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Dynamic Exterior Lighting for Energy and Cost Savings in DoD Installations

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14. ABSTRACT

Exterior lighting for streets, roadways, parking lots, tactical equipment maintenance facilities, and site and area lighting represents nearly 10% of the electrical energy consumed on military bases today. Lighting in these areas typically consists of high pressure sodium or sometimes metal halide lamps and are normally controlled by photo-sensors located centrally or sometimes on each fixture. This limited functionality includes turning the light on in the evening and off in the morning regardless of the occupancy levels of the areas concerned thereby leaving significant room for energy savings with smart controls. The goal of this project has been to quantify energy and cost saving and reduce the environmental impact as measured by reduced carbon emission. Our approach included improving the quality and quantity of light compared to pre-retrofit conditions by demonstrating advanced light sources (LED luminaires replacing HPS lamps) with three lighting controls systems varying in cost and performance. The systems are called: Dynadimmer; Starsense RF; and Light-On-Demand (LOD) and applied in three selected areas, namely, a

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List of Acronyms

Acronym	***Definitions***
AC	*Alternate Current*
ANSI	*American National Standards Institute*
ARS	*Application Requirement Specification*
ASHRAE	*American Society of Heating, Refrigerating, and Air-Conditioning Engineers*
AMU	*Average-to-Minimum Uniformity Ratio*
BkWh	*Billion kiloWatt hours*
BLCC	*Building Life Cycle Cost*
BMS	*Building Management System*
BTU	*British Thermal Unit*
CALiPER	*Commercially Available LED Product Evaluation and Reporting*
CCT	*Correlated Color Temperature*
CFR	*Code of Federal Regulations*
CLTC	*California Lighting Technology Center*
CoN	*Certificate of Networthiness*
CP	*Control Panel*
C&P	*Cost and Performance*
COTS	*Commercial Off-The-Shelf*
CSA	*Canadian Standards Association*
CV	*Coefficient of Variation*
DALI	*Digital Addressable Lighting Interface*
DC	*Direct Current*
DDE	*Dynamic Data Exchange*
DDP	*Draft Demonstration Plan*
DoD	*Department of Defense*
DoE	*Department of Energy*
DPW	*Directorate of Public Works*
fc	*footcandle*
FCC	*Federal Communications Commission*
EMI	*Electromagnetic Interference*
EO	*Executive Order*
ESTCP	*Environmental Security Technology Certification Program*
EUI	*Energy Use Intensity*
FCC	*Federal Communications Commission*
FDP	*Final Demonstration Plan*
FEMP	*Federal Energy Management Program*
GHG	*Green House Gas*
GUI	*Graphical User Interface*
GSA	*General Services Administration*
GPI	*Grid Points Illuminated*

Acronym	***Definitions***
HID	*High Intensity Discharge*
HPS	*High Pressure Sodium*
IEEE	*Institute of Electrical and Electronics Engineers*
IESNA	*Illuminating Engineering Society of North America*
IT	*Information Technology*
IP	*Internet Protocol*
ISM	*Industrial, Scientific and Medical*
LAN	*Local Area Network*
LCCA	*Life-Cycle Cost Analysis*
LED	*Light Emitting Diode*
LOD	*Light-On-Demand*
LPD	*Lighting Power Density*
MCSI	*Maintenance Cost Savings Intensity*
MMT	*Million Metric Tons*
MMU	*Max-to-Min Uniformity Ratio*
NEMA	*National Electrical Manufacturers Association*
NIST	*National Institute of Standards and Technologies*
OCA	*Outdoor Configuration Assistant*
OLC	*Outdoor Lighting Controller*
PC	*Personal Computer*
PENAC	*Philips Electronics North America Corporation*
PI	*Principal Investigator*
PLE	*Philips Lighting Electronics*
PMT	*Program Management Team*
PNLCS	*Philips Networked Lighting Control System*
PO	*Performance Objective*
PRNA	*Philips Research North America*
R&D	*Research and Development*
ROI	*Return on Investment*
RF	*Radio Frequency*
RFQ	*Request for Quotation*
RUFMA	*Rotational Unit Field Maintenance Area*
SC	*Segment Controller*
SEMS	*SERDP and ESTCP Management System*
SIR	*Savings/Investment Ratio*
SSL	*Solid-State Lighting*
TEMF	*Tactical Equipment Maintenance Facilities*
UFC	*Unified Facilities Criteria*
UL	*Underwriters Laboratories Inc.*
USB	*Universal Serial Bus*

Executive Summary

Exterior lighting for streets, roadways, parking lots, and other outside sites represents nearly 10% 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 saving, 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 (LED luminaires replacing 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 objective of 50%) were achieved over the demonstration period of one year in an Administration building parking lot (Welcome Center B4700) on 36 LED luminaires. Average illuminance level was slightly increased (2.0 fc vs 1.8 fc), and distribution uniformity was substantially improved (7.4 vs 168) over pre-retrofit.

Starsense is a 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 the time. 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 one year of operation. Average illuminance was increased from 0.5 fc to 0.7 fc (on roadway sections) and 1.2 fc (at intersections) and distribution uniformity was substantially improved (3.7 vs 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 tactical equipment maintenance facility (TEMF) with 42 fixtures. The new system demonstrated energy savings of

92% (exceeding objective of 50%) while maintaining the same average illuminance with improved uniformity (1.9 vs 10.6) over pre-retrofit conditions.

In all three systems, the lighting levels exceeded IES 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 Yrs.) of more than 2.0 and payback of less than 5 years for Dynadimmer and LOD and less than 8 Yrs. for Starsense in areas where average cost of electricity is $0.10 or more per 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 DoD bases including, multiple Air Force bases, Fort Bliss, Fort Knox, Fort Dodge and others. The learnings 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 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 DoD facilities and can be classified into two broad categories namely roadways and site & area. Roadways include major and minor streets and site & area include buildings adjacent and open 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. These systems are tailored to apply to three selected areas at Fort Sill, OK. These areas include an Administration building parking lot, a major roadway and a tactical equipment maintenance facility. The initial baseline energy consumption and traffic volume of these three areas were measured over a period of at least three 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. Intermediate progress reports have been provided periodically and results are being published externally as appropriate. At the completion of the system demonstration, the results will be analyzed and documented in this final report.

The primary intent of this project was 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 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 site & area 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 REGULATORY DRIVERS

External lighting is driven by several regulatory standards and codes including, ASHRAE 90.1; California Title 24; IESNA RP-8, recommendations for roadway lighting; and IESNA RP-20, recommendations for parking lot. In addition to these, DoD design guidelines [UFC 3-530-01: DoD Design: Interior, Exterior, Lighting and Controls] provide information on its requirements. Furthermore DoD has defined its own goals for each installation as defined in [Department of Defense Annual Energy Management Report, Ref ID: 4-EA9D0F0] including a goal to use 30 percent less energy than ASHRAE 90.1.

The technologies demonstrated in this project were aimed at increasing energy efficiency of exterior lighting and thereby saving energy, cost and environmental emissions. These are driven by a number of executive orders and DoD directives. The most significant ones for the DoD and other federal facilities are as follows:

- The Energy Policy Act of 2005
- Federal Leadership in High Performance and Sustainable Buildings. Memorandum of Understanding of 2006
- Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation management of 2007
- The Energy Independence and Security Act of 2007
- Army Energy Security Implementation Strategy of 2009
- Executive Order 13514 – Federal Leadership in Environmental, Energy and Economic Performance of 2009
- Unified Facilities Criteria (UFC) 3-400-01 Energy Conservation, with changes of 2008
- DoD Directive (DoDD) 5134.01 (Reference (a)), reissues DoD Instruction 4170.11 (Reference (b)) to reflect changes in Public Laws 110-140 and 109-58 (References (c) and (d) respectively) and requirements of Executive Order (E.O.) 13423 (Reference (e))
- DoDD 4140.25 (Reference (f)) and provides guidance, assigns responsibilities, and prescribes procedures for DoD installation energy management.

Activities undertaken in this project have been complementary with other efforts in the public sector. DoE's SSL program has invested over $250 million on improving LED technologies during the last 10 years and continues to invest in this area to develop and bring to market technologies in this space. These and other global industrial initiatives are expected to go a long way toward complying with the EO 13423 that mandates 30 % energy reduction in federal buildings and installations by 2015 to a 2003 baseline.

1.3 OBJECTIVE OF THE DEMONSTRATION

The main objective of this project was 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 were tailored to suit the unique characteristics of the target DoD applications. Evidence was 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 our goal was threefold. First, we replaced the magnetically ballasted HPS lamps with higher overall efficiency and longer life light sources such as LEDs to significantly improve light color and distribution. Second, we controlled the light levels 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, with two of our systems (Starsense Remote Light Management and Light-On-Demand) we monitored and controlled the light sources continuously from a central location. This enabled rapid determination of lamp failures and allowed lamp replacement promptly and efficiently, while addressing health and safety aspects, if any (see Appendix A).

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 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;
3) **Light-On-Demand (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 was matched to the use area such that both energy savings and cost are optimal compared to the existing baseline. Furthermore, the systems allowed scalability and extension for additional installation when required. The combined effect of these technologies, when adopted DoD wide, will be substantial energy and cost reductions, lower environmental impact, and easier/lower cost of maintenance of the systems. This will take DoD far along the path to energy security and meeting its energy savings goals.

