you have heard a lot about on TV.

The Acme audit starts like many other audits. After a normal workday, you hop on an evening flight, rent a car, arrive at the hotel a little later than expected and begin to acclimate to the three-hour time change.

When you arrive at the Acme warehouse the next morning, the POC seems a somewhat short and pressed for time. Frankly, he seems a little surprised to see you. He asks if you brought your hard hat, safety glasses and steel-toe shoes. You haven't. To make matters worse, there isn't a spare pair of steel-toe shoes in your size. In any case, the POC doesn't have time to escort you through the building today or any time this week.

The POC tells you to come back next week and to be prepared this time. You agree to reschedule. Aside from the additional travel costs, you are going to have to reschedule two other audits that were assigned to you for next week.

Despite the setbacks, you return next week renewed and confident.

The POC says that that lighting makes up about 90% of their total electrical consumption. The warehouse operations consist of pick-and-pack, shipping and return processing. Storage aisles are only occupied on a sporadic basis.

Due to their recent growth, the racking has been reconfigured from its original layout, reducing the spacing between racks to only eight feet. The reconfiguration resulted in many of the highbay fixtures being located directly above the racking. Without drawing any correlation, the POC laments about the recent rise in pick errors and near-misses with the forklifts.

As you begin the audit, the POC escorts you through the building in the most random way. You skip some offices and several pick aisles and double-back to areas you already covered. The POC is only showing you areas that have been a problem in the past and, worse, he is lingering at each location recounting insufferably long tales about each problem. You're worried about finishing the audit before your evening flight.

When you finally get to the office area, you discover that Acme has already retrofitted the troffers with Type-A TLED lamps that operate on traditional fluorescent ballasts. The POC tells you not to audit this area because, "it's already LED."

After asking, the POC reveals that the TLEDs seemed to be the best and lowest cost solution at the time; however, the ballasts are routinely failing. This has created a lot of recent work orders and his internal customers are not happy. As you look around, you notice that many of the lenses are discolored or broken and many of the fixtures are damaged. The ceiling tiles adjacent to the fixtures are broken or out of place.

After completing the audit of the office and warehouse, you look at the exterior lighting. The POC tells you about some recent "safety and security related events" that have occurred in the neighborhood and in the parking lot. The parking lot lighting was originally installed by the utility with a long-term contract via their outdoor lighting program rate schedule. Shortly after purchasing the building, the utility contract came to an end and Acme purchased the lights from the utility at their residual value. The lights, as well as the 30-foot wood poles, are showing their age and have extensive deterioration.

The momentum has picked up and you are able to finish the audit and get back to the airport just in time to catch your flight.

1. What measures should you have undertaken ahead of arriving on site that might have resulted in being able to complete the audit the first time?
a) Schedule a meaningful introductory phone call with the POC to kick-off your relationship.
b) During the call, ask about pain points and set expectations for the audit; mention the scope of your travel plans and confirm you have an appointment.
c) Send a follow-up email confirming your conversation and recapping the important points; attach your audit check list and confirm the next steps.
d) All of the above

2. What measures should you have taken the first week you arrived that would have kept your audit on schedule?
a) Ask if the POC could designate an alternate escort to take his or her place.
b) Ask the POC if Acme's rules would allow you to conduct the audit on your own.
c) Arrive prepared with your own hard hat, safety glasses and steel-toe shoes.
d) All of the above

3. When the POC begins to escort you in a random way, what should you do to get back on track?
a) Follow the POC's direction; you can follow up on missed areas later.
b) Show your audit plan to the POC and explain its importance to all stakeholders.
c) Inform the POC that his pain points are important to you and confirm that you will be able to return to the areas he is showing you in the order originally planned.
d) B and C

4. Regarding the fixtures retrofitted with Type-A TLEDs, how do you capture the technical data and document this as a potential sales opportunity?
a) Open fixtures to document the existing fluorescent ballast specification.
b) Take photos and/or audio notes to document the damaged fixtures, lenses and ceiling tiles.
c) Check the condition of the lamp sockets.
d) All of the above

5. What should you do when you encounter the fixtures retrofitted with Type-A TLEDs?
a) Learn more about the ballast failures to understand how you can provide a solution for this problem.
b) Continue to ask questions about the POC's pain points and understand the problems he is encountering.
c) Notify the salesperson about the pain points when you complete the audit.
d) All of the above

