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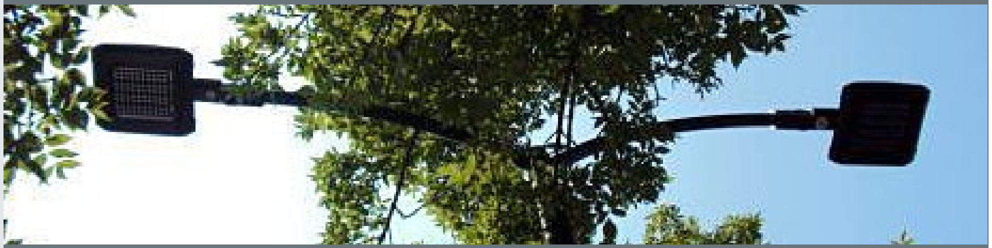
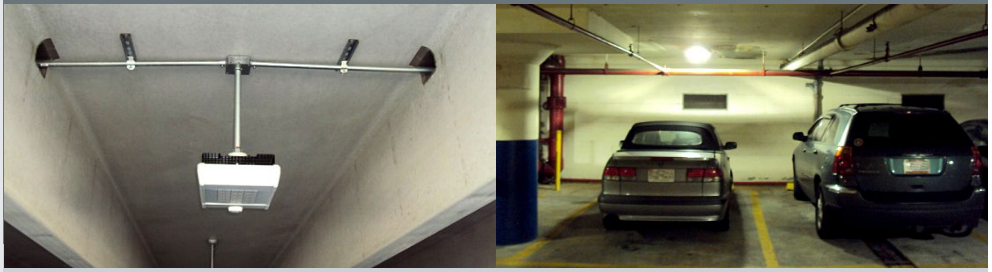
GATEWAY
Demonstrations



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



October 2012

Prepared for:

Solid-State Lighting Program
Building Technologies Program
Office of Energy Efficiency and
Renewable Energy
U.S. Department of Energy

Prepared by:

Pacific Northwest National
Laboratory

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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PNNL-21923

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

Final Report Prepared in Support of the U.S. DOE GATEWAY Solid-State Lighting Technology Demonstration Program

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October 2012

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

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Preface

This document includes observations and results derived from a variety of lighting demonstration projects conducted under the U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting Technology Demonstration Program. The program supports demonstrations of high-performance solid-state lighting (SSL) products in order to develop empirical data and experience with in-the-field applications of this advanced lighting technology. The program provides a source of independent, third-party data for use in decision making by lighting users and professionals; this data should always be considered in combination with other information relevant to the application under examination. Although GATEWAY strives to demonstrate products that are readily available and to measure their performance under real-world conditions, DOE does not endorse any commercial product or guarantee that users will achieve the same results. DOE recommends consultation with a knowledgeable lighting professional before undertaking any investment.

Executive Summary

Occupancy sensor (motion detection) systems are gaining traction as an effective technological approach to reducing energy use in exterior commercial lighting applications. Done correctly, occupancy sensors can substantially enhance the savings from an already efficient lighting system. However, this technology is confronted by several potential challenges and pitfalls that can leave a significant amount of the prospective savings on the table.

This report describes actual experiences from field installations of occupancy sensor controlled light-emitting diode (LED) lighting at two parking structures and two parking lots. The relative levels of success at these installations reflect a marked range of potential outcomes—from an *additional* 76% in energy savings (i.e., after those gained by the initial conversion to LED) to virtually no additional savings (Table S.1).

Several issues that influenced savings were encountered in these early stage installations:

- **Deficiencies in product design** – Such issues most likely stemmed from inexperience at the time with deploying occupancy sensors in exterior parking applications. In one case, it appeared that the products were not adequately designed to withstand sustained exposure to the environment; and as a result the sensors were physically deteriorating after only a season or two of operation. Presumably, manufacturers are giving such early implementation issues high priority as they gain experience in these applications.
- **Installation designs using sensor technology not sufficiently adapted to the individual site –** These included inadequate or incorrect sensor coverage, which can be an artifact of the sensing technologies presently used (primarily passive-infrared) and related limitations as the required area of coverage is increased. The latter limitations directly scale with sensor mounting heights and the physical distance between sensors, both of which tend to be relatively high and/or long in the subject applications, leaving significant gaps in sensor coverage. Innovative design approaches (e.g., addition of remote sensors or use of asymmetric coverage patterns) or even new sensing technology may be required to address the related issues.
- **Lack of dedicated commissioning/optimization of the installed systems** – Factors such as widely varying time delay settings between sensors delivered to the jobsite by the manufacturer, and low power settings that produce more light than needed during periods of non-activity reduce the effectiveness of the sensor-based system. Although these factors are user-adjustable and thus potentially controllable during installation, they had sometimes not been addressed when the subject systems were initially installed. A related factor is the relative ease of adjustment afforded by the equipment design; in at least one case described in this report, adjustments to the time delay setting required the turning of a small non-indexed set screw, an imprecise trial-and-error process that resulted in inconsistent settings between luminaires.
- **System designs incorporating overlapping controls over the same luminaire operation** – At one of the example installations, an astronomical time clock in an above-ground parking structure turns off the perimeter lighting during the daytime. This perimeter lighting is also controlled by occupancy sensors, but because the lights are off an average of half of the daily operating period, the savings derived from those sensors are likewise immediately reduced by half. Use of the time clock control on these perimeter luminaires thereby doubles the payback period of the occupancy sensors compared

with the interior luminaires within the same building that operate on a 24-hour schedule. In another installation reviewed here, all of the luminaires in a retail parking lot are turned off for a period in the early morning, again eliminating any corresponding savings the occupancy sensors might generate during that period. In such cases where the potential for conflicting controls may be present, incremental investments should be examined to determine if they might be more effectively put to use elsewhere.

Table S.1. Summary of lighting and sensor data from four field installations

Project	Underground Parking Garage	Above-ground Parking Structure	Retail Plaza Parking Lot	Commercial Office Parking Lot
Application Type	Interior	Interior	Exterior	Exterior
Construction Type	Retrofit	New Construction	Retrofit	Retrofit
Building Type Supporting	Office	University	Retail	Office
Assigned Parking Spaces	Yes	No	No	No
Flow of Traffic	One way	Multi-directional	Multi-directional	Multi-directional
New Light Source	LED	LED	LED	LED
Original Light Source	HPS	HPS[a]	HPS and MH	MH
Fixture Spacing	25’-38’[b]	28’x58’	120’x150’	125’x75-135’[c]
Fixture Mounting Height (ft)	9	8	33	22
Sensor : Fixture Ratio	1:1	1:1	1:1	1:1
Sensor Mounting	Fixture	Fixture	Fixture	Fixture
Sensor Type	PIR	PIR	PIR	PIR
Sensor Manufacturer	Brand “B”	Brand “A”	Brand “A”	Brand “A”
Reduction in Fixture Power at Low Setting	90%	33%	67%	63%
Energy Savings Achieved from Sensors[d]	76%	19%	37%	N/A[e]
Daylight Response	NA	Off	Off	Off
False-Positive Signals Encountered	Yes	No	Yes	Yes
Initial Time Delay (minutes)	10	20	10	15
Adjusted Time Delay (minutes)	2.5	2 – 5	NA	NA
Original Time Delay Setting as Expected	Mostly	No	No	No

HPS is high-pressure sodium; MH is metal halide; PIR is passive infrared.
(a) The “baseline” or incumbent system used for comparison existed on paper only.
(b) Fixtures are staggered with non-uniform spacing. Values represent range of linear distances between fixtures.
(c) Includes two separate areas of the parking lot.
(d) Relative to the same LED system without sensors.
(e) Energy savings cannot be reported for this site. See section 3.2.

It must be emphasized that the energy savings potential of different measures are not always directly additive when combined. A conversion from HID to LED that by itself achieves a 52 % reduction in energy use, as was the case for the underground parking garage in the first column of the table, cannot achieve an additional 76 % energy savings from the subsequent deployment of occupancy controls, *relative to the original HID system*. The occupancy controls reduced the energy used *by the new LED system* by 76 %, but the additional savings relative to the original HID system in this hallmark example “only” amounted to 36 %. Despite the obvious mathematics in this extreme case (52 % + 76 % = 128 %, an impossibility), energy savings claims are subject to easy misinterpretation if they are not clearly indicated against which baseline (original HID or new LED) they apply. Similarly erroneous sums that are less than 100%, for example, may not be as readily identifiable when quoted out of context.

The experiences and observations described in this report are intended to bring these and related issues into focus for those considering the use of occupancy sensor based control systems in their own applications. Ultimately, care must be taken in the design, selection, and commissioning/optimization of a sensor-controlled lighting installation, or else the only guaranteed result may be its cost.

Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CPUC	California Public Utilities Commission
DOE	U.S. Department of Energy
FEMP	Federal Energy Management Program
HID	high-intensity discharge
HPS	high-pressure sodium
IESNA	Illuminating Engineering Society of North America
LED	light-emitting diode
LRC	Lighting Research Center
MH	metal halide
NEMA	National Electrical Manufacturer’s Association
PIR	passive infrared
SSL	solid-state lighting

Contents

Figures

Tables

1.0 Introduction

Although occupancy sensors based on motion detection are commonly used in interior commercial lighting, several factors have restricted their use in exterior and parking structure[1, 2] environments. Most notably, exterior environments have less defined boundaries and more detrimental (and variable) ambient conditions, and are typically much larger in scale than interiors. In addition, operating characteristics like long restrike and warm-up times of high-intensity discharge (HID) lamps— currently the most prominent light source used in parking and exterior applications—render many occupancy-based control options infeasible.

Interest in combining motion detection equipment with various parking and exterior lighting applications has recently begun to proliferate throughout the energy efficiency, energy regulatory, and lighting communities. Light-emitting diode (LED) lighting technologies offer instantly variable output without the adverse effects of traditional products, and have opened the door to significant potential energy savings, enhanced security, and reduced light pollution. For these reasons, a number of regulatory and utility efforts are incorporating or encouraging more extensive use of motion detection technology in exterior lot and parking structure applications. Some notable examples include the following:

- ANSI/ASHRAE/IESNA[3] Standard. 90.1-2010 states that occupancy sensors can be applied to comply with exterior power reduction requirements for parking areas, signage, and other exterior lighting except for façade and landscaping.
- The California Code of Regulations, Title 24, Section 130.2 (2013 draft) requires that all lights in parking structures must include occupancy controls for reducing light levels during vacant periods. The same requirement applies to parking lots with light poles less than 24 feet high (including base).
- The Illinois ComEd Smart Ideas program offers a $135 per fixture incentive for replacing HID fixtures with sensor-controlled parking garage bi-level fixtures (ComEd 2012, p. 3).

Although there are notable exceptions to the current movement toward motion detection in these applications (e.g., the International Energy Conservation Code 2009 and its proposed modifications for 2012), the trend is clear: Future use of motion detection in these applications is assured as the perpetual pursuit of further reductions in lighting system energy use continues.

Based on experience to date implementing occupancy sensor equipment in exterior and parking applications,[4] the authors have identified several issues that help to determine whether energy savings and other expected benefits of these systems are fully realized. Some of these issues arise from the use of legacy equipment in new applications with characteristics that differ from those for which the equipment was originally designed. Others involve manufacturing defects or issues of quality control. Yet others

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[1] Parking structures comprise hybrid interior/exterior spaces. They are often considered exterior due to the lack of space conditioning and open-air construction; however, the top covering and walls also make them interior spaces. The Internal Revenue Service officially designates them interior spaces for tax purposes related to energy efficient commercial buildings (http://www.irs.gov/irb/2008-14_IRB/ar12.html#d0e4216).

[2] The terms "parking structure" and "parking garage" are used interchangeably throughout this report.

[3] ANSI is ANSI International; ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers; IESNA is the Illuminating Engineering Society of North America.

[4] Through participation in the U.S. Department of Energy GATEWAY Solid-State Lighting Technology Demonstration Program, http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html.

pertain to whether operation of the equipment has been appropriately paired (or designed) with the needs of the application, or taken into account its related integration with the operating environment. Finally, whether or not the system was ever fully commissioned following installation is a critical issue pertaining to systems of all types. Examples of each of these are found in the brief case studies presented later in this report.

1.1 Lamp and Luminaire Technology

Parking lots, parking structures, and exterior areas are presently illuminated by a host of different light source technologies. Each technology has relative advantages and disadvantages, and may be individually favored or avoided for a variety of reasons.

- **HID**, including both metal halide (MH) and high-pressure sodium (HPS), is the most prevalent technology used to illuminate surface lots. HID lamps are efficacious, operate effectively in a wide range of ambient temperatures, and easily produce enough lumen output for mounting on widely spaced poles. MH lamps typically offer better color rendering and have a cooler color temperature than HPS lamps; this improves visibility through increased color contrast and contributes to the general perception that MH lamps are more visually pleasing, but sacrifices luminous efficacy and lamp life slightly, relative to HPS lamps. In the past, almost all HID systems used magnetic ballasts; newer electronic ballasts may allow for bi-level operation or a minimal range of dimming. However, dimming tends to degrade lamp lifetime, to the point that manufacturers void the warranty if dimmed below a certain threshold.[1,2] In addition, because HID ballasts become less efficient as their electric loads are reduced, dimming causes light output to decrease more rapidly than power use. Combined, these factors significantly limit dimming's potential benefit relative to other technologies with more compatible characteristics, as suggested by the relatively low penetration of dimming HID systems in the market to date.
- **Fluorescent** lighting is the most prominent technology used (in terms of numbers of installed lamps) in parking garages[3] because of its relatively low cost, high efficiency, and long life. However, unlike HID point sources, the broad area of emission from fluorescent lamps makes precise optical control difficult, limiting fluorescent use in applications where large areas must be illuminated from regularly spaced locations. Additionally, fluorescent lamps can have difficulty starting in extreme cold temperatures. Fluorescent lamps offer desirable color characteristics and can be dimmed with appropriate ballasts, although lamp life can be reduced when switched off rather than dimmed due to cumulative degradation of the electrodes.
- **Induction** lighting technology has many characteristics similar to fluorescent, but has no electrodes, eliminating the risk of reducing lamp life with increased on-off cycles. Induction products are long-lived and can be an attractive option in many situations, although at present claim only a small portion of the exterior and parking structure lighting markets.