To ensure that these new technologies meet all the DoD regulations and operating requirements in terms of ease of installation and use, the demonstration is designed to address various aspects of deployment. 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 three 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 therefrom, 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, already the Starsense system (for streets and roadways) is being considered for base wide deployment in Fort Sill (2,833 light points) as well as in a section of Fort Bliss (2,375 light points). Additional DoD installations are considering deployment as well.

The base personnel (DPW) have been trained in the operation and maintenance 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 US 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 operation and maintenance of the systems. The demonstration systems and associated equipment remain with the DoD site for continued use.

2 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

The functionality, architecture and operation of each of the systems 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 control of outdoor lighting has long been limited to switching it on or off based on a photo-sensor, time clock or a combination of both. Many of the outdoor areas are over-lit at off peak, low traffic or outlying sections. The lack of specific area/fixture lumen control results in higher energy consumption and light pollution and significant maintenance cost as fixtures age. 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 detected).

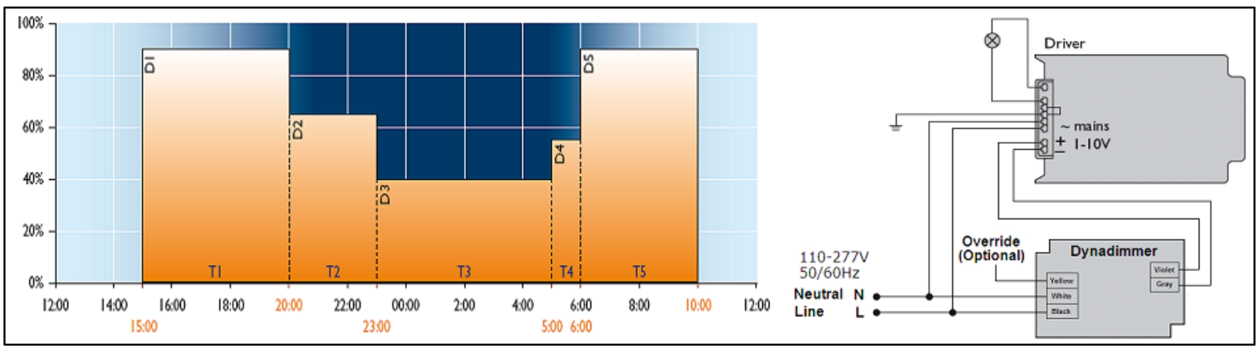


Figure 1: Dynadimmer Sample Dimming Profile

Architecture: The Dynadimmer functionality is "built-in" to the programmable LED Xitanium driver that powers the LED engine within the fixture. The LED driver is programed at the factory or in the field to enable the Dynadimmer functionality and pre-set a program based on the input from the customer. *Note: The Dynadimmer functionality is also available in a stand-alone configuration for driver technologies that do not have this built-in functionality. The stand-alone version communicates with the driver through a 0-10V input.*

Operation: Dimming levels and time periods are configured with a laptop or tablet software tool that communicates with the LED driver over a digital interface. The controller uses an adaptive algorithm that counts the time that the lights were turned on over the last 3 days and determines a mid-point, which is used as an intelligent reference point to apply the dimming schedule.

In case of a power failure, the controller will reset the reference time and lights will be turned on/off as usual and dimming will be disabled until the new mid-point reference is calculated after 3 days. Field re-programing of the LED driver is achieved by connecting to the driver located in the fixture. The significant benefit is that the fixtures are all "custom programmable" based on location, lumen level requirements, traffic patterns, area usage, security or facility operations.

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 providing energy savings during low traffic hours and enhanced lighting for problematic neighborhoods for added security.

Chronological Summary: The predecessor to the Xitanium intelligent LED/HID drivers was the stand-alone Dynadimmer module. The Dynadimmer external module was preceded by the Chronosense module designed to provide bi-level dimming capability for magnetic ballasted HID light sources. Both the Xitanium intelligent driver and the stand-alone module are released products now and available for mass deployment.

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.

Anecdotal Observations:

1. In new installations the chief customer comment is that the system is not working. When the Dynadimmer systems begin the dimming cycle, usually 100% to 80% for example, the drop is not easily discriminated by the naked eye. Only after an amp meter is placed on the circuit does the customer believe the system is working.
2. LED dimming can be much deeper than originally planned on paper. This is due to the same factors in #1 plus the fact that LED fixtures have a lower lumen level but a much better uniformity so the difference late at night is barely noticeable even down to 30% levels.
3. Field reprogramming is almost always undertaken after the system has been in operation for a month or two to "fine tune" the levels and shed more energy. One fact is that since every fixture can be programed separately, it opens up the possibility to control fixtures closer to the building, bus stop, and intersection at a different dimming level than out in an open parking lot with no activity.

2.1.2 STARSENSE

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

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. Solution can be leveraged for smart grid connections, and implementation of demand response strategies such as dynamic load shedding.

Architecture: Starsense deploys a Remote Light Management System for outdoor lighting based on two-way wireless communication using the latest wireless mesh network technology. Starsense has a scalable architecture in which each luminaire, equipped with an RF Outdoor Lighting Controller (OLC) for use with both magnetic ballasts and electronic drivers. OLCs are controlled with a segment controller (SC). The SC is also equipped with a similar RF module, but provides an additional interface to connect to the remote management application through a wired or wireless link (e.g. cellular interfaces). The RF modules are compliant with the IEEE 802.15.4 standard [4] and transmit in the 915 MHz band approved for unlicensed operation (according to FCC 47 CFR Section 15.247). They form a self-healing wireless mesh network that provides reliable connectivity to and from the SC, and back-end management server including a database. The remote light management application is CityTouch LightWave, a newly developed, user friendly, map based service. Commissioning of the Starsense system is done through the specially designed Outdoor Configuration Assistant (OCA) tool.

Operation: After installation and commissioning, OLCs will periodically report status and metering information to the SC, which will forward the data to the management station. CityTouch LightWave service enables operators to visualize the locations and status of the luminaires, send commands to individual or groups of luminaires, and access system reports, alarms and data trend analysis based on stored data. System faults (e.g. lamp failures) are reported immediately and alarms can be sent directly to an operator, if needed. The management application also gives operators detailed information on which areas are critical and which areas can wait for maintenance. A local photo-sensor at each luminaire can be used to turn the lights on and off, thereby ensuring that the lights will always turn on at night in case of control system failures.

The system features are:

- User friendly, web-based end-user interface
- Commissioning based on collected asset information
- Sub-GHz frequency for communication between SC and OLC
- Secure, advanced encrypted communication
- Over the air upgradeable software for the RF OLC node
- Communication is based on self-healing mesh network protocol
- RF OLC node can communicate with DALI and 0-10V drivers
- Segment Controller can handle up to 1,500 RF OLC nodes (depending on network topology)

The system benefits are:

- No IT costs (e.g. software installation costs, server acquisition and maintenance)

- Easy access from anywhere
- Continuous updates and automatic backups
- Reliable system – long communication range, limited interference, graceful degradation mechanisms
- No risk for hostile take-over of the lighting system
- Future upgrades of the RF OLC node can be done remotely
- All light points in the network can be reached and addressed
- Freedom to select any driver
- Tools to advise the location of the segment controller anywhere in the wireless mesh network

Technical specifications are summarized in Table 1:

Table 1: Technical Specifications of Starsense System

Radio Frequency	900 MHz ISM band (915 MHz)
Range	Approximately 300m between nodes
Security	Advanced encryption standard at 128-bit security level
Lifetime	110,000 hours with less than 10% failures
Accuracy of integrated power meter	> 95%
Ambient Temperature Range	-30C to +55C
Regulatory Approvals	UL, CSA, FCC

