ESTCP
Cost and Performance Report

(EW-201141)

Dynamic Exterior Lighting for Energy and Cost Savings in DoD Installations

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COST & PERFORMANCE REPORT
Project: EW-201141

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ACRONYMS AND ABBREVIATIONS

AMU	average-to-minimum uniformity ratio
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BTU	British thermal unit
CCT	correlated color temperature
CCT(K)	correlated color temperature in Kelvin
cd/m^2	candela per square metre
CLTC	California Lighting Technology Center
CT	current transformer
CV	coefficient of variation
dB	decibel
DoD	Department of Defense
DoDD	Department of Defense Directive
DPW	Directorate of Public Works
EO	Executive Order
ESTCP	Environmental Security Technology Certification Program
EUI	energy use intensity
fc	footcandle
FCC	Federal Communications Commission
GPI	grid points illuminated
HOU	hours of use
HPS	high pressure sodium
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
ISM	industrial, scientific and medical
IT	information technology
kWh	kilowatt hour
LED	light emitting diode
LOD	Light-On-Demand
lum	lumen
MHz	megahertz
MMU	max-to-min uniformity ratio
mW	megawatt

ACRONYMS AND ABBREVIATIONS (continued)

N/A	not applicable
NEC	Network Enterprise Center
NEMA	National Electrical Manufacturers Association
O&M	operation and maintenance
OLC	outdoor lighting controller
PMT	Project Management Team
PO	performance objective
RF	radio frequency
RP	Recommended Practice
RUFMA	Rotational Unit Field Maintenance Area
SC	segment controller
SIOH	supervision, inspection and overhead
SIR	savings to investment ratio
TEMF	tactical equipment maintenance facility
UFC	Unified Facilities Criteria
V	volt
VPN	virtual private network
w	watt

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EXECUTIVE SUMMARY

Exterior lighting for streets, roadways, parking lots, and other outside sites represents nearly 10 percent (%) of the electricity consumed on military bases. Lighting in these areas typically consists of high pressure sodium or sometimes metal halide lamps that are normally controlled by photo-sensors, located centrally or sometimes on each fixture. This limited functionality includes turning the lights on in the evening and off in the morning regardless of occupancy levels, thereby consuming more electricity than necessary.

The goal of this project was to quantify electricity savings and cost savings, achieved through the use of advanced lighting sources and smart lighting controls. Our approach included improving the quality and quantity of light compared to pre-retrofit conditions by demonstrating advanced light sources (light emitting diode [LED] luminaires replacing high pressure sodium [HPS] lamps) with three lighting controls systems developed by Philips Lighting. The Dynadimmer, Starsense, and Light-On-Demand (LOD) systems were demonstrated at a parking lot, a major roadway, and a tactical equipment maintenance facility (TEMF), respectively. All demonstrations were completed at Fort Sill.

The Dynadimmer system is a standalone fixture-by-fixture control architecture where the light level is controlled by a preprogrammed dimming profile as a function of time by a controller integrated in the LED driver. This configuration allows energy and cost savings by dimming the light levels during periods of low occupancy. Energy and cost savings of 66% (exceeding the objective of 50%) were achieved on 36 LED luminaires over the demonstration period of 1 year in an administration building parking lot (Welcome Center B4700). Average illuminance level was slightly increased (2.0 footcandles [fc] versus 1.8 fc), and distribution uniformity was substantially improved (7.4 versus 168) over pre-retrofit.

Starsense is a radio frequency (RF) mesh networked system where each light fixture is controlled independently using an Outdoor Lighting Controller (OLC) module placed on top of the LED fixture. The OLCs are set to a programmable dimming profile and the entire lighting network is displayed on a remote dashboard allowing remote visualization and control of the system at all times. A lighting management service software called CityTouch is provided to allow easy interaction, detailed asset management functions and fault detection, energy usage reports and real-time control. Deployed on a main road through the base (Sheridan Road) on 40 LED luminaires, energy savings of 59% (exceeding objective of 50%) were achieved over 1 year of operation. Average illuminance was increased from 0.5 fc to 0.7 fc on roadway sections; 1.2 fc at intersections; and distribution uniformity was substantially improved (3.7 versus 42) compared to pre-retrofit conditions.

The LOD system is based on the Starsense mesh network and adds motion detection sensors in the network allowing dynamic adaptive control of the light levels in each fixture. System configuration software allows flexible deployment of the sensors and light fixtures as well as asset management, energy reporting, and extensive data visualization features. This system replaced HPS lamps with LED light fixtures and was deployed in a TEMF with 42 fixtures. The new system demonstrated energy savings of 92% (exceeding the objective of 50%) while maintaining the same average illuminance with improved uniformity (1.9 versus 10.6) over pre-retrofit conditions.

In all three systems, the lighting levels exceeded Illuminating Engineering Society of North America (IESNA) illuminance requirements. User feedback from questionnaires showed overall satisfaction with the new lighting and a clear preference for the new system compared to the pre-retrofit HPS lighting from functionality and convenience point of view. Based on the results, Fort Sill is considering deploying these systems (specifically the Starsense system, which is a commercially released product). Several thousand Dynadimmer systems have already been deployed to over a dozen Air Force bases. At this time, the LOD system is a research prototype and is being considered as a future product.

Overall, this demonstration project has shown that advanced LED light sources with controls can result in substantial energy and cost savings (60 to 90% depending on the application areas and usage patterns) while improving the quality of light in terms of color rendering and brightness, which has been confirmed by user surveys. Life cycle cost analysis has shown that these systems can provide savings to investment ratio (SIR) (over 20 years) of more than 2.0, payback of less than 5 years for Dynadimmer and LOD, and less than 8 years for Starsense in areas where average cost of electricity is $0.10 or more per kilowatt hour (kWh). Electricity rates vary between $0.044 per kWh to $0.28 per kWh across the USA for industrial customers and are higher for commercial and residential customers. Furthermore the actual rates are determined by negotiations between base administration and the utility companies.

While these exterior lighting systems were demonstrated at Fort Sill, deployment has already been carried out, or is being considered, at several other Department of Defense (DoD) bases, including multiple Air Force bases, Fort Bliss, Fort Knox, Fort Dodge, and others. The results from Fort Sill have been helpful in understanding DoD needs in depth, which allows for wider deployment across DoD thereby enabling substantial energy and cost savings. Beyond energy related costs, the asset management features allow detailed information on the usage of the lighting infrastructure, which can be combined with data analytics to provide improved space utilization resulting in added cost savings.

1.0 INTRODUCTION

Lighting is the most pervasive energy-consuming element at most military installations including building interior and exterior spaces. Exterior lighting is used in many different applications across Department of Defense (DoD) facilities and can be broadly classified into two categories: (1) roadways and (2) sites or areas. Roadways include major and minor streets, while sites or areas include buildings adjacent and open to parking lots, tactical equipment maintenance facilities (TEMF), walkways, parks, recreation areas and building exterior lighting. Typically, these applications consist of old and outdated lighting resulting in energy waste, large environmental footprint, and high running cost.

This project demonstrates three cutting-edge outdoor lighting control systems including advanced light sources, luminaires, and controls tailored to apply to three selected areas at Fort Sill, OK. These areas include an administration building parking lot, a major roadway, and a TEMF. The initial baseline energy consumption and traffic volume of these three areas were measured over a period of at least 3 months while each system was prepared for installation. This was followed by the installation and commissioning of the three systems that all operated for at least a year while monitoring energy consumption and other system operating parameters including system reliability and user perception.

The primary intent of this project 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). The results of this project are expected to help the DoD administration plan deployment of these classes of technologies widely across DoD to achieve its energy and cost savings goals.

1.1 BACKGROUND

DoD consumes 880 Trillion British thermal units (BTU) of energy yearly [1], out of which 169 Trillion BTU is electrical energy. Around 30% of the energy is consumed by the facilities costing around $4 billion annually. Earlier studies [1] on energy consumption across 12 U.S. Army installations nationwide indicate that existing exterior lighting accounts for 7-13% of the total electricity consumption. These exterior lighting systems serving roadways and sites or areas are typically outdated in terms of energy efficiency, lamp lifetime, illumination effectiveness, and lack independent metering.

Typical outdoor lighting installations for parking lots and roadways are magnetically ballasted high pressure sodium (HPS) lamps that are at best controlled by dusk to dawn photocells that allow the lights to turn on at dusk and turn off at dawn. Magnetic ballast driven HPS lamps produce a fixed light output, i.e., not dimmable, and exhibit energy losses between 10 and 15%.

Furthermore, unique to DoD installations, spaces such as outdoor vehicle maintenance areas consisting of high intensity site lighting with illuminance levels far exceeding (as much as 10x) those in typical commercial parking areas are left on 24/7 regardless of the actual occupancy or activity. These products and practices result in low overall energy efficiency, high energy use and high maintenance cost. Therefore, advanced energy efficient lighting solutions present a significant opportunity for improvement.

