U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

GUIDE TO FEMP-DESIGNATED PARKING STRUCTURE LIGHTING

FOR FEDERAL AGENCIES

FEMP Federal Energy Management Program

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National Renewable Energy Laboratory's parking structure utilizes many measures to achieve a parking structure that uses 90% less energy than the baseline energy code.

INTRODUCTION

Legislation and the Federal Acquisition Regulations (FAR) require federal agencies to specify and buy ENERGY STAR® qualified products or, in categories not included in the ENERGY STAR program, products that meet or exceed efficiency requirements designated by the Federal Energy Management Program (FEMP). Agencies that follow requirements to buy efficient products can realize substantial operating cost savings and reduce pollution. As the world's largest consumer, the federal government can lead the entire U.S. market achieve greater energy efficiency while saving taxpayer dollars.

FEMP provides acquisition guidance and federal efficiency requirements across a variety of product categories, including parking garage luminaires, which are a FEMP-designated product category. Federal laws and executive orders mandate that agencies meet these efficiency requirements in all procurement and acquisition actions that are not specifically exempted by law.

The purpose of this guide is to explain in greater detail the FEMP-designated parking garage/structure product category, to show how the equipment can be used to maximize total energy efficiency (using the metrics defined below), and to provide an estimate of the cost effectiveness using FEMP-designated products.

ENERGY EFFICIENCY METRICS

There are different energy efficiency metrics. Although there are several metrics to describe energy efficiency, here we consider three lighting-specific metrics: efficiency (very simple), efficacy (simple), and lighting power density (complex). This guide primarily focuses on efficacy, and demonstrates how efficacy incorporated with other elements can reduce power densities.

Efficiency

Efficiency is a measure of how effectively a device converts input into output. Luminaire efficiency (LE) is the light leaving the luminaire divided by the light generated by the bare lamp (light bulb) when operated outside of the luminaire. Because both values (the light leaving the luminaire and the light generated by the light source[s]) have the same unit, luminaire efficiency is therefore a unitless ratio.

Efficacy

Efficacy is the capacity to produce an effect. In lighting, efficacy is measured in lumens per watt (lm/W, also abbreviated LPW). Efficacy can apply to light sources or luminaires. The greater the efficacy, the more light is generated for the same watts. Most people are familiar with this metric related to vehicles; for example, a car that gets 30 miles per gallon is more efficacious than a car that gets 25 miles per gallon.

FEMP's designated product for lighting focuses on luminaire efficacy and uses the term luminaire efficacy rating (LER). The following page explains how to calculate the LER as well as the relationship between luminaire efficiency and luminaire efficacy.

A key note regarding efficacy is that it counts the emitted lumens irrespective of the direction in which they are emitted, or the usefulness of those lumens. A luminaire can have a lower LER but do a better job of distributing light to the task.

Lighting Power Density (LPD)

Lighting power density (LPD) is the total input power (*i.e.,* including the driver or ballast) multiplied by the total number of luminaires divided by the area in which the equipment is installed. Many energy codes use this metric, however; it does not actually focus on *energy*. Energy is power multiplied by time, so it is important to distinguish between power (watts) and energy (watt-hours). Lighting power density calculations do not indicate any energy savings as a result of the use of lighting controls.

FEMP-DESIGNATED PRODUCTS

As of September 2013, there are FEMP-designated products for lamps (light bulbs), ballasts, interior fluorescent luminaires, industrial high-bay luminaires, and many exterior luminaires. The metric for luminaires is LER. The following provides the LER value for parking garage (also referred to as parking structures in this guide) luminaires as well as helpful calculations.

MEETING ENERGY EFFICIENCY REQUIREMENTS FOR PARKING GARAGE LUMINAIRES

Parking garage luminaires must have a LER of 70 in order to be FEMP-designated (as of the date of this publication, the most current value as well as FEMP-designated products can be found at Covered Product Category: Exterior Lighting). The following explains how to calculate LER for conventional light sources such as fluorescent, metal halide, and induction lighting, as well as light-emitting diode (LED) luminaires.

$$\text{LER} = \frac{\text{total light leaving the luminaire}}{\text{input power}}$$

Conventional Luminaires

Conventional luminaires (non-LED) can use different combinations of lamps, ballasts, and optics, often requiring LER to be calculated. If an LER is not available, buyers may estimate the LER using this formula:

$$\text{LER} = \frac{\text{Luminaire efficiency x lamp lumens}}{\text{lamp+ballast input watts}}$$

LE x lamp lumens, and lamp+ballast (system) input watts are typically found in manufacturers' product catalogs and photometric reports.

The LER formula may be used with generally-available component performance data to determine the minimum performance of other components. For example, known values may be used to calculate the lowest LE necessary to meet an LER requirement:

> A 150-watt high pressure sodium (HPS) lamp produces 15,250 initial lumens with 185 lamp+ballast input watts. What LE is necessary to meet the minimum required LER of 70?

$$\text{LE} = \frac{\text{LER} \times \text{lamp+ballast input watts}}{\text{lamp lumens}} = \frac{70 \text{ lm/W} \times 185 \text{ W}}{15{,}250 \text{ lumens}} = 0.85$$

Therefore, for a minimum required LER of 70, a fixture combined with the lamp and ballast values provided must have an LE of at least 85%.

LED Luminaires

LED luminaires are available in different combinations, but their values are reported for the complete luminaire, not the light source by itself. The complete LED housing includes the fixture, light source (or lamp), and driver (similar to a fluorescent ballast). If an LER is not available, buyers may calculate the LER for LED luminaires using this formula:

$$\text{LER} = \frac{\text{luminaire light output (lumens)}}{\text{input power (watts)}}$$

DESIGN PROCESS

The rest of this document will explain options for energy efficient lighting in parking structures using FEMP-designated luminaires and features accounting for both lighting quality and energy efficiency. Selecting energy efficient equipment, such as FEMP-designated equipment is the first step in energy efficient parking structure lighting. This section addresses a step-by-step process from surveying the site to installation. Key points of the following design process section include:

1. Developing an inventory of equipment
2. Determining lighting quality and quantity needs
3. Incorporating lighting controls
4. Addressing cost effectiveness in the process

PARKING STRUCTURE LIGHTING DESIGN: A STEP-BY-STEP OVERVIEW

STEP 1: CONDUCT COMPLETE INVENTORY

Consider all lighting opportunities and list which luminaires you want to replace, and ask why you want to replace them. Is energy the only issue? If this is a retrofit, be sure to collect information on each existing luminaire that you want to replace (*e.g.,* lamp type(s), mounting height of luminaires, general lighting information). Ramps and entrance areas may use different luminaire types than basic parking areas.

STEP 2: CONSIDER LIGHT QUANTITY AND QUALITY

When considering parking garages, it is common to assume one uniform light level, night or day, is appropriate. The Illuminating Engineering Society of North America (IES) recommends a low light level for basic parking areas and higher light levels for ramps and higher still for entrance areas. Additionally, since most parking garages are lighted 18+ hours per day, ramps and entrance areas should have even higher light levels during daylight hours to help the eye adapt from bright sunshine to the darker interior of the parking structure, or vice versa. Controls should be used to reduce those high light levels at night to help drivers transition from the lighted parking structure to the darker conditions of the street outside the structure.