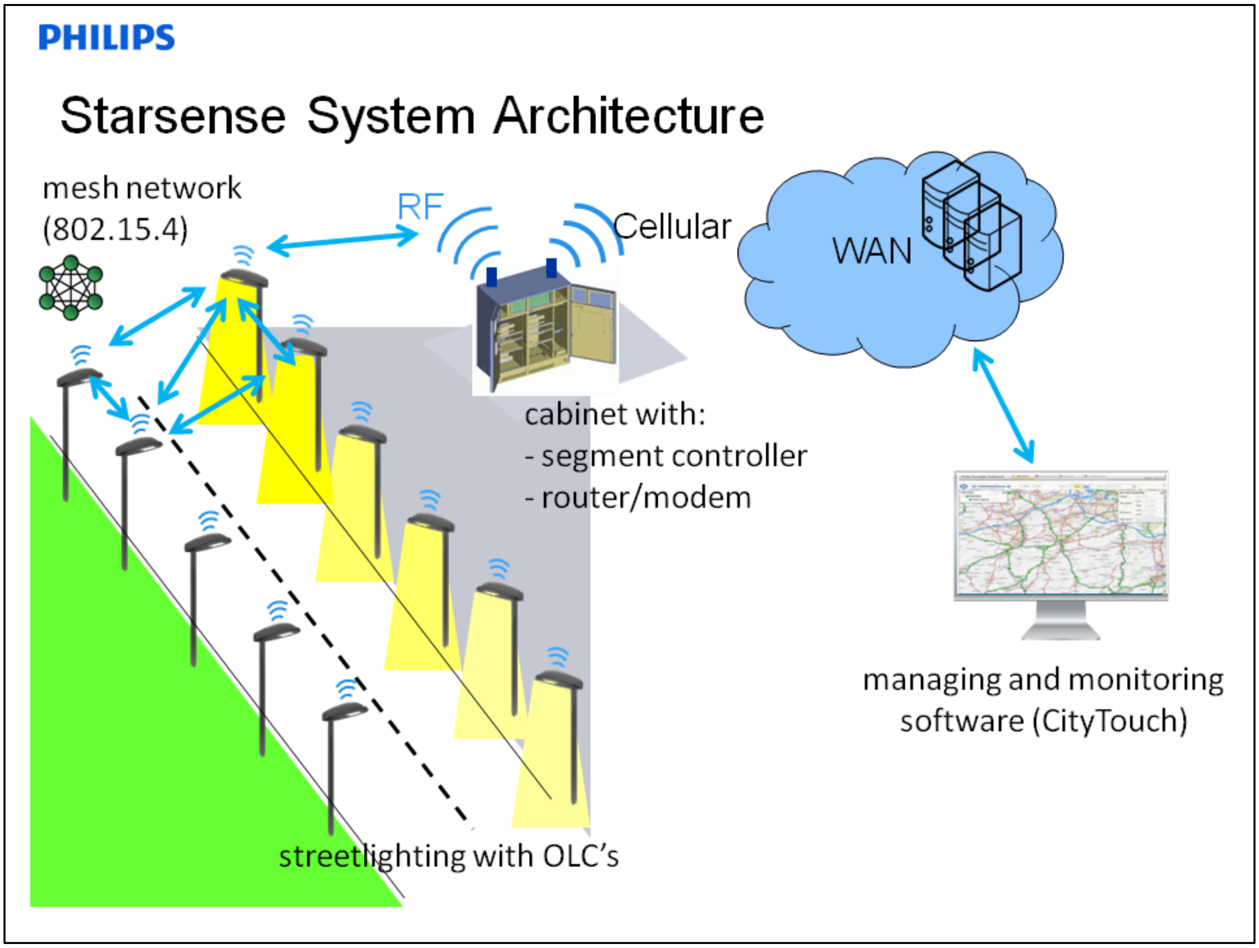


Figure 2: System Architecture of Starsense

Comparison with Existing Technology: The existing luminaire had 250W HPS lamp, and was replaced by 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 also provides asset management, remote fault diagnosis and event report.

Chronological Summary: Philips introduced the Starsense system in early 2011 and initial deployments were in Europe. The European OLC operates on the 868 MHz band and is designed for mounting from inside the luminaire through a 20mm hole, with a connector for wiring to the lamp driver. It is designed to work with 240 volt AC power and is capable of handling 400 watts. Development of the North American versions was started at the same time, in two models – low voltage from 120 to 277 volts, and high voltage from 347 to 480 volts. The NA OLC is capable of handling up to 1000 watts, and the mechanical design is suited for installation on the standard NEMA twist-lock receptacles used for photocells. The NA OLC also features an integral photo sensor to provide photocell operation as a backup to the normal operation based on time schedules.

Since the standard NEMA socket does not provide dimming signal connections, custom modifications have been made to the OLC and the socket to accommodate the signal wires. This requirement has been used to drive the development and ANSI certification of a new socket which is the commercial standard now.

Future Potential for DoD: The Starsense system provides many benefits for DoD, and a few of them 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
- Green image, with reduced energy cost, CO_2 footprint and light pollution

Anecdotal Observations:

The pilot installations have provided valuable information about the infrastructure leading to pre-emptive corrective action. The lamp parameters – voltage, current, power factor and power – can be monitored and compared over time to facilitate proactive maintenance. The system warnings provide information about excessive voltage drops and approaching end-of-life conditions.

2.1.3 LIGHT-ON-DEMAND

LOD is an adaptive lighting system based on Starsense RF and advanced sensing to sense movement in the vicinity of the luminaire, and 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 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.

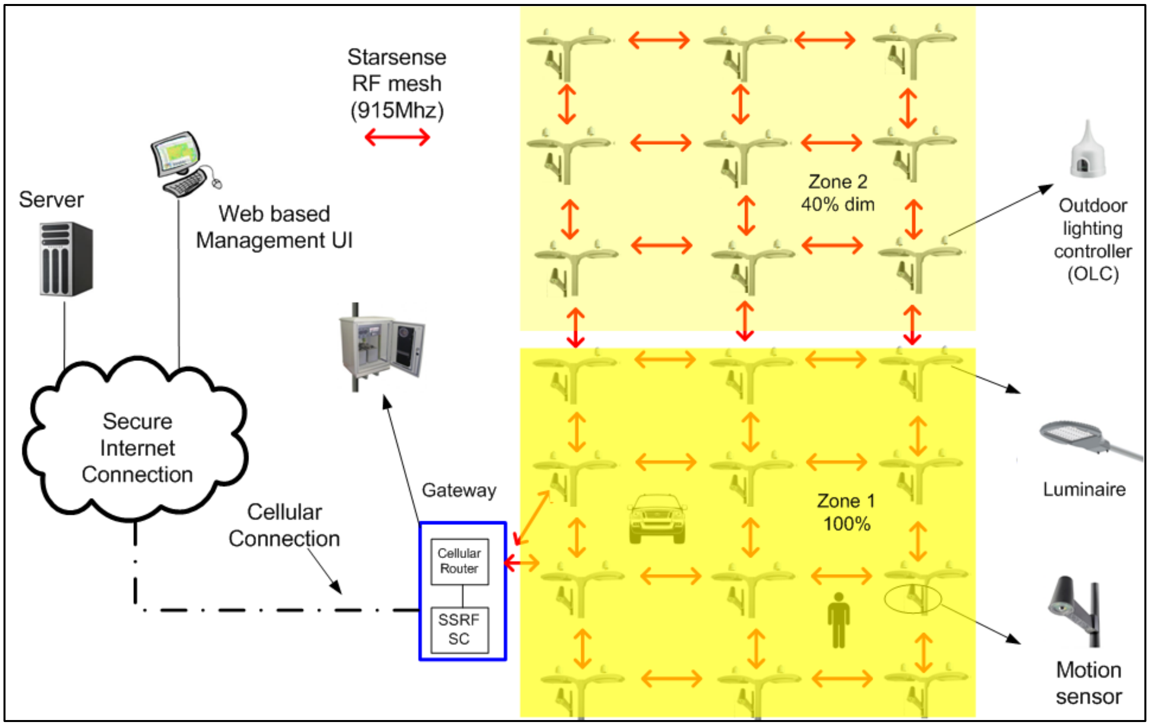


Figure 3: System Architecture and Components

Architecture: Figure 3 shows the system architecture with intelligent sensors that can detect pedestrians, vehicles and other moving objects, and provide event detection information to neighboring luminaires via RF communication through outdoor lighting controllers (OLC). The RF modules operate in the 915 MHz band approved for unlicensed operation (according to FCC 47 CFR Section 15.247) and implement the IEEE 802.15.4 standard. LOD is a scalable system that sensors and OLCs form a wireless mesh network in order to exchange event detection and lighting control information with neighboring luminaires.

Operation: Each LOD sensor unit has a detection zone up to 20m-30m (20m for person detection and 30m for vehicle detection) radius around the luminaire, and once it identifies a pedestrian or car in the detection zone, it triggers the OLC - control module, which can increase the light level. Different light levels can be configured for different moving objects detected. Once an event is detected, the motion sensor RF module sends a message to the neighboring OLCs which can also actuate the lights according to the event. Once a detected object exits the detection zone, after a certain period (e.g. 60 sec), the lights connected to that unit will dim to default (minimum) level, unless it receives another event message from a neighboring luminaire. LOD also exploits the wireless connection for over-the-air upgrades, easy installation, commissioning and maintenance.

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.

Chronological Summary: The LOD system derives the technologies from the Starsense system for wireless control and the LumiMotion system [18] for motion detection. The Starsense system development was started in 2009 and was commercially introduced by Philips in early 2011 with initial deployments in Europe. The development of LumiMotion system was started in 2008 and the commercial was released by Philips in early 2011 for commercial deployments in Europe. At this point Philips is exploring product version of the demonstrated LOD system, based on commercially available sensors and the more generic designed Network Interface Box (NIB) to increase the flexibility to integrate various triggers in the same wireless network.

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

Anecdotal Observations:

The LOD pilot system has been deployed at Philips Briarcliff campus and shows significant energy saving potential and system reliability. Light level changes are often not noticed by the users leading to the wrong conclusion that the systems is not working.

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 ESTCP project resources.

2.2.2 STARSENSE

The Starsense system consists of one or more SCs (Segment Controller) which act as gateways to monitor and control multiple luminaires equipped with OLCs (Outdoor Lighting Controller), the core of the control system. The OLCs and the SCs communicate over a mesh network, with the RF communications based on the IEEE 802.15.4 protocol, using the 900 MHz ISM band in North America. The SCs are equipped with 3G cellular wireless modems and communicate with the CityTouch web-based lighting management service software via the PSTN.

The Starsense OLC, consisting of a radio, control logic including memory, a relay and power supply was initially designed and developed in Europe for that market. It is a through-hole design, to be mounted from inside the luminaire, with just the antenna section outside. North American outdoor fixtures typically use a NEMA standard photocell socket for control, so a new version of the OLC was designed with the correct form factor and a twist-lock connector base and also a light sensor to simulate photo-cell operation as a backup to turning the lights on and off based on the astronomical clock calendar. The European design was not UL compliant, so the NA design incorporated suitable changes.

