U.S. DEPARTMENT OF ENERGY

PNNL-20579

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Exterior Lighting Scoping Study

M.A. Myer

September 2011

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Richland, Washington 99352

Executive Summary

This scoping study characterizes commercial building exterior lighting use and identifies opportunities for additional energy savings through the U.S. Department of Energy (DOE) Commercial Building Energy Alliances (CBEA) program and other deployment measures. (This work was initiated as part of the CBEA fiscal year 2011 portfolio.) This report focuses on exterior lighting in the commercial buildings sector and examines aspects of lighting systems and their installation that can affect energy use. The aspects examined include:

- lighting controls;
- luminaires (light fixtures); and
- existing DOE exterior lighting programs.

The characteristics of outdoor lighting related to each of these aspects are explored to identify opportunities for improved energy savings that Alliance members and others can take advantage of. These opportunities then also become potential areas for DOE to support. PNNL identified several significant opportunities for saving energy and reducing utility costs. Each has significant energy savings potential and represents the best of the opportunities identified in this study. Although actual savings in real application cannot be determined given the many variables of exterior lighting application, the opportunities discussed below are generally in order of expected savings potential.

Energy usage

DOE estimates that 303 terawatt-hours (TWh) of electricity was used by the commercial sector for lighting in 2009, which includes commercial and institutional buildings and public street and highway lighting (DOE EIA 2010). This 303 TWh is roughly 23 percent of commercial electricity consumption. Definitive estimates for interior versus exterior lighting energy usage are hard to come by, but exterior lighting accounts for at least 8 percent of lighting energy use and probably more (Navigant 2002).

Highway and street lighting

Roadway lighting is not owned by commercial buildings, and is also often owned by utilities. DOE estimates that street (roadway) lighting uses 23.1 TWh/yr of electricity (DOE 2011). Identifying energy savings in this area is challenging because of legal hurdles (e.g., revised tariffs) and given the fact that utilities may lack motivation to replace the lighting because they perform maintenance on the lighting as well. DOE has a program—the Municipal Solid-State Street Lighting Consortium (MSSSLC)—that is focused on replacing conventional street lighting with sold-state lighting based technologies.

Parking garage structure performance specification application and update

DOE estimates that parking structures use 29.1 TWh/year of lighting energy annually (DOE 2011). The luminaires in parking structures typically operate 18 hours per day or more, and parking structures have infrequent occupancy times as well as low occupancy. DOE has a performance lighting specification, developed by the CBEA Lighting Project Team, for high efficiency parking structure lighting.[1] This specification is aggressive compared to current standard practice because it specifies light levels at but not above Illuminating Engineering Society of North America (IES) recommendations and

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

limits allowed power density. This prevents parking structures from being over- lighted or using inefficient lighting technology. The specification sets a minimum of 40 percent of energy savings compared to ANSI/ASHRAE/IES[2] Standard 90.1-2007, with even more energy savings being possible through the use of lighting controls. In addition to the energy savings, the specification sets the power density requirements so the site can qualify for a federal tax deduction (also known as the 179D tax deduction, the location in the tax code). However, the newer ANSI/ASHRAE/IES Standard 90.1-2010 has lowered the power density and has control requirements similar to those in the CBEA parking structure specification.

Although this specification is in place and is being used by some, there are opportunities for DOE to help other organizations adopt it until standard design using the specification becomes common practice and is universally accepted. This may include direct training for the broader community of commercial businesses as well as lighting designers, distributors, and others who are unfamiliar with the technology(s). Continued assistance to help large commercial organizations promote use of the specification (energy efficiency and sustainability) as part of their corporate strategy is also important. Additionally, there may be value in supporting an update of the specification to include more advanced control strategies that are in line with the most recent energy standard requirements (i.e., ANSI/ASHRAE/IES Standard 90.1-2010).

Site lighting (parking lot) specification application and update

DOE estimates that parking lots use 22 TWh of electricity annually (DOE 2011). A site lighting (parking lot) specification, developed in close consultation with Alliance members, has been completed, is available for download from DOE's website[3], and is being applied by some Alliance members. Savings from the use of the specification is typically in the range of 50 to 80 percent of current lighting energy compared to ANSI/ASHRAE/IESNA Standard 90.1-2007. If implemented in all parking lots across the country, this could equate to 11 to 18 TWh per year in energy savings. Note that the values in the newer ANSI/ASHRAE/IESNA Standard 90.1-2010 are close to the values in the specification.

The specification also provides other requirements for lighting uniformity and quality, as well as control strategies. This level of aggressive specification is critical to saving energy, but may inhibit its quick adoption in the market. There may be opportunities for DOE to help overcome initial hesitation using similar training and/or assistance as identified for the site lighting specification. DOE could also support updates of the specification to enable more advanced controls in order to provide a more energy effective specification.

Control application guidance

Many current and planned exterior applications have or will have no controls beyond simple on/off or dawn-to-dusk control. As lighting technologies improve and power allowances become more restricted (through energy code requirements), controls represent the largest remaining area for lighting savings.

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[2] American National Standards Institute, American Socieity of Heating, Refrigerating and Air-Conditioning Engineers, Illuminating Engineering Society of North America.
[3] http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/led_site_lighting_spec_06_09.pdf

This is supported by a interior lighting scoping study completed for DOE,[4] which concluded that controls and their effective application is the number one need in the industry and the best source for energy savings. Control savings for most exterior applications can easily be 30 to 50 percent. This is a direct result of the understanding that most commercial sites are not open through the night and therefore full output of the entire exterior lighting design is not required after business hours. More advanced control strategies are available and written into the most recent voluntary energy codes, which are eventually considered for adoption by states and local jurisdictions. Advanced control options could be applied to most exterior lighting with appropriate guidance. This includes building façade, landscaping, parking, walkway and plaza lighting as well as some signage and advertising. DOE could support the development of a guide/specification that provides information and application requirements for the different applications in exterior lighting. Alliance members and others could use this guide to help maintenance, retrofit, and new installation staff develop controls for their projects.

Wallpack (wall mounted) lighting specification

After street/highway, parking structure, and parking lot lighting, wallpacks (luminaires mounted to the wall) use the most energy in exterior lighting. Due to their widespread use, wallpacks are a promising source of potential energy savings. Exact energy use estimates are hard to come by, but anecdotal evidence suggests a sizable amount of energy, but certainly less than what parking lots or structures use annually. Wallpack luminaires are typically wall-mounted lighting on exterior surfaces that cast light on lower wall surfaces and the surfaces below. Wallpack lighting represents one of the more common exterior lighting applications and is found in designs for most building types to provide a sense of building presence, security, or corporate branding. In reality, wallpacks have a limited purpose beyond offering a sense of building presence, and fixture efficiencies are historically low. Currently, there is no CBEA product specification for wallpack lighting, although some Alliance members have expressed support for one. A specification that provides some rational application requirements and minimum product efficiency could support an eventual change in typical energy use in this application. DOE could help develop an effective general specification that would serve as design criteria for wallpack application at all building types.

[4] This study was completed by Pacific Northwest National Laboratory (PNNL) in February 2010 for DOE internal use.

Recommendations

This section lists the recommendations contained within this scoping study. It also provides a brief statement of the rationale for each recommendation and the primary pros and cons. Options are listed in the order of appearance within the scoping study and not based on energy savings potential.

Option 1 DOE might consider supporting research and development towards a better photosensor and photodiode technologies

Rationale: A large amount of exterior lighting is controlled via photosensor technology and more robust technology would support more effective energy savings. Photosensors have a much shorter lifespan than new lighting sources, and can leave luminaires operating during the day when ample daylight is available.

Pros: Additional energy savings from turning off errant operating luminaires. Lower maintenance cost with more robust and longer life products.

Cons: Existing technology works “okay”—owners might ask “Why fix what is not broken?”; other issues like dirt and debris cannot be mitigated using technology.

Option 2 DOE could support the development of network/wireless-based controls for exterior applications, while working with CBEA members to help ensure that building owner needs and concerns are addressed.

Rationale: Controls represent the largest energy savings potential. However, running communication signal lines to the luminaires is very costly. Much like in buildings, wireless communication represents the greatest potential for existing sites.

Pros: Retrofit applications have the highest potential for energy savings due to the large market of existing applications compared to new construction.

Cons: Effective network/wireless controls can be expensive to implement and may require the development of extensive format variation.

Option 3 DOE may consider supporting research and development and commercialization for occupancy sensors in more exterior applications.

Rationale: Parking lots and structures are commonly lighted during periods of little and even no occupancy. Sensors offer high energy savings potential, but there are still technological hurdles for application in larger and higher pole locations. Energy code bodies are currently offering this control as a compliance option and will continue to consider it as an absolute requirement in certain applications.

Pros: High energy savings potential both at the site level and the national level; could increase the sense of security by increasing the lighting when movement occurs.

Cons: Not a short-term project or application; current sensors have limitations in coverage areas which will be a potentially difficult hurdle; current sensors have false-positive sensing issues for some applications.

Option 4 DOE could support the application of exterior lighting shutoff and lighting reduction of all DOE/federal facilities in accordance with the latest available commercial energy codes and standards.

Rationale: Newly adopted energy codes require the exterior lighting be turned off or reduced in some level after business or occupancy hours at night. Following this practice at DOE sites would not only save DOE energy, but also show the public how the practice works.

Pros: Use of such controls at DOE facilities sets a good example and will support market development of effective controls.

Cons: May be difficult to enforce facility directives without additional organizational directives.

Option 5 Continue to support LED site lighting specification.

Rationale: Site lighting or parking lots often operate 12 hours or more. The CBEA specification already exists, and through continued support the specification will lead to greater energy savings.

Pros: Significant energy use application; specification already exists; it has already been used by some companies, indicating that market may be approaching tipping point for wide-scale application.

Cons: Specification already exists, and thus the relative return on investment might be greater elsewhere.

Option 6 DOE may consider developing a technology specification for bollards that incorporates the use of sensors.

Rationale: Typical bollards are extremely inefficient—roughly only 25 percent of the light leaves the luminaire. Although these luminaires are used selectively and represent low energy usage on a national level, technologies exist to save large amounts of energy within this particular application

Pros: Near-term project with significant energy savings achievable within the application because energy efficient technologies exist today

Cons: Typically expensive per luminaire; quantity low per site and thus low national energy savings potential in absolute sense.

Option 7 Continue to support high-efficiency parking structure specification.

Rationale: Parking structures typically operate 18 hours or more, and energy savings can be gained by taking advantage of daylight and low continuous occupancy of the space. The CBEA specification already exists, and through continued support the specification will lead to greater market uptake and national energy savings.

Pros: Significant energy use category and significant energy savings potential; specification already exists; works with 179D tax deduction; ahead of most energy codes in the space.

Cons: Because specification already exists, relative return on investment might be greater elsewhere.

Option 8 DOE could consider developing a technology specification for wallpacks and incorporate the use of sensors.

Rationale: Although exact energy usage estimates are not available, anecdotal data suggests that 20 percent of the energy used at a site is directly attributable to wallpacks and typically the next highest use behind parking areas. Conventional wallpacks are often ineffective, inefficient and sometimes create offensive glare. A specification could improve the performance of this luminaire type.

Pros: Roughly 20 percent of building exterior energy usage; typically represent more than 20 percent of the luminaires on site increasing the potential for volume purchase aspects; new energy efficient luminaires incorporating could save at least 40 percent of the energy compared to typical products on the market.

Cons: Need to address luminaires located near emergency doors, which require egress/code integration; Also need to address general building perimeter security issues.

Option 9 Integrate CBEA specifications into AEDGs.

Rationale: Many recommendations in the ASHRAE Advanced Energy Design Guide (AEDG) for 50 percent savings for small to medium office buildings are very similar to those in the CBEA LED Site Lighting Specification. The specification includes more information than provided in the high level recommendations in the AEDG. Sharing resources across multiple DOE products encourages the use of the products.

Pros: Product already exists, thus requiring little additional work beyond pairing the two resources.

Cons: Tracking use of the AEDG is difficult and tracking the use of the specification within the AEDG will be even more difficult, *Option 10 Increase awareness and use of the FEMP Exterior Lighting Guide.*

Rationale: The guide provides excellent high-level recommendations and information about exterior lighting. Most of the information in the guide is very applicable beyond the federal building sector.

Pros: Guide already exists.

Cons: Although the guide is available online, additional resources (time and money) would be required to increase use of the guide.

Option 11 Continue updating FEMP's web site and related specifications.

Rationale: FEMP is already in a position to have a direct effect on federal agencies and sites. Updating the web site with additional exterior SSL resources, including the FEMP specifications could lead to greater energy savings.

Pros: Communication and deployment avenue(s) already exist.

Cons: Requires additional resources (time and money).

Acronyms and Abbreviations

AEDG	Advanced Energy Design Guide
AFG	above finished grade
ARRA	American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CALiPER	Commercially Available LED Product Evaluation and Reporting
CBP	Commercial Building Partnership
CFL	compact fluorescent lamp
CLTC	California Lighting Technology Center
CMH	ceramic metal halide
CRI	color rendering index
DOE	U.S. Department of Energy
EMS	emergency management system
EPAct	Energy Policy Act of 2005
FEMP	Federal Energy Management Program
GSA	General Services Administration
HID	high-intensity discharge
HPS	high-pressure sodium
IES	Illuminating Engineering Society of North America
LED	light-emitting diode
LMC	Lighting Market Characterization
MH	metal halide
MSSSLC	Municipal Solid-State Street Lighting Consortium
MV	mercury vapor
NEMA	National Electrical Manufacturers Association
PLC	power line carrier
PMH	pulse-start metal halide
PNNL	Pacific Northwest National Laboratory
SSL	solid-state lighting
TER	target efficacy rating

Contents

Figures

Tables

1.0 Exterior Lighting Energy Usage

This scoping study examines exterior lighting applications and energy use to assist U.S. Department of Energy (DOE) Commercial Building Energy Alliance (CBEA) members and the DOE in selecting projects to pursue.

1.1 Energy Information Agency

DOE estimates that lighting roughly used 300 terawatt-hours (TWh) of electricity 2010, which includes lighting for commercial and institutional buildings, public streets, and highways (DOE EIA 2010). This approximate 300 TWh is roughly 22 percent of commercial electricity consumption.