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[1] The effect of dimming on HID lamp life depends on how long lamps are operated in the dimmed mode, the type of dimming system, and how deeply lamps are dimmed. According to the National Electrical Manufacturer's Association, MH should not be dimmed below 50% to 70% of lamp wattage, and HPS should not be dimmed below 50% of lamp wattage (NEMA 2010).

[2] For a real-world test of HID dimming, see the Federal Energy Management Program Fact Sheet *Dimming Controllers Offer Potential Energy Savings in Outdoor Lighting* (FEMP 2010).

[3] (Navigant, 2011), Table 3.6.

- **LED** luminaires are now a viable alternative to conventional technologies in the applications under discussion, and in many cases offer improved efficacy, color quality, and luminous intensity distributions. Notably, LEDs can be dimmed much more easily and to lower levels than HID (~10% versus ~50%) without sacrificing lifetime. In fact, operating LEDs at lower drive currents tends to reduce lumen depreciation while simultaneously increasing efficacy. The favorable dimming capabilities of LEDs can substantially improve the cost-effectiveness of sensing technology, and in fact are strongly correlated with the emerging development of advanced control systems for exterior lighting applications. However, there are still technical issues, such as visible flicker, with the use of dimming equipment in many situations that require resolution before these systems can achieve widespread implementation.

Table 1.1 summarizes the characteristics of each of these lighting sources and their use in parking garage and parking lot applications.

Table 1.1. Parking lot and parking structure lighting technology characteristics

Technology	% of Installed stock (by # of lamps)[a]		Average Initial Luminaire Efficacy (lumen/watt)		Occupancy Sensor Compatibility	Light Source Lifetime (hours)
	Garage	Lot	Garage	Lot		
HID	38.6	92.6	55	68[b]	Low	10,000 - 40,000
Fluorescent	45.9[c]	N.S.[d]	86	65 - 75[e]	High	24,000 - 46,000
Induction	7.4	N.S.	56	54[f]	Medium	100,000[g]
LED	4.1	4.6	>50[h]	72[i]	High	35,000 - 100,000+[j]

(a) The number of lamps installed differs from the square footage illuminated by each source type due to differences in individual lamp output and consequent requirement for multiple fluorescent lamps in a given fixture.
(b) Assumes average 75% fixture efficiency and a lamp-ballast system efficacy of 90 lumens per watt based on the range of available lamps and ballast options (LRC 2004).
(c) (Navigant, 2011), Table 3.6.
(d) N.S. indicates that the data source did not specify. Non-specified sources represent only 0.1% of parking lots.
(e) Range is based on a relatively small sample size due to limited market share.
(f) Based on a survey of induction manufacturers.
(g) Does not include potential generator (power supply) failure.
(h) Per the May 2010 CALiPER Round 10 Report (DOE 2010), efficacy expected to have increased significantly in the time since.
(i) Per LED Lighting Facts as of October 2, 2012, listed as Outdoor Area/Roadway Fixture (DOE 2012).
(j) LED product life is a combined function of lumen maintenance and other aspects of the LED system.

1.2 Sensor Technology

Occupancy sensors are used to moderate light output (and thus power) and can be either integrated into individual luminaires or mounted remotely. Luminaires with integral sensors, specifically LED luminaires that are individually controlled, are becoming common and widely available. These luminaires offer relatively simple installation and can be a practical option in parking applications.

Alternatively, remote sensors potentially can control multiple luminaires, such as those along an entire driving lane. The need for fewer sensors can help offset additional labor (installation and commissioning) and material costs of the control system, and remote sensors can be strategically located to address concerns about “dead zones” (i.e., areas of inadequate sensor coverage). However, remote sensors require a carefully planned design to maximize overall system performance.

The period between the last detected motion and the response of the system (dropping from high to low output state) is referred to as the delay. The optimal delay setting varies based on the application, but plays a key role in energy savings potential; longer delay periods reduce energy savings by keeping the luminaires in the high output state longer, providing more light but using more energy. The delay setting is field-adjustable for most if not all sensors; however, depending on the site (e.g., a parking lot), gaining access to the adjustment device may require a bucket truck and other specialized equipment along with their attendant costs.

Different technologies are used for detecting motion, generally depending on the application. Most sensors designed for interior applications employ ultrasonic or passive infrared (PIR) technologies, or dual-sensing technologies (e.g., both ultrasonic and PIR), to help reduce the occurrence of false positives that incorrectly invoke a response. Exterior and parking structure applications frequently introduce additional challenges to conventional sensors, however. For example, the required area of coverage is usually larger and often lacks wall enclosures to reflect a sonic signal. Issues are compounded as sensor mounting height increases and in situations where the devices are directly exposed to the elements. In exterior and parking garage applications, PIR is generally the favored approach because of its simple operation and relatively low power requirement. All four installations reviewed in this report employ PIR sensors.

1.2.1 Passive-Infrared Occupancy Sensors

PIR sensors identify movement by detecting differences in infrared radiation using a pyroelectric chip. Most commonly, a Fresnel lens (or set of lenses) directs energy toward the sensor from a wide field of view (Figure 1.1). The plastic lens both protects and provides optics for the sensor, but is transparent to the infrared radiation. The segments of the Fresnel lens create distinct radial zones of detection so that the field of view for PIR sensors is not continuous. Motion is detected when an object (e.g., a pedestrian or vehicle) emitting a different level of heat radiation enters the background within a given zone. The lens focuses the heat from the object on the pyroelectric chip, creating an electric signal that is manipulated and transferred via control circuitry to the output level of the luminaire.

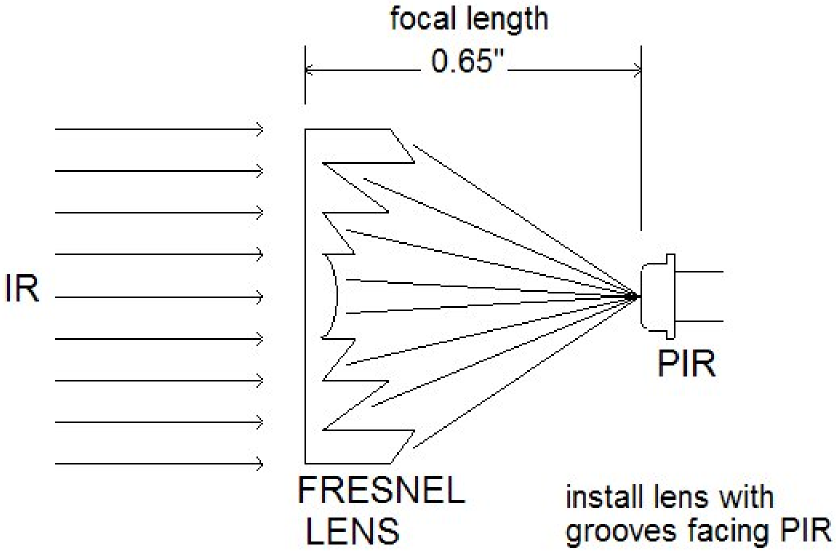

Figure 1.1. Fresnel lens for a pyroelectric infrared device (Source: Glolab 2011)

A challenge for PIR sensors in parking structures is that they require line of sight for detection. Structural and utility elements in both above- and below-ground applications can inhibit line of sight (Figure 1.2) and so require special design. Intermittent blockage from large parked vehicles can present similar issues, with the added complication of being transitory and relatively unpredictable.

Figure 1.2. Line of sight can be challenged by a variety of obstructions

2.0 Occupancy Sensors in GATEWAY Parking Structure Projects

The U.S. Department of Energy (DOE) GATEWAY Solid-State Lighting Technology Demonstration Program evaluates LED products in real-world, general illumination applications. Because of the improved compatibility of LEDs with digital control systems, GATEWAY is increasingly evaluating ancillary systems like motion detection equipment as well. The use and evaluation of sensors in four separate installations—all of which involve automotive parking applications either in exterior lots or in underground and above-ground structures—provides a basis for understanding the effectiveness and some potential pitfalls of this technology. The two categories, parking structures and parking lots, are discussed separately in Sections 2 and 3 of this document.

Motion detection adds unpredictability to system operation in that it is virtually impossible to know precisely when and how often users will cross a sensor's path. The energy savings of all four sites discussed here are therefore based on data logging equipment that documented the exact periods of time the metered luminaires spent in the high, low (i.e., dimmed), and off states. Metering also revealed information about actual luminaire operation, including differences in actual versus expected delay settings, atypical or uncharacteristic luminaire behavior, and faulty sensors.

2.1 Underground Parking Garage | Washington, D.C.

This project replaced 19 ceiling-mounted 100 W (129.5 W including ballast) HPS fixtures with LED luminaires; all were located on one floor of an underground parking garage for an office building. For security, this parking garage is lighted 24 hours per day, 365 days per year, despite the structure's predictable pattern of use, with little to no traffic during nights, weekends, and holidays. The majority of parking spaces in the garage are assigned; therefore, users are familiar with the general space and specifically the area where they park (the time searching for a space is minimal). This consistent schedule makes the facility an ideal candidate for use of motion detectors.

The LED luminaires in this installation contained integral motion sensors capable of reducing their power draw to 10% and entering a low state of illumination (Figure 2.1 and Figure 2.2). Relative to the 129.5 W of the incumbent HPS, the LED products yield 52% power savings in the high state and 95% power savings in the low state. The time delay was pre-set at the factory at 10 minutes.

Following installation, facilities staff at the structure described the operation of the luminaires and control system as "flawless," and satisfaction ratings of facility users were reportedly very high. However, upon installation of data loggers at a later date, two luminaires were discovered to be operating erratically. Both showed an inconsistent tendency to remain in the high state beyond the 10-minute delay setting once activated. One luminaire sometimes remained in the high state for several hours, even though most neighboring luminaires showed no such behavior. The second luminaire exhibited similar behavior, but was more intermittent. Discussions with the manufacturer revealed that certain models of occupancy sensors can be affected by high airflow from nearby exhaust vents or return air exchangers. The manufacturer suggested checking to see if there was an air return nearby or if the relevant products were close to any form of airflow (artificial or natural). Indeed, the first luminaire was found to be in the direct flow path of a high volume air diffuser about 25 feet away, and the second unit was next in line downstream. Seasonal variations in the errant behavior appear to support a theory based on volume of airflow; more errant behavior was observed during summer, when airflow is higher.

Figure 2.1. Occupied parking space with LED luminaire in low state (10% full power)

Figure 2.2. Occupied parking space with LED luminaire in high state (100% full power)

Because of the low mounting height (about 9 feet), adequate coverage by the sensor was more easily achieved than in other types of parking installations where sensors may be located much higher above the ground (e.g., more than 20 feet). This remained true despite a relatively non-uniform spacing among luminaires of between 25 to 38 feet. However, using the manufacturer's estimate of floor area illuminated by the luminaires at this site yields a sensor coverage of only 64%.[1] Figure 2.3 depicts a portion of the garage floor area with the approximate sensor coverage superimposed. Though coverage is somewhat less than 100%, no issues related to inadequate system response have been reported by users to date.

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[1] That is, the total square feet of coverage of the sensors divided by the total square feet of illumination.

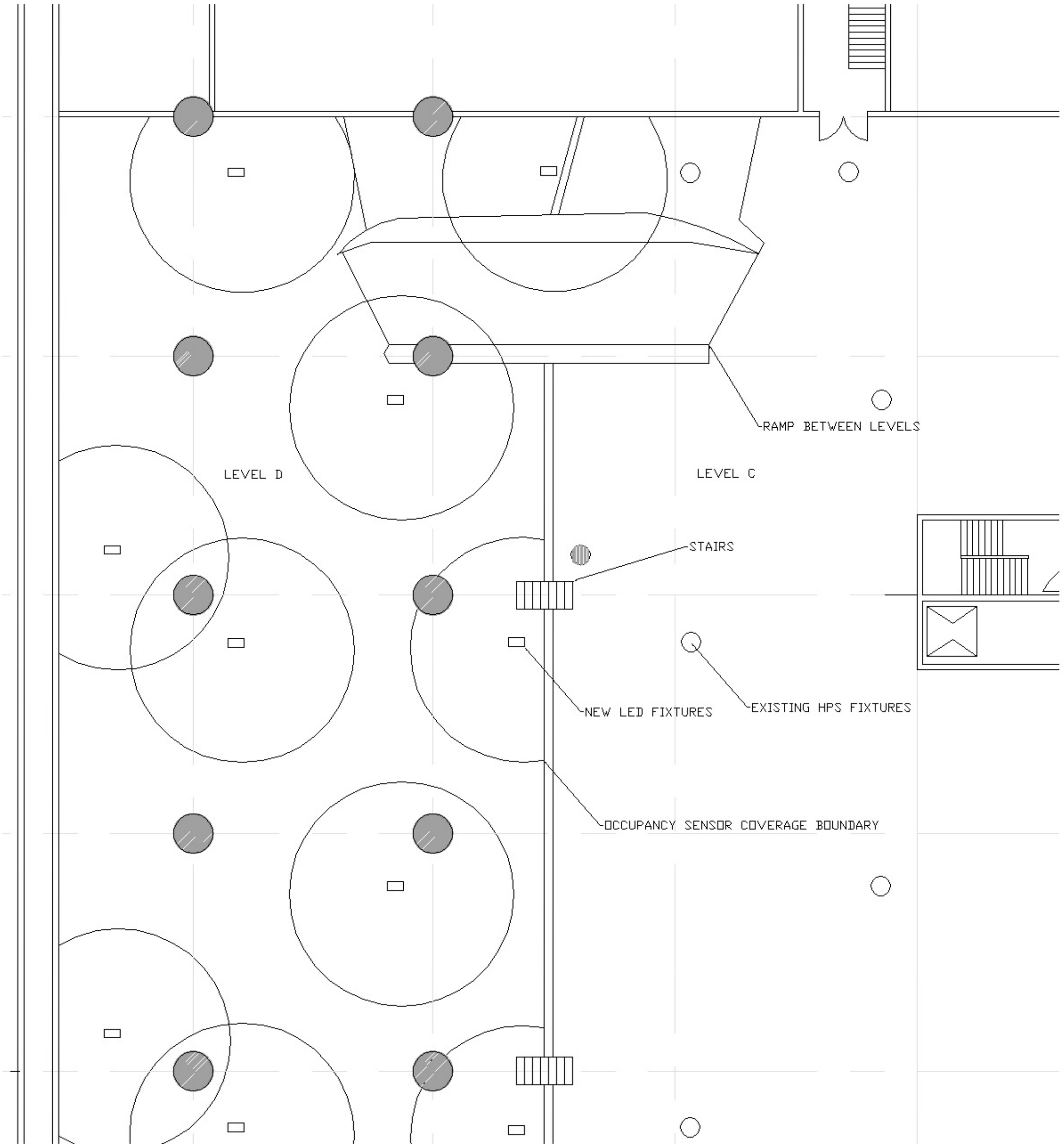

Figure 2.3. A portion of the underground parking structure depicting sensor coverage for the LED luminaires. At the mounting height of 9 feet, the circles indicated are approximately 30 feet in diameter.