6. During the audit, which opportunities can you ask about to potentially to increase project revenue/scope?
a) Other buildings on the property outside the audit scope.
b) Potential controls applications that have not been discussed
c) Areas currently out of the audit scope.
d) All of the above

7. Aside from the traditional physical assets and energy profile of the building, what other information should an auditor collect if it is offered?
a) Competitor information
b) Metrics for project acceptance
c) A and B
d) None of the above

8. Documenting damaged fixtures and discolored or broken lenses is important because:
a) They can become a sales opportunity, increasing project revenue.
b) It ensures the job is done right, enhancing customer satisfaction.
c) A and B
d) None of the above

9. Documenting broken lenses, damaged fixtures and cracked ceiling tiles is important because it avoids potential liability for preexisting damage during the project installation.
a) True
b) False

10. Documenting broken fixtures has the following advantage(s):
a) Eliminates the possibility of a building occupant being hurt by a broken lens.
b) Eliminates restocking fees and change orders based on wrongly specified material.
c) Eliminates the costs of returning to the site for these measures; reduces customer inconvenience of multiple trips.
d) B and C

11. In the Acme warehouse, the safe movement of people, equipment and vehicles is probably not impacted in any way by the storage racks being relocated under some of the highbay fixtures.
a) True
b) False

12. What are you likely to find as a result of the storage racking reconfiguration?
a) Fixtures damaged by product, pallets and/or lifts.
b) Dim aisles with harsh shadows.
c) Inadequate light levels for the task at hand, i.e. reading rack or product labels.
d) All of the above

13. How should you audit the reconfigured storage racking area in the warehouse?
a) Capture light level readings directly under each highbay and draw out a wiring diagram from the panel to each highbay.
b) Record the dimensions of the warehouse, including the dimensions of each aisle and rack.
c) Draw the footprint of the reconfigured racks and note where the highbays are located.
d) B and C

14. Truss height is important in warehouses because good design practice often places light fixtures just above the bottom of each truss to avoid damage by forklifts.
a) True
b) False

15. What information must be collected and provided to the lighting designer so the design team can create an accurate photometric model?
a) Architectural drawings, ideally with dimensions.
b) A blueprint of the reconfigured racking, hand sketched if not available.
c) Reflected ceiling plans (RCPs) or a sketched lighting layout with conduit and panel locations.
d) All of the above

16. There is no need to specify different fixtures, controls or light levels throughout the warehouse based on the task being performed.
a) True
b) False

17. Since racking aisles often characterized by short bursts of sporadic traffic, they may present a good opportunity for occupancy controls.
a) True
b) False

18. What data points do you need to collect to address the pain points with the parking lot lighting?
a) Pole dimensions, distance between poles and building and distance between the poles.
b) Photos and light level readings after dark.
c) The lighting layout of the lot, drawn on a printed Google Earth image.
d) All of the above

19. What data points do you need to collect so that the lighting designer/ specifier can successfully replace the area lights formally owned by the utility?
a) Pole material, condition and color; fixture mounting type.
b) Utility bill; fixture power factor.
c) Fixture voltage; access and heights for replacement.
d) A and C

20. When conducting the audit, you should evaluate the actual lighting needs for the task being performed versus seeking to match current lumen outputs. This helps to avoid issues with overlighting and can reduce energy consumption.
a) True
b) False

21. Exterior wall-mounted fixtures may have emergency ballasts, for example, in the case of providing lighting for an egress walkway or supplying security lighting.
a) True
b) False

22. Choosing the proper lift equipment is an important determining factor in the efficiency, safety and profitability of the project.
a) True
b) False

23. The POC tells you that the parking lot fixtures must be installed during the normal workday when there will be vehicles in the parking lot. In addition to appropriate traffic control equipment, what type of equipment would you recommend?
a) Telescoping boom lift
b) Scissors lift
c) Narrow access lift
d) None of the above

24. A scissor lift is best known for its simple, one-direction, horizontal movement.
a) True
b) False

25. Once in the up position, the basket of the scissors lift can be safely articulated into place over the warehouse racks to access the highbay fixtures.
a) True
b) False