Lighting uniformity on the pavement surface must also be considered for safe vehicle and pedestrian interaction. Too much contrast between bright and darker areas makes it more difficult to see people and vehicles in the darker areas. Luminaires that distribute light evenly on the garage floor and onto interior walls, and lighting layouts with appropriate spacing, are crucial to the lighting design. Consequently, one-for-one replacement may not be an option when specific light levels and uniformity ratios are targeted. Consider recommending light surface colors, as lighting ceilings and vertical surfaces will increase reflected light in the garage, improving light levels and uniformity of light on the floor as well as making pedestrians and their faces more visible. You can refer to IES resources or your local lighting professional for assistance. Contact the International Association of Lighting Designers and/or the Illuminating Engineering Society of North America to locate lighting professionals.

STEP 3: CONSIDER CONTROLS FOR TRANSITION AREAS

Using controls to adjust light levels for changing daylight and occupant activity will help save energy. Parking garage ramps and entrance areas require higher light levels during daylight hours, as described earlier. Consider adding photosensors to reduce ramp and entrance lighting levels to save additional energy at night. If considering adding occupancy sensors to turn lights down or off during low activity periods, consider whether to turn off individual luminaires or reduce output for a group of luminaires. Turning off luminaires may result in poorer lighting uniformity on the pavement and increased shadows that may make occupants feel less safe. However, some technologies require special dimming ballasts for high/low controls scenarios. For some technologies, such as fluorescent, an inexpensive alternative is dual-circuiting multi-lamp luminaires, allowing the controls to turn off some lamps within the luminaires, which reduces energy use while helping maintain uniform lighting.

STEP 4: SOLICIT BIDS

After selecting the right technology for your parking garage, and specifying the appropriate lighting systems and layout to deliver lighting quality and quantity, a request for proposal can be prepared that will deliver the desired results from bidders. (See resources at the end of this guide for information about selecting the right technology.)

STEP 5: COST EFFECTIVENESS

Once you have pricing and cost inputs from several sources, you can evaluate the cost effectiveness including simple payback period, return on investment, life-cycle cost (LCC) analysis, and savings-to-investment ratio. This will allow you to make the appropriate final decision. There are free calculators and LCC analysis tools are offered by FEMP and by various product manufacturers and utility programs. Example cost effectiveness calculations are provided at the end of this guide.

STEP 6: PURCHASE AND INSTALL

Clearly identify required specifications and warranties in your purchase order or contract. Most parking structure lighting systems will not require commissioning unless controls are involved. If controls are involved, be sure to identify who is responsible for commissioning before signing the purchase order. Lastly, remember to file for any utility incentives within the required period of time after completion.

CONSTRUCTION TIP

Parking structure retrofits can be done in small increments, where sections of the parking structure are blocked off while the lighting is replaced. This can allow equipment costs to be phased and allow the parking structure to remain open and operational during the transition.

COMPONENTS OF THE DESIGN

There are many components that have to be considered before the design process can occur. The structure design (above or below ground, materials, etc.) coupled with the features of the luminaire (distribution, color, etc.) and how the luminaires are placed in the structure all affect the energy usage of the lighting system. Significant components of the following components of the design section include:

1. The effects of building design on the lighting
2. How the materials used in building the structure affect energy usage in the space
3. How light levels and color qualities affect the design and energy usage
4. A review of different luminaire distributions

BUILDING DESIGN CONSIDERATIONS

The energy use of a parking structure is affected by the building design. In belowground structures, air handling requires more energy. In above ground structures, daylighting can be incorporated to reduce the lighting usage. For parking structures above ground, consider how the top deck is designed. Even materials (painted vs. raw concrete) or construction type (flat vs. dropped beam ceiling) will affect the lighting energy usage, as explained in the following sections.

Figure 1. National Renewable Energy Laboratory's parking structure – open building design allows for daylight design. The design of the parking structure can affect the energy performance of the structure more than luminaire selection.

Location

Parking structures are constructed to provide the most parking possible within the available footprint. The location of the parking structure is often affected by the location of buildings and roadways.

Incorporating Daylight

If the parking structure is above ground, daylight can easily be incorporated into the design. Because of the cost of materials and the use of the space, many above ground structures are either open to the air or incorporate windows. When possible, include daylight in the design from the beginning, as the National Renewable Energy Laboratory did in their recent parking structure (see Figure 1). Tufts University designed a parking structure where the exterior facade allowed openings that deliver diffused daylight (Figure 2).

Figure 2. Tufts University incorporates daylighting into their parking structure.

Top Deck

The top deck in an above ground parking structure can be a design challenge. It is often open to the sky, which usually requires the use of poles to provide lighting. However, the pole height may be limited because bucket trucks used to maintain pole lighting may be too tall to fit in the low-height ceilings of the parking structure. This makes lighting maintenance on the top deck difficult. Recently, parking sites have been integrating photovoltaics (PV) into the top deck of parking structures. The introduction of PV panels offers two benefits: (1) panels can help provide power for the luminaires and (2) the luminaires can be located on the underside of the PV panels, allowing for better placement and enabling maintenance.

MATERIAL SELECTION

Figure 3. Arizona State University parking structure with painted white ceiling and other high reflectance materials.

Figure 4. Corporate parking structure in Phoenix, AZ, where light is absorbed by the adjacent structural supports.

The FEMP-designated program focuses on the luminaire efficacy rating, but the materials used in the parking structure matter more than the efficacy of a luminaire. Technologies improve and luminaires can be replaced, while initial selection of materials will be a permanent characteristic with the longest lasting effect on the lighting performance in the parking structure.

The appearance of a space is strongly affected by light reflecting off surfaces. Parking structures are known for absorbing light and, in some cases, appearing dark and uninviting, in part because of the low reflectance of concrete and other materials. Structural beams, water pipes, and signage can also block light and make the space feel darker.

Most above ground parking structures are open to the air. This means that light directed to perimeter walls with daylight openings passes directly out of the parking structure. This reduces the usable light from any fixture regardless of the efficacy of the luminaire, and may result in glare for people outside the structure.

Where possible, factor the surface finishes into the design, or paint the ceiling and walls white or a very light color. Periodic cleaning with high-pressure water can help maintain a clean and bright appearance, but this needs to be factored into the operational plans of the structure.

Contrast is just as important as lighting for visibility in a parking structure. In Figure 3, the ceiling, beams, and upper columns are painted white, dramatically increasing the amount of light on all surfaces. The bottom of each column is painted a darker color than the ceiling, to help drivers see and avoid the columns. Each floor can have a different column color to help with wayfinding. Consider painting wheel stops or using different materials to help users identify the barriers, ramps, pedestrian lanes, exit lanes, and stairwells.