1.2 Lighting

DOE is updating their summary analysis about lighting usage, the Lighting Market Characterization (LMC), but the study is not yet complete. Therefore, the 2001 version (Navigant 2002), which is most current, provides the basis for energy usage and other values of lighting related to exterior lighting. The LMC is 10 years old, and in that time the U.S. population has grown as has the stock of the built environment. Although buildings and technologies have become more efficient in that time as well, the overall usage still has increased.

The 2001 LMC estimates that outdoor stationary lighting is 8 percent of the total lighting energy in the United States (table ES-1 of the LMC). The LMC aggregates exterior lighting energy usage at a commercial or industrial site in the respective category. Therefore, the “outdoor stationary” category does not include parking lighting, façade lighting, step lighting, landscape lighting, wall packs, or any exterior lighting at a commercial or an industrial site.

Site energy is the energy used by the end use whereas primary (source) energy is the raw fuel (e.g., coal or natural gas) before any transformation to secondary (e.g., electricity) or tertiary energy. Primary energy is typically presented in tables and analysis because it is useful in understanding generating capacity and the need or reduction of power plants. Site energy is presented because this is what end users actually pay for in their bill. Due to inefficiencies at both the power generation site as well as the transmission system, there is roughly a 65 percent loss in the conversion from primary energy to site energy.

Table 1-1. National Energy Use for Lighting Disaggregated by Sector 2001

Sector	Site Energy (TWh/yr)	Primary Energy (quads)	Percent of Total
Residential	208	2.2	27
Commercial	391	4.2	51
Industrial	108	1.2	14
Outdoor Stationary	58	0.6	8
Totals	765	8.2	100

Outdoor stationary energy usage is considerable, estimated to be around 57.8 TWh[a] per year according to the LMC (Navigant 2002). Table 5-20 of the LMC (shown here as Figure 1-1) breaks down the lighting energy use as follows.

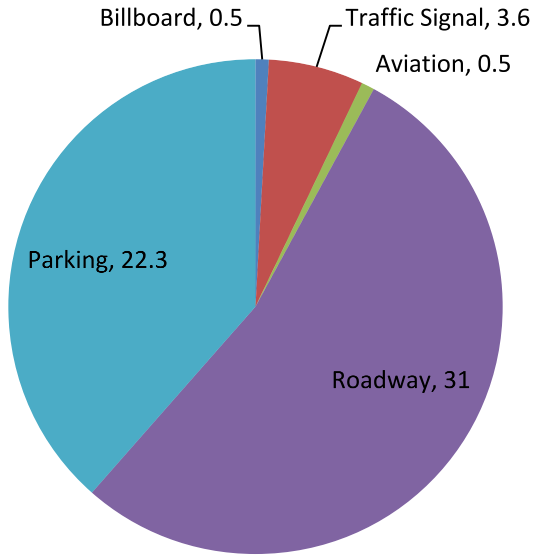

Figure 1-1. Exterior Lighting Energy Usage per DOE Lighting Market Characterization

Note: Due to rounding, the numbers in Figure 1-1 do not add up to 57.8 TWh.

1.3 DOE Solid-State Lighting Niche Report

In 2011, DOE published a new report, *Energy Savings Estimates of Light-Emitting Diodes (LEDs) in Niche Lighting Applications* (DOE 2011). The report focuses on niche applications for LEDs in both interior and exterior application. This scoping study focuses on exterior lighting in general and is technology neutral. However, the niche report estimates energy usage in outdoor lighting, and those values are used to estimate energy usage of different lighting technologies (Table 1-2).

Table 1-2. Estimated Annual National Outdoor Lighting Energy Usage 2011

Sector	Annual Energy (TWh)
Area Lighting	67.3
Flood	60.0
Street	23.1
Highway	29.7
Parking Structure (Garage)	28.1
Parking Lot	23.0
Totals	231.2

[a] For consistency, all units of energy are converted into terawatt-hours (TWh). TWh are 10^9 times larger than kilowatt-hours (kWh)). “Quads” are quadrillion (10^15) British thermal units and typically are given in primary energy terms. A quad is roughly 293 times larger than one TWh.

The niche report is not a survey, but rather a summary estimate. The energy values were calculated by estimating the typical operating hours multiplied by the assumed input power of the luminaires.

1.4 Energy Estimate Summary

The different reports identified above use various methodologies, data sets, and are from different points in time. Since the niche report is the most current (2011), this scoping study draws on those energy use estimates.

2.0 Lighting Controls Review

Installing efficient equipment helps save energy, but too often the "time" component of energy (power × time) is overlooked. At some point, technology efficiency will reach a practical limit and the controls that manage the equipment will have the maximum effect on energy savings. Lighting controls can turn off or dim the lighting during low occupancy, when sufficient daylight is available, at scheduled times of low use, or by other automatic means. Lighting controls can be categorized by primary strategy type, and each type has specific capabilities and capacities. Primary strategies include photosensors (daylighting-based controls), energy management control systems (network-based controls), time clocks (time-based lighting controls), and occupancy sensors (occupancy-based sensors).

2.1 Daylighting-Based Controls

Many exterior fixtures (parking lot and roadway) are controlled by photosensors/photodiodes. Typically these are devices mounted to a luminaire that turn the light on around dusk and off at dawn based on the sensitivity setting of the sensor. Because the on/off mechanism is triggered by the amount of daylight, fixtures may operate on rainy or extremely overcast days when there is insufficient daylight.

2.1.1 Energy Savings Potential

When a photosensor/photodiode fails or is covered in dirt or grime, the fixture can operate during the daytime. Fixtures in this condition are known as "day burners." It is common to see the lighting on in a parking lot in the middle of the day because of day burners, and no light source is immune. Energy loss from this issue will vary based on site location and environmental conditions but the availability of more robust sensor technology could help eliminate this loss.

2.1.2 Device Lifetime

Many municipalities have converted to LED or induction sources because of the long lifetime expected of these light sources. The cost effectiveness of these retrofits is often based on deferred maintenance. However, if the photosensor controlling the light fixture fails, then the deferred maintenance is not fully realized. This is because it is most cost-effective to repair/replace the entire lighting unit (fixture, photosensor, lamp) at one time so it does not provide a cost savings if the photo sensor fails before the lamp

2.1.3 Sensitivity Issues

The diode senses the amount of daylight. Dirt, leaves, bugs, bird fouling, and other environmental elements can build up on the sensors. Better and more sensitive sensors are needed.

Option 1	*DOE might consider supporting research and development towards better photosensor and photodiode technologies.*

2.2 Network-Based Controls

Network-based controls are also known as energy management systems (EMSs). With this control, the luminaires are wired for communication and in some cases provide two-way communication where a central system can receive information from the luminaire about temperature, current, and other environmental aspects. Network-based controls can monitor the temperature at the luminaire, which can be especially useful for LED luminaire performance because of the luminaire's sensitivity to extreme or prolonged elevated temperature. Network-based control systems can also monitor the current draw at the luminaire, which can be used to alert facilities personnel that it may be time to replace the lamp.

2.2.1 Energy Savings Potential

The energy savings stem from either dimming or turning off the luminaires. Some EMSs turn off the lights on a schedule; however, if the systems deviate from the standard schedules, no energy is saved. Figure 2-1 to Figure 2-3 show an example of the energy savings and how the systems operate. These images are from a company (Virticus) that makes a network-based control system. The figures show that during the night some of the luminaires in the parking lot can be turned off.

The computer rendered image in Figure 2-1 shows all of the luminaires in the parking lot operating from dusk to 11:00 pm.

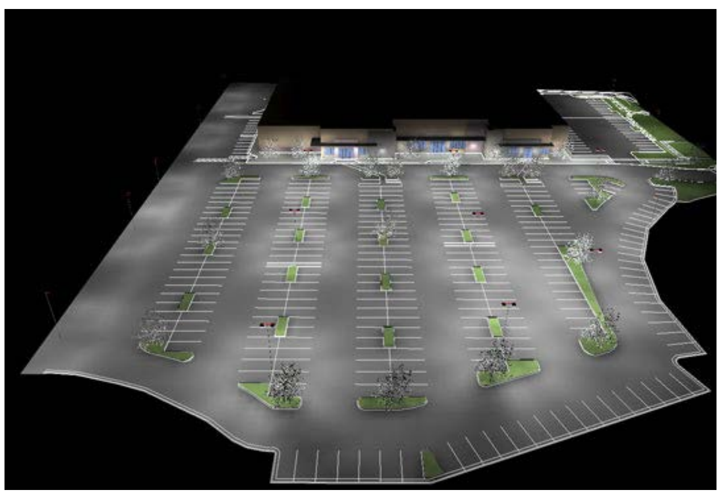

Figure 2-1. Time-Based Control Dusk to 11:00 pm (Image from Virticus)

From 11:00 pm to 2:00 am, fewer people visit the plaza. Figure 2-2 shows the luminaires along the perimeter (upper-right hand and upper left-hand portions of the figure) turned off. Depending on the technology, the lighting in the center of the parking lot could also be dimmed during this time period.

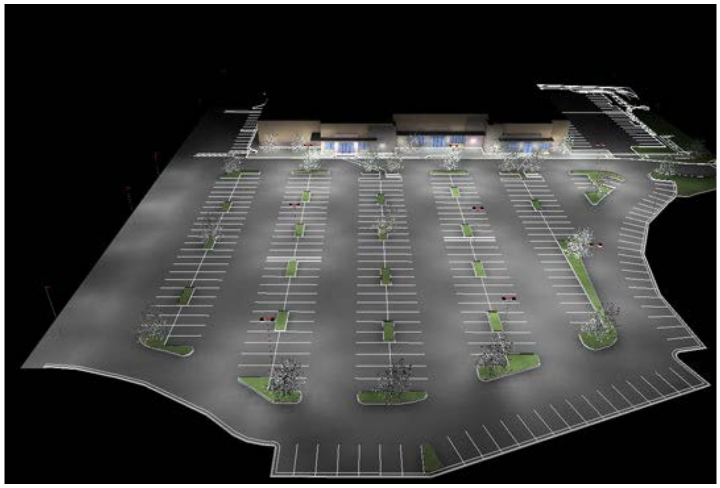

Figure 2-2. Time-Based Control 11:00 pm to 2:00 am

From 2:00 am to dawn, nobody visits the plaza. As shown in Figure 2-3, the only lights on are the luminaires located along the front of the building, the main drive aisle. This provides a sense of security and deters would-be vandals.

Figure 2-3. Time-Based Control from 2:00 a.m. to Dawn

The Federal Emergency Management Program (FEMP) exterior Lighting Guide includes a case study from Fort Benning where wireless controls manufactured by LonMark were used to control outdoor lighting (U.S. Army 2011, LonMark 2011). Neither the Army's web site nor the LonMark case study provide the actual energy savings estimate. Both provide an estimate of money saved ($200,000) for the system remotely turning on and off the field and basketball court lights. Using the national average 2009 commercial electricity[f] rate of $0.1021 per kWh, PNNL estimates that the LonMark system here saves 1.96 TWh/yr.

Network-based controls are being explored for use with roadway applications. DOE's GATEWAY program will test network-based controls in the Portland, OR area in the spring of 2011. Industry

[f] Energy Information Agency
http:/www.eia.gov/totalenergy/data/annual/pdf/sec8_39.pdf

accepted recommendations for roadway lighting are based on pedestrian/vehicle conflict and the volume of traffic. As night progresses, traffic decreases and less light is typically needed. A network-based control system would be one method of reducing the light levels, and consequently energy use, based on these changing conditions.

2.2.2 Issues

In new construction installations, the network-based control technology is easily deployed. However, there are far fewer new construction projects or large scale renovations (involving trenching and rewiring) than retrofits of sites. More energy savings can be achieved by applying network-based controls to the large retrofit market, where rewiring is not economical. Control systems using wireless or power-line carrier (PLC) technology can be applied effectively in these cases.

Wireless receivers can be installed in existing luminaires to receive a signal to either turn off or dim the luminaire. Wireless protocols for exterior applications are still being developed to address signal type differences and distance issues. For instance, the distance between roadway luminaires can easily exceed 150 ft, which may be a difficult distance to accommodate for the wireless signals.

PLC systems send control signals over the lines that supply power to the luminaire. The biggest limitation of this control system is how the wires supplying power are run. If the wires powering the luminaires are not installed in a specific pattern, the signals may not reach the luminaire.

Option 2 *DOE could support the development of network/wireless-based controls for exterior applications, while working with CBEA members to help ensure that building owner needs and concerns are addressed.*

2.3 Occupancy/Movement-Based Controls

Occupancy sensors have long been used in interior environments where occupancy is infrequent. The application of occupancy sensors in exterior applications has been very limited, primarily because much of the exterior lighting was provided by light sources (e.g., high-intensity discharge (HID) lamps) that are difficult to dim or are difficult to turn on and off because of long restart times. However, the use of new technologies for exterior applications has allowed occupancy sensors to be used more readily in exterior environments.

2.3.1 Energy Savings Potential

A study for DOE by the Lawrence Berkeley National Laboratory (LBNL 2010) attributed an estimated 20 percent energy savings in parking lot/garages to occupancy sensors. DOE's solid-state lighting (SSL) GATEWAY program currently has multiple demonstrations of LED lighting systems using occupancy sensors in exterior applications. Energy savings at each of the spaces are expected to be at least 20 percent from the use of the sensors. Figure 2-4 (provided by BetaLED) shows a typical exterior occupancy sensor application with two pole-mounted luminaires configured back-to-back. The round circle between the rectangular fixture and the pole is the occupancy sensor that controls the fixture.

Figure 2-4. Parking Lot Luminaire – Manchester, NH (Credit: BetaLED)

Figure 2-5 shows the expected standard exterior lighting operation controlled only by the presence of daylight, with lighting remaining on all night. Figure 2-6 shows the power use of a recent GATEWAY application of occupancy sensors in a retail parking area where the sensors reduce the overall lighting to a lower level when the space is unoccupied and outright turned off in the middle of the night. In the standard time clock operation, the lights turn on around 7:30 pm and off at 6:30 am whether or not anyone is in the parking lot. Empty spaces are lighted all night. In contrast, in Figure 2-6 the occupancy sensor is reducing output when no one is in the parking lot. This is during the middle of winter in the northeast, when the sun sets around 4:30 pm, so the lights turned on around 3:00 pm. When occupancy in the parking lot trails off (at 10:04 pm), the sensor reduces the output. As cars come and go, the lights turn on to full output. When no activity occurs in the parking lot, the light output is reduced. Security is always a potential issue when lighting is being reduced or turned off. Motion (occupancy) sensors have been used in mostly residential applications for a long time and now due to new technologies are finding their way into the commercial market.