1.2 OBJECTIVE OF THE DEMONSTRATION

The main objective of this project 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 order to accomplish this goal, three complementary systems based on scalable control and communication technologies are proposed, each targeting different exterior lighting applications (e.g., street lighting, parking lots, and vehicle maintenance areas) and offering different levels of functionality, energy, and maintenance cost savings. The systems deployed have been tailored to suit the unique characteristics of the target DoD applications. Evidence has been gathered to substantiate energy savings, payback time, performance and reliability of these systems and the results are used to estimate broad DoD benefits.

In the demonstration project, the goal has been threefold. First, the magnetically ballasted HPS lamps were replaced with higher overall efficiency and longer life light sources, such as light emitting diodes (LED) to significantly improve light color and distribution. Second, the light levels were controlled by dimming the light sources to values appropriate for the traffic volumes under consideration. This allowed additional energy savings depending on the usage patterns. Third, two of the systems (Remote Light Management and Light-On-Demand [LOD]) were monitored and the light sources were controlled continuously from a central location. This enables rapid determination of lamp failures and allows lamp replacement promptly and efficiently. The three systems demonstrated are:

1) **Intelligent LED Xitanium drivers with Dynadimmer** function enabled for standalone dimming profile in normal parking areas;
2) **The Starsense radio frequency (RF) wireless networked remote light management system on the roadway** for continuous monitoring and light level control on a base-wide or even DoD wide via cloud based service; and
3) **LOD or adaptive lighting control and data management system** based on the same Starsense RF wireless networked system to which motion sensors have been added in TEMF, or similar vehicle parking areas with continuous monitoring and control including cloud based base-wide or even DoD wide control.

Each technology is matched to the use area such that both energy savings and cost are optimal compared to the existing baseline.

The performance, cost, and benefits have been validated by starting with detailed measurement of the baseline energy use, lighting distribution, and traffic volume in each area over a period of at least 3 months. These measured results have been compared with the same measurements carried out with the new systems over a period of a year or so to ensure inclusion of seasonal variations. Overall, energy savings well in excess of 50% have been demonstrated for all three systems with the LOD system in TEMF exhibiting over 90% energy savings over baseline.

Based on these measured results, and insights gained, it is possible to define the application space more precisely so that these findings can be applicable to other DoD installations with similar conditions and requirements. Furthermore, the process followed will lead to providing a pathway to future deployment in other DoD installations. Based on the results at Fort Sill, the

Starsense system (for streets and roadways) is already being considered for base-wide deployment (2,833 light points). Fort Bliss will also utilize the system in a section of their installation (2,375 light points). Other DoD installations are also considering deployment.

The base personnel (Directorate of Public Works [DPW]) have been trained in the operation and maintenance (O&M) of these advanced systems to a level that they can comfortably deploy them and easily quantify the benefits in terms of energy and cost savings. They were engaged in the project execution early on so that they could learn the process fully. The savings in maintenance cost and time as well as the ease of monitoring the system operation and faults have helped convince the DPW personnel of the benefits.

A successful demonstration in terms of providing comfortable lighting to the users and saving energy and cost at the same time will go a long way towards acceptance of this technology. Surveys and questionnaires have been deployed to address this fully. The choice of the demonstrations areas have been dictated by visibility to base personnel as well as visitors.

This demonstration has helped the project team learn about the unique requirements of DoD installations in terms of technical performance as well as protocols for working in the DoD environment. The project has created jobs in development and installation of the systems, thus benefitting the U.S. economy. With broad deployment of the systems within DoD, energy savings will accrue helping the nation move towards energy independence. The deliverables of the project included detailed technical reports, presentations, and training for DoD individuals in O&M of the systems. The demonstration systems and associated equipment remain with the DoD site for continued use.

1.3 REGULATORY DRIVERS

External lighting is driven by several regulatory standards and codes including: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1; California Title 24; Illuminating Engineering Society of North America (IESNA) Recommend Practice (RP)-8, recommendations for roadway lighting; and IESNA RP-20, recommendations for parking lot. In addition to these, DoD design guidelines (Unified Facilities Criteria [UFC] 3-530-01; DoD Design: Interior, Exterior, Lighting and Controls) provide information on its requirements. Furthermore, DoD has determined its own goals for each installation (as defined in the DoD Annual Energy Management Report, Reference ID: 4-EA9D0F0), including a goal to use 30 percent less energy than ASHRAE 90.1.

The technologies being demonstrated in this project are aimed at increasing energy efficiency of exterior lighting — thereby saving energy, cost, and environmental footprint. These are driven by a number of executive orders (EO) and DoD directives (DoDD) including: the Energy Policy Act of 2005; EO 13514; EO 13514; DoDD 5134.01; and DoDD 4140.25.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The functionality, architecture, and operation of each of the system are described below.

2.1.1 XITANIUM LED DRIVER WITH DYNADIMMER FUNCTIONALITY

Dynadimmer is one of three built-in features that provide adaptive light level control based on customized dimming schedules.

Functionality: The Dynadimmer functionality within the LED driver enables users to save energy by dimming lights at pre-configured periods. For instance, lower levels can be used late at night, high levels at peak times, and medium levels during the transitional periods. The controller can be configured to execute five levels of dimming based on the location of the fixture, lumen requirements by time of day, and dim to any level that the user wishes at set periods. An example schedule is shown in Figure 1. The internal Dynadimmer works in conjunction with an existing photo-sensor or time clock that is currently used to turn the lights on/off. Additional functionality within the LED driver also supports an input from an external sensor (e.g., motion), which can be used in combination with the dimming profile to improve on safety (e.g., boost light when movement is detected).

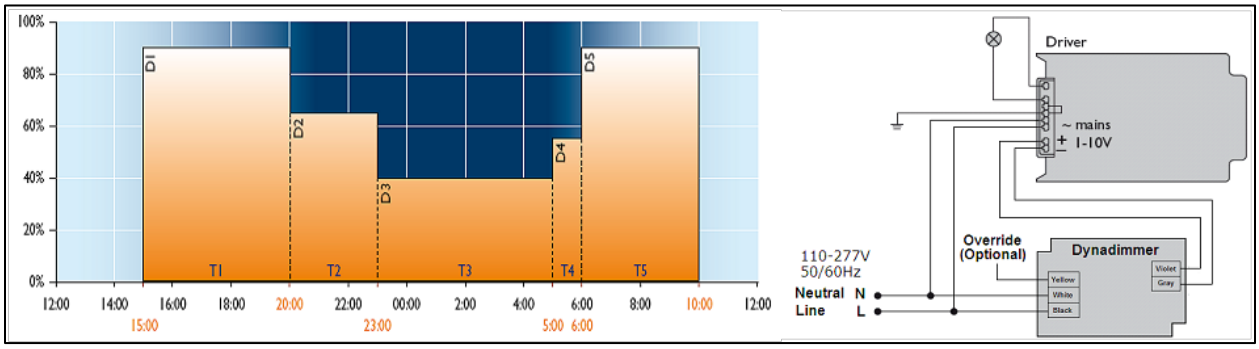

Figure 1. Dynadimmer sample dimming profile.

Comparison to Existing Technology: Compared to the existing approach consisting of photocell and/or time clock combination to turn on the lights after dusk and turn them off at daybreak, the Dynadimmer system allows a pre-programmed dimming profile to control the light level during the active period while providing energy savings during low traffic hours and enhanced lighting for problematic neighborhoods for added security.

Future Potential for DoD: Dynadimmer is an appropriate solution for applications where a simple and flexible local fixture control is required to provide maximum energy savings while minimizing the installation and upfront cost and associated payback period. The retrofit applications of existing light sources will require a 0-10 volt dimming interface to the drivers.

2.1.2 STARSENSE

Starsense is a wireless networked system enabling remote light management, monitoring, diagnostics, and control based on time and photo-sensors.

Functionality: Starsense is a fully networked outdoor lighting control and management system that enables remote diagnostics, monitoring, metering, and control of light levels. This system enables control strategies in which light levels can be controlled to suit actual needs, taking into account time, traffic density, remaining daylight level, road construction, accidents, and weather circumstances. Real-time status monitoring, fault-detection, and energy metering features facilitate proactive maintenance, thereby reducing down time and maintenance costs and providing accurate energy consumption reports. This solution can be leveraged for smart grid connections and implementation of demand response strategies such as dynamic load shedding.