Luminaire operation in the high state is only needed between the time a vehicle enters a parking space and when the occupants exit the vehicle. Should the delay setting be shorter than this and the luminaire return to the low state, the motion sensors will again be activated the moment a door is opened (assuming adequate sensor coverage) or when a walking person passes through a covered zone. As a result, it was postulated that the default 10-minute delay setting was longer than necessary.

To investigate, facilities staff manually reduced the delay setting to 2.5 minutes to increase the percentage of time the luminaires spent in the low setting. Figure 2.4 and Figure 2.5 display the behavior for the same luminaire, identified as Fixture 1, on the same day of the week, but on different dates corresponding to the separate delay settings. Although the patterns appear quite similar in aggregate, the more frequent switching between high and low states resulting from the shorter delay setting makes the latter much more active.

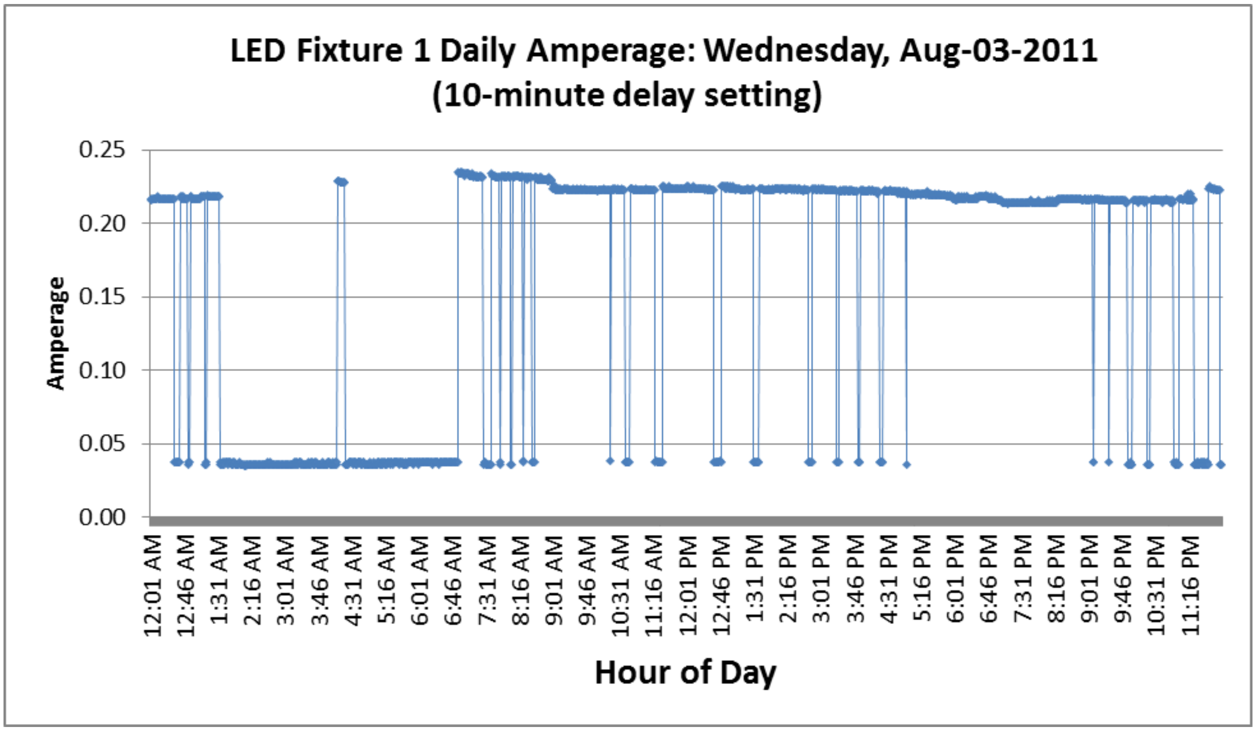

Figure 2.4. LED luminaire daily amperage profile (10-minute delay) Wednesday, August 3, 2011, for the office underground parking structure

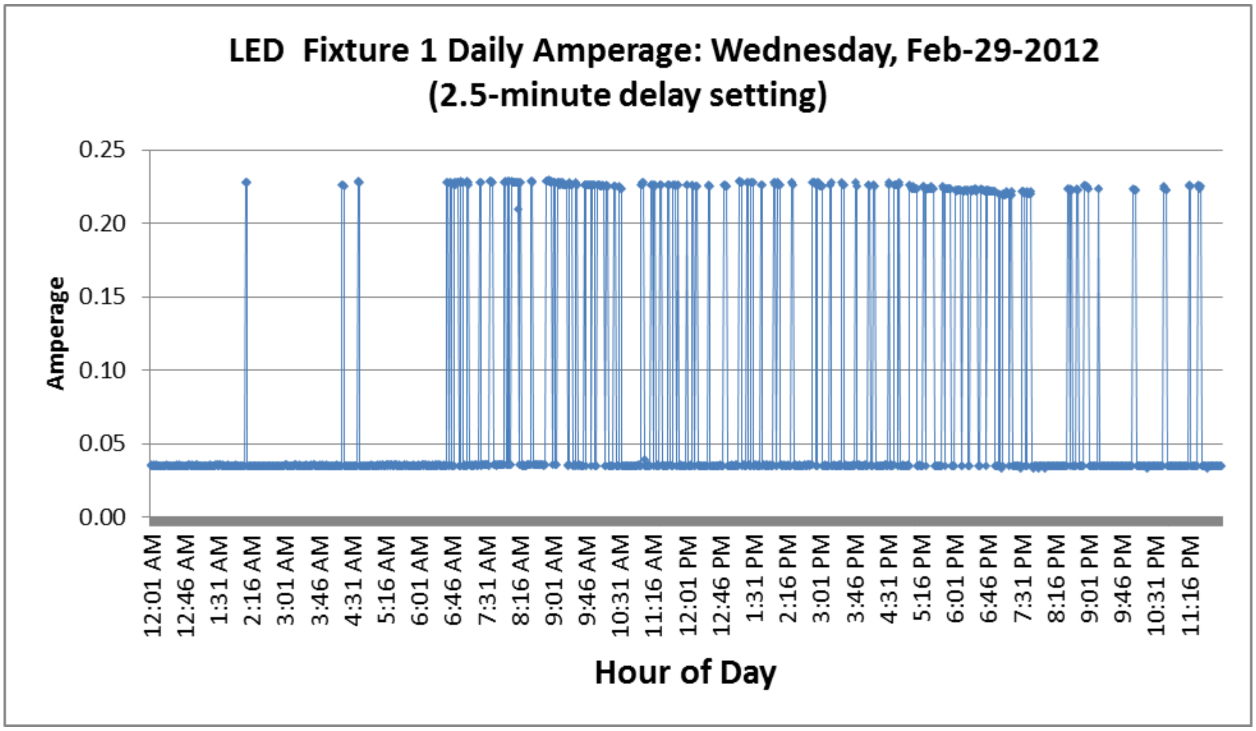

Figure 2.5. LED luminaire daily amperage profile (2.5-minute delay) Wednesday, February 29, 2012, for the office underground parking structure

2.1.1 Energy Savings from the Occupancy Sensor

Table 2.1 presents the cumulative effect of the different time settings for all 19 LED luminaires. Energy savings relative to the original HPS baseline amounted to 74% at the 10-minute setting and 88% at the 2.5-minute setting. If the initial 10-minute LED setting is instead used as the baseline rather than the HPS (i.e., yielding a projected 134 kWh/yr per fixture at 2.5 minutes versus 293 kWh/yr per fixture at 10 minutes), the gain in savings from simply adjusting the occupancy sensor delay is an impressive 54 %.

No complaints about the shorter delay setting have been received from the parking structure users to date, quite possibly because few have even noticed.

Table 2.1. Summary results of annual energy use and savings

Luminaire and Delay Setting	Annual Energy Use (kWh/yr per luminaire)	Annual Energy Savings (kWh/yr per luminaire)	
Baseline HID	1,134	NA	NA
Phase 1: LED (10-minute delay)	293	841	74%
Phase 2: LED (2.5-minute delay)	134	1,000	88%

2.2 Above-Ground Parking Structure | Rockville, MD

This new-construction, above-ground parking structure demonstration project in a university setting included 144 LED luminaires installed on six levels (Figure 2.6). Perimeter luminaires are controlled by an astronomical time clock so that they are off during daytime hours, whereas the interior luminaires operate 24 hours per day. Figure 2.7 shows a diagram of a typical floor layout. Both groups of luminaires are mounted nominally 8 feet above the floor at spacing of approximately 28 by 58 feet, and are controlled by integral PIR motion sensors (Figure 2.8 and Figure 2.9). The motion sensors adjust the LED luminaires from a high power state of 102 W to a low power state of 68 W (33% reduction) when no movement is detected; the luminaires have a default delay setting of 20 minutes. Relative to the design baseline 150 W HPS system (188 W input power),[1] the LED installation represents a 46% savings at high power and a 64% savings at low power.

At this project site, a non-intrusive metering method was accomplished using a standard time-series lighting logger coupled with a custom-made fiber optic light pipe. Rather than measuring input current or power level directly, the system records the luminaire's state (i.e., off, low, or high) by evaluating relative illuminance from the luminaire. The fiber optic light pipe is visible at lower right in Figure 2.9.

Figure 2.6. Site of exterior parking structure GATEWAY demonstration

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[1] Being a newly constructed building, the "baseline system" design existed on paper only, and was provided for this evaluation by the building owner.

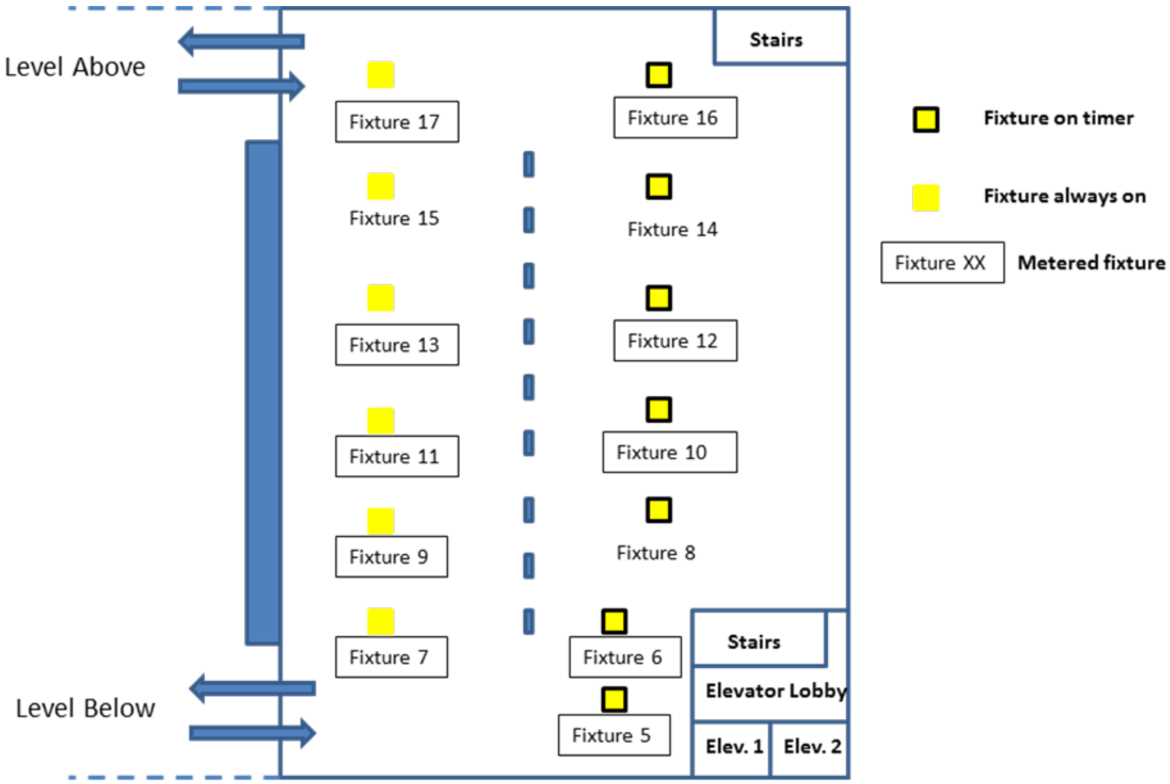

Figure 2.7. Demonstration parking deck 3 luminaire layout and traffic flow. Daylight enters from the right side of the graphic.

Figure 2.8. LED luminaire and pendant installation

Figure 2.9. Close-up of LED luminaire and integral motion sensor (metering light pipe also shown)

2.2.1 Occupancy Sensor Settings

This project was evaluated in two phases. The first phase was completed using the factory-set delay period of 20 minutes and resulted in roughly 55% savings over the baseline fixture design. In the second phase, the delay was reduced to periods of between 2 and 5 minutes. The unintentional variability in the latter was an artifact of the very small potentiometer set screw used for adjusting the delay, which had limited indexing guidance to facilitate uniform settings from luminaire to luminaire.[1]

2.2.1.1 Long (20-minute) Time Delay

Figure 2.10 through Figure 2.13 present typical daily profiles of operating states for the LED luminaires with the factory default delay setting of 20 minutes. The luminaires exhibited a variety of operating profiles depending on the time of day and day of the week over the 8-month period data was collected. Figure 2.10 and Figure 2.11 show perimeter fixtures controlled by time clock during data collection in late spring of 2011, which were switched off between 5:30 a.m. and 8:30 p.m. at that time of year. Figure 2.12 and Figure 2.13 show interior fixtures that operate 24/7.