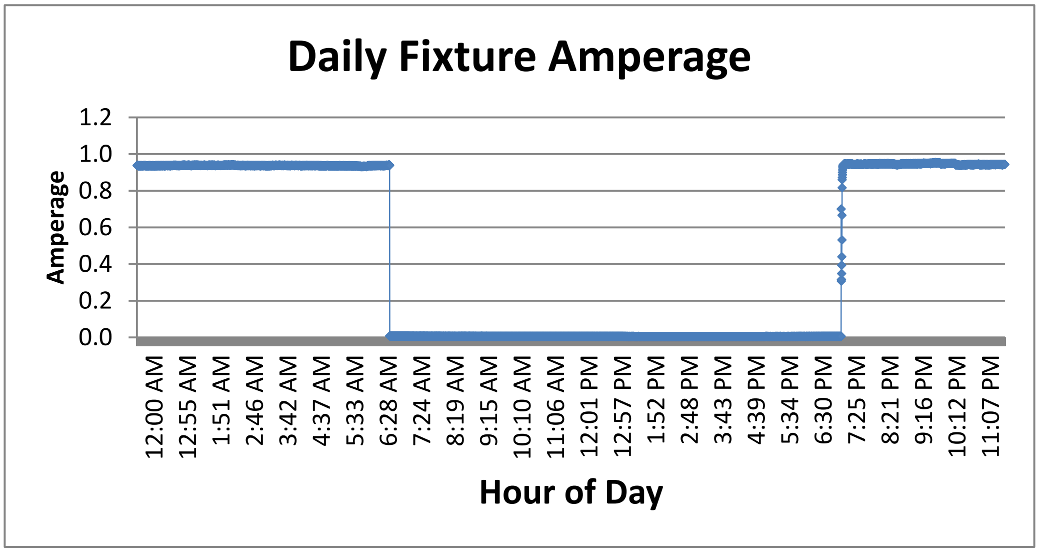

Figure 2-5. Current Draw of Parking Lot Fixture Controlled by Ambient-Lighting

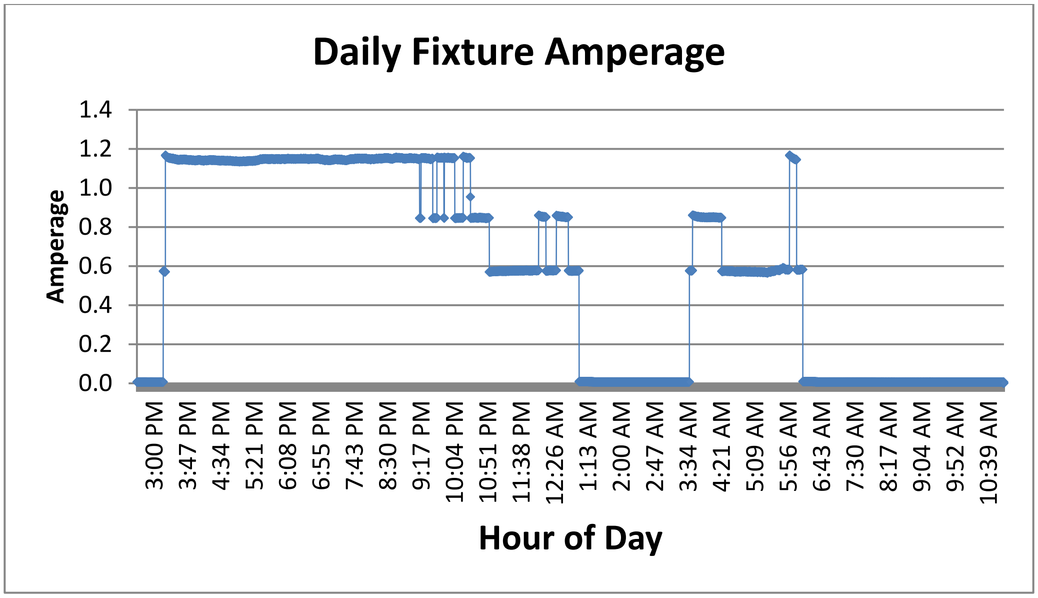

Figure 2-6. Sample Current Draw of Parking Lot Fixture Controlled by Occupancy Sensors

Figure 2-7 is for a different site that is a corporate office building. At 12:00 am Sunday morning, the lights are at low output because no one is working. Around 2:00 am, someone (cleaning crew, security) enters the parking lot and the light output increases. During the day, the lights are off (7:00 am to 7:30 pm). On Monday night, the lights come on at full output around 7:30 pm. As office workers leave, the light output goes from full (1.1 amps) to medium (0.8 amps) as the workers trigger different lights as they leave.

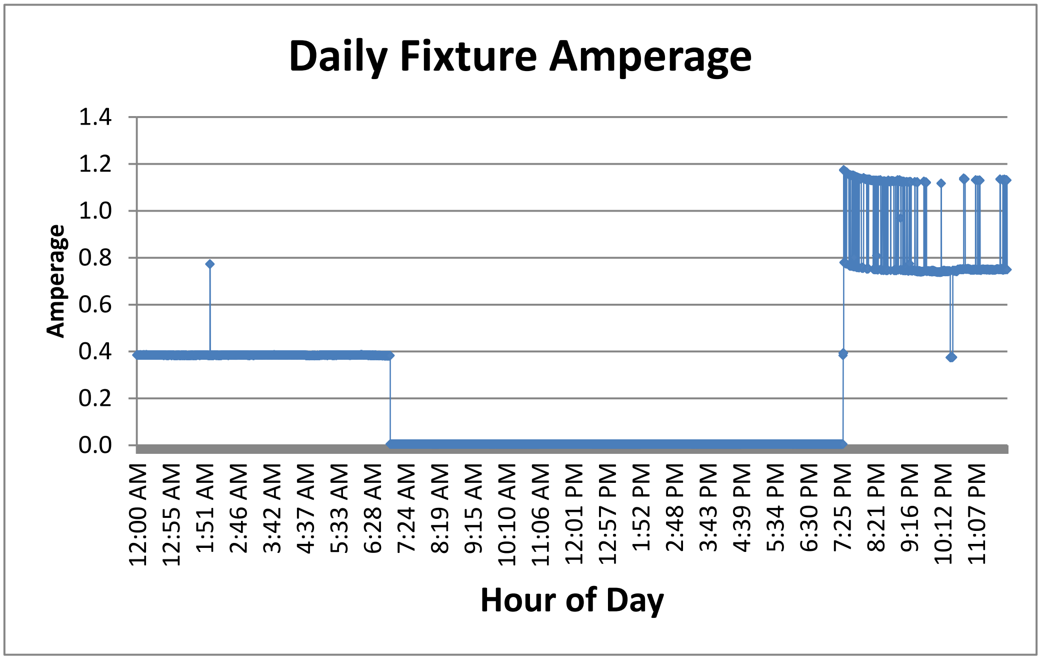

Figure 2-7. Sample Current Draw (on a Sunday) of Another Parking Lot Fixture Controlled by Occupancy Sensors

2.3.2 Issues

Spacing between parking lot poles tends to be roughly four times (or greater than) the mounting height of the luminaire. For an installation with luminaires mounted 30 ft above the ground, the poles could be mounted around 120 ft or more apart. This distance can affect occupancy sensors in parking lots. Figure 2-8 shows a parking lot layout from a recent DOE GATEWAY demonstration where high-pressure sodium (HPS) luminaires were replaced with LED luminaires that had integral sensors in the luminaire heads (PNNL 2010a). The gray circles in the figure depict the coverage pattern of the occupancy sensors. Although the occupancy sensors are effective at saving energy by reducing the lighting when no one is in the space, the coverage pattern makes them ineffective. If a person or car entered the area between the circles, the lights would not be triggered.

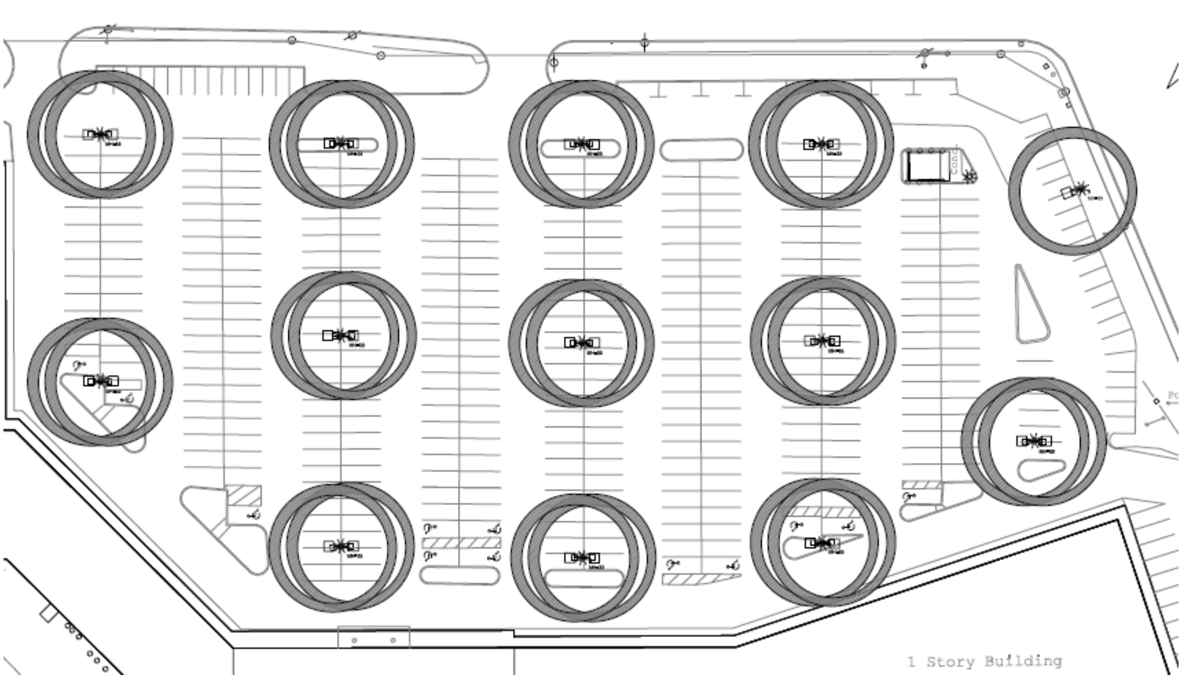

Figure 2-8. Parking Lot Occupancy Sensor Coverage

Potential solutions to the coverage pattern include:

- widening the angle of the sensor and/or moving the sensor location to a point lower on the poles to provide a greater area coverage; or
- creating a network of sensors that communicate with each other for one pole to be aware that the adjacent pole is on and the next pole might need to turn on.

A recent DOE study (GATEWAY-T.J. Maxx Phase II - in draft form) involving occupancy sensors found false-triggers of the sensors were caused by pole movement due to wind and other environmental elements. These false triggers can significantly erode the energy savings capability of the system. Development of a different sensor type or format that eliminates these inherent exterior application issues could support more effective application of this optimal control option and therefore provide for the maximum savings possible in these environments..

Option 3 *DOE may consider supporting research and development and commercialization for more advanced and robust occupancy sensors that are applicable in more exterior environments.*

2.4 Time-Based Controls

The most common type of time-based control is the astronomical time clock. These devices can be simple and small and installed individually around a site. Other systems can be installed centrally and configured to control a larger overall lighting system. The time clock follows the calendar, adjusting turn-on and turn-off times in relation to dusk and dawn. The time clock can also change the lighting based on a fixed time. Depending on the specific clock capabilities, it is also possible to have a time clock turn on the lighting at dusk and off at a preset time (e.g., 12:00 am).

2.4.1 Energy Savings Potential

The energy savings potential of this technology will vary significantly as it depends directly on the potential for scheduling lighting-off periods to match the specific business operational needs. Most energy codes require the use of time-based controls or something similar to shut off lighting after business hours. However, attention to the settings of these types of controls provides the biggest energy savings.

Option 4 *DOE could support the application of exterior lighting shutoff and lighting reduction of all DOE/federal facilities in accordance with the latest available commercial energy codes and standard.*

3.0 Luminaires Overview

Some luminaires (also known as fixtures) offer energy savings potential either through better design (e.g., new light sources or different design) or by incorporating controls. The following section reviews typical types of exterior luminaires, typical sources used with said sources, and related aspects.

3.1 Area Luminaires

Area luminaires encompass parking lot and walkway luminaires. These luminaires light a broad area of hardscape. In some cases, post-top luminaires are used to light walkways, but those luminaires are very different from arm-mounted area luminaires. Post-top luminaires are addressed later in this section. Arm-mounted area luminaires are mounted to a pole and have a short to long arm. Figure 3-1 shows an area luminaire lighting the sidewalk (hardscape) entrance to an office building.

Figure 3-1. Area Luminaire Lighting Hardscape – Burlington, MA (Credit: PNNL)

3.1.1 Overview of Area Luminaires

Area luminaires draw the most power on the site, and they use the most energy because of the high power demand (watts) and long operating hours.

3.1.2 Energy Savings Potential of Area Luminaires

Parking lot and area luminaires (pole-mounted luminaires that comprise much of exterior lighting) typically have downward fixture efficiencies[1] between 54.8 and 88.7 percent, with an average of 75.3 percent (McColgan et al. 2004). In other words, roughly one quarter of the light is not delivered to the application when using conventional luminaires, which are primarily high-pressure sodium and metal halide lamps.

The luminaires typically operate all night because controls or multi-level output operation of conventional luminaires is not currently possible.