DESIGN TIP

In addition to the material, the structural design can affect lighting and ultimately energy usage. Beams are common in parking structures, but absorb light (Figure 4). Lowering the luminaire is one way to mitigate this issue. Incorporating the lighting design early in the process is one way for a new construction facility to mitigate some of these issues. Lighting should not be an afterthought.

LIGHTING DESIGN CONSIDERATIONS

Lighting a parking structure involves more than just using high-efficiency equipment. Several choices need to be made regarding the lighting and the desired results, including:

a. *Luminaire distribution* – distribution determines the direction and intensity of the light leaving the luminaire. Typical distributions and how they affect the lighting design are discussed on page 10 of this document.

b. *Color qualities* – the color of the lighting and how things appear in the space matters as much as the amount and types of lighting in the space. The basic color qualities of lighting are discussed on page 11 of this document.

c. *Luminaire Layout* – where the efficient equipment is placed is as important as how it is used. The advantages and disadvantages of different luminaire layouts are addressed on the pages that follow.

d. *Desired results* – most lighting recommendations or requirements start with illuminance. This is the amount of light falling on a horizontal or vertical surface (lumens per square foot or square meter). The metric in the U.S. is the footcandle (fc) which is one lumen per square foot. The corresponding metric system unit is one lux (lx), which is one lumen per square meter. 1 fc is approximately equal to 10 lux.

The current guidance from the IES, which is referenced by most federal design requirements (including the military Unified Facilities Criteria), is RP-20-98. It is expected that RP-20 will be updated in the near future.

RP-20-98 recommends a minimum illuminance (horizontal and vertical) for different parts of parking structures. In addition to the minimum values, RP-20 also recommends uniformity ratios. RP-20 focuses on the ratio of the maximum to the minimum illuminance values and tries to limit extreme ranges of illuminance values. Table 1 provides the current IES lighting recommendations, although these may change in the next iteration of RP-20. RP-20 also provides guidelines for taking lighting measurements and what factors (*e.g.,* daylight, light loss factors) should be included in the calculations.

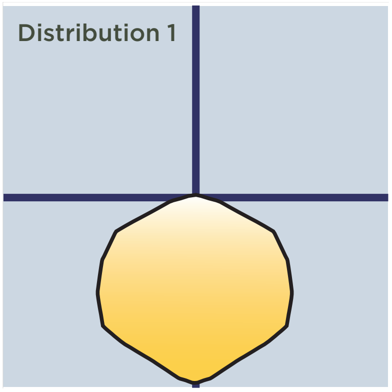
Table 1. RP-20-98 Parking Structure Illuminance Recommendations.

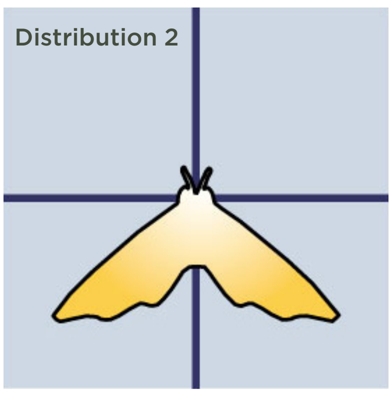
		Minimum Horizontal Illuminance	Maximum/Minimum Horizontal Uniformity Ratio	Minimum Vertical Illuminance
Basic		1 fc	10:1	0.5 fc
Ramps				
	Day[1]	2 fc	10:1	1.0 fc
	Night	1 fc	10:1	0.5 fc
Entrance Areas[2]				
	Day[1]	50 fc		25 fc
	Night	1 fc	10:1	0.5 fc
Stairways		2 fc		1.0 fc

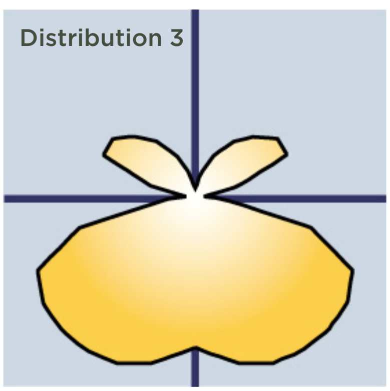
[1]Daylight may be considered in the design calculation.

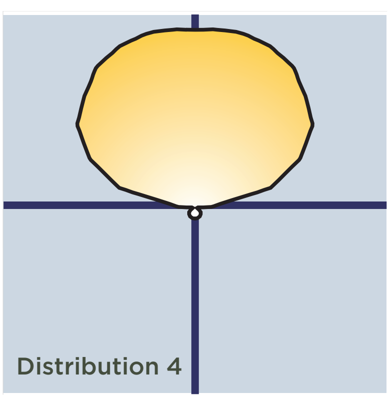
[2]A high illuminance level for about the first 65 feet inside the structure is needed to help with the transition from bright daylight to a lower internal level.

RP-20-98 recommends that additional analyses of a subset of points can be computed (see RP-20 for more information). In addition, RP-20-98 recommends starting a design with an average overall illuminance of 5 fc; but this can be higher if more lighting is required. Computer software allows for computing average, maximum, and minimum values and even a specified range of values. The scenarios in this FEMP guide show the percent of calculation points between 1 and 10 fc. If the design is for an average overall illuminance of 5 fc, the higher the percentage of points in the range between 1 and 10 fc means that the design intent is being achieved and the average is not being skewed by any extreme values. Ideally, more than 80% of the points will be in the desired range.









LUMINAIRE DISTRIBUTION

The minimum FEMP-designated luminaire efficacy rating is only one aspect of energy efficient design. Distribution can be more important than the LER of a luminaire. FEMP does not state a minimum requirement or characterize distribution because the necessary luminaire distribution is affected by the design of the space, the desired lighting results, glare control, and desired lighting aesthetics. Photometric distribution is like a building fastener—screws work in some applications while rivets are better in others.

A photometric distribution illustrates how much light intensity is leaving the luminaire and in which directions. In distribution 1–4 (shown to the left), the intersection of the crosshairs is the center of the luminaire with the bottom vertical line being below the fixture and the top vertical line being above the fixture. The intensity in a specific direction is proportional to the length of the ray from the crosshairs to the outline of the pattern. The following four distributions are typical of different parking structure luminaires.

Distribution 1: This is a "cosine distribution"—the highest intensity of distribution is directly below the luminaire. This distribution can be effective in meeting an average requirement for illuminance, but might prevent the lighting system from meeting the required or desired lighting uniformity. For many parking structures, the other distributions discussed below should be used over this type of distribution.

Distribution 2: This distribution is sometimes called a "batwing" distribution (common in parking structures)—which means that more light is emitted at wide angles than directly below the luminaire. This allows for a wider spacing between luminaires and more uniform lighting on the ground surface. There is a small uplight component in this distribution as well. It is not part of all batwing distributions, but can be useful for providing a small amount of uplight in a parking structure. (All of the pattern that is above the crosshairs indicates upward light.)