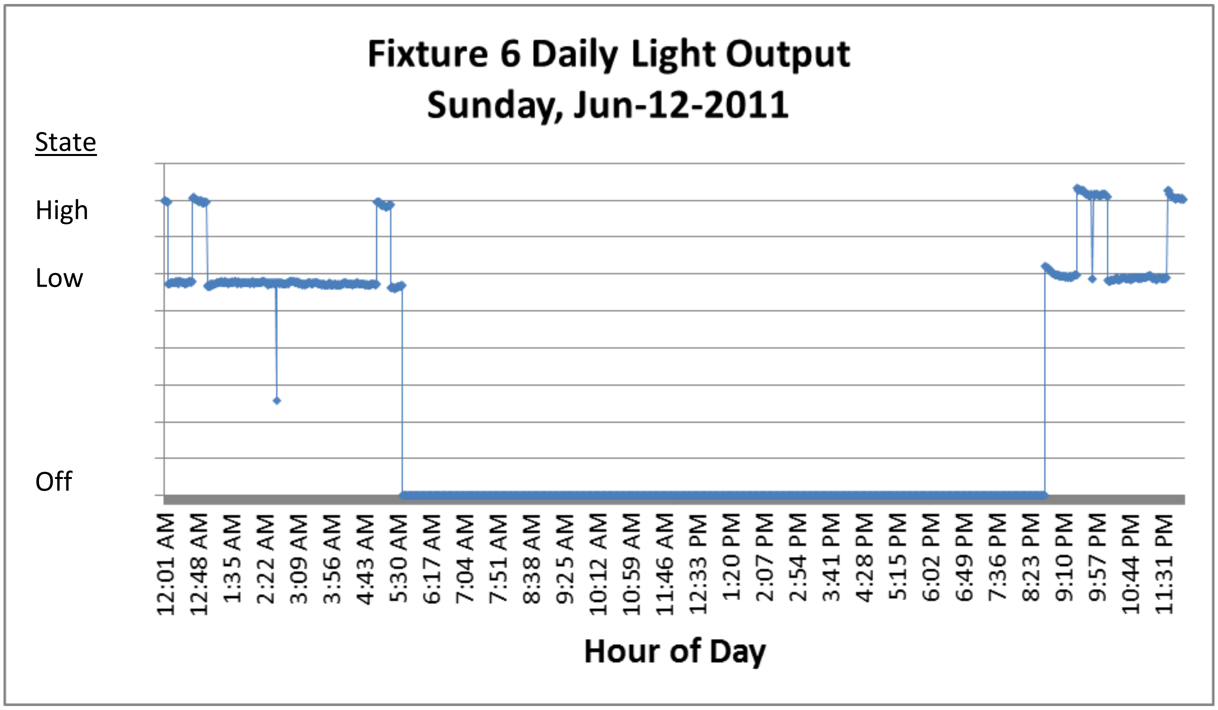

Figure 2.10. Perimeter, daily usage profile (20-minute delay) Sunday, June 12, 2011

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[1] Achieving consistency among these luminaires would require trial-and-error to adjust each individual setting, move out of detection range, manually time the delay, and readjust and repeat as needed. Time limitations prevented such a laborious procedure for this demonstration project, and would likely deter a typical user as well.

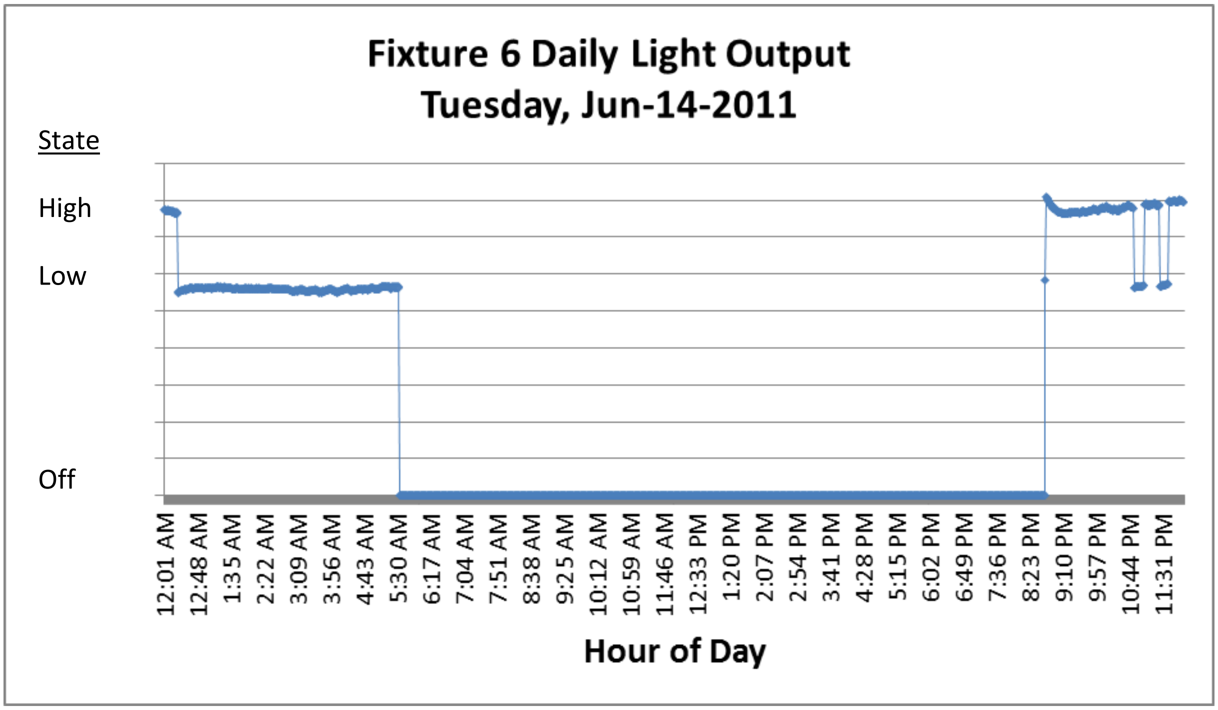

Figure 2.11. Perimeter, daily usage profile (20-minute delay) Tuesday, June 14, 2011

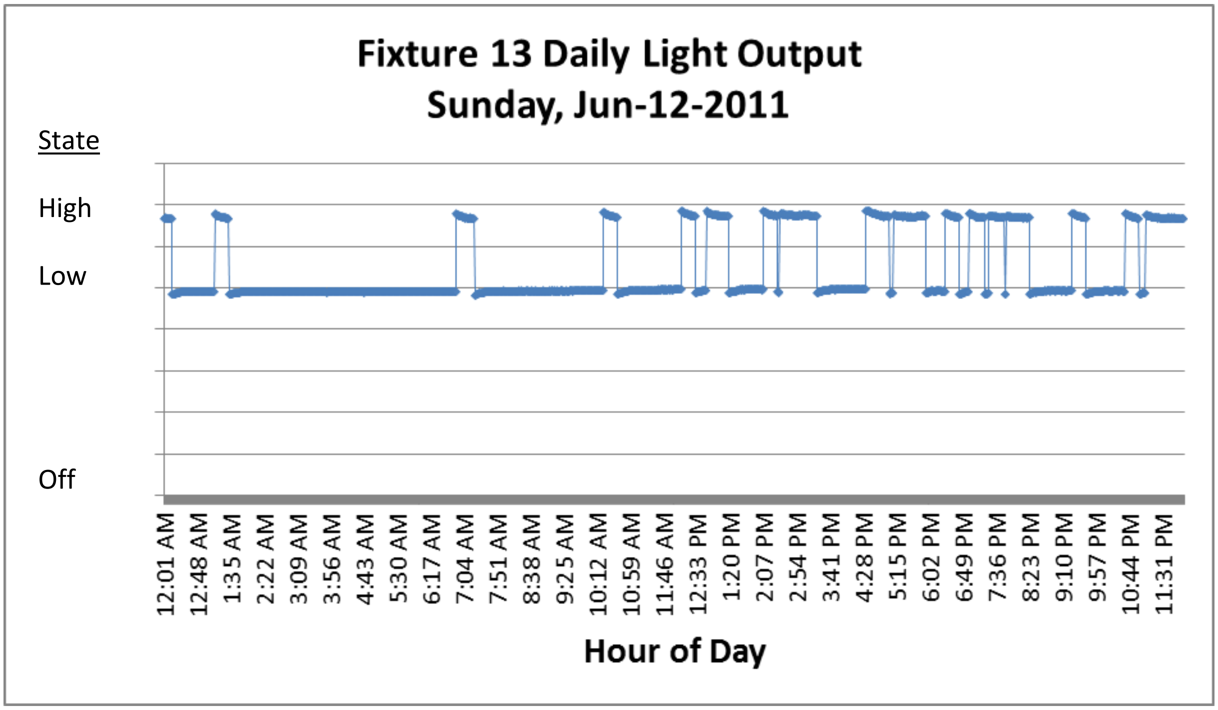

Figure 2.12. Interior, daily usage profile (20-minute delay) Sunday, June 12, 2011

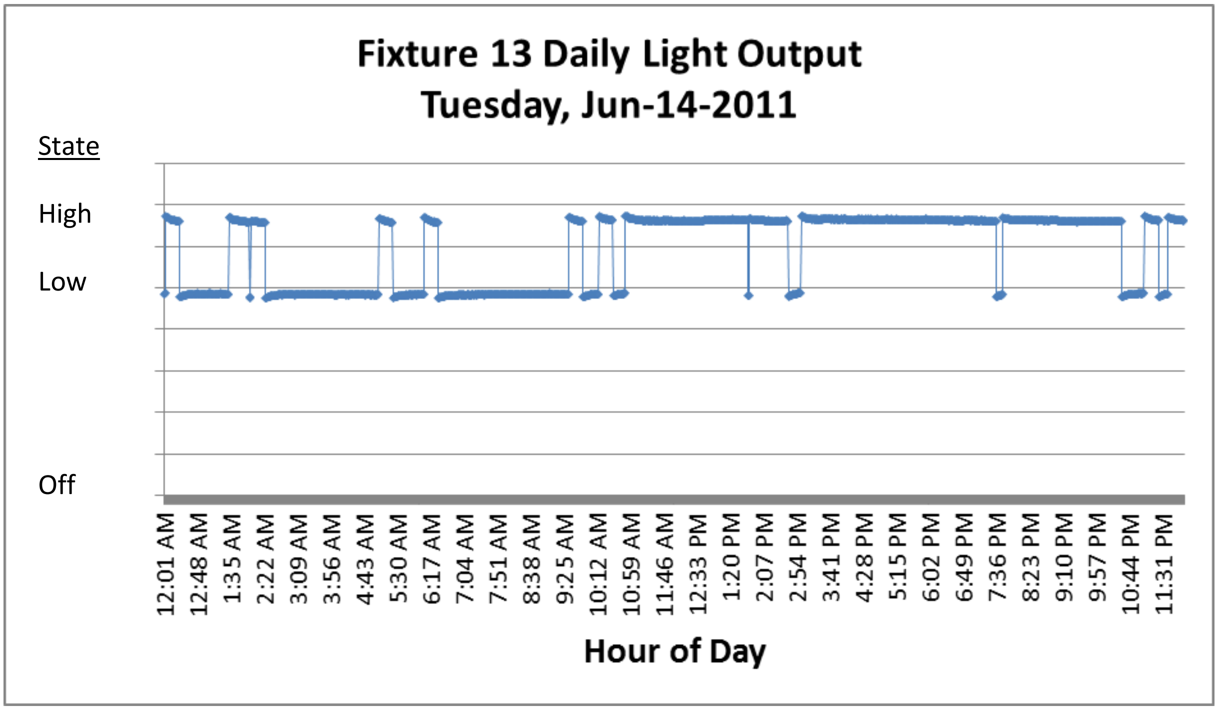

Figure 2.13. Interior, daily usage profile (20-minute delay) Tuesday, June 14, 2011

2.2.1.2 Reduced Time Delay

After reducing the delay settings in the second phase, data was collected over a 2-month period for 10 of the LED luminaires. Figure 2.14 through Figure 2.17 present typical daily operating profiles for the luminaires with the delay setting between 2 and 5 minutes, recorded during February 2012.

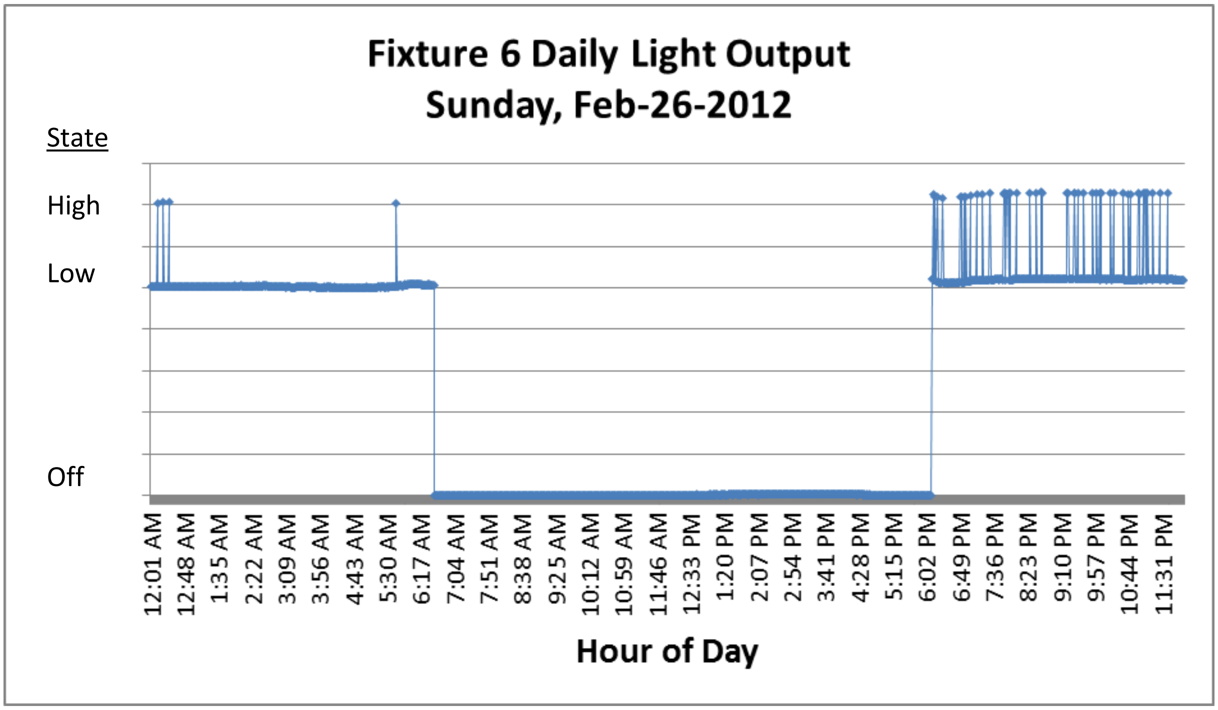

Figure 2.14. Perimeter, daily usage profile (~2 minute delay) Tuesday, February 26, 2012