3.1.2.1 Energy Savings at the Fixture Level

The low fixture efficiency is a start for energy savings. Reducing the amount of light absorbed within the fixture reduces the amount of overall light needed. The ENERGY STAR[2] program explored a specification for area luminaires. The major limitation with the metric is how to characterize and value the distribution of the luminaire. Crediting an area luminaire solely for luminaire efficacy is a limited approach and would probably not lead to energy savings on a system level. The CBEA LED site lighting specification minimizes site energy use while addressing light levels. Energy use has to be examined at a site level rather than at the fixture level.

3.1.2.2 Energy Savings from Controls

Area luminaires work with the greatest variety of lighting controls. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Many area luminaires are controlled via photosensors. The luminaires are turned on and off at dusk and dawn, respectively.
- Network-based controls: Some of these luminaires are often connected to basic energy management systems and more recently to advanced network-based control systems.
- Occupancy-based controls: Recent demonstrations have experimented with occupancy sensors controlling area luminaires. Coverage of the sensor is limited, but the technology is evolving for this application.
- Time-based controls: Connected to either a basic time switch or an EMS, area luminaires are often controlled via time-based controls.

[1] Downward efficiency is the percentage of light emitted by the luminaire between 0 and 90°. It is typically reported for area, parking, and roadway luminaires. Although additional light may be emitted above 90°, it provides no value to lighting the intended surfaces.
[2] See section 4.4 for more information about ENERGY STAR

Option 5 *Continue to support effective use of exterior lighting through existing LED site lighting specifications.*

3.2 Bollards

Bollards serve multiple functions on a site, providing additional illumination for pedestrians (see Figure 3-2) and, in front of certain buildings, acting as a security/safety barrier by preventing vehicles from driving through the façade of the building (see Figure 3-3).

Figure 3-2. Bollards Along a Walkway – Troy, NY (Credit: PNNL)

Figure 3-3. Bollards at Wal-Mart – Leavenworth, KS (Credit: PNNL)

3.2.1 Overview of Bollards

Bollards are typically made of concrete or some other heavy material. Typical light sources are HPS, metal halide (MH), and compact fluorescent lamps (CFLs). LED bollards recently entered the market. Bollards are typically 42 in. above finished grade (AFG) or less with the light source at the top of the luminaire. Because the light source is near the ground, these luminaires usually need extensive shielding to reduce/prevent glare. This shielding reduces the fixture efficiency of bollards. Typical bollard efficiency is around 25 percent, meaning that 75 percent of the light generated by the light source never leaves the luminaire.

3.2.2 Energy Savings Potential of Bollard Luminaires

Bollards constitute a very small portion of luminaires installed on a given site. The overall low height of the luminaire requires more luminaires to sufficiently light a given space. The size and construction of bollards increase the first cost of the luminaire. These reasons limit the use of bollards on a site. Since the luminaires are mounted low to the ground, the power draw of the luminaires is rather low (typically less than 150W). Combining the low power draw of the luminaire and the sparse installation of luminaires on site means that on a national level the energy savings potential of these luminaires is very low.

On the fixture level, the use of small directional sources (e.g., LEDs) can increase the fixture efficiency of the bollard. Greater fixture efficiency means that more light is leaving the luminaire. If more light is leaving the luminaire, then less light is needed initially leading to energy savings.

An SSL ENERGY STAR specification exists for bollards. As of September 2011, one manufacturer, BetaLED, had four bollards carry the ENERGY STAR label. Per the changes in ENERGY STAR, no new bollards will acquire the ENERGY STAR label in the near future. New optical design based on new/emerging light sources is essential for reducing the fixture losses. LED bollards have made more gains in the market. Plasma or induction lamps would lead to the same low fixture efficiency situation that currently exists. The small size and modularity of LEDs allows for the LEDs to be arranged around the bollard, increasing the light output while reducing the absorption within the fixture.

3.2.2.1 Energy Savings at the Fixture Level

The extremely low fixture efficiency (average 25 percent) offers significant energy savings potential. If the luminaires can be designed to maximize light output and coverage while minimizing glare through superior optical design, energy savings can be achieved.

The SSL ENERGY STAR specification for bollards requires a minimum 500 lumens output, light to be delivered in specific zones, and a minimum luminaire efficacy of 26 lm/W.

3.2.2.2 Energy Savings from Controls

Of the control options reviewed in this report, occupancy-based controls are the best for additional energy savings for bollards. Occupancy-based sensors make sense. For instance, the bollards along the walkway in Figure 3-2 operate all night regardless of whether pedestrians pass by. Integrating occupancy sensors into the luminaires would help save energy by reducing output in the middle of the night when no one is near the luminaire. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Current control strategy.
- Network-based controls: Current control strategy.
- Occupancy-based controls: Integral bollards have been introduced in the market that combine occupancy sensors and bi-level output LEDs. The output becomes low when the occupancy near the bollard is low.
- Time-based controls: Current control strategy.

The California Lighting Technology Center (CLTC) did demonstrations through their Public Interest Energy Research Program (PIER) of bi-level LED bollards at sites in California (PIER 2010a). The bi-level bollard was estimated to save between 50 and 85 percent energy compared to incumbent HID and fluorescent bollards. Some of these savings stem from fewer optical losses with an LED bollard, but a larger share is attributed to the occupancy sensors reducing the amount of light when the area is unoccupied.

Option 6 *DOE may consider developing a technology specification for bollards that incorporates the use of sensors.*

3.3 Canopy Fixtures

Canopies are hybrid exterior spaces in that the space is covered but there are no walls and the space is not conditioned. In researching this fixture type for the scoping study, three types of canopy fixtures were found: surface-mounted, recessed, and high-bay.

Figure 3-4 is of a potential DOE GATEWAY demonstration site in La Jolla, California. The site is a gas station considering replacing the existing metal halide lighting with LEDs on one side of the station and induction luminaires on the other. The interest in LEDs or induction sources is mostly because of the potential to using sensors to reduce light levels somewhat when not servicing a car.

Figure 3-4. Canopy Fixtures at Gas Station – San Diego, CA (Credit PNNL)

During the 2010 semi-annual Retailer Energy Alliance meeting in Minneapolis, MN, representatives from Lowe's inquired about energy efficient options for high-bay canopy fixtures (see Figure 3-5). High-bay fixtures are the inverted mushroom-shaped fixtures often installed in "big box" spaces. These fixtures are not the typical exterior canopy fixture type. In recent years, energy efficient replacements to metal halide high-bay fixtures have included MH fixtures with electronic ballasts, MH fixtures with smaller lamps, and converting to high-intensity fluorescent fixtures. Since nearly all high-bay fixtures are installed in interior spaces, they are beyond the purview of this study.

Figure 3-5. Lowe's Canopy Fixtures – Framingham, MA (Credit: PNNL)

3.3.1 Overview of Canopy Luminaires

Canopy luminaires are surface-mounted or recessed downlight luminaires. Typical light sources are HPS and MH lamps. Induction and LED luminaires recently entered the market. Canopies are at least 12 ft AFG and greater. Since the canopy covers the area where cars, SUVs, and large trucks driver under, which increases the height of the canopy, point sources are needed to direct the light down to the work plane. Canopy luminaires are typically between 64 and 90 percent efficient.

3.3.1.1 Energy Savings Potential of Canopy Luminaires

Virtually all gas stations in the country incorporate these luminaires. Outside of gas stations, some big box retailers have canopies attached to the buildings, but other than that these luminaires are seldom used. But that is the limit of the use of luminaires, so savings at the national level is sizable, but not significant for canopy luminaires. These luminaires typically have long operating hours because even during the daytime these luminaires are needed because the canopy obscures the daylight. Skylights are not typically incorporated into canopies presumably due to structural and mechanical issues associated with the canopy or water proofing concerns.

Lighting controls offer the greatest energy savings potential, followed by improving the luminaires for canopy luminaires.

3.3.1.2 Energy Savings at the Fixture Level

Improving the luminaire design is a possible source of energy savings. However, since the luminaire is already pretty efficient, the energy savings would probably be around 10 to 20 percent.

3.3.1.3 Energy Savings from Controls

Of the control options reviewed in this report, occupancy-based controls are the best for additional energy savings for canopy luminaires. The occupancy under a canopy is unpredictable and not constant. Turning off or reducing the light when the canopy is not in use would save energy. A review of use controls with this luminaire type is outlined below:

- Ambient-light based controls: Unless the canopy has integral skylights (like some big box stores), this strategy cannot be pursued.
- Network-based controls: There is potential for the use of network-based controls, but unless the network either turns off or reduces the light output via ambient-light based controls, occupancy based, or time-based controls, no energy will be saved.
- Occupancy-based controls: The canopy defines the area and provides a structure on which to mount the sensor. As a vehicle drives under the canopy, then the sensor can be triggered. Gas stations could take advantage of this strategy by reducing the light when no one is under the canopy or using the fuel pumps.
- Time-based controls: For sites associated with a building with a specific schedule (e.g., a gas station where the fuel pumps stop working at 12:00 am), time-based controls could either turn off or reduce the lighting, indicating that the canopy is not in service.

Because the occupancy under a canopy is unpredictable and each application is different, is it difficult to generalize potential energy savings or cost-effectiveness. However, all of these options are potential energy saving opportunities.

3.4 Floodlight

Floodlight luminaires are veritable luminaires in the exterior market. The focus of the luminaire is to focus/direct light, so not only do floodlight luminaires light flags, building facades, architectural features, but floodlights can also provide general illumination when an area luminaire cannot be sufficiently utilized. Figure 3-6 shows a parking lot in Chicago lighted that uses floodlight luminaires to light the parking lot rather than traditional area luminaire for a parking lot.

Figure 3-6. Floodlight Luminaires in a Parking Lot – Chicago, IL (Credit: PNNL)

3.4.1 Overview of Floodlight Luminaires

Floodlight luminaires are yoke-mounted luminaires aimed and oriented at an object or a façade. The purpose of the luminaires is to highlight a feature, enhance an architectural feature, illuminate an object, or for security purposes. Typical light sources are HPS and MH lamps and occasionally incandescent/halogen and CFL lamps. Recently, LED floodlight luminaires have entered the market. The light source needs to be small for optical reasons and to enable the luminaire to create high intensity beams to light a surface that is usually very far away. Fixture efficiency is low, but necessary because as the optics get more sophisticated fixture efficiency decreases. Luminaires using LEDs where there are fewer losses optically could mean energy savings for floodlight luminaires.

3.4.1.1 Energy Savings Potential of Floodlight Luminaires

Floodlight luminaires are not installed on every site. Therefore, the national level of savings is limited. Lighting controls do not represent a source for savings; therefore, luminaire improvements are the only source for energy savings.

3.4.1.2 Energy Savings at the Fixture Level

Improving the luminaire design is a possible source of energy savings. Traditional luminaire design has been around a lamp with a large lumen package. Typically these lamps have been physically large. Recent lamp designs have allowed for large lumen packages in more compact lamps. Designing around a smaller source can help with the optical design and allow for less light to be absorbed. By not designing the fixture around a conventional light source and using a LED instead is another potential source for savings. Conventional systems use reflectors and lenses which both absorb light generated by the lamp. LED optical systems typically have less absorption than conventional systems. Therefore by changing to LEDs less light could be absorbed.

3.4.1.3 Energy Savings from Controls

Control options for floodlight luminaires are limited. The luminaire could be located out of the vicinity of the occupant, making it hard to know how the control strategy needs to work. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Many floodlights are connected to photocells to turn off the luminaires when there is sufficient daylight. This control strategy would not lead to energy savings unless standard operation changes.
- Network-based controls: Not applicable for floodlight luminaires.
- Occupancy-based controls: Not applicable. The floodlight luminaire highlights a surface that can be far away from the viewer. Occupancy sensor coverage can be virtually impossible for floodlight luminaires.
- Time-based controls: If the element or the area being lighted can be turned off at some point in the night, then this strategy could lead to energy savings. For instance, if the luminaire could be turned off at 2:00 am rather than operating until dawn.

3.5 Parking Structure (Garage) Luminaires

Parking structures are hybrid spaces. All floors of a parking structure are covered except for the top deck. However, most structures are only loosely “enclosed” in that walls have large openings to the environment and the spaces are not heated or cooled. The enclosed aspect of the structure makes the space an “interior” space, but in application many consider the spaces to be exterior environments. This study places them in the exterior environment, but acknowledges the duality of the space and provides recommendations related to the interior aspects of the space.

Parking structure luminaires are either surface-mounted to the structure or suspended. These luminaires are typically mounted between 8 and 12 ft AFG (see Figure 3-7), and tend to be spaced three to five times the distance of the mounting height of the luminaire. The function of the luminaire is to provide transition illumination between the daylighted area and covered parking structure and to provide general illumination within the structure.

Figure 3-7. Parking Structure – Wellesley, MA (Credit PNNL)

Parking structures are difficult to light because there are multiple obstructions in the space, including the support structures of the parking decks, water pipes for sprinklers, signage, and columns. Also, the surfaces within the space are often bare concrete and do not reflect well—typical reflectance values are virtually always less than 50 percent, meaning that more light is absorbed by the surface than is reflected. Finally, the walls of the space are open to the environment or use grates. This is a two-sided issue for lighting. The openness allows in daylight, but also means that light that is directed to a wall does not strike a solid surface and actually leaves the parking structure.

3.5.1 Overview of Parking Structure Luminaires

Parking structure luminaires use the most varied types of light sources of any of the fixtures types within the scope of this report. Sources include small point sources (i.e., CFLs, HPS, induction, LED, and MH) and large sources (i.e., linear fluorescent). Fixture efficiency for these luminaires typically ranges between 60 to 90 percent.

Table 3-1 is an excerpt from Table 3.6 of the DOE LED Savings in Niche Markets report (DOE 2011). Fluorescent lamps represent the plurality of light sources used in parking structures. However, more structures are lighted by HPS and MH lamps. The sheer number of fluorescent lamps is greater, but that is because more fluorescent lamps and luminaires are needed when lighting a parking structure. Light sources that do not work easily with lighting controls, HPS and MH combined, represent a sizable share of lamps used to light parking structures.