26. Accurately identifying and documenting how the mounting type of the existing fixtures is important because:
a) The proposed solution must be compatible with the current mounting style.
b) Since the mount conveys the return voltage, an incompatible mount can adversely impact the power factor profile in the building driving up energy costs.
c) Selecting a solution with the wrong mounting style can impact the profitability of the project.
d) A and C

27. Identifying the type of whip or electrical cable used by the existing highbay fixtures is important to make sure the proposed solution is compatible with the existing wiring.
a) True
b) False

28. Accurately identifying and documenting the current whip or electrical cable on the existing fixtures is important because:
a) The proposed solution must be compatible with the current whip or cable type.
b) It will impact the bill of materials (BOM) and the labor estimate.
c) It is important to maintain compliance with code.
d) All of the above

29. What is the likely cause of all the ballast failures with the Type-A TLED fixtures?

a) Most likely, there was a voltage spike on the office lighting circuit.
b) Most likely, it is a power factor issue with the facility.
c) Most likely, the fixtures were relamped with new TLED lamps, but the existing fluorescent ballasts were left in place. They are reaching end-of-life due to their age.
d) Most likely, the occupants of the space are disabling the ballasts to reduce eye strain and veiling reflections on their computer screens.

30. Why would you encourage the POC to let you audit the office area even though he says "it's already LED"?

a) They are having trouble with ballast failures and you may be able to help them with this issue.
b) There is an advantage to replacing/retrofitting all the light fixtures at one time so that everything is under one warranty and there's one number to call for any issues that arise.
c) The office area may be overlit if they replaced the fluorescent lamps one-for-one with TLEDs.
d) All of the above

31. The POC wants to address the lighting in the parking lot due to some car break-ins that have occurred at other warehouses in this industrial park. This is an example of what kind of lighting concern?

a) Safety
b) Security
c) Reliability
d) Shield

32. The POC wants to address the lighting in the parking lot after a near-miss between a delivery truck and one of the workers. This is an example of what kind of lighting concern?

a) Safety
b) Security
c) Reliability
d) Shield

33. Increasing light levels to discourage individuals from loitering is an example of using lighting to address a safety concern.

a) True
b) False

34. Using guards on pole mounted area lights near the perimeter of the property is an example of using lighting to address a security concern.

a) True
b) False

35. Light trespass is an example of a lighting security concern.

a) True
b) False

36. Which of the following statements is true regarding the POC's assertion that lighting represents 90% of the utility bill for this location?

a) A 90:10 ratio of lighting to other loads is fairly typical for a warehouse.
b) 90% seems extraordinarily high; typically, the number is around 40%. Further investigation is warranted.
c) A warehouse in Indiana is typically an unconditioned space, so there isn't any electricity usage for HVAC; thus, 90% is exactly right
d) Both A and C

CHAPTER 8: LIGHTING TECHNOLOGY STUDY QUESTIONS

1. In a lamp code, "T" means the lamp is:
a) Tubular
b) Thermal protection
c) Tall
d) Tested by Underwriters Laboratories, Inc. (UL)

2. MOL stands for:
a) Maximum overall length
b) Maximum overall light
c) Minimum overall light
d) Minimum overall length

3. What is the diameter of a T8 lamp?
a) 1 inch
b) 0.5 inches
c) 1.5 inches
d) 5/8 inches

4. A T5HO lamp produces:
a) More light than a T5 lamp
b) Less light than a T5 lamp
c) Light levels that degrade rapidly compared to a T5 lamp
d) The same amount of light as a T8 lamp

5. Which is true of CFL lamps with screw-in bases?
a) They are self-ballasted
b) They are twice as efficient as lamps with bi-pin or 4-pin bases
c) They are a pre-heat lamp
d) They are shatter-proof

6. What is the purpose of a ballast? Select all that apply.
a) Start the lamp
b) Regulate the current
c) Balance the luminaire
d) Thermal management

7. An instant-start F96T12 lamp is how many inches long?
a) 96
b) 9
c) 12
d) 48

8. What is the most common fluorescent lamp shape?
a) Linear
b) Circular
c) Globe-shaped
d) U-shaped

9. What is the major contributing factor to shortened HID ballast life?
a) Heat
b) Dirt
c) Extended burn hours
d) Lumen depreciation

10. If you light an object using an LPS lamp, what color will the object appear?
a) Gray, black, or yellow
b) Reddish-yellow
c) Bluish-white
d) Bright white