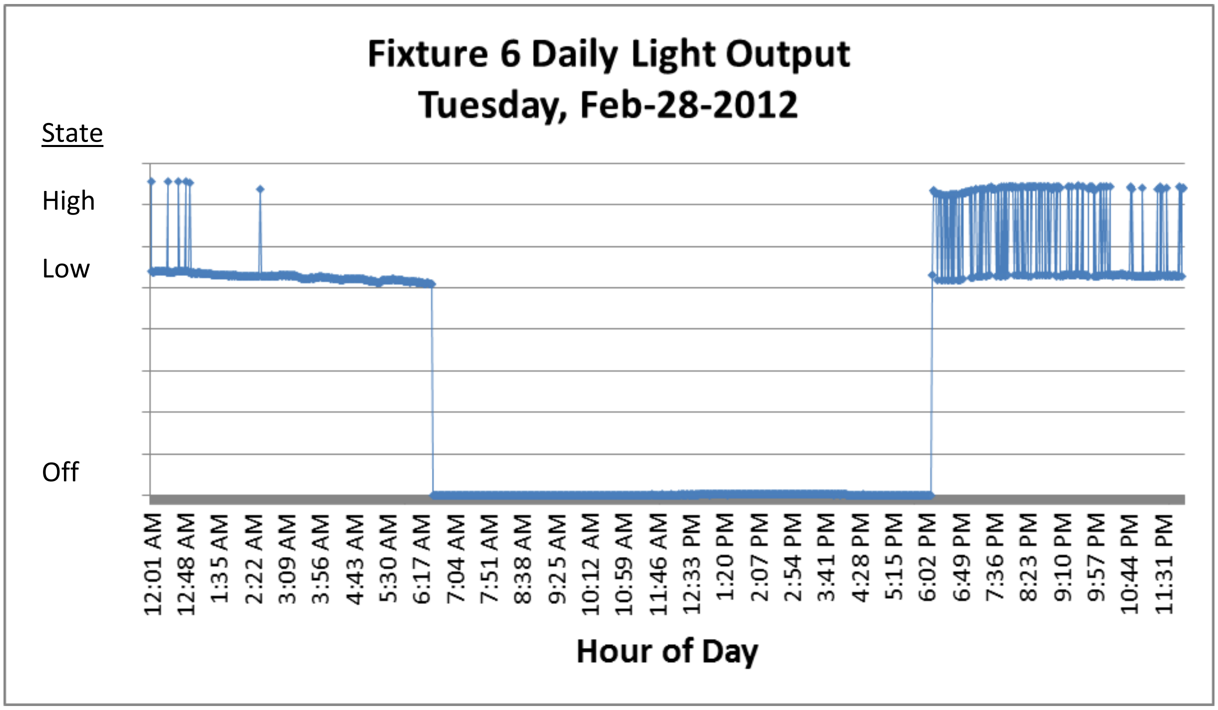

Figure 2.15. Perimeter, daily usage profile (~2 minute delay) Tuesday, February 28, 2012

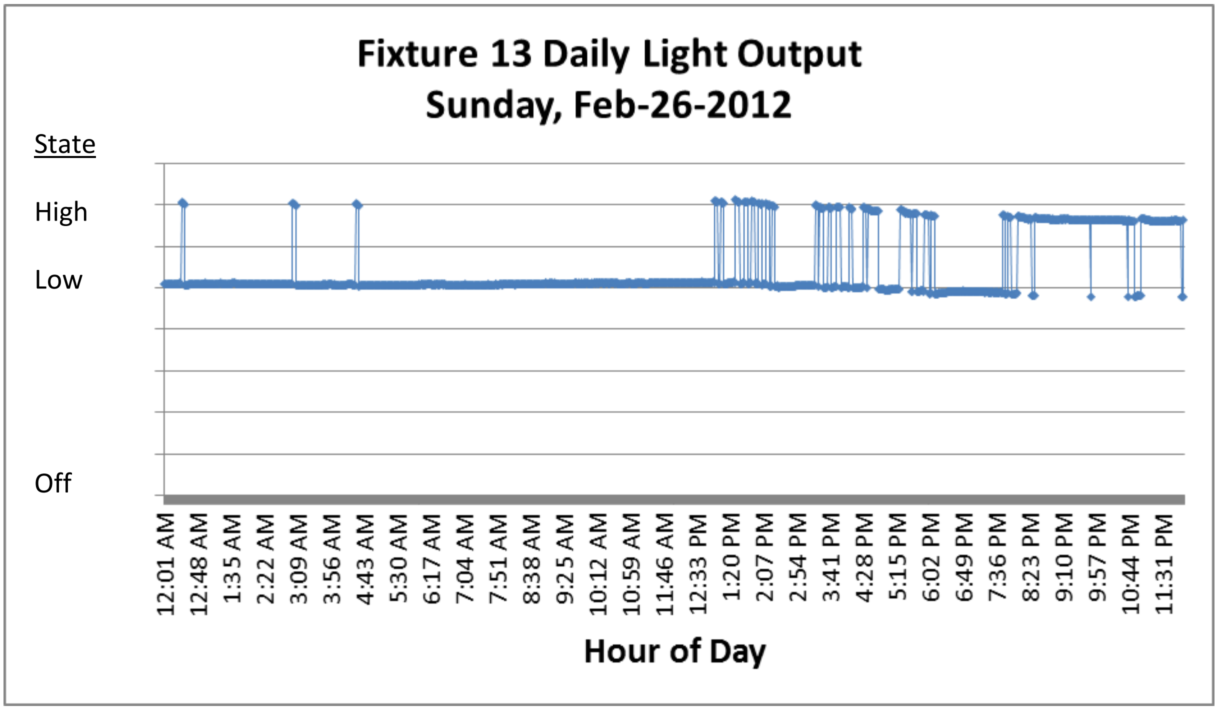

Figure 2.16. Interior, daily usage profile (~5 minute delay) Sunday, February 26, 2012

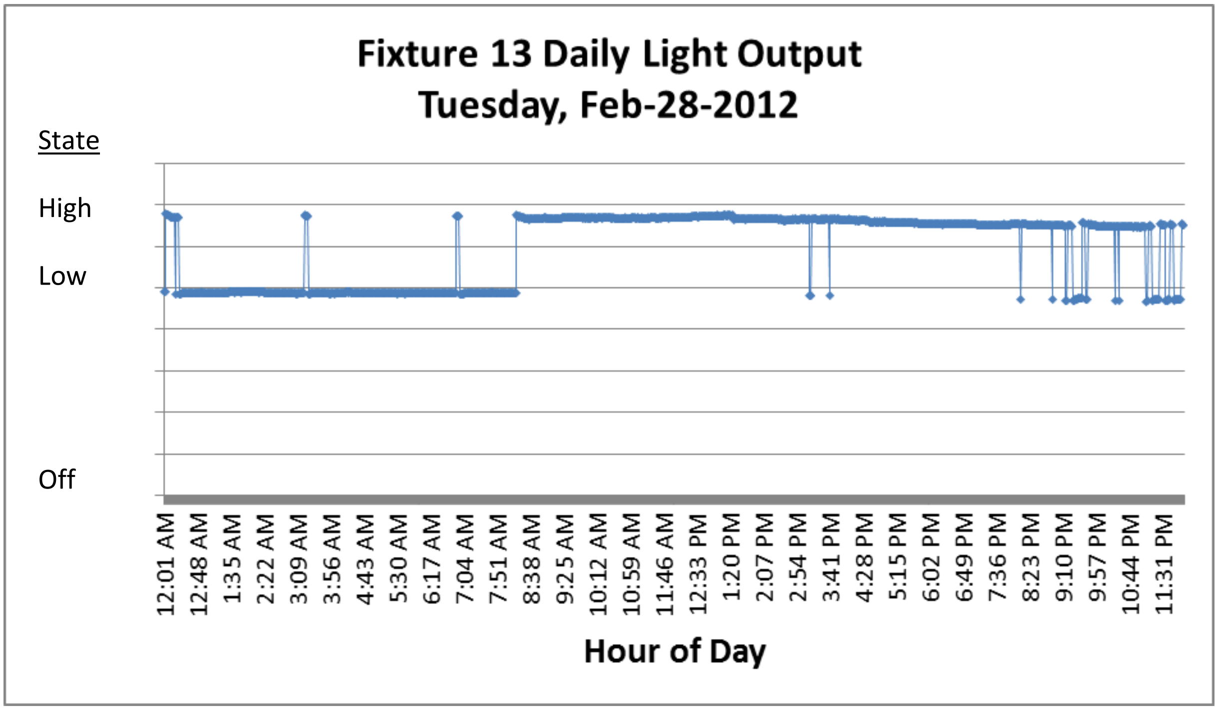

Figure 2.17. Interior, daily usage profile (~5 minute delay) Tuesday, February 28, 2012

2.2.2 Energy Savings from Occupancy Sensors

Table 2.2 presents a summary of annual energy use, annual energy savings, and percent savings relative to the baseline fixtures. This analysis used the metered run time data along with individual luminaire performance data to calculate energy use and savings.

Table 2.2. Summary results of annual energy use and savings, exterior parking structure

Fixture/ Delay	Annual Energy Use (kWh/fixture/yr)		Annual Energy Savings (kWh/fixture/yr)				
	Interior	Perimeter	Interior	Perimeter	Interior	Perimeter	Combined
Baseline HPS	1,646	779	NA	NA	NA	NA	NA
Phase 1: LED (20 min delay)	739	344	908	435	55.1%	55.9%	55.4%
Phase 2: LED with 2 to 5 min delay	715	323	932	456	56.6%	58.2%	57.2%

Table 2.3 extends the energy use and corresponding savings estimates across all 144 LED luminaires in the parking structure, and breaks out the portion contributed by the operation of the occupancy sensors at the original 20-minute delay setting.[1]

Table 2.3. Energy savings contribution from sensors, exterior parking structure

	Daily Operating Hours[a]			Power Draw (W)			Annual Energy Use (kWh)[b]		Energy Savings Contribution from Sensors	
	High	Low	Off	High	Low	Off	Base[c]	W/Sensors[d]	kWh	Percent
Interior	10.4	13.6	0	102	68	NA	64,333	52,182	12,152	18.9%
Perimeter	5.1	6.9	12	102	68	0	32,167	26,001	6,165	19.2%
Totals							96,500	78,183	18,317	19.0%

(a) Based on metered data during the period of evaluation, at the original 20 minute delay setting.
(b) For 144 luminaires total, split evenly among interior and perimeter locations (72/72).
(c) Based on all LED luminaires in high state for entire period of operation.
(d) Calculated result assumes percent times spent in each mode reported in the first column remain consistent throughout the year.

See Section 4 for discussion of the results.

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[1] The significant variability among luminaire time delays following their adjustment at this site (yielding settings between 2 and 5 minutes) rendered accurate estimation/extrapolation across the garage infeasible, so the initial setting is used for calculations in Table 2.3. As evident in the last column of Table 2.2, however, the adjustment of time delay at this site imparted only a minor benefit to the overall savings achieved.

3.0 Occupancy Sensors in GATEWAY Parking Lot Projects

The two demonstration sites discussed in this section are both exterior parking lot applications. Parking lots are particularly challenging for occupancy sensors because they are typically large, open areas (leading to widely spaced luminaires at substantial mounting heights) and because the devices are directly exposed to environmental conditions.

3.1 Retail Plaza Parking Lot | Manchester, NH

This project retrofitted the lighting in an exterior shopping center parking lot with 25 LED luminaires on 13 poles, mounted 33 feet above finished grade on approximately 120 by 150 foot spacing. All poles but one have two luminaires installed in close proximity, virtually back to back. Each luminaire is outfitted with an integral PIR motion sensor, reportedly set at the factory to a delay of 15 minutes. In dropping to low, the sensor reduces power from 234 to 78 W, for a savings of 67%. The electric current at each pole was monitored over two periods in November 2009 and March 2010 to document the operating profiles of the new sensor-controlled LED luminaires.

In this installation, it quickly became evident that a) large areas between poles were outside the coverage range of the sensors; b) there was significant overlap in coverage between sensors on the two luminaires sharing the same pole; and c) some variability existed between time delay settings among the installed luminaires. Due to the overlap in coverage, if one luminaire on a pole was triggered into high state, the other usually also switched into high despite ostensibly being aimed over the adjacent lane. Although some overlap in coverage is justified because PIR sensors require line-of-sight for detection,[1] excessive overlap reduces energy savings.

Figure 3.1 superimposes sensor coverage (shown as smaller gray circles in the diagram) according to the manufacturer's data— approximately 60 feet diameter at this mounting height—for each luminaire over the lighter gray area that indicates where calculated illuminance above 0.5 fc is achieved.[2] The apparent gaps in coverage are large enough to support an observation that vehicles could easily traverse the parking lot after hours and virtually avoid detection. The parking lot is approximately 151,000 square feet, whereas the area monitored by the sensors covers only about 45,000 square feet, or about 30% of the total area.

As at the other sites described in this report, metering the luminaire operating profiles revealed some unexpected behaviors. The manufacturer's reported time delay setting was 15 minutes, but all of the luminaires had settings different from this. Of the 25 luminaires, 21 were set to a 10-minute delay, 3 were set to 5 minutes, and 1 was set to 30 seconds. Another interesting finding was that one luminaire—indicated in Figure 3.1 with a red arrow—at first appeared to be subject to false tripping. This luminaire, the only one on its individual pole, was spending an inordinate amount of time in the high illumination state. Further investigation revealed that a portion of the sensor coverage extended out of the parking lot

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[1] For example, given the configuration of the luminaires, having only one sensor per pole would allow the pole itself to block a significant viewing angle, leaving a large gap in coverage.

[2] Corresponding to IES recommendations for enhanced security. IESNA RP-20-98, *IESNA Lighting for Parking Facilities*.

and onto the neighboring street (a busy thoroughfare); the sensor was being tripped by vehicles passing in the nearest lane.