Table 3-1. Parking Structure Light Installed Base

Application	Lamp Type	Percentage	Number of Lights (000s)
Parking Structure	Incandescent	1.6	600
	Halogen	2.2	800
	Fluorescent	45.9	16,600
	Induction	7.4	2,700
	Mercury Vapor	0.1	44
	High Pressure Sodium	23.2	8,500
	Metal Halide	15.3	5,600
	LED	4.1	1,500
	Total	100	36,400

3.5.2 Energy Savings Potential of Parking Structure Luminaires

DOE estimates that parking structure lighting in the U.S. uses 28.1 TWh/yr of electricity, and that converting to LED luminaires would provide 7.7 TWh/yr of savings (DOE 2011). The report does not factor in the use of controls in this energy savings estimate. The report estimates that parking structure lighting operates 6750 hours per year (18 hours per day × 365 days).

Occupancy is not constant at parking structures—it varies by both time of day and season for a parking structure supporting a mall/shopping district. Occupancy is probably predictable for a structure supporting a transportation terminal. Occupants find a spot, park, and leave the structure, so the overall actual “occupied” time is very low. Therefore, the greatest energy savings potential exists with the use of controls that take advantage of the available abundant daylight and/or low occupancy of the space.

Another option is to increase the reflectance value of the materials in the space. The materials in parking structures are often left untreated and have low reflectance values. If architectural features change in the space, less energy is needed to light the space.

3.5.2.1 Energy Savings at the Fixture Level

The CBEA High Efficiency Lighting Specification attempts to qualify good luminaire performance. The National Electrical Manufacturers Association (NEMA) target efficacy rating (TER) is a method for comparing different luminaires. The methodology for calculating the specific TER of a parking structure is limited in current practice.

3.5.2.2 Energy Savings from Controls

Energy savings from controls are so significant that the next revision of ANSI/ASHRAE/IES Standard 90.1-2010 will require the use of lighting controls. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Daylight can affect a significant portion of the luminaires within the space, specifically at the entrance/exit and the perimeters. IES recommends higher light levels at entrances/exits to allow drivers to quickly adapt from the daylighted road to the covered parking area

(IESNA 1998). Often many luminaires are clustered near the entrance/exit (see Figure 3-8). If these luminaires are not circuited properly and are not connected to a photocell, the entrance/exit is drastically over lighted at night. Ambient-based controls are necessary to reduce the lighting at night. This not only saves energy, but also aids the driver.

Figure 3-8. Parking Structure Entrance/Exit – Natick, MA (Credit: PNNL)

Usually the perimeter wall construction of a parking structure lets in ample daylight (Figure 3-9). The luminaires within a certain distance of the perimeter wall could be connected to a photocell and either dimmed or turned off in response to the available daylight.

Figure 3-9. Parking Structure with Daylight – San Francisco, CA (Credit PNNL)

- Network-based controls: Not applicable
- Occupancy-based controls: Occupancy sensors are a great option for a space where occupancy is infrequent and usually brief. The sensors can switch between low output and high, providing a sense of security while saving energy. Multiple utilities offer incentives for sensors, specifically in parking structure applications. If a mall or office building parking structure closes at 10:00 pm, occupants would not be expected in the parking structure at 2:00 am. Recently DOE participated in multiple

demonstrations of this control strategy in parking structures, including an installation at the Department of Labor.

Figure 3-10 shows the use pattern of LED luminaires installed below the Department of Labor building during a typical office day. The lights operate at full output from 6:00 am to 10:00 am, when most people are coming to work. There is a lull during the morning hours and the lights go to low output. During the late afternoon, 3:00 pm to 7:00 pm, the lights operate at full mostly because the occupancy is high with people leaving for the day. Through the night, the lights remain virtually in the low output when there is no occupancy.

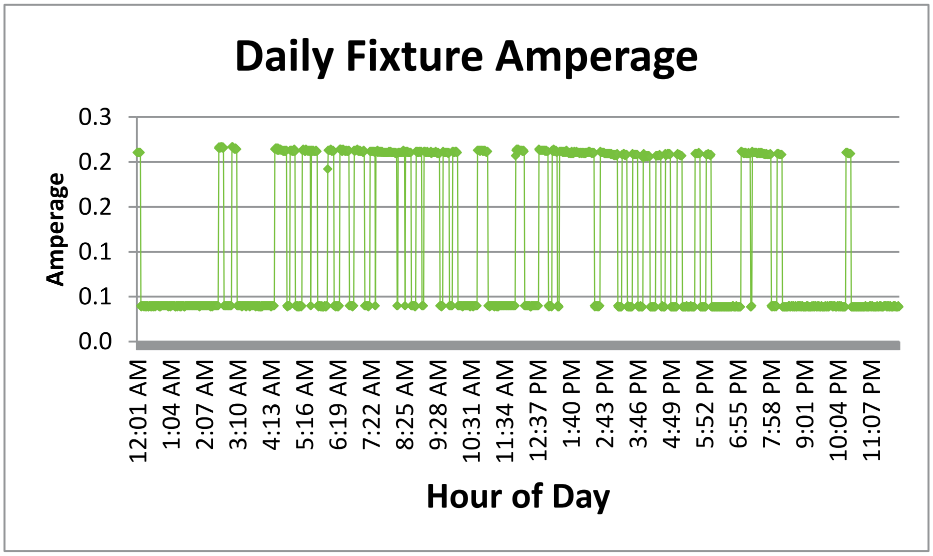

Figure 3-10. Department of Labor Parking Deck (Office Day)

Figure 3-11 shows the use pattern of LED luminaires installed below the Department of Labor building during a typical weekend day. Other than when it appears that a worker arrives in the early morning and then leaves in the evening, the luminaries operate in the low state. Without controls, the lighting would be operating at full in a completely empty parking deck. Preliminary estimates from the data indicate that the luminaires only operate in the high state for 30 percent of the time. Many variables affect the operating profile of occupancy sensors in parking structures, including the flow of traffic, time out period, and occupant type.

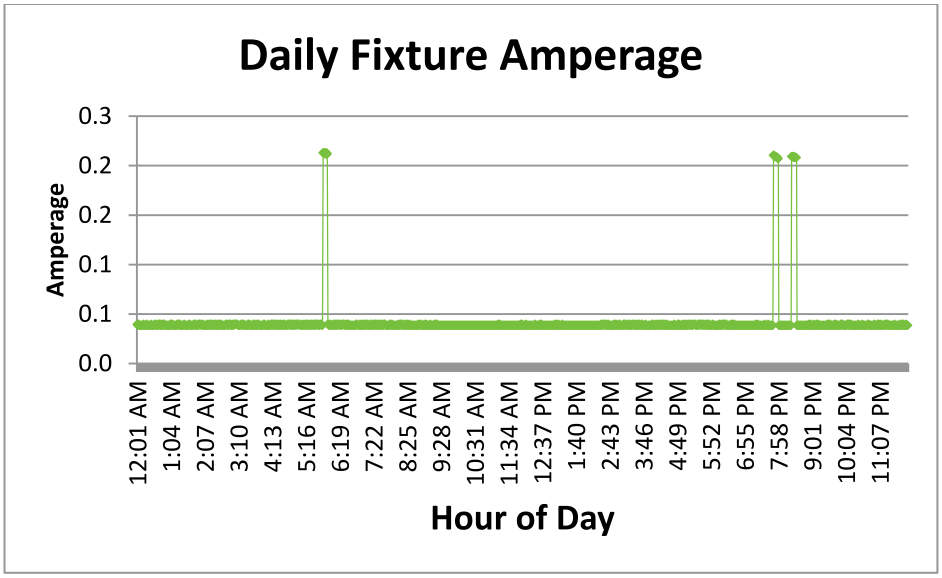

Figure 3-11. Department of Labor Parking Deck (Weekend)

The CLTC demonstrated, at multiple California state universities, bi-level parking structure luminaires using both induction (PIER 2010b) and LED (PIER 2010c) light sources. CLTC estimated that energy savings of 30 percent or more could be attributed to the use of the bi-level technology and sensors.

- Time-based controls: Unless the structure physically closes, the lights in a parking structure cannot be turned off based on time. Even if a parking structure closes at a given time, most sites would not consider this option for security reasons.

3.5.2.3 Energy Savings from Architectural Changes

The finish or reflectance value of the materials used in a space affects the amount of light there. Darker finishes have lower reflectance values; the lower the reflectance, the more light is absorbed. Typical reflectance values for a parking structure are less than 50 percent for the ceiling, 30 percent for the walls, and 20 percent for the floor. The low reflectance values mean that more light is needed from the luminaire from the start. One way to increase the amount of light in the space is to increase the reflectance values of the surfaces. Figure 3-12 and Figure 3-13 show the extreme effects of reflectance values. Figure 3-12 is a parking structure lighted by LEDs at Arizona State University. The ceiling and columns are painted white to reflect light within the space. Figure 3-13 is a parking structure attached to an Embassy Suites hotel in Portland, OR. The ceiling is a dark, unpainted metal and the walls are blackened concrete. Although the photos are at different exposure settings, the figures demonstrate how the material finish influences the amount of light within the space.

Figure 3-12. LED Lighting at a Parking Structure at Arizona State University – Tempe, AZ (Credit: PNNL)

Figure 3-13. Fluorescent Lighting at a Parking Structure at an Embassy Suites – Portland, OR (Credit: PNNL)

3.5.3 Federal Financial Incentive(s)

Of the applications reviewed in this scoping study, parking structures are the only one eligible for a federal financial incentive. Parking structures have a unique cost effectiveness element with respect to exterior lighting. The Internal Revenue Service published a bulletin extending the Energy Policy Act 2005 (EPAct) tax deduction to parking structures (IRS 2009). The tax deduction is set to expire in 2013. The maximum incentive is $0.60 per square foot if the power density of the parking structure is 40 percent less than ANSI/ASHRAE/IES Standard 90.1-2001. The benefit is that parking structures represent significant floor space, but the overall luminaire quantity is low. Whereas interior spaces typically have luminaires that cover 60 ft^2, parking structure luminaires cover an area of around 100 ft^2 or more. This translates to a low fixture density. Therefore, a site can redo the parking structure lighting to maximize the EPAct tax deduction with a minimum of equipment costs.

Option 7 *Continue to support high-efficiency parking structure specification.*

3.6 Post-Top Luminaires

Post-top luminaires are typically used for ornamental and aesthetic reasons at a pedestrian scale. The luminaire (head) is mounted on top of the pole, typically between 8 and 16 ft AFG. These luminaires are sometimes called “acorns” or “gumballs” because of their shape. Figure 3-14 shows a post-top luminaire lighting walkways between college dormitories in Troy, NY.

Figure 3-14. Post-Top Luminaire on College Campus – Troy, NY (Credit: PNNL)

3.6.1 Overview of Post-Top Luminaires

Typical light sources for post-top luminaires are HID lamps and CFLs. Induction and LED post-top luminaires have been recently introduced. Efficiency for post-top luminaires can be very high, which means that the light leaves the luminaire, but it does not mean that the light is delivered to the walking surface. The problem is that many post-top luminaires emit a significant amount of light above the luminaire; 20 percent or more is not uncommon. This uplight is wasted light. Better optical design could reduce uplight.

3.6.2 Energy Savings Potential of Post-Top Luminaires

Post-top luminaires tend to be one of the more expensive luminaires (per piece). Since the poles are mounted close together, this further drives up the cost. The low mounting height and optics of the luminaires limit their effectiveness in lighting large areas. For all of these reasons, post-top luminaires are installed in low numbers at most sites. Even on a national level, post-top luminaires represent a small number of exterior luminaires. For instance, New York City’s Central Park, one of the largest (843 acres

[2.5 miles long x 0.5 miles wide]) public parks in the U.S., only has 1,600 post-top luminaires installed along pathways and the adjacent grounds. To put this in perspective, Manhattan's FDR Drive is only 13 miles long by 0.019 miles wide (157 acres) and has about the same number of roadway fixtures.

3.6.2.1 Energy Savings at the Fixture Level

Energy savings at the fixture level stem from better fixture design. Using sources that direct the light to the walking surface increases energy efficiency. This is easier with smaller light sources because of the construction/aesthetics of post-top luminaires. Small sources like new metal halide, light-emitting plasma, and LEDs are good possibilities for the optical needs of the post-top luminaires. Therefore efforts should be directed to redesign the luminaires with new light sources either through specifications or possible regulation.

3.6.2.2 Energy Savings from Controls

Exploring different control designs and using different light sources can produce energy savings. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Photocells, either integral to the luminaire or at the start of the circuit, turn post-top luminaires on and off, typically at dusk and dawn, respectively. Since this is the current control strategy, energy savings can only be achieved by combining it with another strategy.
- Network-based controls: Possible, but limited in application to the site requirements, For example, a campus may have the need for lighting to change in response to someone pushing an emergency call button.
- Occupancy-based controls: Limited potential in that the low mounting height of the luminaire limits the coverage of the sensor. However, sensors could be networked and incorporated into multiple luminaires such that as a person passes the first luminaire and triggers the sensor, the others in the network receive a signal that someone is in the area. This networking could use logic or algorithms to turn on different luminaires as warranted.
- Time-based controls: Other than photocells, time clocks are the primary control mechanism for post-top luminaires. By incorporating bi-level output into the luminaire, the post-top could be turned down at a certain time. For instance, if the luminaires are used in a park that closes at midnight, the luminaires could reduce output at midnight. This saves energy, but still provides some light for security needs.

3.7 Roadway (Streetlight) Luminaires

Roadway luminaires, commonly called streetlights, are typically mounted onto poles with arms at 20 to 30 ft AFG. High-mast luminaires light freeway interchanges and are excluded from this category[3]. The function of the luminaire is to light the roadway; however, cars have headlights that provide forward illumination.

[3] High-mast luminaires are not included within this report because the primary DOE program is the CBEA. Virtually no CBEA member use high-mast luminaires. High-mast luminaires are only used in selective areas. The current technology used with high-mast luminaires is as efficient as is currently possible.