The standard NEMA socket accommodated only three AC power connections – power input, switched output and common. So while the initial version of the OLC did include the analog (0 to 10 volts) and the digital (DALI) dimming circuitry, there was no easy way to provide an interface between the dimming output signals of the OLC and the dimming inputs of electronic drivers in the luminaire. So for the initial research test-bed developed in Briarcliff research campus, a hole was drilled in the base of the OLC at the center, and a corresponding hole was drilled in the ANSI receptacle so that two dimming signal wires could be brought out and connected.

To test this 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 and the type of luminaire to be deployed at Fort Sill. A complete Starsense system with OLCs, Segment Controller, 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 we identified a number of design weakness in course of time. These were rectified in subsequent designs before we 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 ANSI towards a new socket for dimming controller as a replacement for the standard NEMA socket. This effort resulted first in a new receptacle design that allowed for the connection of the dimming signals, using a RCA type jack in the center of the three AC power connections and was introduced by GE. This was the prime candidate being considered for the new ANSI standard for a photocell with dimming control and was made available in the market first. Therefore it was used for the luminaires at the Fort Sill demonstration project installation. The OLC base was modified to add a mating RCA plug for the dimming signals, and those OLCs are currently in use at Fort Sill.

Unfortunately the GE design was not accepted by the ANSI standards committee, and an alternate newly proposed design by Acuity was chosen instead to become the new ANSI standard for the dimmable photocell receptacle. The dimming signal contacts are on the outer periphery of the receptacle. The receptacle can actually accommodate four low voltage signals, but only two are used. These sockets and receptacles were later made available in the market. Therefore new OLCs with the mating base and the appropriate form factors were designed and released. The luminaires at the site will be reworked to change the GE version receptacle 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 1,500 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 Light–On-Demand (LOD) system is based on the Starsense platform for the networking aspects and consists of luminaires with outdoor lighting controllers (OLCs) as described earlier, but with a motion sensor system for each light fixture. The same wireless mesh network as in Starsense is deployed with a key difference in the use of the sensor system. This camera based sensor system consists of a camera module, image acquisition system, digital signal processing system to extract the relevant motion information (e.g. vehicles vs pedestrians) from image sequences, radio to transmit the resulting information to the OLC, relevant interfaces and power supply. This sensor system was designed from scratch including the hardware and firmware and was major effort in the first phase. The OLC on the other hand was derived from the Starsense system and used the same hardware but with a different firmware to accommodate the sensor signal. A completely new management system including backend processing and visualization software was developed for this LOD system as it needed unique functionality compared to the Starsense system. The backend with intuitive user interface was designed for ease of use as well as scalability and flexibility for rapid deployment including configuration and commissioning.

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 segment controller, 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 2 provides the distinguishing characteristics of the three systems. The functionality, architecture and operation of each system are subsequently described.

Table 2: 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.

	Dynadimmer	**Starsense**	**LOD**
Connectivity	N/A	Wireless (915 MHz ISM band radio) + remote wireless data link from SC to management 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

2.3.1 XITANIUM LED DRIVER AND DYNADIMMER FUNCTIONALITY

- ***Performance Advantages:*** Converting Magnetic HID to Lumen Controlled LED is an enormous boost to the cost to operate outdoor lighting systems. Several control technologies have been combined into a single driver that is program selectable reducing the component costs and installation complexity inside the fixture housing. The design also future proofs the fixtures as other external control systems may be developed that enhance the ability of the system to control and save energy. Reduction in system energy consumption is base lined at 50% of the existing system due to LED conversion. Dynadimmer provides additional energy savings by reducing the output of the fixtures in 5 steps over its nightly period of operation.
- ***Cost Advantages:*** Cost for this feature is included with the LED driver at a cost of $0.25 per watt to cover factory programming of the feature set. Modifications in the field are accomplished using a standard laptop and a DALI interface module with software provided at no charge. Typical field re-programming cost is $20.00 per fixture if performed by a lighting maintenance company.
- ***Performance Limitations:*** Compared to the other systems being demonstrated, the Dynadimmer is a stand-alone system fixture by fixture. It is not networked and therefore does not have a remote control or visualization capability as with the other systems. Infant mortality associated with the deployment of electronic components is less than 0.1%. Surge protection must be provided in each fixture.
- ***Cost Limitations:*** The cost limitations of the deployment of Dynadimmer are not significant. Now that the functionality has been combined into the latest intelligent drivers the costs continue to decline as production volumes increase. In applications requiring frequent changes to the dimming profile, it can become costly with the

Dynadimmer system as this will involve accessing the Dynadimmer module fixture by fixture.

- ***Social Acceptance:*** The chief difficulty that we have had in deploying the technology is the lack of experience with the technology. Dimming of LED fixtures is very subtle and customers often report that the systems are not working.

2.3.2 STARSENSE FUNCTIONALITY

- ***Performance Advantages:*** Combined with dimmable advanced light sources such as LEDs, the Starsense system increases the efficiency of the streetlights by a combination of high efficient light generation, distribution and dimming while preserving the required light levels and color. Furthermore, by providing fully networked and remote monitoring facility, the system allows identification and prompt rectification of faults resulting in improved maintenance at lower overall cost. Additionally the energy monitoring/metering feature allows improved energy planning and cost savings based on actual usage rather than estimated usage as is commonly done presently. The Starsense system operates in the sub-GHz band, which allows for greater distance between nodes and overall range, as compared to systems operating on the higher frequency bands. It is easily extendable for system expansion over time. The over-the-air upgrade feature allows for new features to be added without major disruptions. The CityTouch lighting management service software provides many user friendly features, and is constantly being improved to take advantage of newer technologies.
- ***Cost Advantages:*** With a single segment controller able to monitor and control up to 250 OLCs (the number is increased to 1,500 with the latest software release), the Starsense system is very cost effective for large installations. The installation and commissioning costs are also low, with the OLCs pluggable on the new ANSI certified NEMA receptacles which can also be used for photocells. The Segment Controller only needs AC power, and installation is straightforward, as it can be mounted on a pole, wall or a platform.
- ***Performance Limitations:*** The Starsense system is most efficient when the installation forms a good mesh network, providing a lot of redundancy. Scattered lighting installation with many small clusters spread over a large geographical area will either need separate segment controllers or bridge OLCs linking the clusters. Natural barriers which prevent line of sight between nodes, or other RF barriers would also need special consideration. In case wireless communication is not allowed, the system can be set up with wired links using, for instance, power line communication. This is not a desirable option as power line communications in the US are not very reliable due to the frequent use of transformers in the distribution sections. To circumvent this problem, repeaters could be deployed adding to the cost of the system. It should be noted that the Starsense system uses 900 MHz FCC certified ISM band and does not interfere with the military bands and thus poses no problem during operation.
- ***Cost Limitations:*** As explained earlier, the Starsense system is not very cost effective for very small, stand-alone clusters.

- ***Social Acceptance:*** As with many control systems, with initial training and familiarizing with the system use it is simple and intuitive for the system operator. In essence it is analogous to typical web-based control systems. For users experiencing the new lighting system either as an automobile driver or pedestrian, the typical response is a pleasant one primarily due to the level and quality of illumination matching the need of the situation.

2.3.3 LOD FUNCTIONALITY

- ***Performance Advantages:*** Similar to the Starsense system, the LOD system provides high efficient LED lamps and drivers that save energy, cost and GHG emission. The use of special sensors with smart image classification algorithms enables a high level of energy savings without compromising convenience, safety and security. The LOD system operates in the sub-GHz band, which allows for greater distance between nodes and overall range, as compared to systems operating on the higher frequency bands. It is easily extendable for system expansion over time. The over-the-air upgrade feature allows for new functions to be added without major disruptions.
- ***Cost Advantages:*** LOD system provides various options in configuring the system. The basic version of the system does not need the segment controller and backend server. The advanced version of the system needs only light version segment controller and PC software for single site operation. The premium version needs segment controller and backend server for multi-site operation. Both basic version and advanced version are cost effective. The premium version can also be cost effective for large scale multi-site deployment. The installation and commissioning costs are also low, with the OLCs pluggable on the new ANSI certified NEMA receptacles and can also be used for photocells. The wireless presence sensor needs only AC power and the placement is flexible as it can be mounted on a pole or wall. The Segment Controller only needs AC power, and installation is straightforward, as it can be mounted on a pole, wall or a platform.
- ***Performance Limitations:*** The LOD system is best for deployment in the site/area with gateway access and/or direct traffic. The wireless communication would not be an issue given that site/area lighting can form good mesh network. As with the Starsense system, if for some reason wireless communication is not allowed, it is possible to use power line communication or wired communication links. These are not desirable primarily due to cost and/or reliability reasons, as mentioned earlier. Also it should be again noted that the wireless signals use FCC certified ISM band and does not interfere with the military bands.
- ***Cost Limitations:*** The initial investment of the LOD system is higher than the Starsense system due to the addition of the sensors. But it provides significantly more energy savings and return over the time. As a result the overall SIR and payback are better than the other two systems.
- ***Social Acceptance:*** Operation of the LOD system is user friendly and expected to be easily learnt within a short time. Once the system is set up and starts stable operation, it is expected to be seamless and should not require operator intervention except for experimental reasons.

3 PERFORMANCE OBJECTIVES

3.1 PERFORMANCE OBJECTIVE TABLE

The three outdoor lighting control systems will be evaluated against the performance objectives stated in Table 3. Quantitative and qualitative analyses will be performed to assess the successfulness in meeting these performance objectives. The terms used in performance objectives 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 or lux, when footcandles or lux are determined using the photopic luminous efficiency function. The photopic luminous efficiency function applies to visual stimuli at luminance levels above approximately 3 cd/m2 (high light levels).