11. HPS and MH lamps most often have what type of base?
a) Screw-in design
b) Bi pin
c) Recessed single contact
d) Mogul Bi post

12. Dimming ballasts are available for both fluorescent and HID lamps.
a) True
b) False

13. Ballast Efficacy Factor (BEF) is a measurement used to compare similar lighting systems based upon light output and input power. BEF = Ballast Factor x 100/Input Watts.
a) True
b) False

14. A Low Power Factor Ballast (LPF) is a ballast with a power factor of 0.80 or higher.
a) True
b) False

15. Lumen Depreciation (lumen maintenance) is the decrease in _____.
a) Lumen output of a light source over time
b) Footcandles at 50% of the average rated life
c) Input voltage after the lamp has been operating 100 hours
d) Energy required by the system at 25% of the average rated life

16. _____ is the rate at which energy is taken from an electrical system or dissipated by a load, expressed in watts (W); typically expressed in volt-amperes (V-A).
a) Power
b) Lamp Crest Factor
c) Efficacy
d) Frequency

17. Which lamp type holds the highest CRI rating?
a) Incandescent
b) Trichromatic (tri-phosphor) fluorescent
c) "White Sodium" high pressure sodium
d) Metal halide

18. _____ is defined as 0% of rated light output at 90 degrees above nadir.
a) Full cutoff
b) Non-cutoff
c) Type IV
d) NEMA II

19. The F40T10 fluorescent lamp's diameter is _____ inches compared to _____ inches for the standard T-12 and _____ inches for the T-8.
a) 1 ¼, 1 ½, 1
b) 1, 1 ½, 1 ¼
c) 1 ½, 1 ¼, 1
d) 1 ¼, 1, 1 ½

20. In the case of high pressure sodium lamps, group relamping can also be useful to:
a) Prevent "cycling" that can occur at end of life
b) Minimize color shift and possibility of non-passive failure at end of life
c) Increase luminaire interior surface reflectance
d) Improve color rendering

21. What metric is used to measure light output from a luminaire?
a) Lumens
b) Footcandles
c) Candelas/sq.ft.
d) Lumens per watt

22. What metric is used to measure brightness?
a) Candelas/sq.ft.
b) Footcandles
c) Lumens
d) Lumens per watt

23. The measure of light output from a lamp operated by a commercial ballast, as compared to a laboratory standard reference ballast, is called:
a) Ballast factor
b) Power factor
c) Coefficient of utilization
d) Luminescence

24. What are the consequences of a lack of uniformity of light levels in an office? Select all that apply.
a) Visual fatigue
b) Uneven task illumination
c) Improved productivity
d) Increased UV degradation

25. Which of the following is/are recommended method(s) for dealing with glare? Select all that apply.
a) Parabolic louvers or other diffusing media
b) Indirect lighting
c) Relocating the light source
d) De-lamp offending luminaires

26. What are direct results of light luminaire cleaning? Select all that apply.
a) Helps maintain the luminaire's intended light distribution
b) Increases reflectance of interior luminaire surfaces
c) Enables lenses to transmit more light
d) Reduces maintenance costs

27. When troubleshooting an LED lighting system, what component is most likely to fail?
a) LED driver
b) Heat sink
c) Individual LED's
d) Lens

28. Which of the following would be a luminaire classified according to function?
a) Downlighting
b) Fluorescent
c) LED
d) Localized lighting

29. Which of the following would be a luminaire classified according to light source?
a) Fluorescent
b) Parking lot
c) Downlighting
d) Localized lighting

30. A semi-indirect luminaire emits ____% of its light upward and ____% of its light downward.
a) 60-90; 10-40
b) 0-10; 90-100
c) 40-60; 40-60
d) 90-100; 0-10

31. Which of the following is a way to classify a luminaire according to how it distributes light? Select all that apply.
a) Symmetric or asymmetric
b) Width of the beam of light striking the workplane
c) CIE system
d) Accent

32. In accordance with the NFPA Life Safety Code, the emergency lighting system must be tested for _____ minutes annually to ensure that the battery has enough charge to perform this task.
a) 90
b) 5
c) 15
d) 60

33. Why is documentation of all emergency lighting system tests needed? Select all that apply.
a) It is required by the National Electrical Code
b) It is needed for proof that the test was done
c) It verifies energy consumption
d) It is required for the manufacturer