3.7.1 Overview of Roadway Luminaires

Typical light sources for roadway luminaires are HID lamps, with HPS lamps being the most common. HPS lamps are often used because of the long rated life of the lamp and the high efficacy of the source. Notably, the city of Chicago has started replacing some of their HPS streetlights with ceramic metal halide streetlights. Chicago estimates $1.8 million in electrical savings as well as a reduction of nearly 15,000 metric tons of carbon dioxide by replacing over 16,000 luminaires ceramic metal halide luminaires (Wray 2011, Holliday 2011).[4] In recent years, municipalities and utilities have begun experimenting with induction and LED luminaires for roadway luminaires. The city of Greensburg, KS, which was quite literally destroyed by a tornado, chose to replace all street lights in the city during the rebuilding phase with LED luminaires. Greensburg appears to be the first city in the US to use all-LED street lights and projects 40 percent energy savings compared to standard metal halide street lights[5] and cost the city 70 percent less in operating costs per year (NREL 2009). Typical fixture efficacy of conventional roadway luminaires is between 70 and 75 percent.

Table 3-2 is an excerpt of Table 3.2 of the DOE LED Savings in Niche Markets report (DOE 2011). Nearly all light sources in roadway lighting are HPS lamps. Mercury vapor is the next largest installed light source technology. Considering the age of mercury vapor technology and the limitation on the supply of mercury vapor ballasts, there are some 4 million luminaires ripe for replacement.

Table 3-2. Roadway Light Installed Base

Application	Lamp Type	Percentage	Number of Lights (000s)
Street Lighting	Incandescent	0.1	18
	Mercury Vapor	15.9	4,200
	Low Pressure Sodium	0.4	100
	High Pressure Sodium	80.9	21,500
	Metal Halide	2.5	700
	LED	0.2	69
	Total	100	26,500
Highway Lighting	Induction	8.5	2,200
	Low Pressure Sodium	0.4	100
	High Pressure Sodium	86.1	22,500
	Metal Halide	5.0	1,300
	Total	100	26,100

[4] At the light source level, HPS is more efficacious than CMH. However, the system installed in Chicago uses an electronic ballast and the lamp, ballast, and fixture are designed together to maximize performance. HPS is also a narrow-band light source (mostly emits “orange-white” light) whereas CMH is a broad-band light source (emits light across the spectrum). The IES in July published the 10th edition of the Lighting Handbook allowing for spectral multipliers – meaning that light source efficacy calculations can be different at low light levels. This new calculation would benefit CMH and reduce the performance of HPS.

[5] There are 2 major types of metal halide: probe-start and pulse-start. Within the pulse-start family, there are quartz and ceramic arc tubes. It is not entirely apparent which type of metal halide lamp Greensburg, KS originally had installed.

3.7.1.1 Energy Savings at the Fixture Level

DOE estimates that street lights use 23.1 TWh/yr of electricity (DOE 2011). An additional 29.7 TWh/yr is used by highway lights. The niche report estimates 10 TWh/yr of savings per luminaire type if 100 percent market penetration of LEDs luminaires occurred.

Potential for energy savings of roadway luminaires stems from pairing the light source with new optical distributions. New, smaller metal halide lamps (e.g., Philips CosmoPolis), light-emitting plasma, and LEDs allow for innovative fixture design. Less light is absorbed within the luminaire and thus more reaches the task plane. The optics also allow for more effective distributions. Induction lamps have been considered by different locations. PGE&E of New Jersey recently starting installing roadway luminaires with induction lamps. However, induction lamps are much larger than conventional or emerging roadway light sources, which limits the optical design for induction-based roadway luminaires.

3.7.1.2 Energy Savings from Controls

Controls have limited use in street lighting applications. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Most streetlight luminaires are controlled by ambient-based controls. Photocells/diodes turn on/off the fixtures at dusk and dawn, respectively. These controls are also the reason that streetlights may operate on an overcast day.
- Network-based controls: Possible, but limited in application to the site requirements. Delft University of Technology in the Netherlands recently installed LED intelligent street lighting system on campus for testing. Through the use of wireless communication and occupancy sensors, the lighting system dims when there are no cars, cyclists, or pedestrians in the vicinity. Electricity savings are projected at 80 percent (ScienceDaily 2011).

  The Department of Defense's (DOD) has a program focusing on bi-level demand-sensitive LED street lighting systems slated for completion in 2013[6]. The focus of the project is develop LED systems that can dim. The energy savings associated with the project are approximately 50 percent or more compared to conventional systems. The project is currently in testing and evaluation phase. If positive results stem out of the evaluation phase, the systems could be deployed to DOD facilities. More about the parent program in section.
- Occupancy-based controls: Limited potential since these luminaires light roadways, the sensors would have to be placed very far apart to turn on the lights if a car was moving at sufficient speed.
- Time-based controls: Roadway lighting recommendations are based on traffic flow. The greater the potential pedestrian/vehicle conflict, the more light is recommended. However, traffic flow on a street changes with time; for instance, fewer cars are on the road after 12:00 am. The IESNA Lighting Roadway Committee is considering including adaptive lighting recommendations in the 2011 version of RP-8, *Recommended Practice for Roadway Lighting*.

[6] http://www.serdp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201017

3.8 Steplights

Steplight luminaires (steplights) are mounted close to the ground or walking surface, typically below 3 ft AFG (see Figure 3-15), and illuminate steps, building entrances, or walkways for safe passage. Typically, these luminaires are recessed into the wall material; however, a small portion of the luminaire is surface-mounted.

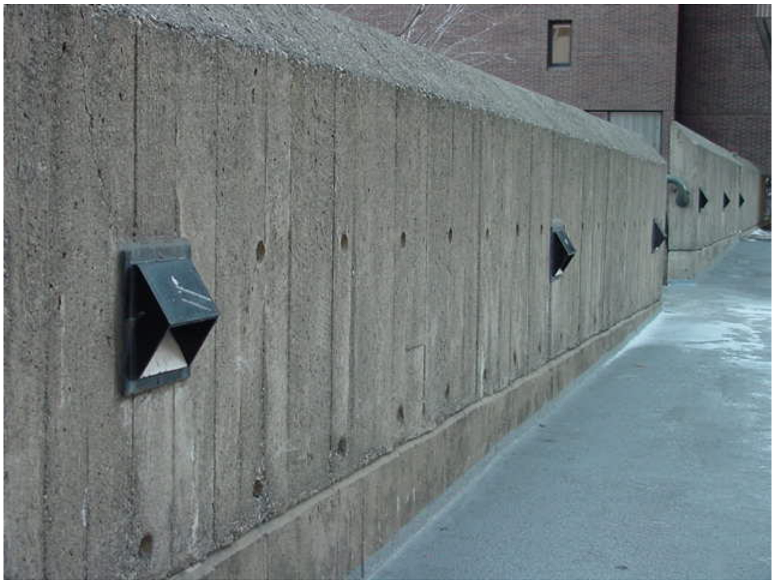

Figure 3-15. Steplights Along a Walkway – Troy, NY (Credit: PNNL)

3.8.1 Overview of Steplight Luminaires

Typical light sources for steplights include small point sources (i.e., CFLs, incandescent, HPS, MH, and LED) because the luminaire cannot accommodate large sources (i.e., linear fluorescent). Since these luminaires are near the ground, their coverage pattern is rather limited. Typical fixture efficiency is very low (often less than 40 percent) because the luminaire is easily within view and therefore must be well shielded with louvers or hoods to reduce glare. The attempts to mitigate/reduce glare limits the light output of the fixture. In addition, debris and other objects can block the light coming from the luminaire.

3.8.2 Energy Savings Potential of Steplight Luminaires

Potential energy savings exist in exploring new solutions to the conventional steplight luminaire. However, steplights represent a small portion of the energy used in exterior lighting in commercial sites because they are needed in fewer locations (near stairs, near doors, and other limited places) than other lighting sources. Furthermore, the typical rated power of these luminaires tends to be low. The combination of low number of fixtures typically installed on the site and the low power of the light source limits the site potential. Thus, although the energy savings at the fixture level might seem significant, new steplight solutions would have little effect on the national level.

3.8.2.1 Energy Savings at the Fixture Level

The low fixture efficiency (40 percent) offers significant energy savings potential. If the luminaires can be designed to maximize light output and coverage while minimizing glare through superior optical design, energy savings can be achieved.

The key to energy savings at the fixture level is increasing output while preventing glare. LEDs are a possible light source that would save energy, because LEDs can be designed into the fixture such that the source is obscured from view (limiting glare) and light is still directed to the walking surface.

3.8.2.2 Energy Savings from Controls

Lighting controls, while very useful for some applications or luminaires, will not likely save energy in steplights. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Not applicable.
- Network-based controls: Not applicable.
- Occupancy-based controls: Sensors that would enable the steplights to go from either "low" or "off" to "high" would be difficult to place. The sensor could not be located within the fixture because by the time the person triggers the sensor to increase the light output, the person is standing virtually next to the fixture. Locating the sensor external to the fixture leads to placement and coverage issues that make this type of control strategy impractical.
- Time-based controls: Selectively turning off certain fixtures during periods of low occupancy works well in large spaces like parking lots, but turning off steplights would limit their function because these fixtures tend to light critical areas near stairs and entry points to buildings.

3.9 Uplights

Uplight luminaires (uplights, also known as in grade) are recessed in the walking surface or the landscape (Figure 3-16) and are used to highlight architectural features (e.g., columns, stucco surface, facades) or landscape (e.g., palm tree canopy).

Figure 3-16. Uplights in Snow – Troy, NY (Credit PNNL)

3.9.1 Overview of Uplight Luminaires

Typical light sources for uplight luminaires are small point sources (i.e., HID, incandescent) that lend themselves to good optical design. Although CFLs are small point sources, good reflector design for an uplight is hard because the source is so large. In recent years, LEDs have been considered for this technology, but LEDs are currently limited in potential. The uplight is similar in concept to a downlight, but inverted and typically has fixture efficiency is around 50 percent. Uplights need a sufficiently large lumen package that can be converted into high intensity and specific beam patterns.

Dark Sky advocates are against this luminaire because if it is poorly aimed the luminaire just emits light into the night sky. In recent years, these luminaires have been a bit of a safety problem. Poorly designed luminaries emit significant heat at the lens of these fixtures. In one case, a shipping box was placed on an uplight by a delivery person and the fixture turned on per the automatic schedule. The box caught fire and burned down the garage of the house. Well-designed luminaires redirect the heat into the bottom of the fixture. The downside of this thermal management is that the fixture is 15 in. or more deep which is more of a construction issue. Dirt and debris is problematic for this luminaire as well because regardless of light source or luminaire efficacy, a pile of leaves has to be physically removed.

3.9.2 Energy Savings Potential of Uplight Luminaires

Strategies for energy savings for uplights are limited. Uplights are only used to highlight visual (architectural or landscape) elements, and are sometimes deemed unnecessary and eliminated from projects to save money. When used on a project, these luminaires are used sparingly.

At the luminaire level, some energy saving potential exists through better optical design. On the national level, these fixtures represent a very small portion of the installed fixtures on a site. Therefore, the overall energy savings potential is low.

3.9.2.1 Energy Savings at the Fixture Level

The low fixture efficiency (50 percent) represents potential energy savings. However, achieving intense and controlled distributions leads to some of the fixtures losses. Currently HID sources represent the best options for this luminaire. The typical HID lamp is an ED-17 lamp. One way to potentially improve the fixture efficiency is to select a smaller (and coincidentally more efficient) MH lamp (e.g., T6).

3.9.2.2 Energy Savings from Controls

Savings from control strategies are limited. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Not applicable.
- Network-based controls: Not applicable.
- Occupancy-based controls: Not applicable.
- Time-based controls: A curfew to turn the lighting off at a certain time should be encouraged or mandated to save energy. For instance, at 2:00 am the façade or column no longer needs to be lighted.

3.10 Wall-Mounted Area Lights (Wallpacks)

Wallpack luminaires (wallpacks) are luminaires surface-mounted to the facades of buildings or walls. The major functions of the luminaires are to light a local area, provide a limited amount of security lighting (see Figure 3-17), and light shallow paved surfaces around the building. In certain places, these luminaires are more cost effective for lighting parts of a parking lot than pole-mounted luminaires. The costs related to pole-mounted luminaires can be significant. For example, wallpacks are often used to light the side parking lot (see Figure 3-18) or rear loading docks because this is easier than trying locate many pole-mounted fixtures close together.

Figure 3-17. Wallpack Lighting Stairs – Natick, MA (Credit: PNNL)

Figure 3-18. Wallpacks Lighting Parking Lot – Granada Hills, CA (Credit: PNNL)

3.10.1 Overview of Wallpack Luminaires

Typical light sources for wallpacks are small point sources (i.e., HID, compact fluorescent) that lend themselves to good optical design. In recent years, LEDs have made inroads in this application. Typical wallpack fixture efficiency varies. However, with wallpacks, greater efficiency does not mean more light directed to the ground/task plane. Wallpacks are often Dark Sky offending luminaires in that the fixtures can emit light into the night sky or be a source of light trespass. The wallpacks can be very “efficient” in that a significant portion of the light generated by the lamp leaves the fixture. However, if that light does not reach the task plane, the fixture is not effective.

Recent manufacturer literature highlights some of the issues with wallpack luminaires. Guth Lighting has a long history in manufacturing wallpack luminaires. In their March 2009 marketing literature for an LED wallpack (SUNDOWNER), Guth highlights the optical issues related to conventional wallpacks. "HID and CFL wallpacks use reflectors to redirect the light. Efficiency is 35 to 55 percent. Of that 20 to 30 percent hits the building wall and 15 to 20 percent goes straight down. (Guth 2009)"

These luminaires are often mounted over doors. There is an emergency lighting requirement for egress. High efficacy sources like HID lamps are limited in that that they do not work for emergency lighting since an "instant on" function is not available with the sources. Figure 3-19 shows a real installation where the wallpack is the black fixture and uses an MH lamp. For emergency purposes, this site also installed the small halogen gray fixture. When the emergency lighting is needed, this fixture turns on and lights the area for egress. Having to purchase and install duplicate fixtures is costly and not aesthetically pleasing.

Figure 3-19. Multiple Wallpacks over Door – Burlington, MA (Credit PNNL)

3.10.2 Energy Savings Potential of Wallpack Luminaires

At the luminaire level, energy saving potential exists through better optical design and through the use of lighting controls. These luminaires are located typically 12 ft AFG, which allows for the use of lighting controls.

On the national level, the energy savings potential of these luminaires is significant.