Scotopic Illuminance: Density of luminous flux incident on a surface expressed in footcandles or lux, when footcandles or lux are determined using the scotopic luminous efficiency function. The scotopic luminous efficiency function applies to visual stimuli at luminance level below approximately 0.001 cd/m2 (very low light levels).

Table 3: Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Energy performance	Annual Energy Use Intensity (EUI) per luminaire expressed as kWh/yr/luminaire	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 % of Grid Points Illuminated (GPI) and average illuminance, coefficient of variation (CV), average-to-min uniformity ratio (AMU), and max-to-min uniformity ratio (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]

Performance Objective	Metric	Data Requirements	Success Criteria
	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
Cost effectiveness	- Savings/Investment Ratio (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 operation and maintenance	Level of satisfaction of facility personnel with operation, monitoring and maintenance of the systems	Feedback from base operations personnel on operation and maintenance functionalities	Systems perform reliably. Management tools improve operations and maintenance.

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

The following describes each performance objective listed in Table 3.

3.2.1 ENERGY PERFORMANCE = ANNUAL ENERGY USE PER LUMINAIRE

- **Purpose:** Energy performance must be measured to determine the energy consumption of existing and demonstration luminaires. This PO will provide the necessary information for direct comparison of technologies in order to determine annual energy savings.
- **Metric:** Annual Energy Use Intensity per luminaire = EUI [unit: (kWh/yr/luminaire)].
- **Data:** Data loggers will collect current measurements over time. These measurements will vary depending on the input power of each luminaire. Current measurements will

then be converted to power (W) by using the system's voltage rating, and furthermore converted to kWh by multiplying by its annual operating hours.

- **Analytical Methodology:** Full year data has been collected as a set of time series energy data. This data has been used to calculate annual energy use.
- **Success Criteria:** Success will be achieved by measurement of a 50% or greater reduction in annual EUI per luminaire for each system compared with the metered baseline.

3.2.2 MAINTENANCE IMPLICATIONS = ANNUAL MAINTENANCE COST SAVINGS PER LUMINAIRE

- **Purpose:** Maintenance costs must be calculated to determine the costs and benefits associated with the demonstration technologies. Maintenance costs result primarily from end-of-life replacement needs. This PO will provide the necessary information for direct comparison of maintenance costs, based on system lifetime, for incumbent and demonstrated technologies.
- **Metric:** Annual Maintenance Cost Savings Intensity = MCSI [unit: ($US/luminaire).
- **Data:** Luminaire service cycles (estimated operating hours between re-lamping) will be calculated based on manufacturers reported performance data. This data will be combined with estimates of labor and materials necessary to complete a re-lamping. Costs for the incumbent and demonstration technologies will be compared to determine a value of expected annual savings.
- **Analytical Methodology:** Maintenance costs will be estimated based on average labor rates and product costs. These costs will be combined with manufacturer's published data on lamp life, to calculate annual maintenance costs and savings.
- **Success Criteria:** Success will be achieved by measurement of a 40% or greater reduction in annual MCSI per luminaire for each system as compared with the metered baseline.

3.2.3 LIGHTING PERFORMANCE = DELIVERED LIGHTING PERFORMANCE OF LUMINAIRES

- **Purpose:** Lighting Performance, in terms of light levels and uniformity, must be calculated for incumbent and demonstration luminaires to ensure demonstration luminaires meet or exceed the performance of incumbent technologies. In addition, lighting performance evaluations will demonstrate how new technologies perform relative to industry recommended practice.
- **Metric:** Illuminance and uniformity metrics including % of Grid Points Illuminated (GPI), average illuminance, coefficient of variation (CV), average-to-min uniformity ratio (AMU), maximum-to-minimum uniformity ratio (MMU), and Correlated Color Temperature in Kelvin – CCT(K).
- **Data:** Photopic and scotopic illuminance measurements will be recorded, over a defined grid test area, for incumbent and demonstrated luminaires. CCT will be measured using a chromometer.

- **Analytical Methodology:** Illuminance maps will be generated using data obtained. Measured illuminance values will be used to calculate GPI, CV, AMU, and MMU.
- **Success Criteria:** Success will be achieved by demonstrating dynamic lumen output with improvements in lighting distribution compared to baseline while complying with applicable recommended standards.

Photopic Illuminance, which has traditionally been used to evaluate luminous performance, has major shortcomings, both in terms of the metric itself and the units used to measure it. Meeting the illuminance requirements of current standards does not necessarily mean good lighting conditions. This issue is further addressed in Appendix G.

3.2.4 COST EFFECTIVENESS = QUANTATIVE BENEFIT ACHIEVED FROM INVESTMENT

- **Purpose:** Cost effectiveness must be calculated to determine the feasibility of the project.
- **Metric:** Savings/Investment Ratio (SIR) and Simple Payback Period.
- **Data:** Estimated savings from reduced energy use and maintenance costs, over specified periods, will be compared to the total cost of the project.
- **Analytical Methodology:** Savings will be estimated for 10 and 20 years, and then SIR will be calculated.
- **Success Criteria:** Success will be achieved if SIR (10 Years) > 1.0, or SIR (20 years)> 2.0, and Payback <7 years.

3.2.5 SYSTEM RELIABILITY = SYSTEM'S ABILITY TO CONSISTENTLY DELIVER DATA AND MONITOR ENERGY USE

- **Purpose:** System reliability must be monitored to ensure optimization of luminaires and energy use accuracy.
- **Metric:** Success rate of the control system data delivery and metering accuracy.
- **Data:** The system will record unsuccessful data deliveries in the message delivery failure log. Energy use will be recorded in the metering data log.
- **Analytical Methodology:** The success rate will be calculated using the total number of delivery failures and the total number of successful deliveries. Independent energy use measurements compared to the system's reported energy use measurements to quantify the system's metering accuracy.
- **Success Criteria:** Success will be achieved if the data driven system response correctness is 99.9% or greater (which assumes the cellular connection is fully available), and the accuracy of metering functions is at least 95%.

3.2.6 ENHANCED LIGHTING CONDITIONS = INCREASED LIGHTING QUALITY

- **Purpose:** Enhanced lighting conditions must be measured to quantify the change in lighting conditions and ensure user's satisfaction.
- **Metric:** Photographic comparison and surveyed user acceptance.
- **Data:** Ground level and overhead photographs will be taken to give qualitative indication of lighting performance. Feedback from facility personnel (through surveys) will be used to determine overall satisfaction with the lighting performance and control features.
- **Analytical Methodology:** Visual evaluation of pre and post retrofit lighting systems will be used to supplement the quantitative lighting performance data. Facility perceptions of the new systems, in comparison to incumbent systems, will greatly influence broad technology deployment. Stakeholder survey data will be collected and reported in order to fully characterize the performance impacts of the demonstrated technologies, and estimate widespread adoption.
- **Success Criteria:** Success will be achieved by having positive subjective evaluations of increased visual clarity, color perception and lighting uniformity. And user's opinion surveys indicate improved lighting conditions and overall satisfaction.

3.2.7 EASE OF INSTALLATION AND COMMISSIONING = TIME AND TRAINING NEEDED TO SUCCESSFULLY COMPLETE INSTALLATION AND COMMISSIONING

- **Purpose:** Ease of installation and commissioning must be characterized to help quantify the costs associated with technology deployment. In addition, installation and commissioning processes must be understood and successfully applied by installation teams for a technology to be successful.
- **Metric:** Ability of installers to successfully and efficiently install and commission the system.
- **Data:** Feedback from installers on time required to install and commission system.
- **Analytical Methodology:** Survey responses will be collected and documented to assist with technology or process refinements.
- **Success Criteria:** Success will be achieved if installation and commissioning are successfully completed with given standard training.

3.2.8 SATISFACTION WITH OPERATION AND MAINTENANCE = FACILITIES PERSONNEL'S COMFORT USING THE SYSTEM

- **Purpose:** Satisfaction with system operation and required maintenance must be measured to determine any problems with use of the demonstrated system.
- **Metric:** Level of satisfaction of facility personnel with operation, monitoring and maintenance of the systems.
- **Data:** Feedback from base operations personnel on operation and maintenance functionalities.

- **Analytical Methodology:** Survey responses will be collected and documented to understand user satisfaction with the demonstrated technologies.
- **Success Criteria:** Success will be achieved if the systems perform reliably, and management tools improve operations and maintenance.

4 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 SELECTION CRITERIA

For the outdoor lighting technologies being demonstrated, it is desirable to select a site that is representative of majority of the DoD installations in terms of daylight hours (geographical location), usage patterns in terms of volume and type of traffic, security requirements, logistics of operations and command structure. This will ensure that the results obtained can be used to meaningfully estimate the energy and cost savings DoD wide when deployed widely.

Fort Sill is located in Comanche County, Oklahoma with an elevation of 1657 feet and latitude of 34-40’53” N and longitude of 098-31’09” W.

As a typical military installation in terms of outdoor spaces of interest, Fort Sill has available spaces requiring outdoor lighting that can be used for the demonstration. Three commonly encountered areas are main roadways, parking lots and military vehicle maintenance areas. Of these, the military vehicle maintenance areas are unique to many DoD installations and are responsible for a sizable portion of the energy consumption in the outdoor lighting area. Main roadways and parking lots are similar to typical commercial spaces with some unique nuances related to the usage pattern or traffic volume.