Distribution 3: This is a distribution similar to some fluorescent parking structure luminaires. Light is emitted downward and outward, and some light is also emitted up toward the ceiling. A luminaire with this distribution will require luminaires to be spaced closer together, as compared to Distribution 2. The uplighting can be very beneficial if it bounces against a light-colored ceiling or illuminates high-mounted signage.

Distribution 4: This is a purely indirect light fixture because all of the light is emitted above the horizontal line. This is not common for parking structures, but as designers and architects explore the aesthetics and feel of parking structures, purely indirect fixtures are being used in select instances. If a luminaire of this type is selected, careful coordination with the ceiling design is required. The ceiling will need to be high reflectance (painted white) and flat (no dropped beams, sparse signage, no pipes) because the light will be reflected and redistributed off the ceiling.

CORRELATED COLOR TEMPERATURE

Correlated color temperature (CCT) is used to describe the color appearance of a light source. The value is expressed in kelvins (K). A warm light source has a CCT less than roughly 3500 K. A neutral light source has a CCT in the 3500 to 4500 K range. Cool light sources have CCTs greater than 4500 K (see Figure 5).

CCT is not a performance metric: a higher number is not better. Instead, it is a metric that describes the warmth or coolness of the light appearance. CCT is a function of light source chemistry and physics. In some cases, CCTs affect light source efficacy. For example, HPS lamps tend to have CCTs around 2100 K. There are 2800 K HPS lamps, but they are less efficacious than the 2100 K versions. Conversely, phosphor-converted LEDs are typically more efficacious when the CCT is greater than 4500 K.

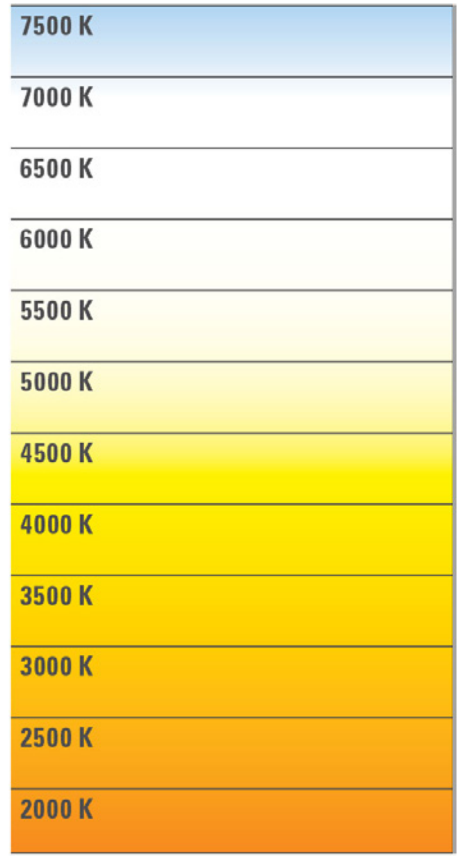


Figure 5. Visual depiction of CCT values shows low CCT values are considered "warm" and high CCT values are considered "cool."

COLOR RENDERING INDEX

Color rendering index (CRI) is used to describe the color accuracy of a light source. It should be noted that CRI only describes one aspect of color. A CRI of 60 and less indicates poor color rendering, 60–70 moderate, 70–80 good, 80–90 very good, and 90+ excellent. Recent research and discussion in the lighting industry has focused on the limitations of CRI. Other metrics have been proposed, but CRI is still the metric of choice in the lighting industry.

CRI is a performance metric where the higher the number, the better. Color discrimination is necessary in a parking structure to help identify clothing, faces, license plates, and vehicles. However, fine color discrimination is not necessary. For some light sources, there can be an increased cost or slight reduction in efficacy for better CRI. Therefore, a CRI greater than 70 is sufficient for the lighting in a parking structure. Higher numbers are fine, but requiring a minimum CRI of 80 or 90 may not provide any tangible benefits in the space.

MORE INFORMATION

For more information about these color characteristics, review **DOE's fact sheet on color quality**. The document was produced for solid-state lighting, but the information is applicable to other technologies.

LUMINAIRE LAYOUT

The layout of the luminaires affects energy usage as well. There are advantages and disadvantages to a single luminaire per bay versus a double luminaire layout.

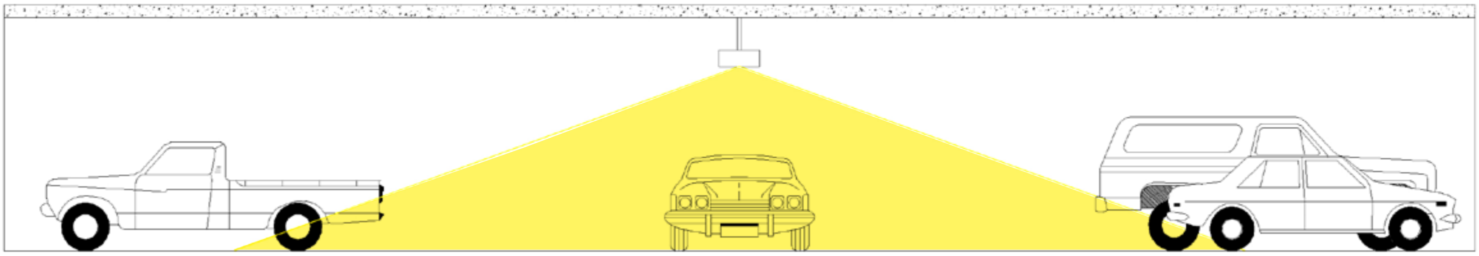


Figure 6. Single luminaire layout.

Advantages:

- Less equipment (luminaires and conduit)
- Less labor time for installation
- Possibly less energy

Disadvantages:

- More glare for driver – luminaire is located right along the drive path
- Luminaire emitting as many lumens as two luminaires
- Shadows cast on outside walls from parked cars
- Lighting uniformity may not be optimal

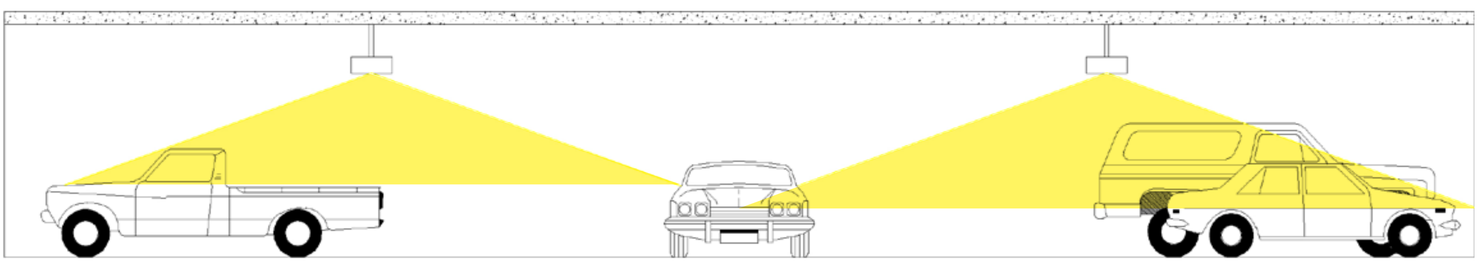


Figure 7. Double luminaire layout.