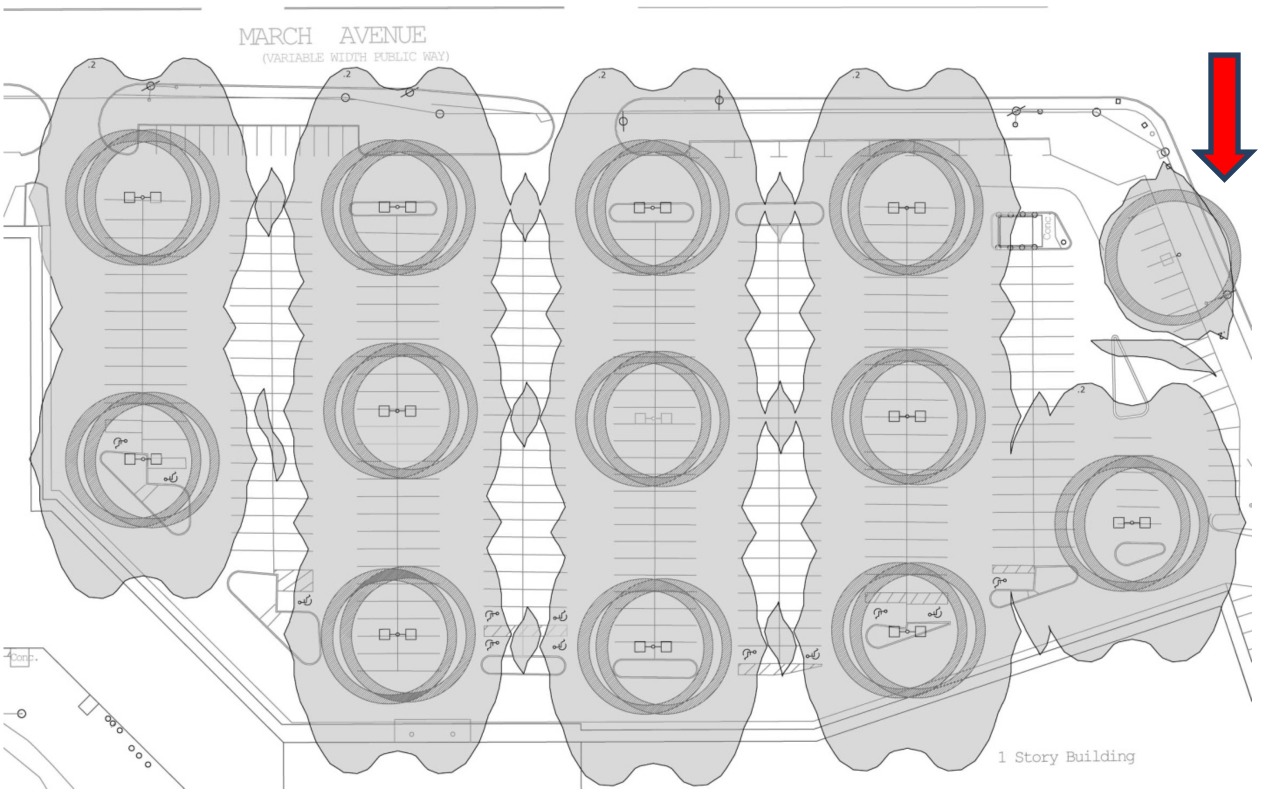

Figure 3.1. Illuminance coverage (light gray area) and occupancy sensor coverage (dark gray circles) in retail parking lot. The red arrow indicates sensor coverage extending beyond the parking lot boundary.

Two graphics generated from the metered data in this installation serve to illustrate some of the issues discussed. Figure 3.2 displays the erroneous operation of the luminaire noted above, clearly showing the influence of the neighboring road traffic. With few exceptions, this luminaire was spending the vast majority of operating time in the high state. In contrast, Figure 3.3 shows the operating profile for a more typical set of luminaires located on a pole elsewhere in the parking lot. Note in this graphic that there are only two brief instances in the displayed 24-hour period where only one luminaire went to high state and not the other (at about 4:00 pm and 7:30 pm); tripping the sensor on one luminaire almost invariably tripped the other luminaire on the same pole due to the overlap in sensor coverage. Also evident is the fact that while these luminaires appear to be adequately detecting movement during normal business hours when vehicles are staying within the prescribed driving lanes, after hours the situation may be different. The drop-off in detected activity appears quite abrupt; while there is no way to determine whether lot activity was missed from this graphic alone, certainly the complete cessation starting at about 9:30 pm is questionable. Data from other poles around the lot (not included here) do show occasional random activity during these after-hour periods, revealing in fact the lot is not as entirely deserted as this graphic might imply. One plausible explanation is that once the parking lot has largely emptied, cars moving through the lot begin to traverse across the painted spaces rather than following the lanes, and thus escape detection.

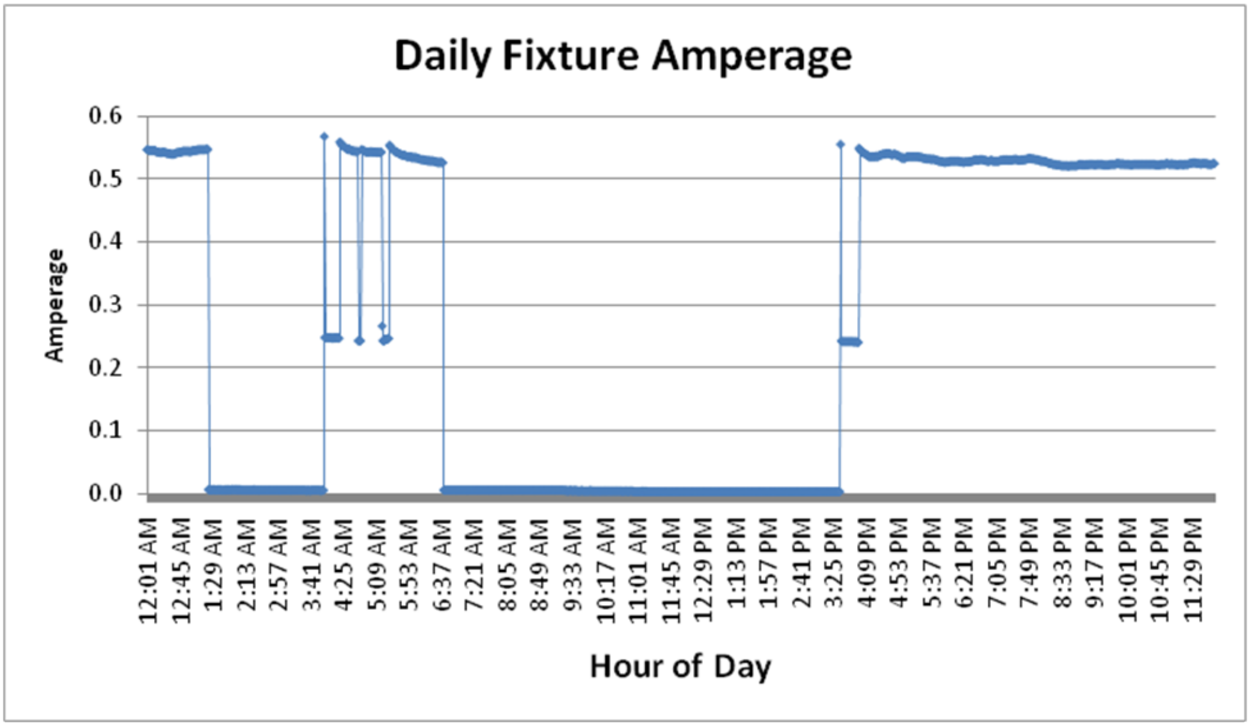

Figure 3.2. Operating profile of luminaire where sensor coverage extended into the nearby roadway. Only one luminaire is installed on this pole. Data recorded Friday, 12-3-2010.

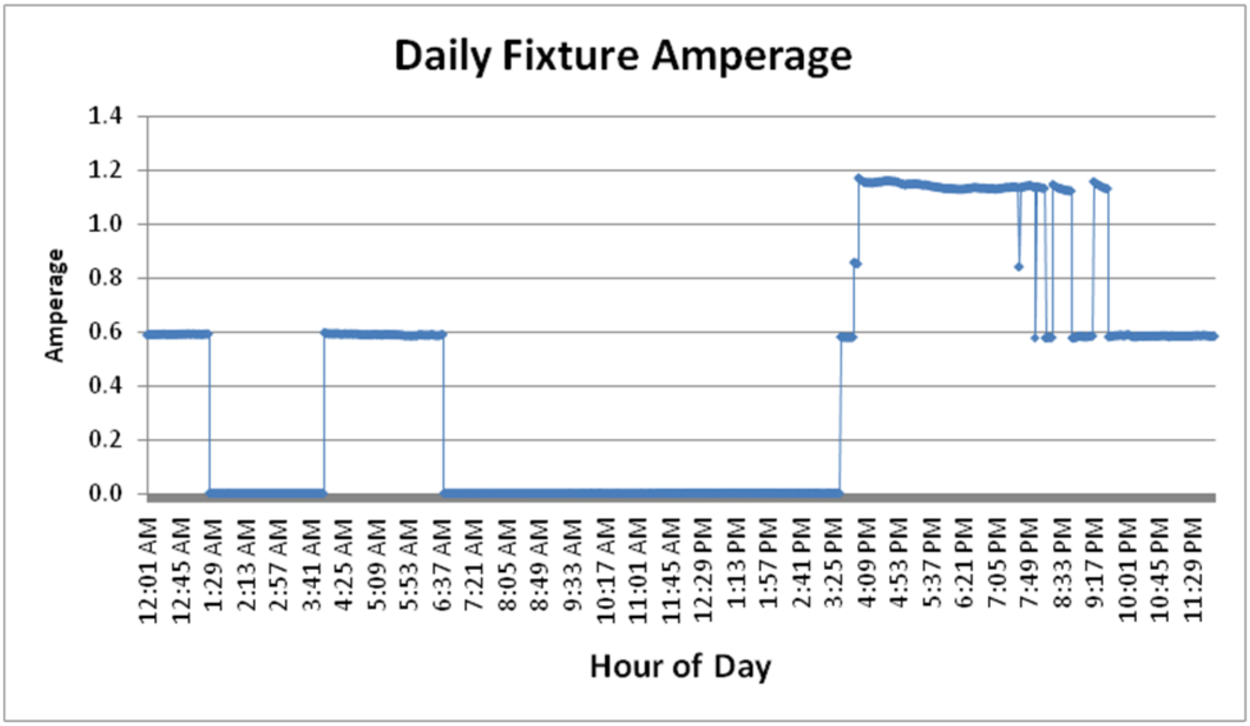

Figure 3.3. Operating profile of luminaires located elsewhere in the parking lot on Friday, 12-3-2010. Two luminaires are mounted on this pole.

3.1.1 Energy Savings from Retail Parking Lot

Table 3.1 provides the average metered results across the entire lot for the periods the two luminaires per pole spent in each of the four possible modes (i.e., both luminaires in high; one high / one low; both in low states; or both off) during the period of evaluation. Table 3.2 reports the calculated annual energy savings resulting from the retrofit. Relative to the original combined 495 W of the HPS lighting (22 units) and 470 W of the MH lighting (6 units), the high state of LED operation (234 W) represents a 57% savings and the low state (74 W) an 86% savings. Averaged across an entire year, assuming the relative percentages of time spent in each mode remain the same,[1] this produces a savings of 34,767 kWh or 73% relative to the original system.

Table 3.1. Plaza exterior parking lot metered results

	Fixture Hours “Off”	Fixture Hours 1 and 2 “On Low”	Fixture Hours 1 or 2 “On Low” Other “On High”	Fixture Hours 1 and 2 “On High”	Totals
Average of All Fixtures	9.8	7.5	0.7	5.9	24
Averages as a Percentage of “On Time”	NA	53.0%	5.1%	41.9%	100%

Table 3.2. Energy savings from LED and occupancy sensor system

System	Qty	Source Type	Luminaire Power (W)	Total Power (W)	Annual Hours	Annual Energy (kWh)	Total Annual Energy (kWh)	% Reduction
Existing	22	HPS	495	10,890	3,468	37,761	47,539	NA
	6	MH	470	2,820	3,468	9,778	[a]	
Retrofit	25	LED - High State	234	5,850	3,468	20,285 [b]	12,773[c]	73%
	25	LED - Low State	78	1,950	3,468	6,762 [b]	[a]	

(a) Included in value immediately above.

(b) The two LED values in this column bound the potential results, representing annual energy used if the luminaires spent their entire operation in the respective high or low state.

(c) Calculated result assumes percent times spent in each mode listed in Table 3.1 remain consistent throughout the year.

Although the owners and resident businesses located within the retail plaza reported high satisfaction with this retrofit, questions remain from a lighting design standpoint as to the effectiveness of its present operating performance. There has been no attempt at this site to adjust the time settings on the luminaires to correct the variability or reduce the setting to a shorter delay. Given a potential for pedestrians or vehicles to traverse much of the lot without tripping sensors due to the gaps in coverage,[2] it is fortunate

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[1] Seasonal variation in a retail parking lot environment challenges such an assumption, because of both the hour of day the lights come on and the corresponding levels of traffic expected at those times. A typical summer evening’s profile should look decidedly different from the Christmas shopping season, for example.

[2] It is furthermore not immediately evident how these issues might be satisfactorily remedied without significant additional expense. The range of coverage needed due to the wide pole spacing presents a formidable challenge for conventional sensing technology, and may require new technologies or specialty optics that, e.g., provide an

that light levels are sufficient to meet IES recommendations for this site even at the low setting. Such a case brings into question the exact purpose of the sensors, however, since this suggests the luminaires might be even more cost-effectively employed at the low output level without the use of sensors altogether, if this approach was acceptable in this retail location.

3.2 Commercial Office Parking Lot | Beaverton, OR

This corporate campus parking lot project involved the installation of LED luminaires, among a variety of other attempted fixes, to remedy numerous illumination issues being reported by employees. The original 400 W nominal MH luminaires had been installed without arms (Figure 3.4) several years earlier, at about 22 feet mounting height on variable pole spacing between 125 by 75 feet to 125 by 135 feet. Since then, vegetation growth had partially obscured the luminaires, and illumination levels around the parking lot had become inadequate. The client was unwilling to pursue aggressive pruning of the vegetation, so among the alternatives attempted was installation of supplemental 200 and 250 W nominal MH luminaires at points around the site. At the time of this demonstration, LED lamps on extended arms with integrated occupancy sensors had recently been installed in a few sections of the parking lot, as shown in Figure 3.5. This figure also includes an inset close-up of one luminaire to highlight its integrated motion detector, visible as a white circular disk at the base of the luminaire.