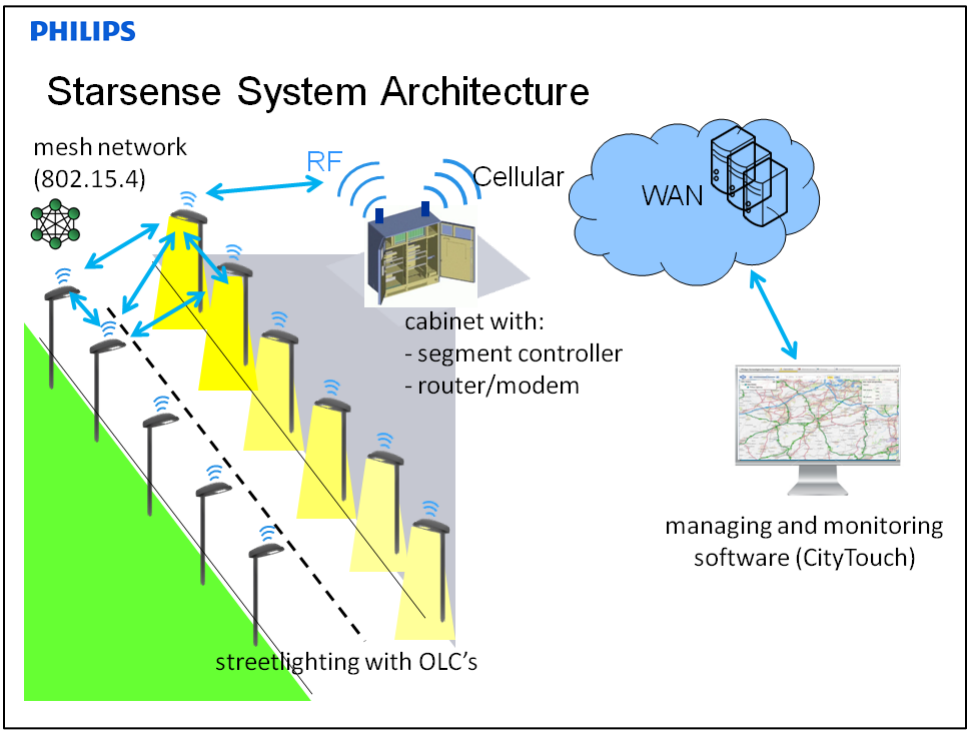

Figure 2. System architecture of Starsense.

Comparison with Existing Technology: The existing luminaire had a 250 watt (W) HPS lamp, and was replaced by a 215W LED luminaire. The existing control was photocell only and has been replaced with Starsense system including photocell control. Unlike the existing (pre-retrofit) system, Starsense is a fully networked system and is able to control each luminaire remotely and individually with dimming capability according to schedule. The Starsense system integrates photocell with schedule-based control and also allows manual override. The system provides remote energy metering at luminaire level and provides asset management, remote fault diagnosis, and event report.

Future Potential for DoD: The Starsense system provides many benefits for DoD, a few are listed below.

- Accurate energy metering and reporting of lamp burning hours;
- Real-time status feedback and override;
- Flexibility to adapt lighting levels;
- Increased safety;
- Asset management of lighting infrastructure;
- Easy and fast installation and commissioning;
- Automatic failure reporting, facilitating more efficient repair and maintenance planning; and
- Green image, with reduced energy cost, CO_2 footprint, and light pollution.

2.1.3 LIGHT-ON-DEMAND

LOD is an adaptive lighting system based on Starsense RF and advanced sensing to identify movement in the vicinity of the luminaire, as well as adjust light levels in a coordinated fashion with neighboring luminaires.

Functionality: LOD is a system consisting of Starsense RF and advanced sensing. The sensing module can sense movement within a coverage area near the luminaire. When a presence is detected, light levels can be increased and the state information can be relayed to neighboring luminaires through a RF module, which can also react accordingly to increase the illumination level. The sensing and light actuation technology can also augment surveillance and emergency response systems by increasing lighting intensity and coverage above normal levels.

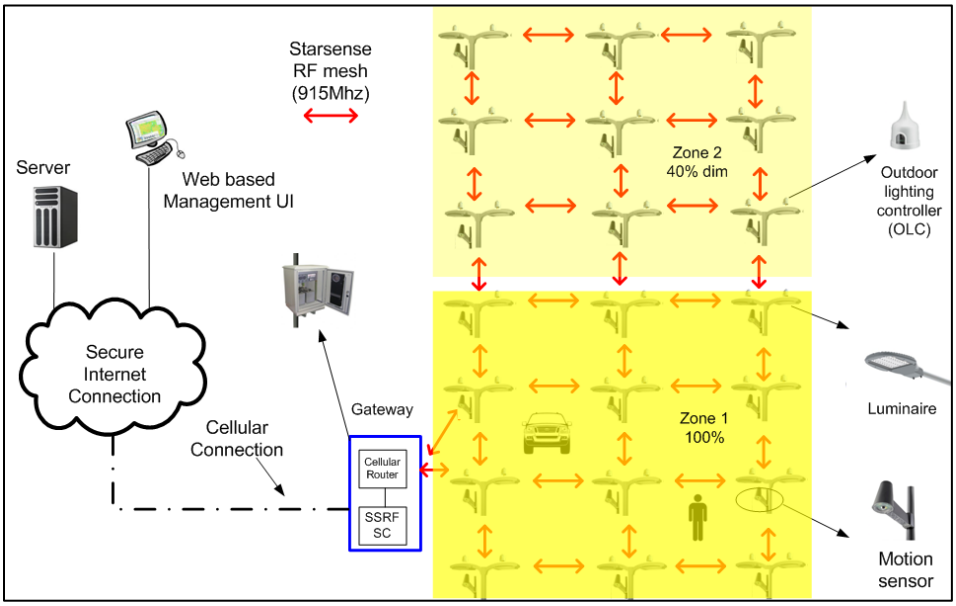

Figure 3. System architecture and components.

Comparison to Existing Technology: Existing technology for area lighting has only photocell based on/off capability and does not include any presence sensing control. LOD system provides fine granularity of lighting control in time and space based on occupancy. It offers the combination of schedule, geography, and presence based control strategies. The system is scalable and flexible for deployment in a variety of site and area lighting applications. LOD system offers easy commissioning based on customer needs.

Future Potential for DoD: Expected applications are: site/area including parking lots, outdoor vehicle maintenance areas such as TEMF in Fort Sill and Rotational Unit Field Maintenance Area (RUFMA) in Fort Irwin. The system can also be used for outdoor parks and residential areas where the traffic flow is low to moderate.

2.2 TECHNOLOGY PROTOTYPE DEVELOPMENT

2.2.1 DYNADIMMER

The Dynadimmer system was in an engineering prototype stage and needed little technology development as such.

During installation, it was decided to use the Xitanium driver system for the chosen LED fixtures and the Dynadimmer functionality was embedded in the drivers. Embedding into the driver was carried out by the commercial product development team and did not use the Environmental Security Technology Certification Program (ESTCP) project resources.

2.2.2 STARSENSE

To test the system concept in the real setting and identify limitations before deploying at Fort Sill, an extensive test bed on a roadway in Briarcliff research campus was constructed with 11 light poles of the same height as at Fort Sill, along with the same type of luminaire to be deployed at Fort Sill. A complete Starsense system with outdoor lighting controllers (OLC), segment controller (SC), modem, and CityTouch management and visualization system was designed and implemented for thorough debugging and testing with the relevant environmental conditions. This turned out to be very beneficial for the project as a number of design weakness were identified in the course of time. These were rectified in subsequent designs before the project team started implementing the system on Sheridan Road at Fort Sill, the first high voltage Starsense system in North America.

The dimming controller OLC requirement led us to drive the American National Standards Institute (ANSI) towards a new socket for dimming controller as a replacement for the standard National Electrical Manufacturers Association (NEMA) socket. This effort resulted first in a new receptacle design. The luminaires at the site will be reworked to the new ANSI standard dimming receptacle, and the new version of the OLCs will be installed and commissioned.

On the OLC firmware and SC software front, the initial release accommodated up to 250 OLCs per SC in the mesh network. The current release can accommodate up to 2,000 OLCs per SC, based on the quality of the mesh. Various other improvements have been made in the hardware and software to increase the immunity to external RF interference.

On the management software, CityTouch is continuously updated to add new features to the dashboard based on customer feedback.

2.2.3 LIGHT-ON-DEMAND

The LOD system is based on the Starsense platform for the networking aspects and consists of luminaires with OLCs as described earlier, but with a motion sensor system for each light fixture. Again, a complete test bed was designed and constructed in one of the parking areas in the Briarcliff campus for thorough debugging and testing. This test bed consisted of 21 luminaires with OLCs and sensor nodes, one SC, modem, laptops for visualization and backend processing, including debugging.

During the course of testing and debugging, multiple versions of the management system had to be developed as new features and performance parameters were included. As a result of this, after the system was designed and installed at Fort Sill there has been no system down time so far after more than a year of operation.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Table 1 provides the distinguishing characteristics of the three systems. The functionality, architecture, and operation of each system are subsequently described.

Table 1. Key features of proposed systems.

	Dynadimmer	Starsense	LOD
System architecture	Integrated driver and control in one package	Fully networked with remote management station	Fully networked with remote management station
Control strategies	Time schedule based dimming	Remote monitoring, metering, time scheduling, and adaptive dimming	Metering, time scheduling, occupancy based dimming, adaptable and predictive multiple luminaire reactions
Supported sensors	Photo-sensor and override input (e.g., movement sensor)	Photo-sensor. Traffic density sensor to be available in the near future	Photo-sensor and advanced motion sensor for reliable detection of pedestrians and vehicles
Applications	Parking lots, street lights	Streets, roads, highways, parking lots, vehicle maintenance areas	Parking lots, walkways, vehicle maintenance areas, low to medium traffic areas
Connectivity	N/A	Wireless (915 MHz ISM band radio) + remote wireless data link from SC to m station	Wireless (915 MHz ISM band radio)
Relative energy savings	+	++	+++
Relative capital and O&M costs	+++ initial capital +++ installation +++ commissioning +++ maintenance	++ initial capital ++ installation ++ commissioning ++ maintenance	+ initial capital + installation + commissioning ++ maintenance
Challenges	Adaptation of schedule and override feature	Robust connectivity, installation and management skills	Reliable sensing, robust connectivity, coverage and configuration

Key for relative ranking: + Low savings or high costs
++ Medium savings or medium costs
+++ High savings or low costs

ISM = industrial, scientific, and medical
MH2 = megahertz
N/A = not applicable

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3.0 PERFORMANCE OBJECTIVES

The three outdoor lighting control systems will be evaluated against the performance objectives (PO) stated in Table 2. Quantitative and qualitative analyses will be performed to assess the successfulness in meeting these POs. The terms used in the POs table are defined below.