Advantages:

- Better potential for using photocontrols to save energy (where possible)
- Allows for better coverage of light – allows light to penetrate further into structure and light vertical surfaces
- Better coverage leads to better uniformity
- Glare in the drive aisle can be reduced because the luminaires are along the periphery

Disadvantages:

- More equipment (luminaires and conduit), means higher cost
- More labor time for installation required
- More sensors and commissioning time if one occupancy sensors is installed per luminaire
- Potentially more energy use

PARKING STRUCTURE LIGHTING DESIGN

There is no one way to design the lighting for a parking structure. This section presents a representative parking structure with lighting designs using the same luminaire layout and spacing to show the different results from two different luminaires, one meeting the FEMP-designated requirements and another not meeting the FEMP requirements. Significant components of the following parking structure lighting design section include:

1. How color qualities and other features affect the design of the space
2. How distribution and luminaire efficacy affect the lighting values
3. How luminaire layout and efficacy affect overall energy usage

Figure 8(a). Photo – perspective of the parking structure

Figure 8(c). Photo – corner of parking structure

Figure 8(b). Photo – entrance during the day

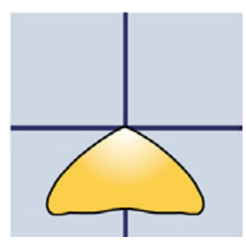
Figure 8(d). Photo – typical ceiling construction

DESIGN SCENARIO OVERVIEW

The photos above depict a parking structure where two different luminaires (a general luminaire and a FEMP-designated luminaire) are compared on the following pages.

Luminaire Basics:
- luminaire lumens
- input watts & LER

The distribution to the right is an example of the existing luminaire in this parking structure. The design scenarios presented in this guide reuse the same lighting layout (spacing between luminaires). As previously stated, LER helps ensure that the luminaire is efficient, but the distribution ensures that the luminaire (and ideally the design) is effective. The following design scenarios compare luminaires with different LER values and distributions, but with the same lighting layout.



The entry and exit areas have higher light levels. This is to help drivers' eyes adapt as they transition from daylighted roads to the covered ("interior") parking areas—as shown by the sharp contrast in the entry photo above. Computer calculation software can render images of the space, as well as calculate the illuminance values on the ceiling, walls, and floor of the space. Software can examine many metrics about lighting quantity as well as quality. The lighting information to the right is shown as sample metrics and are most applicable to parking structures.

Lighting Information:
- Average fc
- Maximum fc
- Minimum fc
- Average:Minimum
- Maximum:Minimum
- % of points 1–10 fc

Lighting power density (LPD) is the metric used by most energy codes. LPD can be calculated by hand, simple spreadsheets, web tools, or in some lighting software.

Lighting Power Density:
- LPD

Figure 9(a). Photo of site

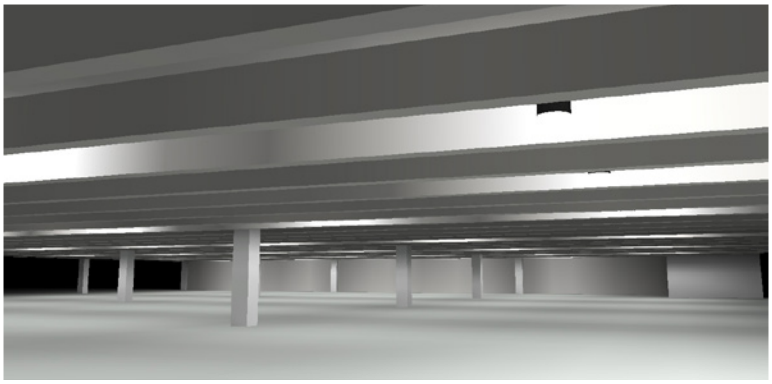


Figure 9(b). Perspective – (computer rendering)

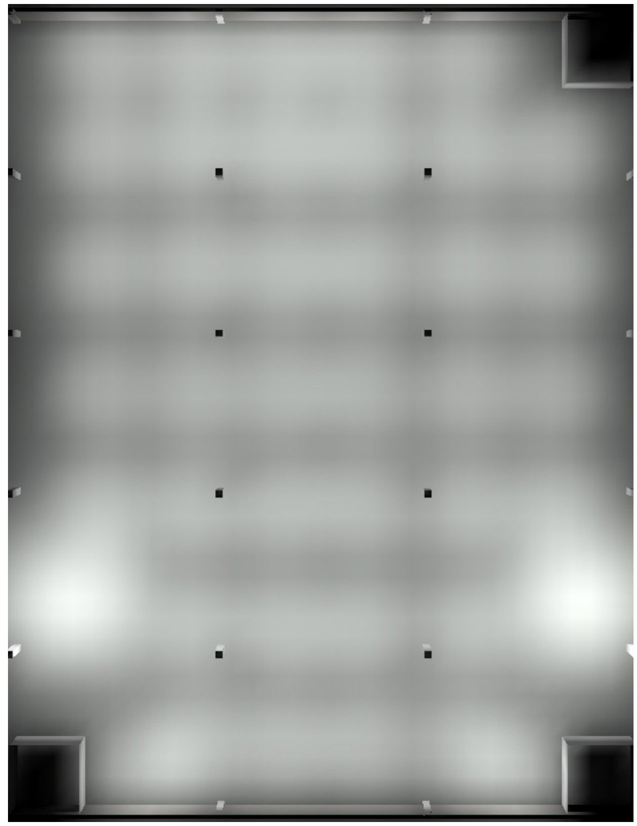


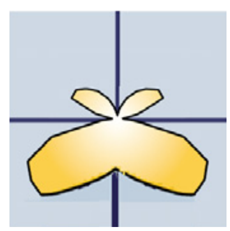
Figure 9(b). Plan view – (computer rendering)

DESIGN SCENARIO – GENERAL LUMINAIRE

This general (non FEMP-Designated) luminaire uses a 100 W pulse-start metal halide lamp that draws 129 W together with the ballast. The CCT is in the 3500–4500 K range, with a CRI in the 70s. The LER is 62 lm/W.

Luminaire Basics:
- 8,058 luminaire lumens
- 129 W input watts – LER: 62

The light distribution plot shows that the luminaire produces a batwing pattern with a small portion of uplight. The batwing distribution is common in parking structure luminaires.



The design with this luminaire meets the minimum illuminance of the RP-20-98 recommendation, but the average is high. Calculated metrics for uniformity (maximum:minimum) are worse than RP-20-98's recommendation of 10:1. However, the portion of points calculated between 1–10 fc is 92%, which means the uniformity is good. Calculations represent the initial values and do not include light loss factors (LLF). LLF should be included and determined per site.