34. Which of the following is a benefit of automatic lighting controls? Select all that apply.
a) Energy savings
b) Flexibility
c) Increased productivity
d) Improved morale

35. PIR occupancy sensors automatically switch lamps based on detected occupancy using a technology that detects changes in _____ in an area.
a) Heat radiation
b) Reflected sound waves
c) Availability of daylight
d) Air flow

36. Wall-switch infrared sensors provide coverage of what area?
a) 1 to 180 degrees
b) 90 to 360 degrees
c) 180 to 360 degrees
d) 0 to 360 degrees

37. Dimming controls are used primarily to:
a) Control light levels
b) Increase lamp life
c) Reduce glare
d) Shed BTU load

38. Ultrasonic occupancy sensors automatically switch lamps based on detected occupancy using a technology that reads changes in _____ in an area.
a) Reflected sound waves
b) Background heat radiation
c) Availability of daylight
d) Air flow

39. If a fluorescent lamp catalog says that a particular lamp will last 20,000 hours at three hours per start and your customer operates it to specifications but lamps start failing at 14,000 hours, what is the most likely cause?
a) Lamps are failing normally in accordance with mortality curve
b) The lamps are being operated by a magnetic ballast
c) Poor cathode heat
d) High ambient temperature inside the luminaire

40. If fluorescent lamp life is reduced for a large group of lamps, what is most likely happening?
a) Frequent starting
b) Low supply voltage
c) No cathode heat
d) Wrong color temperature

41. Ballast Efficacy Factor (BEF) is a measurement used to compare similar lighting systems based upon light output and input power. BEF = Ballast Factor x 100/Input Watts.
a) True
b) False

42. The Color Rendering Index (CRI) is an international system used to rate a lamp's ability to _____.
a) Render object color
b) Emit radiant energy
c) Emit light when heated
d) Produce light after 100 hours

43. A light fixture is also called a(n) _____ and refers to the complete lighting unit, including the lamp, reflector, ballast, socket, wiring, diffuser, and housing.
a) Luminaire
b) Arc Tube
c) Electrode
d) Capacitor

44. _____ is the rate at which energy is taken from an electrical system or dissipated by a load, expressed in watts (W); typically expressed in volt-amperes (V-A).
a) Power
b) Lamp Crest Factor
c) Efficacy
d) Frequency

45. T12, T10, T8, and T5 are representative of industry standard naming for a fluorescent lamp. The T stands for tubular and the numbers that follow represent the diameter in 1/8 inch increments.
a) True
b) False

46. The purpose of the ballast is to "ignite" the gas and maintain a steady electrical circuit in the fluorescent tube.
a) True
b) False

CHAPTER 9: LIGHTING IDENTIFICATION STUDY QUESTIONS

1. The orientation of a pin-based CFL lamp is important because LED replacement lamps are not omni-directional.
a) True
b) False

2. A F28/T5, 4 foot lamp has an actual measurement of 4 feet in length.
a) True
b) False

3. An F28T8/841 lamp has the following characteristics:
a) 4 feet; 28 watts; 70%+ CRI; 4100K CCT
b) 4 feet; 32 watts; 80%+ CRI; 4100K CCT
c) 4 feet; 28 watts; 80%+ CRI; 4100K CCT
d) 4 feet; 28 watts; 80%+ CRI; 3500K CCT

4. The difference between nominal lamp length and actual lamp length is:
a) Nominal length is generally, but not always, the length of the lamp including the sockets
b) Nominal length is the average of all the lamp lengths that are called 4-foot
c) Nominal length is the lamp length from pin–to-pin

5. High pressure sodium lamps:
a) Have a yellow glow
b) Long, thin arc tube
c) Often seen on roadways
d) All of the above

6. A low pressure sodium lamp:
a) Produces a deep orange glow
b) Is used mainly in street and area lighting applications
c) Is often seen around observatories and "dark sky" applications
d) All of the above

7. If you encounter an exit sign with even illumination across the face, what type of exit sign is it likely to be?
a) Incandescent
b) LED
c) Fluorescent
d) OLED

8. Which of the following statements is true regarding emergency lighting?
a) Often, large buildings have an emergency backup generator
b) Often, smaller buildings have a localized emergency backup system with stand-alone bugeye fixtures
c) Emergency backup ballasts are typically found in egress pathways
d) All of the above