Metered Baseline: Measured energy use in the areas under consideration normalized to annual energy use per circuit and per luminaire before retrofit.

Illumination Level or Illuminance: Density of luminous flux incident on a surface typically expressed in footcandles or lux.

Photopic Illuminance: Density of luminous flux incident on a surface expressed in footcandles (fc) or lux, when fc or lux are determined using the photopic luminous efficiency function. The photopic luminous efficiency function applies to visual stimuli at luminance levels approximately above 3 candela per square metre (cd/m^2) (high light levels).

Scotopic Illuminance: Density of luminous flux incident on a surface expressed in fcs or lux, when fcs or lux are determined using the scotopic luminous efficiency function. The scotopic luminous efficiency function applies to visual stimuli at luminance level approximately below 0.001 cd/m^2 (very low light levels).

Table 2. Performance objectives.

PO	Metric	Data Requirements	Success Criteria
Quantitative POs			
Energy performance	Annual EUI per luminaire expressed as kWh/yr/lum	Metered data on electricity usage before and after the installation of new lighting systems	>50% reduction in annual EUI per luminaire for each system compared with metered baseline
Maintenance implications	Annual maintenance cost savings ($US) per luminaire	Luminaire service cycle estimates (e.g., for re-lamp) will be calculated based on product specifications for baseline and new systems taking into account all maintenance needs	>40% reduction in maintenance costs per luminaire per year compared with baseline
Lighting performance	Illuminance and uniformity metrics including % GPI and average illuminance, CV, AMU, and MMU	Photopic and scotopic illuminance measurements over a defined grid test area before and after installation of new lighting systems	Demonstrated dynamic lumen output with improvements in lighting distribution compared to baseline while complying with applicable recommended standards [14][15][17]
	Correlated color temperature in Kelvin – CCT(K)	Measurements using a Chroma meter under the luminaires to calculate CCT(K)	Meet user acceptance in the 4000 to 6000K range

AMU = average-to-min uniformity ratio
CCT(K) = correlated color temperature in Kelvin
CV = coefficient of variation
EUI = energy use intensity
GPI = grid points illuminated
kWh = kilowatt hour
lum = lumen
MMU = max-to-min uniformity ratio

Table 2. Performance objectives (continued).

PO	Metric	Data Requirements	Success Criteria
Quantitative POs (continued)			
Cost effectiveness	- SIR - Simple payback period	Capital costs, historical energy cost, energy usage, installation, commissioning, operating and maintenance costs	SIR (10 years) > 1.0 SIR (20 years) > 2.0 Payback < 7 years
System reliability	Success rate of control system data delivery	Message delivery failure log	> 99.9% data delivery success rate
	Metering accuracy	Metering data log and independent measurements	> 95% accuracy of metering functions
Qualitative Performance Objectives			
Enhanced lighting conditions	Photographic comparisons	Ground level and overhead photographs will be taken to give qualitative indication of lighting performance	Positive subjective evaluation of increased visual clarity, color perception, and lighting uniformity
	User acceptance	Feedback from facility personnel (through surveys) on the overall satisfaction with the lighting performance and control features	User opinion surveys indicate improved lighting conditions, and overall satisfaction
Ease of installation and commissioning	Ability of installers to quickly install and commission the system	Feedback from installers on time required to install and commission system	Installation and commissioning with minimal training
Satisfaction with O&M	Level of satisfaction of facility personnel with operation, monitoring, and maintenance of the systems	Feedback from base operations personnel on O&M functionalities	Systems perform reliably. Management tools improve O&M

SIR = savings to investment ratio

4.0 FACILITY/SITE DESCRIPTION

The Project Management Team (PMT) partnered with DPW to identify suitable buildings at Fort Sill for each technology. The PMT visited Fort Sill several times and screened the candidate sites to arrive at the mutually agreeable site selection proposal.

4.1 FACILITY/SITE LOCATION AND OPERATIONS

4.1.1 DYNADIMMER DEMONSTRATION SITE

The Dynadimmer system is implemented at the Fort Sill Welcome Center Building 4700 parking lot, as shown in Figure 4 (Welcome Center B4700 parking lot). A retrofit of all 20 light poles (36 cobra head fixtures total) with LED luminaires fitted with Dynadimmer controls was performed to provide light level scheduled control for each luminaire individually; the 400W HPS lamps controlled by magnetic ballast on 480 volt (V) three-phase mains power were also replaced.

Figure 4. B4700 parking lot – Dynadimmer demonstration site.

4.1.2 STARSENSE SYSTEM DEMONSTRATION SITE

The Starsense system was implemented on a section of the Sheridan Road covering 38 light poles, as shown in Figure 5. This system consisted of 40 LED luminaires (replacing old cobra head 250W HPS fixtures with magnetic ballast on 480V mains power) and was based on a wireless mesh network for monitoring and control of the light levels from a centralized location.

Sheridan Road, which crosses Fort Sill, may be considered a major roadway within the post, but has low pedestrian/vehicle interaction at night. Sheridan Road is composed of two traffic lanes in each direction, separated by a median turning lane. The road is illuminated from one side only. Pavement is typical, R3 classification.

Figure 5. Section of Sheridan Road – Starsense demonstration site.

4.1.3 LIGHT-ON-DEMAND DEMONSTRATION SITE

LOD system is implemented in a TEMF, located off Tower 2 Road adjoining Tank Trail as shown in Figure 6. All 21 light poles were outfitted with LED luminaires and sensors for controlling the light levels based on the occupancy of the area; 400W HPS shoebox fixtures controlled by magnetic ballast on single-phase 240V mains power were also replaced. A wireless mesh network similar to that of the Starsense system has been employed for monitoring and control.

Figure 6. TEMF off Tower 2 Road – LOD demonstration site.

4.2 COMMUNICATION REQUIREMENTS FOR THE DEMONSTRATION PROJECT

Table 3 shows the communication requirements of our systems and the security measures that we take to protect the system from unauthorized access. For the purpose of the demonstration, a dedicated network infrastructure has been employed, isolated from the existing facility information technology (IT) infrastructure. Specifics of the communication requirements, shown in Table 3 have been provided to the DPW Energy Manager (Christopher Brown) as well as the Netcom and Network Enterprise Center (NEC) (Joseph E. Pearson, Chief Information Assurance Division) departments. As far as the demonstration project was concerned, the project team was told by Mr. Brown to carry out the demonstration as planned since RF usage was confined to Federal Communications Commission (FCC) certified bands only and there was no risk of an interference with the military band. Furthermore, Dr. Galvin also sent a note to Mr. Brown and others referred to by Mr. Brown explaining the purpose of the ESTCP program.

Table 3. Communication requirements and security measures.

Technology description		Starsense	LOD
System Architecture		Figure 2	Figure 3
Use of DoD communication infrastructure		No	No
On-field communication: wireless between lighting controllers, wireless sensors, and segment controller	Connectivity	RF mesh	RF mesh
	Standard	802.15.4	802.15.4
	Chipset	Atmel, FCC certified	Atmel, FCC certified
	Operating frequency	ISM 915MHz	ISM 915MHz
	Channel spacing	2MHz	2MHz
	6 dB bandwidth	730kHz	730kHz
	Transmitted power	10mW	10mW
	Security	AES 128	AES 128
Backend communication: from segment controller to server / management station	Connectivity	Cellular + Internet Isolated from DoD facility IT infrastructure	Cellular + Internet Isolated from DoD facility IT infrastructure
	Security	VPN	VPN
Server– client communication for web based remote management	Connectivity	Cellular + Internet	Cellular + Internet

dB = decibel
mW = megawatts
VPN = virtual private network

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5.0 TEST DESIGN

This section elaborates on the test design principles to validate the performance of the demonstrated technologies.

5.1 TEST DESIGN

Three outdoor lighting control systems were demonstrated in this project together with the incumbent HPS based luminaires that were replaced with energy-efficient LED based lighting sources.

The following aspects were considered in the test design:

1. Performance of the incumbent HPS lighting technology,
2. Installation of new LED lights and associated controls,
3. Performance of the new LED lighting technology, and
4. An analysis of the results to determine if the three systems met the POs (see Section 6 of this report).