Lighting Information:
- Average: 7.3 fc
- Maximum: 19.0 fc
- Minimum: 1.4 fc
- Average:Minimum: 5:1
- Maximum:Minimum: 14:1
- % of points 1–10 fc: 92%

The calculated lighting power density (LPD) for this design is lower than most (but not all) energy codes prescribe. LPDs between 0.15–0.30 watts per square foot (W/sf) are common for existing installations and many new installations.

Lighting Power Density:
- LPD: 0.15 W/sf

Figure 10(a). Photo of site

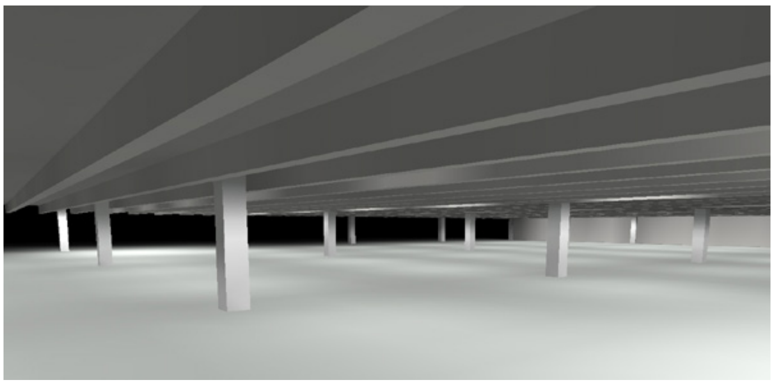


Figure 10(b). Perspective – (computer rendering)

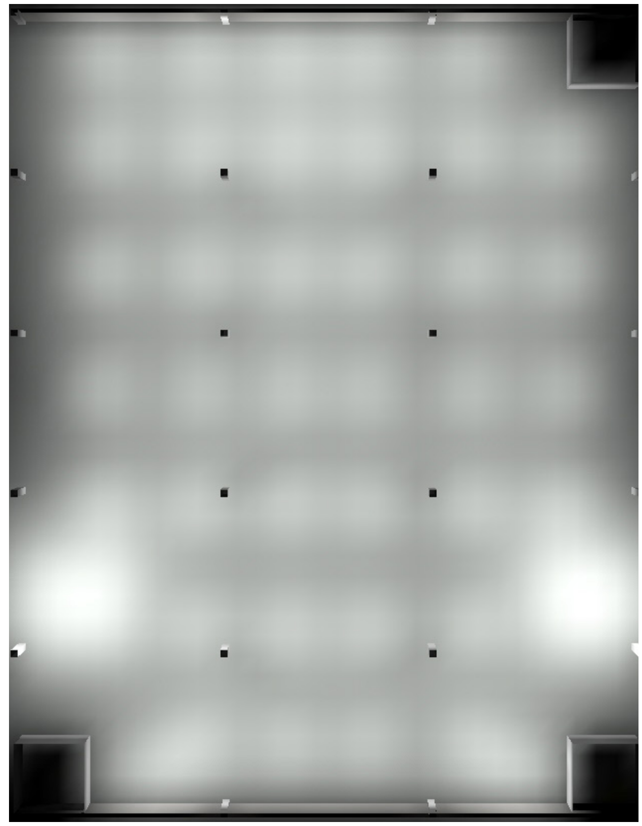


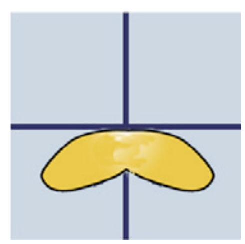
Figure 10(b). Plan view – (computer rendering)

DESIGN SCENARIO – FEMP-DESIGNATED LUMINAIRE

The FEMP-designated luminaire has color qualities of 4000 CCT and a CRI in the 70s. The LER is 75 lm/W. It should be noted that this luminaire emits 25% fewer lumens than the general luminaire in this example.

Luminaire Basics:
- 5,911 luminaire lumens
- 79 W input watts – LER: 75

This distribution does not emit any uplight. The distribution for this luminaire is slightly wider than the general luminaire example. The lower lumen output leads to lower illuminance values. The different distribution leads to better uniformity.



This design has the same minimum illuminance value as the general luminaire design. This design does not meet RP-20's maximum/minimum uniformity of 10:1. In addition, this design has more calculated measurement points in the range between 1–10 fc. LER is an important characteristic, but make sure that the luminaire provides sufficient lumens to meet the targeted light levels. Calculations represent the initial values and do not include light loss factors (LLF). LLF should be included and determined per site.

Lighting Information:
- Average: 6.5 fc
- Maximum: 15.8 fc
- Minimum: 1.3 fc
- Average:Minimum: 5:1
- Maximum:Minimum: 12:1
- % of points 1–10 fc: 95%

The LER is roughly 20% higher than the LER for the general luminaire design. However, the LPD is 40% lower because the selected distribution allows for a luminaire optimization saving additional energy while providing suitable amount of lighting and quality.

Lighting Power Density:
- LPD: 0.09 W/sf

LIGHTING CONTROLS SAVE ENERGY

Installing energy efficient equipment is one step towards an energy efficient design – a good compliment are lighting controls. Energy is power multiplied by time; controls can either reduce the time or power components of the equation. Ideally it is best to install controls at the same time as installing any new or replacement equipment because the electrician is already on site. Parking structures are ideal spaces for multiple types of lighting controls that can yield significant energy savings on top of the efficient luminaires. Significant points of the following lighting controls section include:

1. Types of controls that can be used in parking structures
2. Factors to consider when selecting lighting controls for parking structures
3. Same operation of luminaires with various lighting controls
4. Recommendations to maximize energy savings

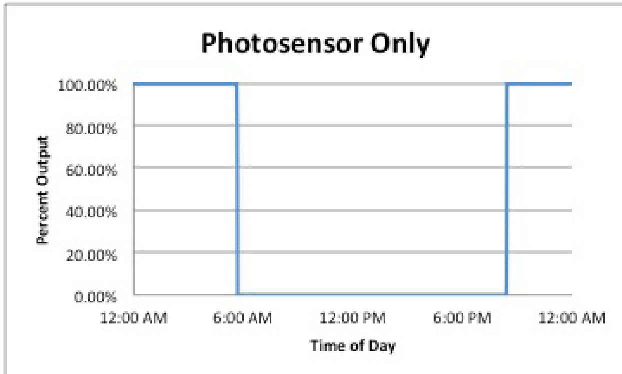


Figure 11. Real time monitoring for a mid-spring day of a luminaire in a parking structure only controlled by a photosensor. The luminaires turn on around sunrise and off around sunset.