9. When encountering difficulty in obtaining an accurate count of emergency fixtures during the physical audit, what are some additional methods of verifying or, at least, accounting for emergency fixtures in the audit?
a) take-offs from reflected ceiling plans
b) Using an estimate of 15% for all likely egress areas when all else fails
c) A and B
d) None of the above

10. Documenting fixture colors is important because non-standard fixture colors are expensive, special-order items with long lead times.
a) True
b) False

11. One of the potential problems with determining lamp wattage from NEMA tags is that the tags are rarely replaced when a fixture has been retrofitted in the past.
a) True
b) False

12. A yellow NEMA tag color suggests what type of lamp?
a) Metal halide
b) Induction
c) High pressure sodium
d) LED

13. A blue NEMA tag labeled 'X1' suggests what type of lamp technology and lamp wattage?
a) Mercury vapor; 1000 watts
b) Mercury vapor; 100 watts
c) High pressure sodium; 1000 watts
d) High pressure sodium; 100 watts

14. The number on the NEMA tag generally is shown with the "last" digit of the lamp wattage truncated.
a) True
b) False

15. Secondary sources for determining lamp wattage are:
a) The light fixture itself
b) Architectural drawings
c) Lamp recycle bins
d) B and C

16. Ballast factor and power factor are the same thing.
a) True
b) False

17. Magnetic ballasts can produce a humming or buzzing sound.
a) True
b) False

18. Tandem wiring fixtures may reduce the following:
a) Material costs
b) Labor costs
c) Maintenance costs
d) All of the above

19. A drawback to tandem wiring fixtures is when the ballast fails, the lamps in both fixtures are inoperable.
a) True
b) False

CHAPTER 10: ENERGY CALCULATIONS STUDY QUESTIONS

1. You install an energy-efficient lamp for $9.00 (lamp plus labor) that saves $6.00 per year in energy. The payback time is how many months?
a) 18 months
b) 15 months
c) 0.67 months
d) 6.7 months

2. The amount of power that a lighting system needs to operate is measured in:
a) W
b) Wh
c) kWh/sq.ft.
d) W/sq.ft.

3. What is the efficacy of a 400W system producing 10,000 lumens of light output?
a) 25 lumens per watt
b) 14 lumens per watt
c) 40 lumens per watt
d) 400 lumens per watt

4. During an audit, you have run into an open office that has existing occupancy sensors and existing daylight controls. The site contact tells you that the open office operates 3,500 hours/year. She adds that the daylight program has been quite well received, operating on a switching basis and saving 40%/year. She isn't sure how effective the occupancy sensors have been, but a typical industry guideline is 30%. Using these guidelines, how do you calculate the hours of operation?
a) The hours of operation are 1,050/year.
b) The hours of operation are 1,470/year.
c) The hours of operation are 2,030/year.
d) The hours of operation are 3,082/year.

5. The following are factors involved in an upgraded fluorescent installation. Use this information to answer the following questions:

	Existing Luminaires	Upgraded Luminaires
# of luminaires	1500	1500
# of lamps per luminaire	4-F40CW	4-F32T8
# of ballasts per luminaire	(2) 2-lamp conventional magnetic	(1) 4-lamp electronic
Input watts	186	106
Hours per year	4000	4000
KWh rate	$0.08	$0.08
Costs of lamps, ballasts, and labor per luminaire		$64.00

6. The energy savings per year is:
a) $38,400.00
b) $120,000.00
c) $96,000.00
d) $15,000.00

7. The simple payback is _____ years.
a) 2.5
b) 3.0
c) 25
d) 5.0

8. The upgraded installation will be group relamped in 5 years. The positive cash flow above and beyond payback of initial investment, at time of the group relamping will be:
a) $96,000.00
b) $38,400.00
c) $120,000.00
d) $76,800.00

9. You have audited an open office that operates 3,500 hours/year. There are (185) 3-lamp T8 troffers (87 watts) and the space is 14,430 square feet. The office was retrofitted in 2014 when the targeted lighting power density was 1.1 watts/square foot. The current lighting power density target is 0.8 watts/square foot and your company is proposing to retrofit the fixtures one-for-one with (3) Type-C TLED lamps and (1) driver with a total of 54 watts/fixture. Which of the following is true?
a) Both the 2014 retrofit and the current proposal comply with the lighting power density targets.
b) The 2014 retrofit did not comply with the lighting power density target, but the current proposal does.
c) Neither the 2014 retrofit nor the current proposal comply with the lighting power density targets.
d) The 2014 retrofit comply with the lighting power density target, but the current proposal will not.