5.2 BASELINE CHARACTERIZATION

The electrical performance of the lighting technologies with the annual EUI (measured in watt-hours per year per luminaire or kWh/yr/lum) were characterized. EUI is derived from the luminaire power (expressed in W) and the annual hours of use (HOU).

$$\text{EUI (kWh/yr/lum)} = \text{Luminaire Power (kW/lum)} \times \text{HOU (hr/yr)} \qquad \text{(eq. 1)}$$

The baseline EUI was calculated for each site, and the results are shown in Table 4. The table provides the annual HOU and luminaire power values used to calculate the baseline EUI. The table also provides the quantity of luminaires at each site and the site-wide annual energy use, purely for reference.

Table 4. Baseline EUI for each site.

Site	EUI (kWh/yr/lum)	Annual HOU (hr/yr)	Luminaire power (W)	QTY (lum)	Annual Energy (MWh/yr)
B4700	1957	4313	453.6	36	70.4
Sheridan Road	1272	4313	295.0	40	50.9
TEMF	1957	4313	453.6	42	82.2

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

5.3.1 DYNADIMMER SYSTEM

A total of 36 fixtures were replaced with 215W LED fixture system with the Dynadimmer functionality enabled in each of the two drivers contained in each fixture. The layout of the deployment is shown in Figure 7. Note that the parking lot is divided into two separate zones.

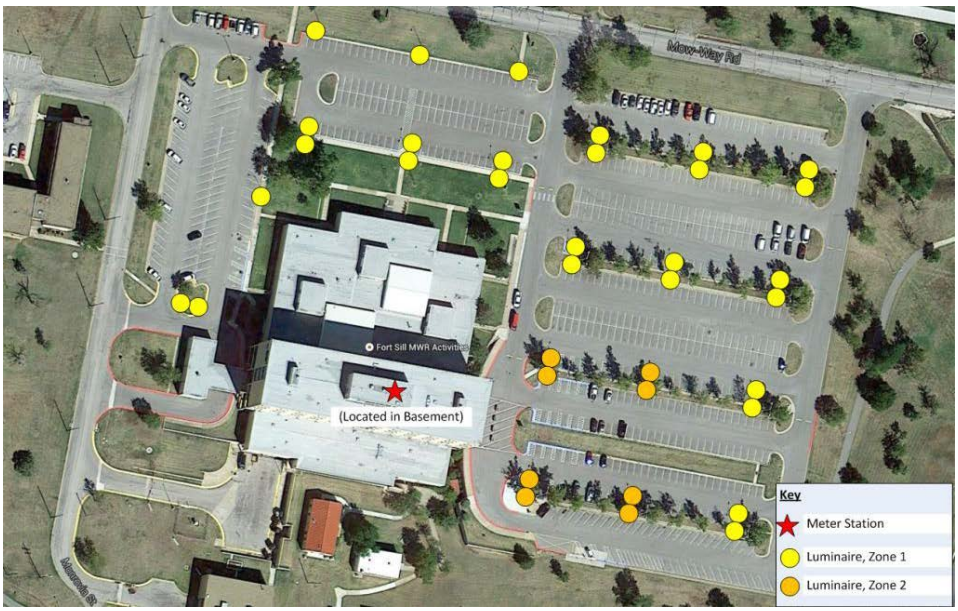

Figure 7. Dynadimmer system at B4700 where the performance of all luminaires is monitored from the electrical panel located in the basement of the welcome center facility.

A dimming schedule is easily created using Dynadimmer configuration software. The software enables the user to obtain not only a quick dimming shape configuration, but also a forecast of energy savings. As shown in Figure 8, the dimming schedule is flexible up to five dimming levels and five time periods.

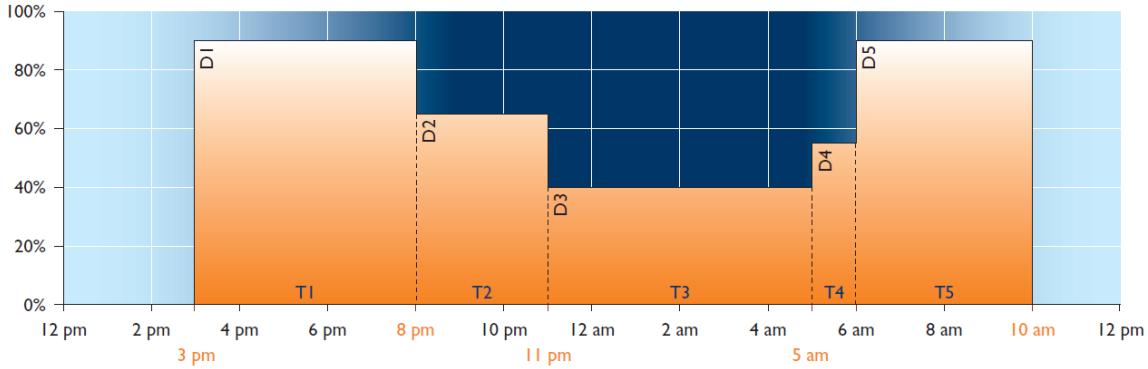

Figure 8. Illustration of Dynadimmer dimming profile.

5.3.2 STARSENSE SYSTEM

Starsense is a fully networked outdoor lighting control and management system that enables remote diagnostics, monitoring, metering, and control of light levels. A total of 40 Starsense luminaires have been deployed along a segment of Sheridan Road at Fort Sill, as shown in Figure 9.

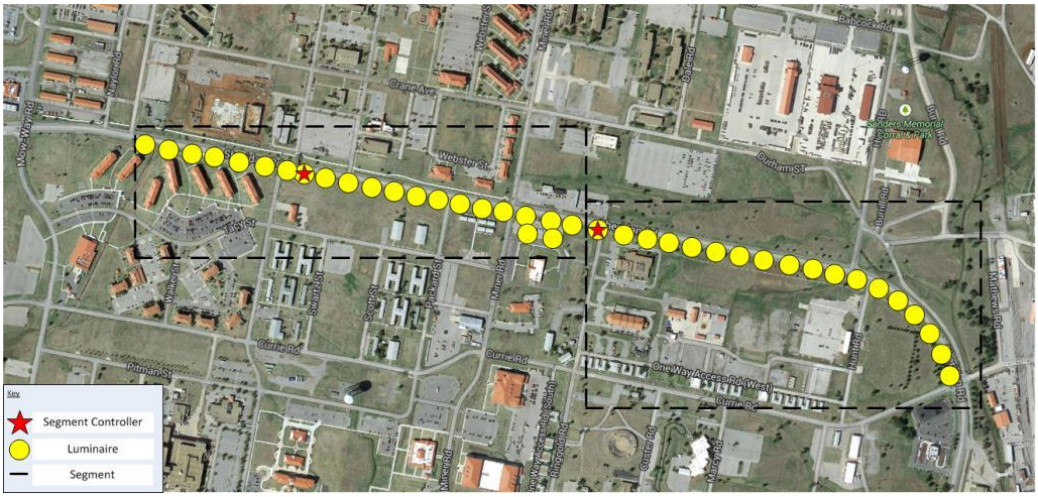

Figure 9. Starsense system installed on Sheridan Road includes two SCs, which control the north (right dashed-box) and south (left dashed-box) halves of the demonstration luminaires.

5.3.3 LOD SYSTEM

The LOD is an adaptive lighting system based on advanced sensing and RF modules that can be connected with luminaires to sense movement in the vicinity of the luminaire, and adjust light levels in a coordinated fashion with neighboring luminaires. A total of 42 LOD luminaires and 42 camera sensors were deployed at the TEMF as shown in Figure 10.

Figure 10. The LOD system installed at the TEMF includes a single SC, which communicates wirelessly with 42 LED luminaires and 42 camera sensors.

5.4 OPERATIONAL TESTING

Systems were installed on site and underwent acceptance testing and commissioning. Training was provided to installers to facilitate quick installation of the systems. Sensors and control strategies were field tested and calibrated to derive the optimal placement and settings for the best system performance. Functional performance tests were conducted to verify and validate the performance of the system. Corrective measures were applied to remedy any non-compliance found during testing. Quantitative and qualitative feedback was gathered using the installer surveys to obtain data on the time, effort, and skill required to install and commission the systems.

5.5 SAMPLE PROTOCOL

The sampling results consist of energy, photometric, and survey results. A summary of each is provided in this section.

5.5.1 ENERGY

Energy logging equipment was installed to monitor the energy use of the technology demonstrations at each of the three test locations. The energy logging equipment included:

- Current transformers (CT),
- Watt-hour transducer, and
- Data logger.

5.5.2 PHOTOMETRIC

The project team characterized the optical performance of the lighting technologies with the illuminance, the correlated color temperature (CCT), and the lighting conditions POs.

In order to obtain a meaningful comparison of EUIs, the optical performance must be consistent across the applications. One goal of assessing the optical performance was to ensure that the reported energy savings were not inflated by diminishing the quality of lighting. To be considered valid, energy savings must not compromise the quality of lighting.

5.5.3 SURVEY SUMMARY

Nine surveys were developed with 10-13 questions each. Three surveys were created for separate audiences of each demonstration site: maintenance, security, and general public. The surveys were distributed to base personnel by the Fort Sill liaison assigned to the project team for this demonstration project. Each survey responder returned from one to three surveys, with the majority of responders returning three surveys each (one per site). As summarized in Table 5 below, 22 surveys were returned from eight total responders reflecting at least seven responses for each demonstration site.