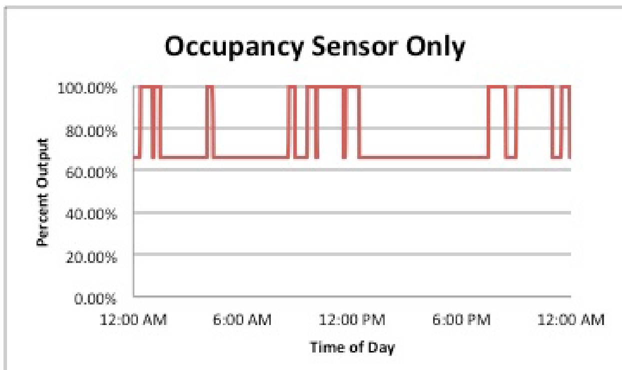


Figure 12. Monitoring for the same structure with an adjacent luminaire only controlled by an occupancy sensor. The sensor reduces the luminaire output by one-third after 20 minutes of no activity detection.

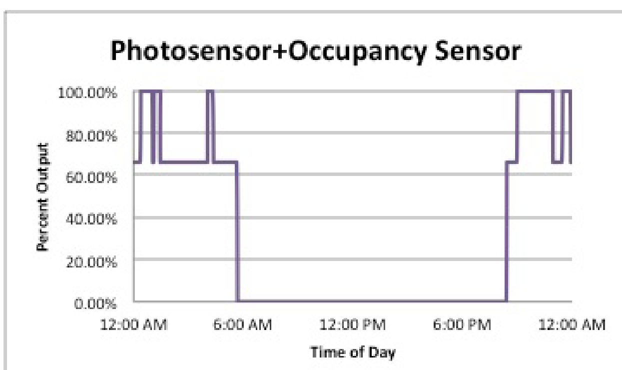


Figure 13. Monitoring for the same structure using both photo and occupancy sensor controls. When daylight is available, the luminaire is off. When it is dark outside, the luminaire is controlled by the occupancy sensor.

PHOTOSENSORS

Parking structures operate throughout the day. Luminaires along the perimeter of the parking structure can be turned off or dimmed when sufficient daylight is available. In recent years, some energy codes have required this feature.

Figure 14. Electric lights off during the day.

Figures 11–13 show monitoring data under different control configurations. Figure 14 is a parking structure in Livermore, CA where daylight is streaming into the space. The electric lighting is turned off because of the ample, free, and energy saving daylight.

Photosensors can yield significant savings, yet the use of them in a parking structure requires careful consideration:

Siting: The adjacent buildings or future buildings (not always possible to know during design) can prevent daylight from entering the space; therefore, a review of the entire site and adjacent sites is necessary.

Vertical optimization: Photosensors are usually most effective on the top floors and less effective in the lowest floors of the structure because the lower floors may be blocked by the adjacent buildings and trees.

Lighting choice: If daylight dimming is going to be used with the sensors, the choice of lighting matters. HID sources can dim, but have limitations in dimming range that can erode some savings potential. Not all induction sources dim easily, but some manufacturers offer bi-level (full output and low output) luminaires that could be used with photosensors. Fluorescent and LED sources can use either dimming or bi-level power supplies to operate with photosensors.

Low output setting: The greatest savings would be achieved by turning off the lights completely. However, often for security concerns (especially at night), the low output setting is a partial reduction in full power of some extent.

Location of the luminaires: As the distance of the luminaire from the parking garage perimeter increases, the effectiveness of the daylight and photosensor diminishes. Lighting simulations can be performed, but a general rule is that beyond 20 ft of the perimeter, the luminaires should not be used with daylight dimming or daylight off without extremely careful design and operation considerations.

OCCUPANCY SENSORS

Parking structures are not occupied continuously, but often are lighted continuously. Occupancy sensors, which have a proven history in interior spaces like warehouses and stairwells, can also be used in parking structures.

More codes are considering requiring this technology for certain areas in parking structures. Many energy efficiency programs offer incentives for using these controls. They can produce significant energy savings (see Table 2), but extra care must be taken during the design phase to ensure seamless and reliable operation.

Type of sensor: Passive-infrared (PIR) sensors are the most common for use in parking structures. They respond when a heat source (such as a vehicle or a pedestrian) moves from one IR-sensitive zone of the sensor's view to another.

Control logic: A single occupancy sensor can control a group of luminaires or each luminaire can have an occupancy sensor assigned to it. If the sensor controls a group of luminaires, the sensor's coverage area must match the area lighted by all of the luminaires. Thus, careful selection and placement of the sensor is needed.

Time delay: The time delay is the period the sensor waits to send its on/off or high/low signal to the luminaire. The shorter the time delay, the greater the savings. An initial time delay of 10 minutes is recommended, and this can be reduced as staff feel comfortable with the setting.

Power reduction: The lighting power reduction is the low output setting and is often described as a percentage of full output. If possible, choose a luminaire where the low setting can be changed in the field, or do extensive mock ups using the low setting before procuring the equipment for your site.

Figures 15–17 show monitoring data under different control configurations.

Table 2. Quick reference for occupancy sensor configurations for savings

	Long Time	Short Time
Little Power Reduction	◔	◑
More Power Reduction	◕	●

The more black in the circle indicates greater savings. Savings are maximized when the time delay is short and there is a more power reduction in the low setting as shown by the solid circle.

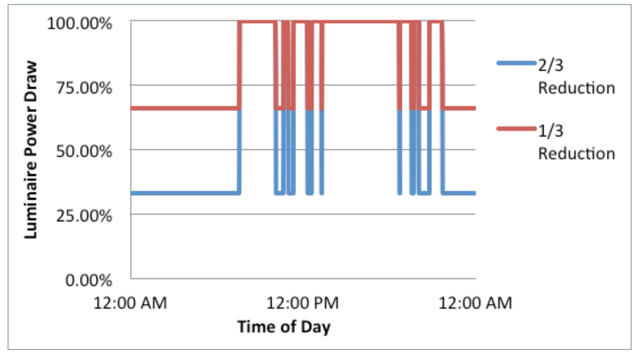


Figure 15. Sample data from an aboveground parking structure supporting an educational campus during the weekday. The figure depicts the usage when the low setting (when no activity is detected) is two-thirds and one-third full power. When the low setting is two-thirds reduction from full power, more energy is saved.

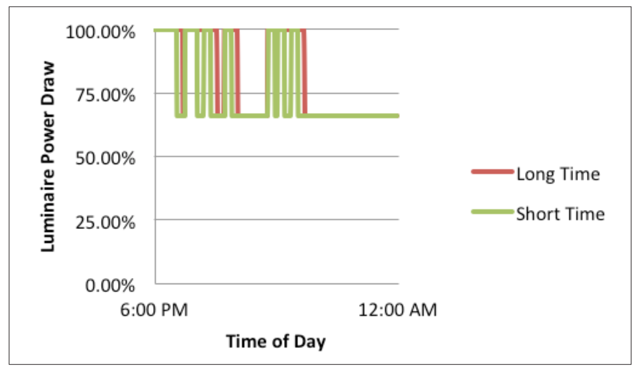


Figure 16. Sample data from an aboveground parking structure supporting an educational campus from 6:00 pm to midnight on a weekday. In the "long time" setting, the luminaire waits for 20 minutes after last activity is detected to go to the low setting. In the "short time" setting, the luminaire waits only for 10 minutes after last activity to go the low setting. The shorter the time delay, the greater the energy savings.