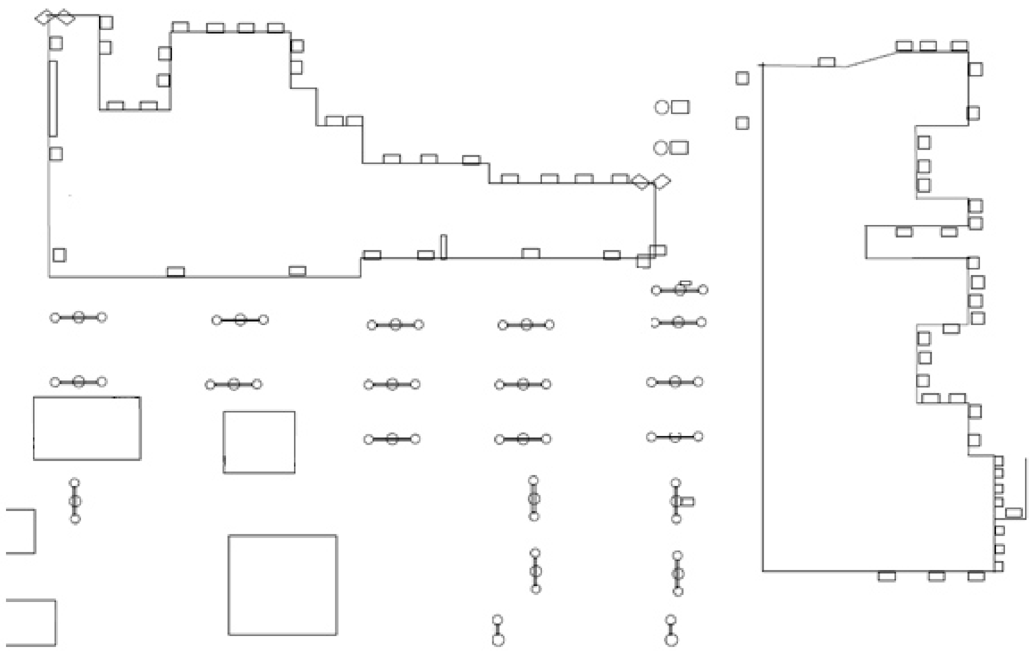

Figure 3-20 is a diagram for a site which of a DOE Commercial Building Partnership project. Part of the project required a baseline energy audit. The small square boxes on the backsides of the building represent wallpacks. The wallpack annual energy use was estimated at 20 percent of the total exterior lighting energy use. In terms of quantities of luminaires, over 60 wallpacks are installed, dwarfing the roughly 30 pole-mounted area lights installed to light the parking lot.

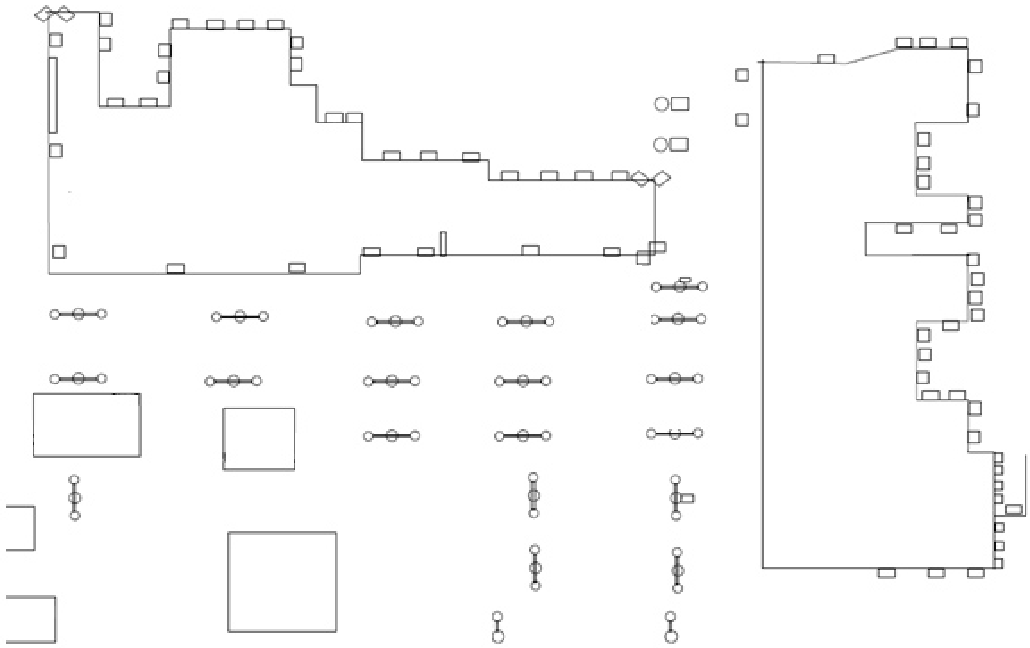

Figure 3-20. Strip Mall Lighting Site Plan

3.10.2.1 Energy Savings at the Fixture Level

DOE's Energy Alliance Technology Screening Program received a submission regarding LED wallpacks (product ID#218)[7]. The screening report identified a potential federal role in the technology that a product specification for this technology could duplicate ENERGY STAR efforts (more about ENERGY STAR below). Note that many utilities offer a variety of financial incentives and qualifications requirements for LED wallpacks.

DOE's Commercially Available LED Product Evaluation and Reporting (CALiPER) program recently tested a number of wallpacks using both conventional and solid-state lighting sources. The Round 10 report found that the LED wallpack luminaire efficacy ranged from 24 to 62 lm/W (DOE 2010). Conventional sources in wallpacks had luminaire efficacy values of 24 lm/W (metal halide) and 47 lm/W (high-pressure sodium).

In developing the ENERGY STAR specification for wallpacks, PNNL surveyed conventional wallpacks. The average fixture efficiency of survey wallpacks was 60 percent with a standard of deviation of 10 percent. The maximum fixture efficiency was 71 percent and the minimum was 39 percent. This means that for almost all conventional wallpacks at least 30 percent of the light generated never leaves the fixture (wasted light). Better optical design can minimize fixture losses. LED-dedicated luminaires are capable of better optical design.

[7] DOE published in the Federal Register a request for information (RFI) about this program on May 26, 2011 (76 FR 30696). DOE held a webinar related to the RFI on July 7, 2011. As a result of the RFI, the webinar, and comments received, DOE has cancelled the program.

The SSL ENERGY STAR program developed a specification for outdoor wall-mounted area luminaires (wallpacks), which was released for comment in August 2008 (EPA 2008). The specification required a minimum amount of light out of the luminaire of 1,300 lumens. The specification had some requirements for zonal lumen density and a minimum luminaire efficacy of 40 lm/W. At this time, no SSL wall packs are listed on the ENERGY STAR web site.[8]

Wallpacks tend to produce too much glare because of their mounting height and function. However, for most luminaire optical systems, the more the light is controlled/directed or glare is mitigated, the more the optical efficiency decreases. The CLTC is working with the manufacturer Philips Gardco to develop a low-glare wallpack (PIER 2008) using a conventional HID lamp. The energy saving potential of the low-glare wallpack is between 20 and 30 percent. However, because of the design requirements to reduce the potential for glare, the luminaire is not “Dark-Sky friendly.” Luminaires that can both mitigate glare and provide little to no uplight are needed.

3.10.2.2 Energy Savings from Controls

Savings from control strategies could be significant. A review of use controls with this luminaire type is outlined below:

- Ambient-based controls: Not applicable.
- Network-based controls: Not applicable.
- Occupancy-based controls: Occupancy sensors could be used to increase the light output from low to high when a person approaches. Philips Gardco offers an LED wallpack that includes a passive infrared motion sensor “capable of detecting motion within 25 feet…When the pedestrian or vehicle leaves the area and no motion is detected for 5 minutes, the system automatically returns to low mode (90 percent reduction in power) to reduce energy and save money” (Gardco 2008).

  Although HID lamps are not typically used with occupancy sensors, in recent years this combination has been explored. The CLTC completed a demonstration with a bi-level metal halide wall pack that operated in full output when people were nearby and operated at 50 percent output when the area was vacant (PIER 2010d). Using the fixture-integral microwave sensor, the luminaire spent 50 percent of a night in low operation.
- Time-based controls: A lighting curfew for these luminaires could be encouraged or mandated.

Option 8	*DOE could consider developing a technology specification for wallpacks and incorporate the use of sensors.*

[8] http://www.energystar.gov/index.cfm?fuseaction=ssl.display_products_com_html

4.0 DOE Exterior Lighting Programs

DOE has multiple ongoing efforts already related to exterior lighting. Below is a brief review of different DOE exterior lighting programs.

4.1 CBEA Lighting Work Group

The Commercial Building Energy Alliances (CBEAs) work with the U.S. Department of Energy (DOE) and its national laboratories to help guide research and encourage industry to move toward energy-efficient design and strategies.[1] The CBEA Lighting Project Team, with members from the Retail, Commercial Real Estate, and Hospital energy alliances developed two performance specifications related to exterior lighting (discussed below). Specifications typically set minimum performance requirements, including any test results or data to support those claims, warranty requirements, and other product or system characteristics that specification developers deem important. Collective CBEA support of these product or performance specifications demonstrates demand to manufacturers and is expected to lead to greater product availability and quality and more competitive pricing.[2]

4.1.1 CBEA LED Site Lighting Specification

The CBEA LED Site Lighting Specification[3] was the first project started by the Lighting & Electrical Project Team of the Retailer Energy Alliance. The focus of the specification was to save energy and limit the end user's exposure to a new and emerging technology. The energy saving potential related to using the specification stems from the lower lighting power densities required in the specification. Depending on the lighting zone and the applicable code, power density reduction is as much as 50 percent below code. Further energy saving potential could be coupled with the use of lighting controls, potentially taking the 50 percent savings to 75 percent or greater. Controls support energy savings even where codes already require stringent power densities HID lighting, typically used to light parking lots, cannot be used effectively with certain controls. LEDs, on the other hand, can be dimmed or used with occupancy sensors. An advantage of the LEDs is that the illuminance values of the specification can be met at the lower power density. LED fixtures do not have fixture losses like traditional HID luminaires, which helps with the energy efficiency of the specification.

4.1.2 CBEA High Efficiency Parking Structure Specification

Following on the heels of the CBEA LED Site Lighting Specification, the CBEA Lighting Work Group started a project focused on parking structures. The basis of this specification was originally borne from a DOE/GSA (General Services Administration) project (see below) and was developed more fully for the CBEA. The specification is for high efficiency lighting in parking structures (also known as garages). The specification promotes the use of light sources that can be easily used with lighting controls (ambient lighting and occupancy-based) including fluorescent, induction, and LEDs. The LPD of the specification is 40 percent below ANSI/ASHRAE/IES Standard 90.1-2001, which allows for the

[1] http://www1.eere.energy.gov/buildings/alliances/
[2] http://www1.eere.energy.gov/buildings/alliances/technologies.html
[3] http://www1.eere.energy.gov/buildings/alliances/parking_lot_lighting.html

maximum EPAct 2005 tax deduction (also known as the 179D tax deduction, the location in the tax code).

4.2 Commercial Building Partnerships[4]

PNNL, LBNL, and NREL are working with companies who have large portfolios of real estate and building stock to develop designs that reduce energy usage in both existing sites (by 30 percent compared to existing energy usage) and new construction (by 50 percent compared to ANSI/ASHRAE/IES Standard 90.1-2004). To participate as a CBP partner, a company must also be a CBEA member. The CBEA lighting specifications are promoted to the CBP company. Often, first cost seriously affects the use of use of the specifications. Beyond the CBEA specifications, DOE supports other exterior lighting decisions at these sites.

4.3 Advanced Energy Design Guides[5]

DOE supported ASHRAE and the IESNA in developing the Advanced Energy Design Guide (AEDG) series of documents. These documents are building-type specific and focus on all of the building systems, not just lighting. Each AEDG has exterior lighting recommendations. Below is an overview of each of the document's recommendations.

4.3.1 K-12 School Buildings

Recommendations in the K-12 School Buildings focus on using high-efficacy, good color quality light sources of pulse-start metal halide (PMH), CFLs, induction, and fluorescent lamps coupled with electronic ballasts. The guide recommends the following:

- Use lighting controls such as an astronomical time clock.
- Use many relatively low wattage sources rather than few high wattage sources; the guide recommends a maximum of 360W PMH lamps.
- Ensure lighting is not significantly brighter than the adjacent street.
- Reduce allowed power density to 0.15 W/ft^2 to save energy.

4.3.2 Small Hospitals and Healthcare Facilities

Recommendations in the Small Hospitals and Healthcare Facilities (Healthcare) focus on using high-efficacy, good color quality light sources of PMH, CFLs, induction, and fluorescent lamps coupled with electronic ballasts. The guide recommends the following:

- Use lighting sources with a minimum efficacy of 60 lm/W.
- Use lighting controls such as astronomical time clock.

[4] http://www1.eere.energy.gov/buildings/commercial_initiative/building_partnerships.html
[5] http://www.ashrae.org/technology/page/938

- Use many relatively low wattage sources rather than few high wattage sources, the guide recommends a maximum of 350W PMH lamps.
- Reduce the allowed power density to 0.10 W/ft^2 to save energy.
- Ensure lighting is not significantly brighter than the adjacent street.

4.3.3 Highway Lodging

Recommendations in the Highway Lodging (Lodging) guide focus on using high-efficacy, good color quality light sources of PMH, CFLs, and fluorescent lamps coupled with electronic ballasts. The Lodging guide recommends the following:

- Use lighting controls such as astronomical time clock.
- Use many relatively low wattage sources rather than few high wattage sources; the guide recommends a maximum of 320W PMH lamps.
- Ensure lighting is not significantly brighter than the adjacent street.
- Reduce the allowed power density to save energy to a zone-based system. The guide recommends 0.10 W/ft^2 for Zone 3. Zone-based power densities are part of the new versions of ANSI/ASHRAE/IES Standard 90.1 and Title 24 as well as DOE's CBEA LED Site Lighting Specification.