Table 5. Number of survey responses by demonstration site survey category.

Site	Maintenance	Security	General
B4700	1	6	0
Sheridan Road	1	6	0
TEMF	1	7	0

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6.0 PERFORMANCE ASSESSMENT

The performance of the demonstration technologies was assessed with eight POs. A summary of all data analysis is provided below. In the remaining sections, substantive analysis of data is carried out in a subsection for each PO.

6.1 SUMMARY OF DATA ANALYSIS

An overview of the data analysis activities contained in Section 6 of this report is provided in Table 6. Additional discussion of the data analysis activities is provided below.

Table 6. Summary of data analysis activities.

PO	Summary of Analysis	Success Criteria	Result
PO1: Energy Performance	Compared demonstration EUI of demonstration to baseline	>50% reduction in EUI	Pass: EUI reduced by at least 50% at all three sites
PO2: Maintenance Implications	Compared annual maintenance cost savings ($US) per luminaire	>40% reduction in annual maintenance cost savings ($US) per luminaire	Pass: annual maintenance cost ($US) per luminaire reduced from $45 to $10
PO3: Lighting Performance	Compared lighting performance with industry standards	Meet or exceed IESNA illuminance recommendations	Pass: demonstration technology met IESNA recommendation at all three sites
PO4: Cost Effectiveness	Compared SIR, simple payback period of demonstrated technologies to baseline	SIR (10 years) > 1.0 SIR (20 years) > 2.0 Payback < 7 years	Pass: Dynadimmer SIR (10 years) 1.99 > 1.0 SIR (20 years) 3.49 > 2.0 Payback 4.29 yrs < 7 yrs
			Partially pass: Starsense SIR (10 years) 1.12 > 1.0 SIR (20 years) 1.96 < 2.0 Payback 7.59 yrs > 7 yrs
			Pass: LOD SIR (10 years) 2.10 > 1.0 SIR (20 years) 3.69 > 2.0 Payback 4.08 yrs < 7 yrs
PO5: System Reliability	Success rate of control system data delivery	> 99.9% data delivery success rate	Pass: 100% data delivery success rate
	Metering accuracy	> 95% accuracy of metering functions	Pass: Starsense Average metering accuracy of 97.56% > 95%
			Partially pass: LOD
PO6: Enhanced Lighting Conditions	Subjective assessment of lighting quality	Improved lighting quality	Pass: Subjective assessment indicates improved visual acuity and color rendering at all sights
PO7: Ease of Installation and Commissioning	Ability of installers to quickly install and commission the system	Installation and commissioning with minimal training	Pass: all three systems were deployed successfully much faster than planned
PO8: Satisfaction with O&M	Survey facility personnel regarding O&M	Improved O&M experience	Pass: Survey results and anecdotal comments indicate improved satisfaction with demonstration technology

6.2 PERFORMANCE ASSESSMENT

6.2.1 PO1: ENERGY PERFORMANCE

The purpose of this analysis was to determine if the annual EUI per luminaire decreased by at least 50% with the new LED lighting technology and controls compared to the incumbent controls and HPS lighting technology. We considered each of the three demonstration sites separately, calculating the EUI for both the HPS and LED lighting technologies for each site.

B4700

The energy use results for the B4700 Welcome Center site are shown in Figure 11. The daily energy use for B4700 was typically about 25 kWh/day less than that predicted for LED without controls (red versus green-dashed). This difference is explained by the curfew dimming operation for days without spikes. However, there are about 30 spikes – instances where the measured energy increased considerably for a short period, sometimes exceeding the predicted LED without controls.

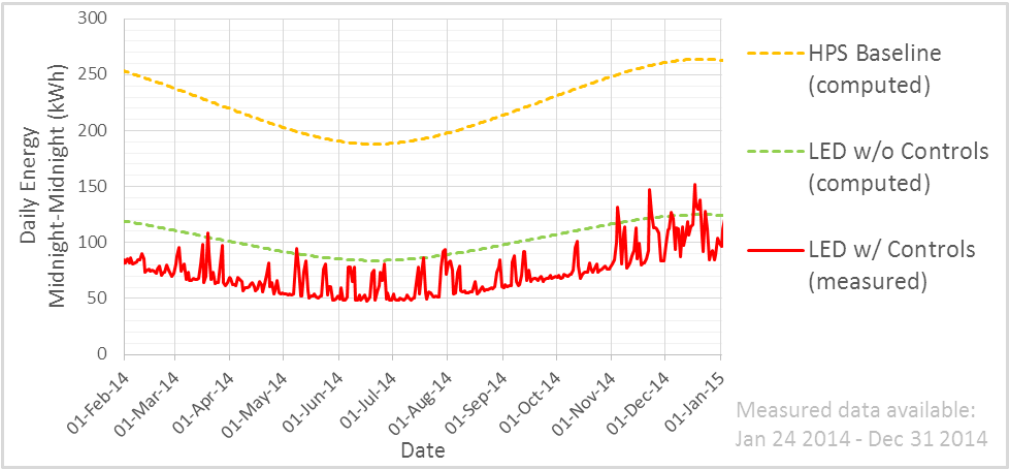


Figure 11. B4700 energy use results.

Sheridan Road

The energy use results for the Sheridan Road site are shown in Figure 12. There were two distinct energy use profiles for Sheridan Road: 1) from January – June the luminaires operated at a constant 80% power (i.e., dimmed by 20%) from dawn to dusk; 2) on June 24, a curfew dimming schedule was implemented reducing the daily energy use by dimming the luminaires to different levels over the course of the night.

The dimming schedule was developed from Illuminating Engineering Society (IES) RP-8 recommended illuminance levels, pneumatic tube traffic counters that recorded vehicle traffic levels at night, and feedback from the Fort Sill liaison. Two separate schedules were implemented: one with higher light levels for intersection-adjacent luminaires and a second with lower light levels for non-intersection-adjacent luminaires. The fluctuation observed in March corresponds with diagnostic activities performed by the project team.

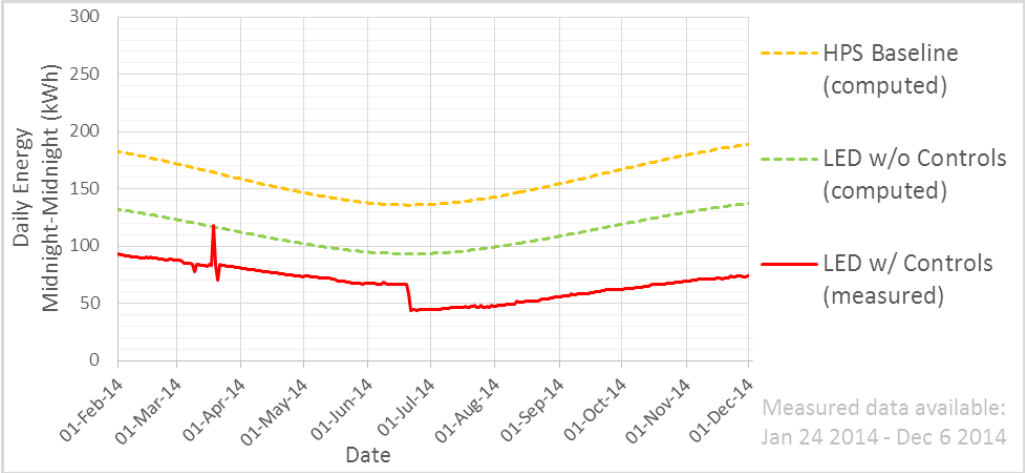


Figure 12. Sheridan Road energy use results.

TEMF

The energy use results for the TEMF site are shown in Figure 13. The TEMF site was the only site equipped with motion sensors. The luminaires operated from dawn to dusk at either 90%-power while occupied or 10%-power while unoccupied.

On most days, there was little or no activity within the TEMF site. As a result, most luminaires operated in LOW mode (i.e., 10% power) for the majority of the logging period. The fluctuations observed in March and late August correspond with diagnostic activities performed by the project team. The apparent loss of power in May was caused by un-informed base personnel who manually turned off the lights to conserve energy. This occurred on several nights before new signage was installed and the issue resolved.