The DPW staff as well as the base command is very supportive of this demonstration as it aligns well with their interests in terms of energy savings goals.

4.2 FACILITY/SITE LOCATION AND OPERATIONS

Three outdoor lighting control systems will be demonstrated in three areas at the Fort Sill premises.

4.3 DYNADIMMER DEMONSTRATION SITE

Dynadimmer system is implemented in the Fort Sill Welcome Center Building 4700 parking lot shown in Figure 4 (Welcome Center B4700 parking lot). Retrofit all 20 light poles (36 fixtures total) with LED luminaires fitted with Dynadimmer controls providing light level scheduled control for each luminaire individually.

Figure 4: B4700 Parking Lot – Dynadimmer Demonstration Site

The demonstration site at the Welcome Center is composed of two primary, surface parking lots located on the east and north sides of the building. The largest lot, located on the east side of the building, has two entry points along its north perimeter, which are accessed via Moway Road. The smaller lot, located along the north of the facility, has a third entry point, also off of Moway Road. The lots are connected via a central drive lane. The lots consist of multiple rows of parking, separated by vegetated medians. Medians contain a combination of grass and 15' – 25' trees. The large lot is approximately 450' x 525'. The smaller lot is approximately 175' x 300'. Both lots have asphalt surfaces.

EXISTING LIGHTING SYSTEMS:

Luminaire Type:	Cobra head
Luminaire Quantity:	36
Pole Quantity:	20
Lamp:	400W HPS
Ballast:	Magnetic
Service:	480V, 3-phase

The existing lighting systems, at this demonstration site, consist of 36 pole-mounted, high pressure sodium (HPS) cobra head style luminaires. Luminaires are twin or single mounted, for a total of 20 standard, 24' steel poles. Each luminaire is connected with a 6' upswept arm, for a luminaire-to-finished-grade mounting distance of approximately 30'. Poles are located approximately 24" from parking space curbs, with a 12" set back from median and perimeter sidewalks.

Luminaires are Type IV distribution, with drop acrylic lenses, and utilize 400 W HPS lamps operating on standard magnetic ballasts. Luminaires consume approximately 460 W each. Field measurements have been conducted to verify this approximation. Luminaires are controlled by twist-lock photocells as well as an astronomical time clock located inside the Welcome Center. Luminaires are fed by 208V, 3-phase power.

4.3.1 STARSENSE SYSTEM DEMONSTRATION SITE

Starsense system is implemented on a section of the Sheridan Road covering 38 light poles shown in Figure 5. This system consists of 40 LED luminaires and is 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 during the 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

The streetlight demonstration site runs from the south entry gate north to the intersection of Sheridan Road and Barbour Road. This length of roadway is straight, with one right curve at the north end of the demonstration area. The roadway consists of five lanes, two in each direction, with a median turn lane. Sheridan Road is illuminated from the east side only. Here the existing HPS lamps and fixtures will be replaced with LED luminaires and wireless connected controllers. A segment controller with wireless remote monitoring capability (using commercial

3G) has been housed in one of the light poles to be defined. All work has been performed during periods (days) so that traffic disruption is minimized.

EXISTING LIGHTING SYSTEMS:

Luminaire Type:	Cobra head
Luminaire Quantity:	40
Pole Quantity:	38
Lamp:	250W HPS
Ballast:	Magnetic
Service:	480V

The existing lighting systems, at this demonstration site, consist of single, pole-mounted, high pressure sodium (HPS) cobra head style luminaires. Luminaires are mounted to 35’ galvanized steel poles, spaced 150’ apart. Each luminaire is connected via a 15’ upswept arm, for a luminaire-to-finished-grade mounting distance of approximately 50’. Poles are located approximately 6’ - 8’ from the edge of traffic lanes.

Luminaires are Type III distribution, with drop acrylic lenses, and utilize 250 W HPS lamps operating on standard magnetic ballasts. Luminaires consume approximately 300 W each, respectively. Field measurements have been conducted to verify this approximation. Luminaires are controlled by twist lock photocells. Luminaires are fed by 480V, single-phase power.

4.3.2 LIGHT-ON-DEMAND (LOD) DEMONSTRATION SITE

Light-On-Demand (LOD) system is implemented in a tactical equipment maintenance facility (TEMF) located off of Tower 2 Road adjoining Tank Trail shown in Figure 6. All 21 light poles have been outfitted with LED luminaires and sensors for controlling the light levels based on the occupancy of the area. 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

The primary use of the TEMF location included in this demonstration program is organizational vehicle storage. The facility consists of secure, graveled parking area only. There are two gates that may be used to access the lot, one on the south side of the lot and the other on the west. Lot size is estimated at 300’ x 150’. In this space, the existing light fixtures (HPS) have been replaced by LED light fixtures on the existing poles and control units have been added on each pole along with camera sensors. A central segment controller with wireless communication devices for remote monitoring (3G) and local control has been housed near the existing switch panels outside the fenced area. All necessary changes were performed during periods (days) when the area is not used for vehicle maintenance. This has been worked out with the DPW personnel so that no disruption was necessary for normal base operations.

EXISTING LIGHTING SYSTEMS:	
Luminaire Type:	Shoebox
Luminaire Quantity:	42
Pole Quantity:	21
Lamp:	400W HPS
Ballast:	Magnetic
Service:	240 V, single phase

The existing lighting systems, at this demonstration site, consist of twin head, pole-mounted, high pressure sodium (HPS) shoebox style luminaires. Luminaires are mounted, via a 5 ¾” arm, to 30’ galvanized steel poles, set on 2.5’ concrete bases. Poles are spaced 50’ apart. Luminaire-to-finished-grade mounting distance is approximately 32.5’.

Luminaires type distribution is unknown. Luminaires have flat acrylic lenses, and utilize 400 W HPS lamps operating on standard magnetic ballasts. Luminaires consume approximately 460W each, respectively. Field measurements have been conducted to verify this approximation. Luminaires are controlled by a single remote photocell located at the northwest perimeter of the lot. Luminaires are fed by 240V, single-phase power.

4.3.3 COMMUNICATION REQUIREMENTS FOR THE DEMONSTRATION PROJECT

Two technologies planned to be demonstrated at Fort Sill involve wireless communication. The first technology is Starsense, which is used for roadway lighting management. The other technology is Light-On-Demand (LOD), for TEMF lighting management. The LOD system is based on Starsense with added wireless motion sensor to further save energy. Figure 7 and Figure 8 show the system architectures and communication requirements of Starsense and LOD respectively. For both systems, the on-field wireless communication between outdoor lighting controllers/sensors and the segment controller (i.e., gateway) is based on FCC certified RF chipset compliant with IEEE 802.15.4 standard. The FCC approved 915 MHz ISM band has been used for many outdoor commercial applications. Reliable transport protocols and self-healing mesh routing algorithms have been implemented to address potential issues encountered in the demonstration areas.

Table 4 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 IT infrastructure. Specifics of the communication requirements, shown in Table 4 have been provided to the DPW Energy Manager (Christopher Brown) as well as the Netcom and NEC (Joseph E. Pearson, Chief Information Assurance Division) departments. As far as the demonstration project was concerned we were told by Mr. Brown to carry out the demonstration as planned since RF usage was confined to FCC certified bands only and there was no risk of an interference with the military band. Further to this Dr. Galvin had also sent a note to Mr. Brown and others referred to by Mr. Brown explaining the purpose of the ESTCP program.

Table 4: Communication Requirements and Security Measures

<table>
<tr><th colspan="2">Technology description</th><th>Starsense</th><th>LOD</th></tr>
<tr><td colspan="2">System Architecture</td><td>Figure 7</td><td>Figure 8</td></tr>
<tr><td colspan="2">Use of DoD communication infrastructure</td><td>NO</td><td>NO</td></tr>
<tr><td rowspan="8">On-field communication:
Wireless between lighting controllers, wireless sensors, and segment controller</td><td>Connectivity</td><td>RF mesh</td><td>RF mesh</td></tr>
<tr><td>Standard</td><td>802.15.4</td><td>802.15.4</td></tr>
<tr><td>Chipset</td><td>Atmel, FCC certified</td><td>Atmel, FCC certified</td></tr>
<tr><td>Operating frequency</td><td>ISM 915MHz</td><td>ISM 915MHz</td></tr>
<tr><td>Channel spacing</td><td>2MHz</td><td>2MHz</td></tr>
<tr><td>6dB bandwidth</td><td>730kHz</td><td>730kHz</td></tr>
<tr><td>Transmitted power</td><td>10mW</td><td>10mW</td></tr>
<tr><td>Security</td><td>AES 128</td><td>AES 128</td></tr>
<tr><td rowspan="2">Backend communication:
from segment controller to server / management station</td><td>Connectivity</td><td>Cellular + Internet
Isolated from DoD facility IT infrastructure</td><td>Cellular + Internet
Isolated from DoD facility IT infrastructure</td></tr>
<tr><td>Security</td><td>VPN</td><td>VPN</td></tr>
<tr><td>Server – client communication
for web based remote management</td><td>Connectivity</td><td>Cellular + Internet</td><td>Cellular + Internet</td></tr>
</table>