The LED products improved illumination levels relative to the earlier HID systems, but still did not fully address the noted deficiencies. Unfortunately, because a fully adequate system was not achieved during the course of this evaluation, accurate energy use estimates and related savings cannot be reported for the project. However, the site still provides a number of relevant observations related to the use and challenges of motion detectors in an exterior parking lot application.

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asymmetric distribution to reduce both overlap and the gaps between poles. Wide pole spacing can be expected to present similar challenges for many parking lot sites looking to implement occupancy sensors in the future.

Figure 3.4. Original 400 W metal halide luminaire

Figure 3.5. Replacement LED luminaires on extended arms and inset highlighting occupancy sensor

Operating state data were acquired in one area containing 11 LED luminaires. A significant variation was found in the time delay setting among the sensors, despite the manufacturer's claim that each delay was factory-preset to 15 minutes. In fact, only 2 of the 11 luminaires were effectively set at 15 minutes; the remaining 9 luminaires had settings varying from 30 seconds to 30 minutes.

In addition to the discrepancy in delay setting, the operating state data revealed a significant problem with false tripping. The data showed unexpected energy use patterns on various evenings—a number of the luminaires were spending a considerable amount of time in the high state during periods when extensive activity in the parking lot seemed unlikely. Because each pole contains two luminaires, there are four possible states of operation: 1) both in the off state (during the day); 2) both in the low state (no movement detected); 3) one in the high state and one in the low state[1]; and, 4) both in the high state. All four levels of operation are visible in Figure 3.6, which shows the daily profile for Sunday, October 18, 2009. Operation in the high state during the early morning hours suggests something other than vehicle or pedestrian traffic in the campus parking lot was causing the sensors to activate.

Further investigation revealed a likely contributing factor, however. Figure 3.7 and Figure 3.8 plot hourly wind speed recorded at a nearby airport against the operating state data for the same pole documented in Figure 3.6. As suggested in both figures, there is an apparent correlation between wind speeds beginning around 8 to10 mph and tripping of one or both of the luminaires into high state.

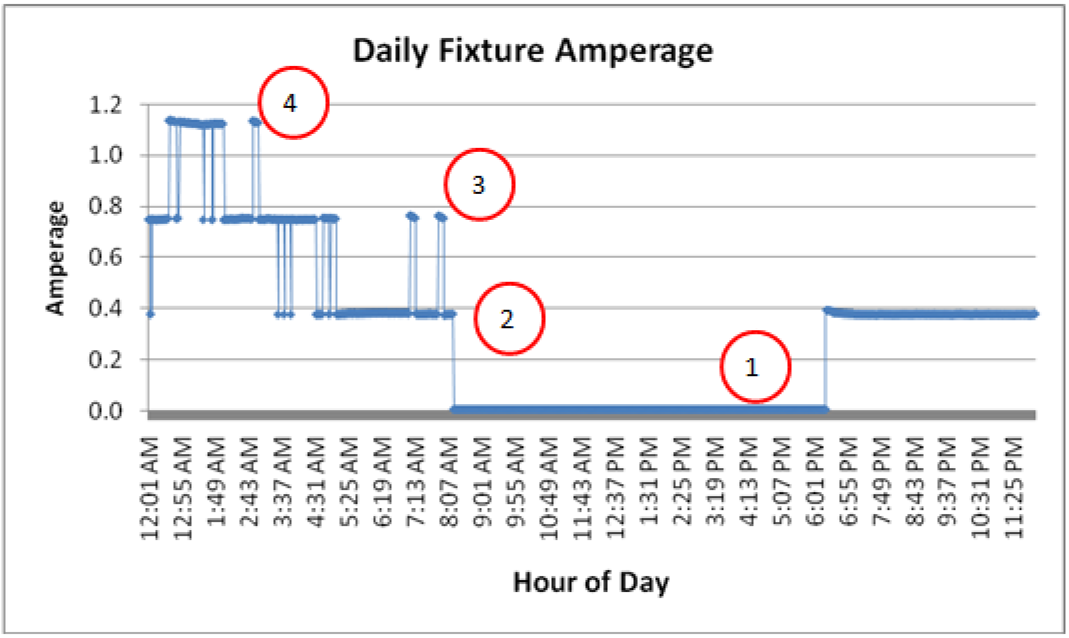

Figure 3.6. Suspected false tripping profile, LED luminaire, Sunday, October 18, 2009. Two fixtures on pole with time delays set at ~10 minutes. All four possible states of operation are shown.

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[1] There are two possible combinations within this state, but they are indistinguishable in the data file.

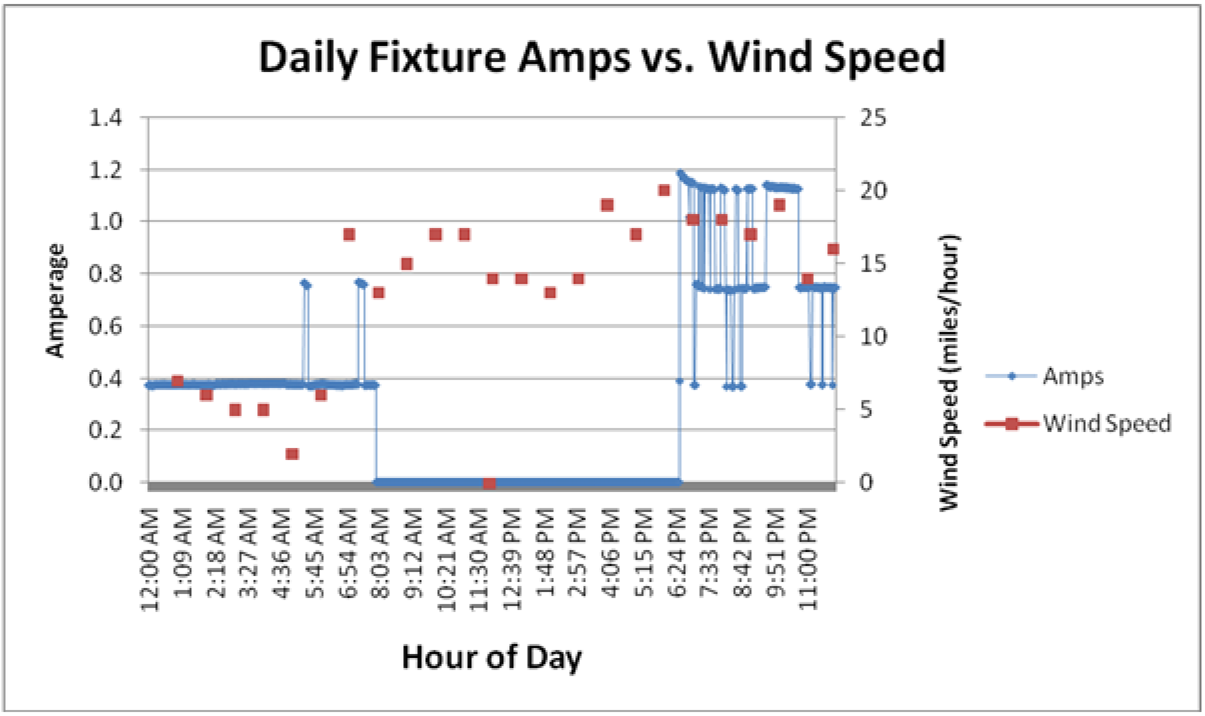

Figure 3.7. Suspected false tripping profile, LED luminaire, Saturday, October 17, 2009 with nearby airport wind speed data overlay

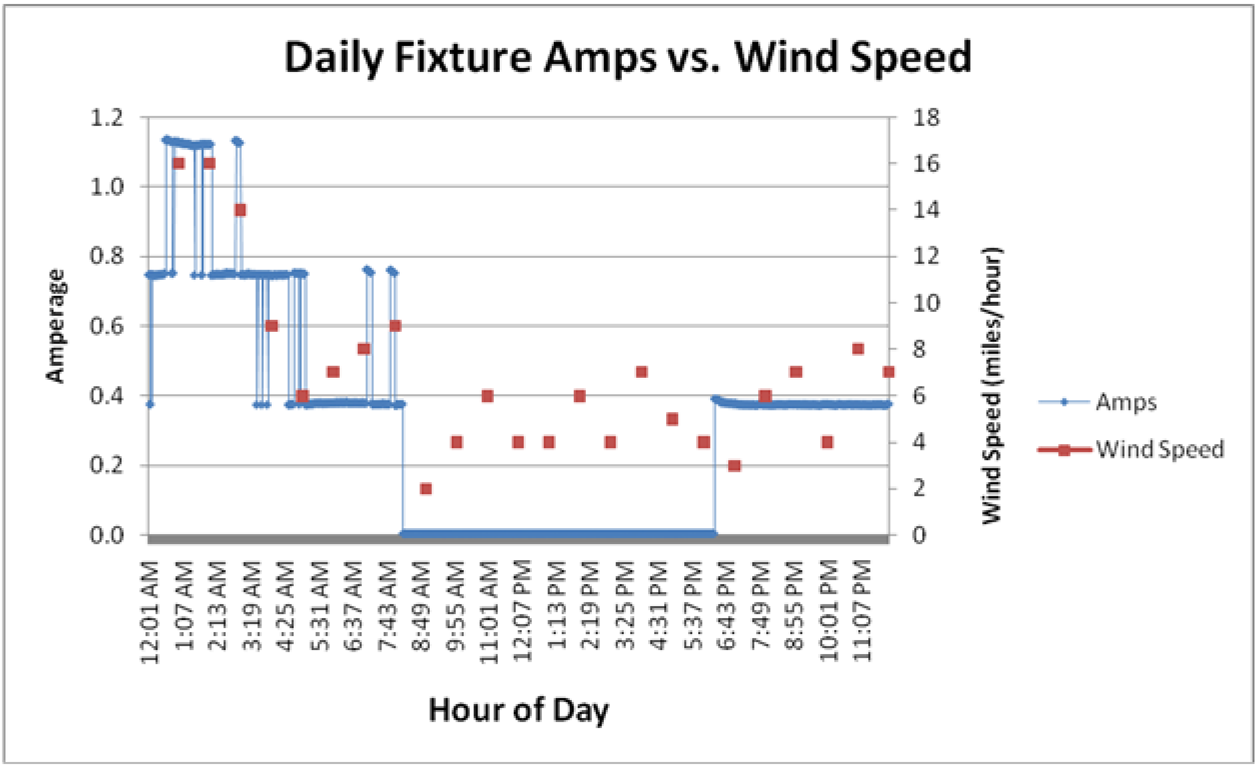

Figure 3.8. Suspected false tripping profile, LED luminaire, Sunday, October 18, 2009 with nearby airport wind speed data overlay

The PIR sensor used in this installation requires both detected motion and a perceived temperature difference between an object and its background to elicit a positive response from the system. If wind-driven movement of branches or of the luminaire itself satisfies the first requirement, various sources of temperature difference might explain the second: retained heat in the pavement, electronics within the luminaire itself heating the sensor lens (creating a temperature differential from the surroundings), or possibly something else. The precise explanation for the false tripping remains undetermined, but the phenomena and correlations evident in the figures above were recorded on multiple nights among multiple luminaires.

A final issue encountered at this site, which became evident several months into the installation, was that a number of the motion sensors had broken or missing lenses, probably caused by weather-related deterioration. The precise impact of this deterioration on luminaire operation was not determined, though presumably the sensor would at least become less sensitive to movement within the design range without the magnifying contribution of the Fresnel lens.

4.0 Discussion

Benefits achieved from use of occupancy sensors in the three case studies where savings can be estimated[1] are summarized in Table 4.1. Not included in this table are the significant portion of total savings that resulted from the initial substitution of LED products for the baseline incumbent technology. Even in high output, the LED products had already provided ≥ 45% energy savings relative to the traditional product they replaced. Addition of the occupancy sensor control offers a more nuanced story, however; although sensors are clearly energy- and cost-effective under the right circumstances, they are not universally so, and often require attention to ensure savings are realized. Reasons underlying the variability in results are discussed in this section, along with potential solutions where available.

Table 4.1. Summary of sensor benefits from three GATEWAY demonstration projects

Project	Underground Parking Garage	Exterior Parking Structure		Retail Plaza Parking Lot
Application Type	Interior	Interior – inboard	Interior – outboard[a]	Exterior
Construction Type	Partial Retrofit	New	New	Retrofit
Completion Date	2010	2009	2009	2009
Number of LED Luminaires	19	72	72	25
Daily Hours of Operation[b]	[c]	[d]	[d]	[d]
High Output	3.7	10.4	5.1	6.2
Low Output	20.3	13.6	6.9	8.0
Off	0	0	12.0	9.8
Power Draw per Luminaire (W)				
High Output State	62	102	102	234
Low Output State	6	68	68	78
Off State	NA	NA	0	1
Site Annual Energy Use (kWh)				
LED Baseline[e]	10,319	64,333	32,167	20,285
With Sensors	2,464	52,182	26,001	12,773
Energy Savings from Sensors	76.1%	18.9%	19.2%	37.0%
Electricity Rate per kWh	$0.14	$0.15	$0.15	$0.14
Annual Cost Savings	$1,100	$1,823	$925	$1,052
Additional Cost for Sensors	$3,800	$6,912	$6,912	$2,400
Sensor Simple Payback (years)	3.5	3.8	7.5	2.3

(a) Outboard fixtures are located around the perimeter of the building and are additionally controlled (on/off) by astronomical time clock.
(b) Based on average data for all luminaires during monitoring periods.
(c) At shortest delay setting (2.5 minutes).
(d) At original factory delay settings.
(e) Assumes all LED luminaires operating in high output state (i.e., without sensors) for all hours of operation.

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[1] Illumination issues at the fourth site were never fully resolved, so energy savings cannot be reported.