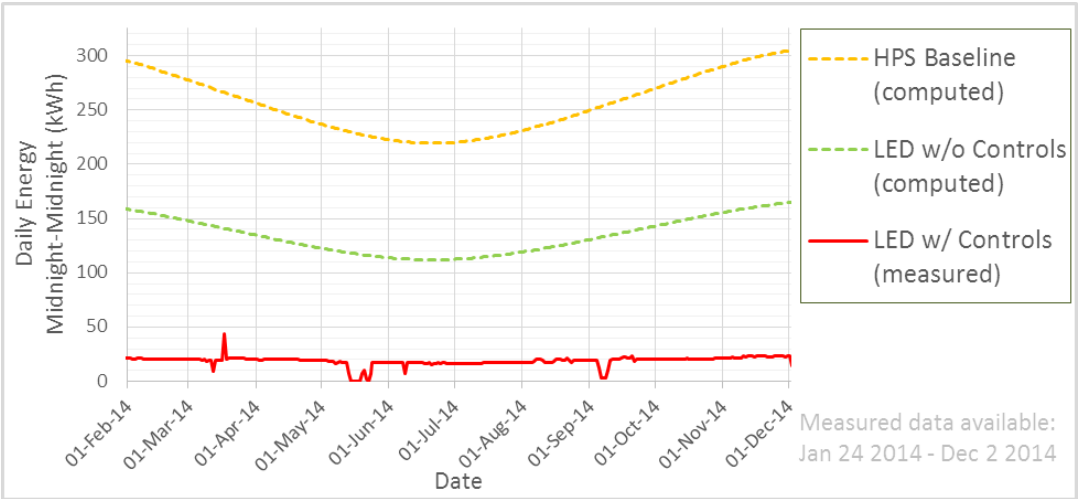


Figure 13. TEMF energy use results.

Measured Energy Analysis
To determine if each site passed the success criteria, the percent reduction in EUI was calculated and assessed whether the reduction was greater than 50%. The results are shown in Table 7. All three sites met the success criteria of >50% reduction in annual EUI over the baseline.

Table 7. Percentage reduction in EUI.

Site	Baseline EUI (kWh/lum)	Post-retrofit EUI (kWh/lum)	Percent Reduction (%)	Pass/Fail?
B4700	1893.9	736.1	61.1%	Pass
Sheridan Road	579.1	235.8	59.3%	Pass
TEMF	1618.9	145.9	91.0%	Pass

6.2.2 PO2: MAINTENANCE IMPLICATIONS

The nominal lifetime of HPS light source is about 20,000 hours. The annual operating hours are 4313, which means the lamp should be replaced every 4 years. The re-lamp cost including labor and materials is about $55. As a result, the annual maintenance cost of HPS based lighting system is high, and the nominal cost is about $45 per luminaire.

The lifetime of LED light source can be as much as 100,000 hours, which means the lamp doesn't need to change over the 20-year service time, and has an estimated annual maintenance cost of approximately $10 per luminaire. This poses great benefits to adopt LED based luminaires.

In addition, the networked lighting control systems, like Starsense and LOD, provide more capability in remote monitoring. This capability will reduce the regular maintenance work a lot. The networked system can detect and report failure instantly. Therefore, no regular patrol is needed to check the status of luminaires. Moreover, with the advanced data analytics function built in the backend, the system can predict the lifetime of luminaires and drivers based on historical operational data. Therefore, the DPW staff can schedule the maintenance work in advance and in a much more coordinated way. All of the above will upgrade the traditional maintenance workflow greatly and save base-wide maintenance cost in total.

6.2.3 PO3A: LIGHTING PERFORMANCE

All of the post-retrofit LED demonstration sites met the IESNA illuminance recommendations. In some cases, the space was possibly over-lit: TEMF and B4700 both exceeded IESNA recommendations by an order of magnitude. The luminaires in these spaces could be dimmed to increase energy savings.

The incumbent technology passed at TEMF, but failed at B4700 and Sheridan Road. The incumbent technology at the TEMF had good uniformity and the average illuminance well above the recommendation. The TEMF was likely over-lit by the HPS technology. At B4700, the average illuminance was well above the recommended, but the uniformity was very poor. Tree cover was most prominent at the B4700, and may have caused the poor uniformity. At Sheridan

Road, both metrics failed to meet IESNA recommendations. Sheridan Road was likely under-lit by the incumbent technology.

6.2.4 PO3B: LIGHTING PERFORMANCE

Security personnel were asked to rate their color recognition ability with the new lighting on a scale of 1-5, where 3 was “adequate” and 5 was “very good.” There were 14 responses with four responses of “very good” and nine responses of “adequate.”

Security personnel are of key interest for this application. Security personnel must be able to accurately identify occupants and activities in exterior spaces at night. This task requires higher visual acuity for more prolonged periods than typical users. Nighttime visual acuity is strongly affected by color temperature.

We concluded that users did accept the color temperature used in this demonstration because, when asked specifically about color recognition, security personnel responded that the lighting was either very good or at least adequate.

6.2.5 PO5A: SYSTEM RELIABILITY

According to the communication reliability test design in Section 5.1, a series of experiments were performed over the period of January 12–22, 2015. A total of 160 rounds of experiments were performed to acquire the OLC sensor control zone information from SC, with 42 inquiries in each round. The saved record shows all 6720 inquiries were performed successfully with good reception of response from OLC. It shows the 100% data delivery success rate in the test period.

6.2.6 PO5B: SYSTEM RELIABILITY

Dynadimmer system doesn’t have the metering function and, therefore, the project team didn’t evaluate the accuracy in the report.

Starsense system has the metering function built into the OLC. The metered energy consumption by the Starsense system was compared to the reference meter installed by California Lighting Technology Center (CLTC) on a monthly basis from February to July 2014. The average accuracy of metering function of Starsense system is 97.56% compared to the reference.

Although LOD system has the metering function built into the OLC, the camera sensor doesn’t have the metering function due to its research advanced development prototype’s nature. The reference meter is Philips AmpLight system, which measures the entire deployment at TEMF in Fort Sill including all luminaires and camera sensors. To get a fair comparison of energy consumption, the project team measured the power consumption of one camera sensor in the lab for a period of time; the average daily energy consumption was 3.2256 kWh. Then, the calibrated energy consumption of all camera sensors was added to the metered value from LOD system and compared the results to the reference. The average metering accuracy of the system is 93.62%. The main reason the system doesn’t pass the PO is because the camera sensor’s energy consumption in the field might differ from what was measured in the lab. As observed in May 2014, the entire site’s electricity was shut down for a few days. The camera’s consumption in the

projected energy consumption was still counted, which was not correct. On the other hand, the camera sensor's energy consumption is really high, which is almost 10% of a luminaire's consumption during the night, which also makes the difference larger if the projection doesn't hold and the power efficient design of sensor is what is needed to improve in the next stage of development.

6.2.7 PO5B: ENHANCED LIGHTING CONDITIONS

Lighting quality improved at all three demonstration sites.

1. Examine the lighting conditions of each demonstration site.

Table 8. Nighttime photos of lighting at Fort Sill demonstration sites.

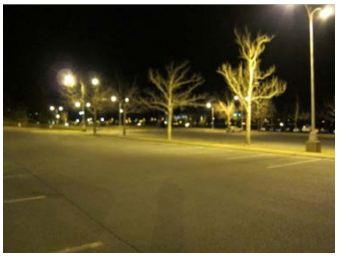
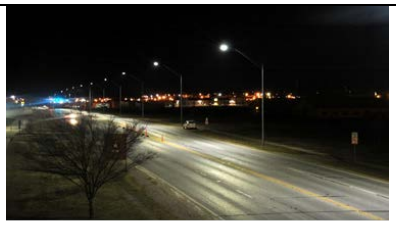
	Pre-Retrofit	Post-Retrofit
B4700		
Sheridan		

Table 8. Nighttime photos of lighting at Fort Sill demonstration sites (continued).

	Pre-Retrofit	Post-Retrofit
TEMF		

2. For each comparison, assess visual clarity, color perception, and lighting uniformity. Determine for each site whether all criteria are met.

The project team evaluated the subjective appearance focusing on three key characteristics: 1) color, or how natural colors appeared; 2) uniformity, or how severely shadows obscured vision; and 3) visual acuity, or how well one could see in general.

Table 9. Subjective assessment of change in lighting conditions.

Demo Site	B4700	Sheridan Road	TEMF
Color perception improved?	Yes	Yes	Yes
Lighting uniformity improved?	Yes	Yes	Yes
Visual acuity improved?	Yes	Yes	Yes
Test result	Pass	Pass	Pass

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7.0 COST ASSESSMENT

This section assesses the cost of three demonstrated lighting control technologies in terms of cost model, cost drivers, and cost estimation of commercial versions of the technologies.

7.1 COST MODEL

The project team has developed and validated the expected life cycle operational costs for the demonstrated technology.

- **National Institute of Standards and Technologies Handbook 135:** Refer to the Life-Cycle Costing Manual for the Federal Energy Management Program as a guide to evaluate energy and water conservation projects. The handbook and its annual supplement are available online at: http://www1.eere.energy.gov/femp/information/download_blcc.html#handbook
- **Life-Cycle Cost Table:** Table 10 highlights the data relevant to the technology the project team will track during the demonstration. The objective of this effort is to estimate life cycle costs at full-scale operation.
- **Life-Cycle Cost Elements:** Briefly describe each cost element, the associated data collection process and relevant data interpretation to determine life-cycle costs for the demonstrated technology.
- **Life-Cycle Cost Timeframe:** Define the timeframe for the life-cycle cost estimate.

Table 10. Life-cycle cost table.