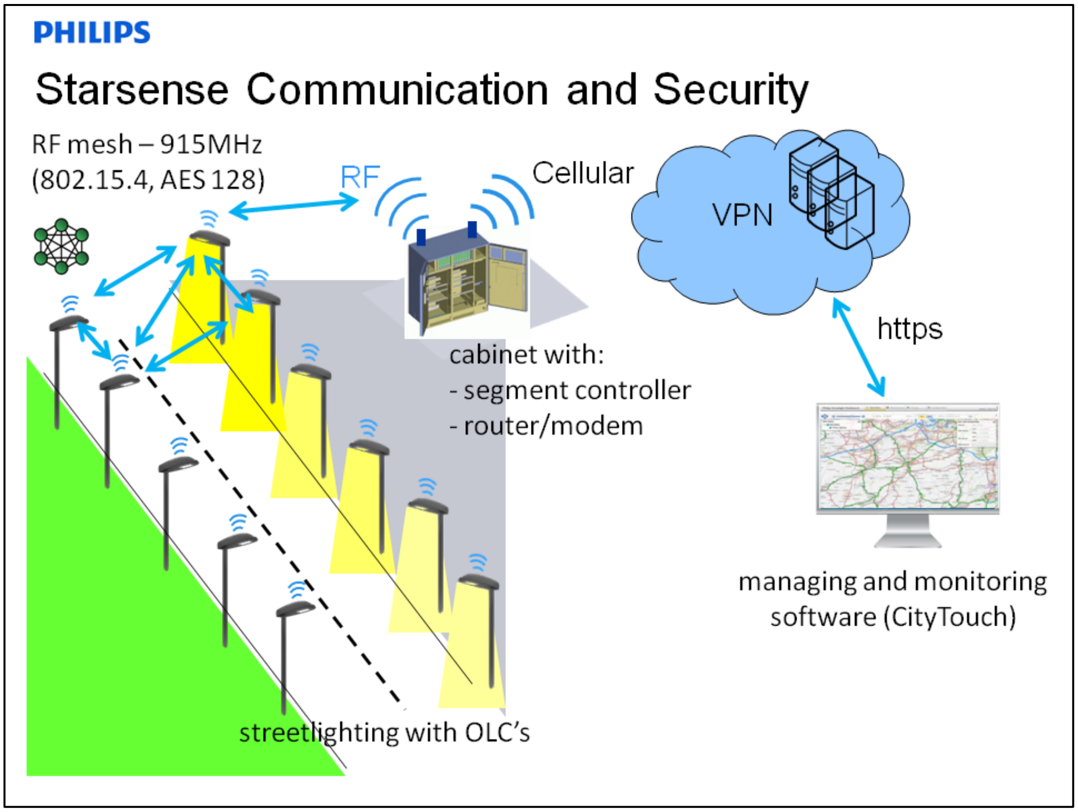


Figure 7: Communication Requirements for Starsense

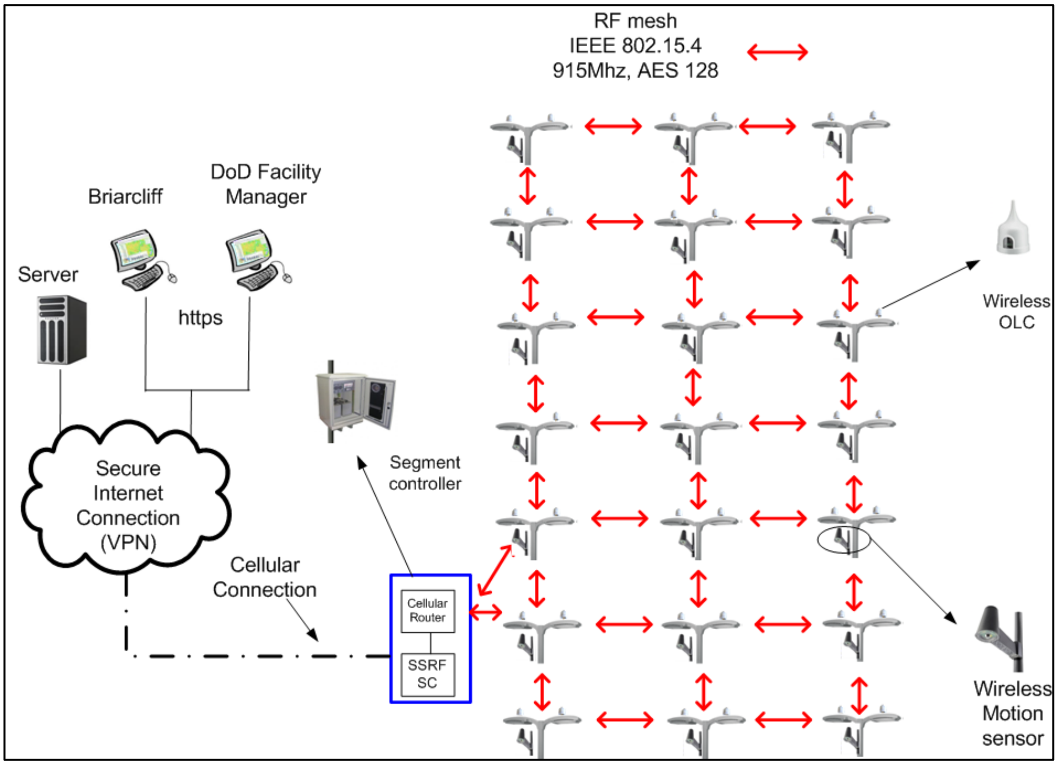


Figure 8: Communication Requirements for Light-On-Demand (LOD)

4.4 SITE-RELATED PERMITS AND REGULATIONS

To validate the required lighting design regulations the following information would be required. This information is needed to calculate the light levels to insure conformance to industry standards. The key contact at Fort Sill is Christopher Brown, DPW Energy Manager. Mr. Brown has coordinated with appropriate engineering staff at Fort Sill to get permits as required. Initial discussions indicated that as long as the designs are in conformance with IES recommendations, it would suffice. These were subsequently confirmed once the detailed designs were reviewed with DPW staff including Mr. Brown.

1. Roadway width, number of lanes
2. Mounting height of the existing luminaires above the roadway
3. Luminaire arm length
4. Setback or position of the pole foundation relative to the edge of the roadway
5. AutoCAD drawing of Sheridan Road if available
6. Illuminating Engineering Society (IES), Recommended Practice Number 8, RP8, required light levels
    a. Roadway classification
        i. Major, Collector or Local
    b. Pedestrian Conflict classification
        i. High, Medium or Low
    c. In lieu of this information if a specific illuminance foot-candle requirement or luminance levels are known, this could be provided as well.

5 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 replacement of the incumbent HPS based luminaires with energy-efficient LED based lighting sources.

5.1.1 HIGH-LEVEL OVERVIEW OF THE TEST DESIGN

The following aspects are considered in the test design:

1. We assessed the performance of the incumbent HPS lighting technology,
2. We installed new LED lights and associated controls,
3. We assessed the performance of the new LED lighting technology,
4. Finally, we analyzed the results to determine if the three systems met the Performance Objectives (i.e. Section 6 of this report).

5.1.2 PERFORMANCE OBJECTIVES OF LIGHTING TECHNOLOGY ASSESSED

We assessed the lighting technology performance in three areas, each with one or more associated performance objectives:

1. Electrical performance
    a. Annual Energy Use Intensity per year
2. Optical performance
    a. Illuminance: minimum maintained average, and max-to-average ratio
    b. Correlated Color Temperature (CCT)
    c. Lighting Conditions
3. User interaction
    a. Satisfaction
    b. System reliability
    c. Maintenance implications
    d. Cost effectiveness
    e. Ease of installation and commissioning

To assess the performance of a lighting technology is to assess the electrical performance characteristics, the optical performance characteristics, and the user preference of the lighting system.

5.1.3 METHODOLOGY TO ACCESS THE ELECTRICAL PERFORMANCE OF A LIGHTING TECHNOLOGY

We characterized the electrical performance of the lighting technologies with by the Annual Energy Use Intensity (EUI, expressed in watt-hours per year per luminaire, or kWh/yr/lum). Whether measured, calculated, or a combination, the EUI is derived from the luminaire power (expressed in watts, W) and the annual hours of use (HOU).

5.1.4 METHODOLOGY TO ACCESS THE OPTICAL PERFORMANCE FOR A LIGHTIG TECHNOLOGY

We characterized the optical performance of the lighting technologies by the illuminance, the correlated color temperature (CCT), and the lighting conditions.

Illuminance is expressed in terms of the minimum maintained average illuminance and the average-minimum uniformity ratio. These metrics are used by the Illuminating Engineering Society (IES) to provide recommendations for different space types or applications. Both of these metrics require taking a grid of measurements in order to capture the distribution of light.

The CCT was evaluated based on laboratory data commissioned by the product manufacturer.

The lighting conditions were assessed by site inspection, feedback from user surveys, and before and after photos.

5.1.5 DATA SOURCES USED IN THE ASSESSMENT

The sources of data from the lighting technology demonstration were as follows:

1. **Energy:** watt-hour transducers collected the combined (all luminaires) energy use of each of the three demonstration sites. The data consists of energy per time unit, recorded in 5-min intervals over a one-year period. The equipment consisted of current transformers, Veris E50B2 watt-hour transducers, and Onset-Hobo U30 data loggers.
2. **Illuminance:** a grid of in-situ field illuminance measurements were taken at each of the demonstration sites. A grid was laid out at each location, and measurements recorded by hand with Konica Minolta T-10A light meters. One grid was recorded for each location under pre-retrofit conditions. Because the post-retrofit systems are capable of dimming, multiple grids at different dim levels were recorded for the post-retrofit technology. The illuminance data was used to assess the “lighting performance” performance objective.
3. **User surveys:** three surveys were developed for general, maintenance or security audiences, and distributed by the Fort Sill liaison. Respondents completed separate questionnaires for each demonstration site. We received 24 responses from 8 respondents

consisting of maintenance or security personnel on base. No responses were received from the general public.