Even among this report's small sample of four installations, a number of issues became apparent that potentially have broader applicability. While some are associated with the quality and operation of the sensors themselves, others have more to do with design and operation of the overall lighting system and the means by which sensors are incorporated into it. Insufficient attention to these details in future installations may lead to noticeable shortfalls in the actual energy savings achieved from occupancy sensor deployment. The issues are not presented in any particular order of importance; all have the potential for significant impact depending on the situation.

4.1 Coverage Area

Currently available occupancy sensors used in interior applications have limited detection range, generally due to the limited needs of a typical interior application and by significant cost constraints associated with extending that range (i.e., it is generally cheaper to install additional remote sensors than extend the range of individual units). Employing similar products in exterior applications can result in "dead zones," that is, large spaces in between poles or other mounting points where sensor coverage is desirable but not possible with the existing detector sensitivity. In general, the greater the distance between sensors, the more (and larger) the dead zones that arise, which in turn increases the likelihood that the system may not adequately respond to movement within the target space. The larger areas often presented by exterior applications thereby pose a challenge to much of the existing stock of occupancy sensing equipment.

Meeting this challenge is not as simple as increasing the radius of coverage from a given sensor. As noted, PIR occupancy sensors are activated when an object with a heat signature distinguishable from the background passes within range of detection. Rather than being a continuous surface, however, the area of coverage is divided into segments that correspond to the design of the Fresnel lens (Figure 4.1). Mounting the sensor at greater heights increases the radius of coverage, but also expands the gaps between segments, increasing the potential for undetected motion. It is even theoretically possible to walk directly toward the sensor without tripping it, given an appropriate starting point. This problem worsens as coverage areas for a given sensor are expanded. Ultimately, achieving greater coverage from a given sensor requires that lens and optical systems of the device be redesigned, or improved sensing chips be used.

As in interior applications, some exterior coverage concerns may be addressed using remote sensors. A possible strategy, for example, is to locate sensors that control multiple luminaires at the entrance and exit points of a given area, although this approach can become complicated in surface lots with less defined boundaries. In addition, because entry and exit points generally receive more traffic than more distant locations, energy savings may be reduced by unnecessarily maintaining illumination at locations where it is not needed.

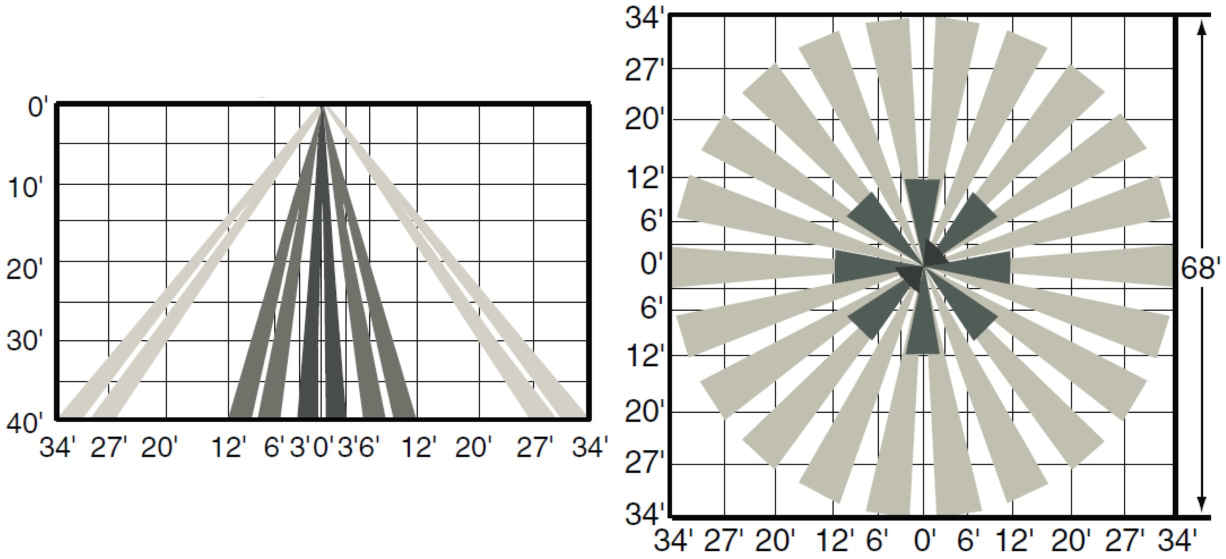

Figure 4.1. The coverage segments of a currently available occupancy sensor intended for use in exterior applications (left: section of beam coverage; right: plan view of beam coverage)

4.2 False Tripping and Environmental Conditions

False tripping, or a false positive response, occurs when a sensor erroneously raises (or maintains) the light level of the luminaire it controls. False positives are a concern because they reduce energy savings by unnecessarily invoking a high state of output. Two of the four sites described in this report exhibited frequent false tripping. In the commercial office parking lot example, the apparent cause was a combination of wind and an undetermined source of perceived temperature difference. In the underground parking structure, a nearby air diffuser appeared to influence the perceived signal of a few nearby units. A third site, the retail exterior parking lot, also suggested some false positive behavior by one sensor, but this was determined to be caused by detection of vehicles passing on the neighboring street—a situation which might be easily addressed with the addition of a simple shield (but was not pursued in this instance).

False negatives (i.e., when a sensor fails to detect motion that it should have) [1] are also of concern. Although this increases energy savings, light levels below IES recommendations can introduce safety and security issues, and potentially annoy users. Due to the manner in which the metering was conducted in these studies, all false negatives went undetected aside from informal reporting that the luminaires were not responding to movement as expected; such reports only surfaced at the commercial office parking lot site. That site was an early installation and may have suffered from various factors related to the limited experience at the time, such as insufficient sensor coverage from the outset (both overall area and sensitivity) and environmental degradation of the lenses which reduced sensitivity even further. Sensor response may have also been influenced by the same issues that were causing the original problems with illumination (i.e., foliage or other interference).

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[1] As distinct from being outside the range of sensor coverage, discussed previously.

High ambient temperatures can present a challenge for PIR motion sensors. To trigger a PIR sensor, the object crossing the band of detection must have an identifiably different temperature profile from its background. This characteristic reduces false detection of wind-blown objects that might have the same surface temperature as the ground, for example. However, issues can arise when wind-blown objects vary in temperature against a heat-absorbing background like black asphalt, while at the same time the heat signatures of pedestrians or vehicles become more difficult to distinguish.

4.3 Appropriate Time Delay

Unnecessarily long time delays can reduce the resulting savings to a point of essentially eliminating them, depending on the situation. There is no rule of thumb for the optimal setting in a given environment, but appropriate selection accounts for a combination of factors, such as the sensitivity of the sensors, the adequacy of sensor coverage within the target space, the duration of activity in the space following detected movement, the difference between high and low illuminance conditions, and general level of activity.[1]

As reported for the underground parking garage site, simply adjusting the delay from 10 minutes to 2.5 minutes substantially increased energy savings at virtually no cost. Because the period that garage users remain in their vehicles after parking is typically minimal, and because sensor coverage and sensitivity is such that users adequately trip the sensors when walking to and from the building entrance, it is possible that no one has even noticed the difference in timing. In any case, the facilities staff has received no complaints about the reduced delay setting.

In contrast, the 20-minute factory default setting of the sensors in the above-ground parking structure significantly compromises their value. A single car passing through the space at least once every 19 minutes, for example, maintains the luminaires in a perpetually high state of illumination. The circumstances that would require such long settings are unclear. However, reducing this particular time delay showed little further benefit due to additional reasons discussed in the following two sections.

4.4 Overlapping Control Systems

Energy savings may be limited by the use of multiple control systems that overlap in operation and hence are not additive. In the above-ground parking structure and retail parking lot case studies, both the baseline savings and the additional savings from reducing the time delay were lessened by different controls applying to the same luminaire. In the parking structure, the luminaires located along the building perimeter are turned off by an astronomical time clock during daylight hours, whereas in the retail lot all lights were turned off from about 1:30-4:00 am. This approach eliminates the possibility for further savings altogether, as it captures virtually 100% of energy use during the period it is in effect. Its impact is readily apparent in the parking structure results (Table 4.1) where the simple payback of the sensors around the perimeter is double that of the interior luminaires.

This observation is not a criticism; for example, no other control strategy can equal the low-cost results of simply turning the lights off if that approach is acceptable. However, especially when such

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[1] The *Parking Garage Lighting and Controls, 2013 California Building Energy Efficiency Standards* (CPUC 2011) showed, via multiple simulations, that the delay setting by itself can drive economic feasibility of individual sensor installation, as a function of the specific sensor location within the structure and related traffic flow.

potential conflicts are present, the design should consider whether incremental control capabilities yield energy savings sufficient to offset their additional cost.

4.5 Low Illumination Setting

Safety or minimum visibility concerns dictate the lowest acceptable illumination levels under dimmed (or off) conditions. In theory, any illumination above this point results in excess energy usage by the lighting system. The minimum acceptable illumination level should be determined, and then the corresponding low power setting of the luminaire established to maintain that level as closely as possible.

In the above-ground parking structure installation, the power difference between high and low states is relatively conservative, providing only about a 30% reduction as compared with 90% in the underground parking garage. One potential explanation for the difference between the two values is that the underground garage securely controls entry to the facility at street level, whereas the above-ground structure allows entry to all comers (and hence may warrant higher minimum levels of illumination). Perhaps with time, owners of the above-ground structure will become more comfortable with further reducing the low illumination level after reliability of the occupancy sensor response has been established and no increase in lighting-related security issues have surfaced.

At 30%, the reduction in illumination roughly corresponds to the point at which a typical eye might only just begin to notice; whether this factor was part of the original design intent in the above-ground structure is unknown. However, the effect of this decision is clearly evident in the comparatively meager additional savings achieved through use of the occupancy sensors, about 19% (Table 4.1). Note that a scalar relationship exists between the percent power reduction among high and low states and the resulting energy savings. Doubling the percent power reduction, for example, from 30% to 60%, directly doubles the corresponding savings rate, at only the cost of the labor required to make the change.

4.6 Commissioning and Optimization

A number of the luminaires arrived at the demonstration sites with time delay settings other than those claimed by the manufacturer, ranging from 30 seconds to 30 minutes in one example where the product was supposed to be factory-set at 20 minutes. In another case, a facility staff member commented that the luminaires did not appear to respond without “driving right under the pole.” These issues underscore the importance of commissioning occupancy sensor based systems to ensure that they are ready and able to deliver the intended performance.

The savings ultimately achieved are heavily influenced by both the time delay and the low illumination level power settings. Ideally, both the intended delay and the low power settings should be confirmed for every luminaire, if possible, prior to actual installation to minimize the effort required for any necessary adjustments. Overall commissioning of the system should also confirm the adequacy of sensor coverage across the target illumination space once the products have been mounted in place, and tweaked or supplemented as necessary to minimize dead spots.

Settings should be periodically revisited (or recommissioned) to determine whether savings are still being achieved or might even be safely increased by additional adjustment. The reverse may also be true, where, for example, increased light output becomes necessary to compensate for lumen depreciation or because the use profile of an area has changed.

4.7 Ease of Adjustment and Manufacturing Quality Control

Adjusting sensor settings is greatly facilitated by components that are easy to set consistently, without specialized tools (or any tools). The simplest approach appears to be an indexed adjustment that allows accurate settings easily interpreted by a typical facility engineer or electrician, accessible from outside the unit. Designs that instead require opening the unit complicate these adjustments, particularly for a user that must do so from a bucket truck, wearing gloves, etc., likely raising costs and error rates. Perhaps in the future manufacturers will offer remote access to both time delay and low power settings through use of wireless communication devices.

Sensor durability issues arose in at least one of the four installations. Exposure to the elements brings new challenges to products that have previously been used primarily in interior or at least semi-protected environments. Addressing this issue should not present a long-term problem for components suppliers, however, and is presumably already considered high priority.

4.8 Exogenous Factors

The additional savings actually realized from installing occupancy sensors is a function of multiple factors. Some of these, like the time delay and low power settings, are user-adjustable while others, like vehicular and pedestrian activity in the space, are exogenous to the lighting system. While the latter example may also be influenced to an extent, for example by controlling access to portions of the illuminated space during non-business hours, it still comprises a largely independent variable that will significantly impact the results achieved. Furthermore, the more open to the public and “random” nature of activity in a space, the more difficult it becomes to accurately predict the results prior to installation.

At best, prospective owners of occupancy sensor-based systems can review the low and high power settings (in W) of the luminaires, and multiply both by the total annual operating hours of the system to bound the range of expected energy use (or can convert the range into operating costs by also multiplying by the cost of electricity). The actual energy ultimately used by the system will fall somewhere in the midst of this range. The maximum potential savings offered by the occupancy sensor controls is in turn calculated by taking the difference between the bounded high and low state values. Note that reducing the low power setting or the time delay setting increases the corresponding savings potential in this calculation, whereas reducing the hours of operation or the wattage the sensors control (e.g., by installing a more efficient light source) serve to decrease the savings potential.

In the end, exogenous factors like the activity detected at a given location will continue to remain primary drivers of the savings actually achieved. Locations of high activity, such as near the facility entrance/exit, may see greatly reduced or even no savings from occupancy sensors whatsoever.

5.0 Conclusions

As occupancy sensors are still a relatively recent addition to the outdoor lighting market, it is unsurprising that some growing pains and lessons learned are accompanying their early use. Different characteristics of users and ambient environments may mean that the greatest success will come from detection equipment and deployment strategies that have been specifically designed for the particular application at hand, and perhaps even customized on site in terms of operation.

Done correctly, the combination of occupancy detection and bi-level dimming systems with efficient exterior lighting can significantly add to the energy savings achieved. However, users should continue to carefully examine the selection of equipment and how it will be integrated into a coordinated system to maximize performance while minimizing inconvenience and negative effects on users of the space.

It should also be recognized that the potential energy and cost savings are finite, and different approaches to achieving them often compete with one another. A control system that is allowed to de-energize the lighting altogether has captured 100% of the possible savings during the time it is in effect, for instance, regardless of the relative efficiency (or inefficiency) of the lighting source. Characteristics of the installation dictate the acceptability of that or any other approach. In all cases, potential savings are asymptotic, so that upgrading to a higher efficacy lighting source, for example, means that less energy use is available from which to generate savings by subsequently adding a control system.

Ultimately, users must balance the costs of each successive efficiency investment with its corresponding incremental savings in concert with the rest of the system, along with any other benefits that investment offers. Insufficient attention to such details risks guaranteed expense against potentially weak or even nonexistent reward.

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