Cost Element	Data Tracked During the Demonstration
Hardware capital costs	Estimates made based on component costs for demonstration
Installation costs	Labor and material required to install
Consumables	Not applicable
Facility operational costs	Reduction in energy required versus baseline data (collected via metering) Remote facility operation service monthly fee if applicable
Maintenance	Frequency of required maintenance Labor and material per maintenance action
Hardware lifetime	Estimate based on components degradation during demonstration
Operator training	Estimate of training costs
Salvage value	Estimate of end-of-life value less removal costs

7.2 COST DRIVERS

The key cost driver of the three demonstrated advanced lighting control solutions is commoditization of hardware components adopted in the system, such as LED luminaires, LED drivers, and OLCs and sensors.

Dynadimmer system is a standalone lighting control system and its cost is naturally scalable to different sizes of deployment. The cost of control hardware and management software of networked Starsense and LOD systems can be amortized over the number of light points and is

thus dependent on the deployment size. Therefore, in Section 7.3 two scenarios will be elaborated, one of which is the demonstration deployment at Fort Sill and the other is a projected reasonable scale of deployment for a representative DoD military base.

The cost associated with labor at the time of installation varies from region to region. It is recommended to have the local engineering service contractor for all the installation and maintenance work instead of having a central team responsible for all the work nation-wide.

The energy cost is also different region by region. Therefore, no nation/federal-wide unanimous utility price exists. Furthermore, every military base can negotiate with local utility company in the region to get a more favorable rate, which is usually kept confidential. Moreover, military bases might get tax incentives from federal and/or state government because of adoption of energy efficient lighting solutions. All these factors need to be considered in determining the actual cost in a particular DoD location.

7.3 DERIVING THE COST OF COMMERCIAL VERSIONS

Table 11 summarizes the breakdown of the commercial cost that reflects the actual cost of the Dynadimmer demonstration project deployed at B4700 administrative building parking lot in Fort Sill. In the calculation below, it is assumed that the total investment costs of the project includes total cost of hardware capital costs, software costs, and installation costs as well as supervision, inspection, and overhead (SIOH) and design costs, which is about 6% and 10% of the total costs.

Table 11. Cost figures of Dynadimmer demonstration project.

	Dynadimmer – Building 4700	
	Baseline	**Demonstration**
Number of fixtures per site	36	
Hardware capital costs including software ($)	11,400	17,064
Installation costs ($)	3,312	4,824
Total investment costs ($)	17,065	25,390
Energy savings percentage of the demonstration system		66%
Annual hours operation per pole	4,313	4,313
Utility price per kWh ($)	0.10	
Annual energy cost ($)	7,049	2,397
Annual energy savings ($)		4,652
Annual maintenance cost ($)	1,620	360
Annual maintenance cost savings ($)		1,260
Simple payback in years (total investment/first-year savings)		4.29
SIR in 10 years		1.99
SIR in 20 years		3.49

Table 12 summarizes the breakdown of the commercial cost that reflects the actual cost of the Starsense demonstration project deployed at Sheridan Road in Fort Sill. Because the size of ESTCP demonstration project is very small for the pilot purposes, 40 nodes share the cost of SC

and the management software. A more realistic large scale deployment will have more nodes, e.g., 1,400 nodes in practice, and the projected cost figures are listed in the same table as well.

Table 12. Cost figures of Starsense demonstration project.

	Starsense – Sheridan Road		Starsense – Projected Installation	
	Baseline	**Demonstration**	**Baseline**	**Projection**
Number of fixtures per site	40		1,400	
Hardware capital costs including software ($)	11,670	30,620	376,150	714,700
Installation costs ($)	3,680	8,400	128,800	294,000
Total investment costs ($)	17,806	45, 263	585,742	1,170,092
Energy savings percentage of the demonstration system		59%		59%
Annual hours operation per pole	4,313	4,313	4,313	4,313
Utility price per kWh ($)	0.10		0.10	
Annual energy cost ($)	5,089	2,087	178,127	73,032
Annual energy savings ($)		3,002		105,095
Annual maintenance cost ($)	1,800	400	63,000	14,000
Annual maintenance cost savings ($)		1,400		49,000
Simple payback in years (total investment/first-year savings)		10.28		7.59
SIR in 10 years		0.83		1.12
SIR in 20 years		1.45		1.96

Table 13 summarizes the breakdown of the commercial cost that reflects the actual cost of the LOD demonstration project deployed at TEMF in Fort Sill. In the calculation, it is assumed that two camera sensors are deployed at the two entrance/exit gates of the TEMF respectively. This assumption is consistent with the usage pattern observed in Fort Sill and will be optimal for this implementation. The size of the LOD ESTCP demonstration project is a representative application of its kind. The larger scale deployment will have more favorable cost figures, as more nodes can share the cost of SC and the management software. The cost figures of a projected deployment with 200 nodes are projected in the same table. In this calculation, it is assumed that one camera sensor will be deployed per 10 fixtures, with 20 camera sensors used in total.

Table 13. Cost figures of LOD demonstration project.

	LOD – TEMF		LOD – Projected Installation	
	Baseline	**Demonstration**	**Baseline**	**Projection**
Number of fixtures per site	42		200	
Hardware capital costs including software ($)	20,690	35,356	94,950	133,000
Installation costs ($)	3,864	9,450	18,400	45,000
Total investment costs ($)	28,482	51,975	585,742	206,480
Energy savings percentage of the demonstration system		92%		92%
Annual hours operation per pole	4,313	4,313	4,313	4,313
Utility price per kWh ($)	0.10		0.10	
Annual energy cost ($)	9,965	797	47,452	3,796
Annual energy savings ($)		9,168		43,656
Annual maintenance cost ($)	1,892	420	9,000	2,000
Annual maintenance cost savings ($)		1,470		7,000
Simple payback in years (total investment/first-year savings)		4.89		4.08
SIR in 10 years		1.75		2.10
SIR in 20 years		3.08		3.69

Table 14 summarizes the overall cost performance of the systems under different considerations as mentioned above.

Table 14. Summary of cost performance of the technologies.

Systems	Simple Payback in Years (Target is < 7 years)	SIR in 20 Years (Target is > 2)
Dynadimmer	4.29	3.49
Starsense demonstration project	10.28	1.45
Starsense practical scale	7.59	1.96
LOD demonstration project	4.89	3.08
LOD practical scale	4.08	3.69

8.0 IMPLEMENTATION ISSUES

The formal project start was delayed by several months due to contractual formalities; however, the engineering design and site preparatory work began in anticipation of the contractual completion. These items included:

1. Design and development of the system components.
2. System integration and full test bedding the proposed systems in Philips prior to implementation at Fort Sill.
3. RF testing was conducted outside of the DoD facilities for two of the systems as they employ wireless communication using FCC certified ISM bands (802.15.4). The project team conducted a wide range of tests using outdoor facilities in Briarcliff, NY, for reliability and robustness. The test bed provided a handful of data on architectures that had been proven in the laboratory environment and needed field testing prior to deployment. Philips was successful in optimizing the system performance by fine tuning the features and system parameters prior to deployment at Fort Sill.
4. Fort Sill administration (DPW staff and Energy Manager) were provided with detailed information on the deployment plan and design prior to the physical work commencing. The project success was treated like a conventional DPW construction project with structured design reviews and approvals along the entire path of the project.
5. Another success factor is that the demonstration project was discussed among all DPW interested parties and declared a short term experiment thereby providing fewer approval formalities, such as the DoD Information Assurance Certification and Accreditation Process. Also, it was found that more latitude was given as long as networks were isolated from the DoD networks and relied on independent servers outside the DoD. This helped in the smooth deployment of the systems with no surprises.

   NOTE: The DoD would find it beneficial in the large scale deployment of these energy conservation systems within the DoD networks in conjunction with the DoD Information Assurance Certification and Accreditation Process certification. The certification process will require an extensive analysis to surface the pros and cons of integrating these systems within the DoD networks.

Installation of the systems was carried out by hiring local electrical contractors who are familiar with Fort Sill contractor rules, personnel, and are certified to operate in the base. Utilizing local contractors allowed us to execute installations and troubleshooting quickly and without interruption. An example of the benefit in using local contractors is discussed below.

During installation, it turned out that one of the three systems, Starsense, deployed on Sheridan Road had a non-uniform illumination on the road and subsequent incorrect optics. Analysis of the optical characteristics (output pattern) of the fixture and the width of the road led to the conclusion that a type 3 optic rather than a type 4 was required. Local contractors were able to retrofit the entire demonstration site in less than a day. The quick turn-around for this correction of system related issues further underwrites the use of local contractors. Staff members of DPW,

security, and general users were interviewed and a detailed survey/questionnaire distributed to solicit feedback on the change to energy efficient technologies. The surveys provided not only Philips with feedback, but gave the Fort Sill Staff a chance to learn and familiarize themselves with the test systems and consider other applications to the DoD facilities. The project team was pleased to find that the level and quality of the lighting improved in all the areas resulting in positive reactions from the end users with the hope that DoD will deploy these systems on a wider basis. The systems deployed were predominately based on commercial off-the-shelf components so both during the test and in the future the DoD should not have procurement related issues.

A significant goal of the project was met in better understanding the needs and constraints deploying new energy technologies within DoD bases. The knowledge gained will be of great benefit as we work towards deployment in other bases. The scalability of the systems has been proven, which is essential for viable deployment across DoD.

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APPENDIX A

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