4.3.4 Small Retail Buildings

Recommendations in the Small Retail Buildings (Retail) guide focus on using high-efficacy, good color quality light sources of PMH, CFLs, and fluorescent lamps coupled with electronic ballasts. The Retail guide recommends the following:

- Use lighting controls such as astronomical time clock.
- Use many relatively low wattage sources rather than few high wattage sources; the guide recommends a maximum of 360W PMH lamps.
- Limit exterior lighting power to 0.15 W/ft^2 for paved areas.
- Reduce the allowed power density to save energy.
- Ensure lighting is not significantly brighter than the adjacent street.

4.3.5 Office Buildings

ASHRAE and DOE are in the process of developing AEDGs for deeper savings than 30 percent. The first AEDG to be posted targeting greater energy savings was for office buildings. This section includes both the recommendations for the 30 and 50 percent savings.

4.3.5.1 Small Office Buildings (30 Percent AEDG)

In 2008, the small office AEDG for 30 percent savings was originally posted. It has since been reposted with errata. Recommendations in the Small Office guide include the following:

- Limit exterior lighting power to 0.10 W/ft^2 for paved areas.
- Avoid the use of decorative façade lighting.
- Use PMH, fluorescent, or CFL amalgam lamps for all general lighting luminaires. Standard HPS lamps are not recommended due to their reduced visibility and poor color-rendering characteristics.
- Use many relatively low wattage sources rather than few high wattage sources.
- Ensure parking lot lighting is not significantly brighter than the adjacent street. Follow IESNA RP-33-1999[6] recommendations for uniformity and illuminance recommendations.
- Use incandescent lamps only on occupancy sensors for lights that are normally off.
- Use lighting controls such as astronomical time clock.
- For parking lot and grounds lighting, use more poles and fixtures rather than fewer fixtures and high-wattage luminaires. Limit lighting in parking and driving areas to not more than 250-watt PMH lamps and limit to 25 ft mounting height in urban areas. Limit to 175 watts in rural areas.
- Do not use floodlights or wallpacks.

4.3.5.2 Small to Medium Office Buildings (50 Percent AEDG)

In 2011, the Small to Medium Office AEDG for 50 percent savings was originally posted. Recommendations in the Small to Medium Office guide include the following:

- Limit exterior lighting power to 0.10 W/ft^2 for parking lots and drives in lighting zones 3 and 4 or to 0.06 W/ft^2 in LZ2 for paved areas.
- Use LED parking lot fixtures with bi-level switching driver that will reduce power between 12:00 am and 6:00 am to no more than 50 percent.
- Limit exterior lighting for walkways to 0.08 W/ft^2 (for $<$10 ft wide [LZ3/LZ4]) and 0.16 W/ft^2 (for $\geq$10 ft wide [LZ3/4]) and 0.07 W/ft^2 (for $<$10 ft wide [LZ2]) and 0.14 W/ft^2 (for $\geq$10 ft wide [LZ2]).
- Avoid the use of decorative façade lighting. If façade lighting is desired limit the lighting power to 0.075 W/ft^2 in LZ3/LZ4 and 0.05 W/ft^2 in LZ2.
- Use LED light sources for all parking lot fixtures. Unlike AEDGs that recommend use of PMH and a maximum power, the 50 percent ADEG does not specify a maximum input power for LED parking lot fixtures.
- Limit poles to 20 ft mounting height and use luminaires that provide all light below the horizontal plane to help eliminate light trespass.

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[6] http://www.ies.org/store/product/lighting-for-exterior-environments-1022.cfm

- Use PMH, fluorescent, CFL amalgam lamps with electronic ballasts for all grounds and building lighting. Standard HPS is not recommended due to reduced visibility and poor color-rendering characteristics.
- Use photocell or astronomical time switches on all exterior lighting. Turn off exterior lighting not designated for security purposes. Design the total exterior lighting power to be reduced to 25 percent of the design level when no occupants are present between 12:00 am and 6:00 am.
- For areas that are intended to be lighted, design with a maximum to minimum illuminance ratio no greater than 30 to 1. Therefore, if the minimum light level is 0.1 then the maximum level in that area should be no greater than 3 fc.

4.3.6 Summary of Recommendations

Table 4-1 lists a comparison summary of the recommendations in the various AEDGs and related documents. The consistent themes in each of these energy saving documents are lower power densities than allowed per code and the use of controls to curb usage which lead to energy savings.

Table 4-1. Summary of AEDG Recommendations

Building Type	AEDG Percent Savings	Parking Lot LPD	Maximum Power	Recommended Source	CRI Recommended	Controls
K-12	30	0.10 W/ft^2	360W	PMH	High	Time Switch
Healthcare	30	0.10 W/ft^2	350W	PMH	High	Time Switch
Lodging	30	0.10 W/ft^2	320W	PMH	High	Time Switch
Small Retail	30	0.15 W/ft^2	360W	PMH	High	Time Switch
Office (Small)	30	0.10 W/ft^2	250W (Urban)	PMH	High	Time Switch
			175W (Rural)	PMH		
Office (Small to Medium)	50	0.10 W/ft^2 (LZ4)	Not specified	LED	High	Time Switch & Bi-Level
		0.10 W/ft^2 (LZ3)		LED		
		0.06 W/ft^2 (LZ2)		LED		

Option 9 *Integrate CBEA specifications into AEDGs.*

4.4 ENERGY STAR

ENERGY STAR is a program jointly managed by both DOE and EPA. ENERGY STAR had specifications for residential light fixtures (RLF) as well as solid-state luminaires (SSL). The two specifications were technology specific and did not overlap. DOE created an overarching luminaires specification, ENERGY STAR Luminaires specification. Version 1.0 of this specification was finalized on February 16, 2011 and will take effect on April 1, 2012. The Luminaires V1.0 specification will replace the Residential Light Fixtures (RLF, V4.2) and Solid State Lighting Luminaires (SSL, V1.3) specifications. After September 15, the Luminaires V1.1 specification will be the primary specification available for the qualification of luminaires; certification bodies will be asked to stop certifying using the old specifications with one exception: the Solid State Lighting Luminaires specification (SSL V1.3) will be available for the qualification of solid state lighting ceiling-mounted luminaires with diffusers, solid state outdoor wall-mounted porch lights and solid state residential grade task lights. This exception will be in place until IES LM-82 is published and LM-82 testing is available at EPA-recognized laboratories.

Versions 1.1 will only be applicable to the following commercial grade luminaires: accent lights, downlight, under cabinet, and portable desk lights. Residential grade luminaires include the same commercial grade luminaires, but outdoor luminaires as well. The residential grade outdoor luminaires include post-mounted luminaires; ceiling and close-to-ceiling mount; porch (wall-mounted); pendant; and security luminaires.

Since the new ENERGY STAR Luminaires specification does not include commercial grade outdoor luminaires, this program is not really applicable to the focus of this scoping study.

4.5 Federal Energy Management Program

DOE's Federal Energy Management Program facilitates the federal government's implementation of sound, cost-effective energy management and investment practices to enhance the nation's energy security and environmental stewardship.[7] One of the functions under FEMP is to provide procurement direction to federal agencies. FEMP has specifications for CFLs; fluorescent lamps, ballasts, and luminaires; downlight luminaires; industrial HID luminaires; and lighting controls. FEMP also provides additional guidance in the Federal Lighting Guide[8] and the Master Specification.[9] FEMP currently does not have explicit specifications regarding exterior luminaires or other technologies.

FEMP has participated in different demonstrations of outdoor lighting technologies. In August 2010, FEMP published two different case studies related to different lighting technologies in a parking lot at a Navy base in California. One case study focused on dimming HID lamps (PNNL 2010b) and the other focused on LED parking lot lighting (PNNL 2010c). The HID dimming study was a 2-year study that found mixed results. Initially, the energy saved seemed to be the same as the reduction in light. After a second set of measurements 2 years later, the energy savings eroded to roughly half the reduction in light. For instance, if the reduction in light was 30 percent, the energy savings were 15 percent. The LED case study found 74 percent energy savings by converting from the existing technology to LEDs.

4.5.1 FEMP Exterior Lighting Guide

This guide has been mentioned throughout this report. This guide includes information about new lighting technologies for exterior applications and lighting controls for exterior applications. This a good resource and should continue to be promoted as planned.

Option 10 *Increase awareness and use of the FEMP Exterior Lighting Guide.*

[7] http://www1.eere.energy.gov/femp/
[8] http://www1.eere.energy.gov/femp/pdfs/fed_light_gde.pdf
[9] http://www1.eere.energy.gov/femp/pdfs/lighting_spec2.pdf

4.5.2 FEMP Outdoor Solid-State Lighting Initiative

In early 2011, DOE started the FEMP Exterior Solid-State Lighting Initiative. The initiative will function in a manner similar to DOE's CBEA Energy Alliance Project Team, where a team of agency staff, with technical support from national labs, address barriers, and develop support tools and materials to help facilitate the increased use of high efficiency products and practices. In this case a team of agency staff identify specific needs that the federal sector needs to address in order to place LEDs in a default position for product purchases. FEMP focuses on SSL technology due to the successes of the DOE SSL Commercialization program, where GATEWAY demonstrations have shown substantial energy savings in exterior applications by the installation of LED products. For example, GATEWAY demonstrated LED post-top luminaires lighting a plaza at the Federal Aviation Administration Research Facility in Atlantic City, NJ (DOE 2008). The energy savings from converting from HPS to LED luminaires was just over 25 percent. However, DOE's CALiPER program has demonstrated that not all LED products are the same, nor do they all perform as claimed. The initiative will involve working with FEMP staff and the Interagency Energy Management Task Force, and is supported by PNNL.

Option 11 *Continue updating FEMP's web site and related specifications.*

4.6 General Services Administration – DOE Support

DOE supports the General Services Administration (GSA), typically through FEMP. However, as part of the American Recovery and Reinvestment Act (ARRA), which provided substantial funding for GSA to upgrade existing facilities, GSA requested additional support from DOE. PNNL is providing technical lighting assistance to GSA for specific ARRA projects. GSA developed an LED Site Lighting Specification[10] based on the CBEA LED Site Lighting Specification. PNNL developed for GSA a specification for parking structures.[11] This specification laid the foundation for the later CBEA High Efficiency Lighting Parking Structure Specification. The overall focus of the ARRA relighting projects was interior lighting projects, so only a limited number of parking lot and structures were relighted as a result.

4.7 Municipal Solid-State Street Lighting Consortium

Initially funded by ARRA, DOE started the DOE Municipal Solid-State Street Lighting Consortium[12] (MSSSLC) to share technical information and experiences related to LED street and area lighting demonstrations. The MSSSLC is similar in structure to both the CBEA Energy Alliance and the FEMP Outdoor SSL Initiative. MSSSLC provides an objective role for evaluating products and providing technical support.

[10] http://www.gsa.gov/graphics/pbs/GSA_ARRA_Parking_Lot_Lighting_Spec.pdf
[11] http://www.gsa.gov/graphics/pbs/GSA_ARRA_Parking_Garage_Lighting_Spec.pdf
[12] http://www1.eere.energy.gov/buildings/ssl/consortium.html

4.8 Strategic Environmental Research and Development Program

The Strategic Environmental Research and Development Program (SERDP) is DoD's environmental science and technology program, executed in partnership with DOE and the Environmental Protection Agency (EPA).[13] SERDP invests in basic and applied research and advanced development. SERDP was established in 1990 by Congress to address DoD environmental issued and DOE and EPA share management authority and responsibility with DoD.

DOE organizations that partner with SERDP include National Energy Technology Laboratory, National Renewable Energy Laboratory, Office of Environment Management, Office of Energy Efficiency and Renewable Energy, and the Office of Biological and Environmental Research.

SERDP currently has two major programs solely focusing on exterior lighting: (1) Dynamic Exterior Lighting for Energy and Cost Savings in DoD Installations[14] and (2) Bi-Level Demand-Sensitive LED Street Lighting Systems.[15] Initial installations of each project is anticipated to be completed in 2013.

The objective of the Dynamic Exterior Lighting for Energy and Cost Savings in DoD installations is to quantify the energy, environmental, and economic benefits of deploying advanced exterior lighting control technologies at a representative U.S. Army installation, Fort Sill, OK. In addition to installing controls, the project is also deploying energy-efficient light sources and luminaires. The control strategies being used are time-based; occupancy-based; and network-based. The project is targeting a minimum a 50 percent reduction in energy usage via this strategy. DoD estimates widespread deployment of these exterior lighting system could save 1.8 TWh per year in energy and $127 million (at $0.071 per kWh) from the energy savings.

The objective of the Bi-Level Demand-Sensitive LED Street Lighting Systems is to design, develop, and deploy a demand-sensitive LED system as a retrofit to existing systems. The control system will have traffic sensing capability through a centralized controller and allow for dimming at each fixture. DoD expects that demand-sensitive LED street lighting system will deliver at least 50 percent reduction in energy compared to existing street lighting systems.

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[13] http://www.serdp.org/About-SERDP-and-ESTCP
[14] http://www.serdp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201141
[15] http://www.serdp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-201017

5.0 Conclusions

Lighting controls represent significant potential for energy savings. Limitations to the deployment of lighting controls stems from both technology and practice. In terms of technologies, many exterior controls need to be further developed, standardized, and demonstrated for sites to truly take advantage of these controls. Controls technology will change when there is a large demand (either voluntary or mandatory) for the technology. In practice, barriers to controls include commissioning, design issues, and, finally, attitudes. Lighting controls require the system to be commissioned for the technology to actually save energy. The lighting system has to be designed with controls in mind; this not only means the placement of luminaires, but related infrastructure. Finally, companies, municipalities, and organizations must be willing to adopt a dynamic lighting system for controls to save energy and be effective. If occupancy sensors are going to be deployed, the site must be willing to accept that the lighting will be at lower levels when people are not there. Sites have to move away from the "brighter is better" model and not light areas from dusk to dawn.

Luminaires are improving and changing like never before. New, energy efficient products are coming to market on their own. Each site has different needs and aesthetics that limit the ability to procure large amounts of any one type of luminaire.

Virtually no one exterior site is composed of a singular luminaire type. Most sites use multiple luminaire types to accomplish a desired appearance or objective. DOE currently has programs deployed related to performance specifications for the major exterior lighting energy use: roadways, parking structures, and parking lots. Focusing on additional luminaire types will lead to some additional energy savings, but increasing focus and support on the existing specifications will probably lead to greater energy savings.

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