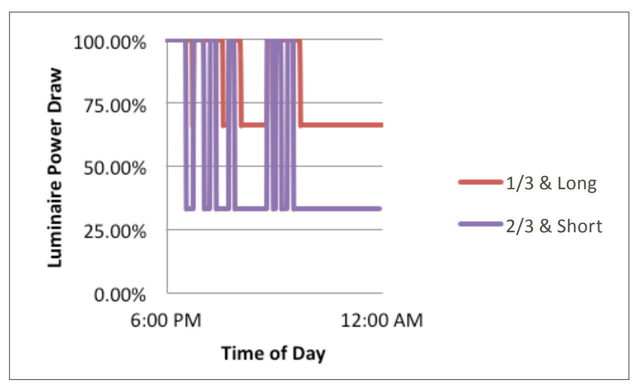


Figure 17. Sample data from an aboveground parking structure supporting an educational campus from 6:00 pm to midnight on a weekday. This graph compares little power reduction and a long time delay to a significant power reduction and a short time delay. Combining the short time delay with the greatest reduction in output permissible can optimize energy savings.

COST-EFFECTIVENESS

An efficient product option is cost-effective relative to a base model when the cost savings (energy and maintenance) exceed any incremental costs, including installation over a comparable functional lifetime. Federal purchasers may assume that products meeting FEMP-designated efficiency requirements are life-cycle cost-effective if the net savings are positive. An example is provided in Table 3, comparing a base model to a luminaire that meets the FEMP requirements. Here, because the luminaire meeting the FEMP requirement's first cost (lamp cost + luminaire price) is less than the "Lifetime Operational Cost Savings" from Table 3, the product is cost-effective. Users wishing to determine cost-effectiveness for their applications may do so using the example provided in Table 3.

Products meeting FEMP-designated efficiency requirements may not be life-cycle cost effective when energy rates are below the federal average or in certain low-use applications. For most applications, purchasers will find that energy-efficient products have the lowest life-cycle cost. In high-use applications or when energy rates are above the federal average, purchasers may save more if they specify products that exceed the federal minimum efficiency requirements. Table 3 is an example, and values will vary by site.

Table 3. Lifetime Savings for Efficient Parking Garage Luminaires

Cost-Effectiveness Example		
Performance	**Base Model**	**Required Level (*minimum LER 70*)**
	Pulse-Start Metal Fixture	**LED Fixture**
Luminaire Efficacy Rating (LER)	62	75
Luminaire Output	8,058 lumens	5,911 lumens
Power Input	129 watts	79 watts
Light Source Life[1]	20,000 hours	75,000 hours
Lamp Cost[2] (a)	$47	---
Luminaire Price[2] (b)	$169	$448
Annual Energy Use[3] (c)	1,130 kWh	692 kWh
Annual Energy Cost[4] (d)	$114	$70
Lifetime Energy Cost[5] (e)	$797	$488
Lifetime Replacement Cost – Lamp (f = a x 2.4)	$113	–
Lifetime Replacement Cost – Labor[6] (g)	$78	–
Total Lifetime Costs[7] (b+e+f+g)	$1,157	$933[8]
Lifetime Cost Savings (Base Model – Required Level)	**–**	**$224**
Lifetime Operational Costs Savings [Base (e+f+g) – Required (e+f+g)]		**$500**

[1] Life value is per manufacturer's data. LED luminaire life encompasses many elements, but this manufacturer claims 75,000 hours for the LEDs (L70) and driver at a drive current of 530 mA in an ambient temperature between 25°–40° C (77°–104° F).

[2] Prices for real products from www.gsaadvantage.com (last accessed February 15, 2013).

[3] Assumes 24 hour x 365 day operation and does not assume the use of lighting controls.

[4] Assumes an electricity rate of $0.10/kWh; substitute your rate as required. Future electricity price are based on federal guidelines and forecasts effective from April 2012 to March 2013.

[5] For this analysis, the lifetime is 9 years. This was calculated by dividing the longest life system (75,000 hours) by 8,760 (24 hours x 365 days).

[6] Assumes an electrical worker spending a set amount of time to replace the lamps in the luminaire. In this case, labor is the sum of the discounted value of the labor and associated equipment costs (e.g., truck lift) to replace a lamp. The assumed labor cost is $65 per hour. Substitute with your data as required.

[7] A real discount rate of 3.0% is based on federal guidelines effective from April 2012 to March 2013.

[8] Discount rate and future costs are the reasons this value does not equal $448 + $488.

RESOURCES

The following are resources from the U.S. Department of Energy (or supported by DOE) that specifically focus on parking structures. DOE also offers general and specific information about lighting.

Low-Energy Parking Structure Design

Lighting plays a prominent role in this 2013 case study by the National Renewable Energy Laboratory of the design and construction of a parking structure that saves 90% of the energy compared to a baseline parking structure.

http://www.nrel.gov/docs/fy13osti/52025.pdf

Lighting, Development, Adoption, and Compliance Guide

This 2012 guide, starting on page 26, provides guidance on complying with energy codes for parking garages and includes important information on lighting controls.

http://www.energycodes.gov/sites/default/files/documents/Lighting_Resource_Guide.pdf

Use of Occupancy Sensors in LED Parking Lot and Garage Applications: Early Experiences

Occupancy sensors in parking structures are somewhat new, but are gaining interest. This 2012 report from the DOE GATEWAY Program highlights both the success and challenges experienced with occupancy sensors in these environments.

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_gateway_sensors.pdf

Lighting Checklist – Parking Garage Lighting

This 2011 checklist is focused on retrofitting parking garages. The checklist contains a comparison of light sources.

http://www1.eere.energy.gov/wip/solutioncenter/pdfs/doe_eecbg_parking_factsheet.pdf

Exterior Lighting Guide for Federal Agencies

This 2010 guide for federal agencies provides tips for evaluating light sources, performing lighting audits, and pairing lamps with lighting controls. It focuses on exterior applications and parking structures.

http://cltc.ucdavis.edu/images/documents/publications_reports/DOE_FEMP_Exterior_Lighting_Guide.pdf

Demonstration Assessment of Light-Emitting Diode (LED) Area Lights for a Commercial Garage

This 2008 report from the U.S. Department of Energy Program highlights a demonstration that saved roughly 60% of the energy compared to the existing system. The luminaires installed in 2008 had an LER of 60 lm/W, but the efficiency of the technology has increased since that time.

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_ppmc.pdf

CBEA High-Efficiency Parking Structure Lighting Specification

This parking structure lighting performance specification is intended to provide adequate illumination in parking structures/garages, and save energy by reducing the installed power density of equipment below code as well as using controls to further reduce energy use.

http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/creea_parking_structure_spec.pdf

The Department of Energy's Federal Energy Management Program's (FEMP) mission is to facilitate the Federal government's implementation of sound, cost-effective energy management and investment practices to enhance the nation's energy security and environmental stewardship.

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