10. The local utility is offering a rebate of $0.05/kWh of savings on T8 to LED measures so long as each new fixture saves at least 30 watts over the existing unit. Your site has (1257) 2-lamp F32T8 troffers with an existing system wattage of 59 watts. Your company will be replacing these fixtures on a one-for-one basis with a 28-watt LED volumetric basket troffer. During the pre-inspection walk, the utility agreed that the fixtures will burn 2,200 hours/year. How much will your rebate be?
a) $3,871.36
b) $4,286.37
c) $8,157.93
d) This measure doesn't meet the minimum savings/fixture, so it's not eligible for rebates.

CHECKING YOUR UNDERSTANDING: ANSWER KEY

Chapter 1: Introduction to Lighting

1b, 2b, 3a, 4c, 5d, 6b, 7a, 8a, 9d, 10c, 11a, 12c, 13b

Chapter 2: Incandescent Lighting

1b, 2a, 3c, 4c, 5a, 6c, 7b, 8b, 9a, 10d, 11a, 12c

Chapter 3: Fluorescent Lighting

1d, 2c, 3b, 4a, 5d, 6b, 7c, 8c, 9c, 10d, 11b, 12a, 13d, 14c, 15c, 16d, 17c, 18b, 19d, 20b, 21a, 22c, 23d, 24b

Chapter 4: High-Intensity Discharge Lighting

1c, 2c, 3a, 4d, 5d, 6a, 7c, 8c, 9b, 10a, 11c, 12d, 13b

Chapter 5: Lighting Audits

1a, 2a, 3a, 4a, 5a, 6a, 7a, 8a, 9a, 10a, 11a, 12a, 13a, 14a, 15c

Chapter 6: Digital vs. Paper Audits

1c, 2b, 3d, 4a, 5d, 6d, 7b, 8d, 9d, 10d, 11b, 12b, 13c, 14c, 15b

Chapter 7: Lighting Audits Case Studies

Audit Scenario: Healthcare – 1a, 2a, 3d, 4a, 5a, 6d, 7d, 8d, 9a, 10c, 11b, 12d, 13d, 14b, 15a, 16d, 17d, 18a, 19d, 20b, 21d, 22d, 23b, 24b, 25a, 26d, 27d, 28b, 29b, 30a, 31d, 32b, 33d, 34b, 35a

Audit Scenario: Automotive Dealership – 1d, 2d, 3d, 4d, 5d, 6b, 7c, 8c, 9c, 10d, 11b, 12c, 13d, 14d, 15a, 16a, 17b, 18d, 19d, 20d, 21c, 22a, 23d, 24a, 25d, 26b, 27a, 28a, 29d, 30b, 31b, 32c, 33b, 34a, 35a, 36?, 37d, 38?

Audit Scenario: Warehouse – 1d, 2d, 3d, 4d, 5d, 6d, 7c, 8c, 9a, 10d, 11b, 12d, 13d, 14a, 15d, 16b, 17a, 18d, 19d, 20a, 21a, 22a, 23a, 24b, 25b, 26d, 27a, 28d, 29c, 30d, 31b, 32a, 33b, 34b, 35b, 36?

Chapter 8: Lighting Technology

1a, 2a, 3a, 4a, 5a, 6a&b, 7a, 8a, 9a, 10a, 11a, 12a, 13a, 14b, 15a, 16a, 17a, 18a, 19a, 20a, 21a, 22a, 23a, 24a&b, 25a,b,&c, 26a,b,&c, 27a, 28a, 29a, 30a, 31a,b,&c, 32a, 33a&b, 34a&b, 35a, 36a, 37a, 38a, 39a, 40a, 41a, 42a, 43a, 44a, 45a

Chapter 9: Lighting Identification

1a, 2b, 3c, 4a, 5d, 6d, 7b, 8d, 9c, 10a, 11a, 12c, 13a, 14a, 15d, 16b, 17a, 18d, 19a

Chapter 10: Energy Calculations

1a, 2a, 3a, 4b, 6a, 7a, 8a, 9b, 10b