5.2 BASELINE CHARACTERIZATION

The baseline used in this project is related to energy use and illuminance.

5.2.1 ENERGY BASELINE

We characterized the electrical performance of the lighting technologies with the Annual Energy Use Intensity (EUI, measured in watt-hours per year per luminaire or kWh/yr/lum). The energy use baseline was the baseline-EUI. EUI is derived from the luminaire power (expressed in watts, W) and the annual hours of use (HOU).

EUI (kWh/yr/lum) = Luminaire Power (kW/lum) × HOU (hr/yr) (eq. 1)

The baseline EUI was calculated for each site, and the results are shown in Table 5. 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 5: 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

The following sections provide more details regarding the luminaire power and hours of use that were used to calculate these baseline values.

Luminaire Power: The same incumbent luminaire type was used at both the B4700 Welcome Center and at the TEMF demonstration sites: a 400 W nominal high pressure sodium (HPS) luminaire. This nominal wattage does not include a ballast factor, which will increase the actual luminaire power beyond the nominal power. A 400 W nominal HPS luminaire with standard ballast will draw approximately 460 watts. One time current measurements were taken at the TEMF to verify the luminaire power. The measurements were taken at on two poles selected at random. Each pole was twin-mounted with two fixtures per pole, so a total of four luminaires were measured. The luminaire power was calculated using the nominal voltage, 240 Vac. The final baseline luminaire power for both B4700 and the TEMF was 453.6 watts per luminaire.

Table 6: Baseline One-Time Measurements Recorded at TEMF

Location	Nominal Voltage (RMS volts)	Current (amps)	Power (watts)	Watts/Fixture
Pole #1	240	3.77	904.80	452.40
Pole #2	240	3.79	909.60	454.80
Average			907.20	453.60

The Sheridan Road demonstration site was initially slated for a section of Sheridan Road with the same type of luminaires as the B4700 and TEMF demonstration sites. The Sheridan Road test location was changed during the installation phase. The final Sheridan Road test location utilized a 250 W HPS luminaire instead of the 400 W. The Sheridan Road luminaire power was calculated assuming a ballast factor of 0.83, resulting in the luminaire power of 295 W per luminaire.

Hours of Use: At B4700 we installed energy logging equipment and recorded current (amps) for 15 days to establish the baseline hours of operation at B4700. This data confirmed that the outdoor luminaires operated on a dawn-to-dusk schedule: the luminaires came on at dusk and turned off at daybreak without any dimming. The exact time that luminaires turned on or off was controlled by photocell. The luminaires were typically on past sunrise-sunset about two hours per day. The luminaires would turn on about one hour before sunset and turn off about one hour after sunrise. Based on these observations, we defined the annual Hours of Use (HOU) as being equal to the annual hours of darkness for the geographic region (i.e. Fort Sill, OK). We determined the annual hours of darkness from National Oceanic and Atmospheric Administration (NOAA) astronomical sunrise/sunset times. The sunrise/sunset times for 2014 in Fort Sill, OK are shown in Figure 9. The resulting annual hours of darkness were 4313.39 hr/yr. This approach can be used to calculate the baseline HOU for any date range.

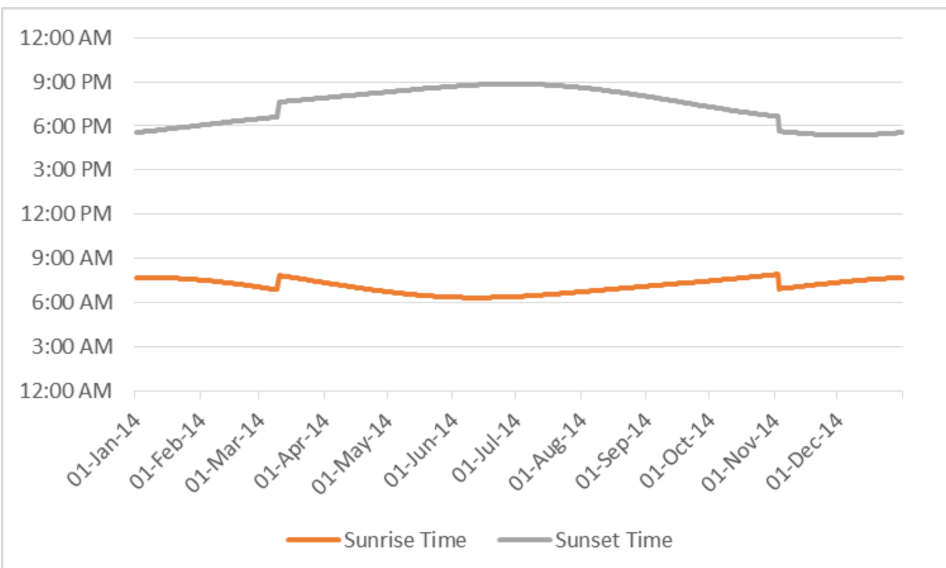


Figure 9: Sunrise/Sunset Times for 2014 in Fort Sill, OK

5.2.2 ILLUMINANCE BASELINE

A grid of illuminance measurements was recorded for each demonstration site to establish the illuminance baseline. For analysis purposes, the baseline consists of the metrics: average illuminance and average-to-minimum uniformity ratio. Contour plots of the illuminance distribution are not used for analysis, but are presented in this report for reference. The following sections provide the baseline illuminance metrics, contour plots, and discussion for each of the three demonstration sites.

5.2.2.1 B4700

CLTC completed photometric measurements of the east lot at B4700. Existing luminaires provided an average of 1.88 fc at grade. The existing lighting was found to have overall poor uniformity, as much of the light was focused in small areas beneath each luminaire. Lamps were not new, and measurements represent the pre-retrofit conditions. The existing lighting conditions were below Illuminating Engineering Society of North America (IESNA) recommended values.

Illuminance:

Average	1.88 fc
Minimum	0.20 fc
Maximum	8.40 fc
Uniformity	42 to 1

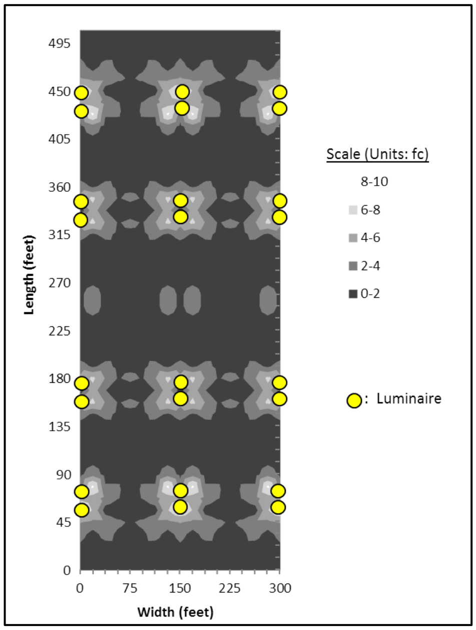


Figure 10: Baseline Illuminance for B4700 (Dynadimmer Demonstration Site)

The baseline illuminance measurements were recorded so as to be representative of the site. The contour plot visualization (Figure 10) was generated by plotting these illuminance measurements, and then replicating the plot symmetrically for the area of the parking lot.

The approximate luminaire locations are shown in Figure 11.

Figure 11: Baseline Illuminance for B4700 (Dynadimmer Demonstration Site) with Measurement Locations Shown

5.2.2.2 SHERIDAN ROAD

CLTC conducted photometric measurements of the existing 400 W HPS streetlights located along Sheridan Road. Existing luminaires deliver an average of 0.45 fc at grade. Areas between luminaires were found to receive no detectable light. Figure 12 shows the existing photometric conditions along Sheridan road. Lamps were not new, and measurements represent pre-retrofit conditions. Pre-retrofit lighting conditions were below IESNA recommended values. Values for existing average illuminance and maximum illuminance are provided below. The uniformity ratio could not be calculated because areas of Sheridan Road receive no measurable light from the existing lighting systems.

Illuminance:

Average 0.45 fc

Minimum 0.0 fc

Maximum 2.1 fc

Uniformity N/A

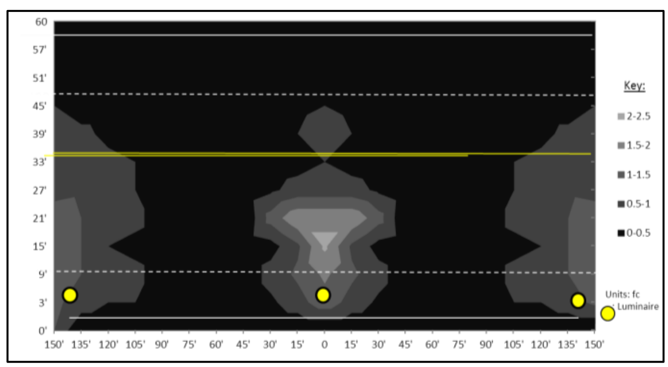


Figure 12: Baseline Illuminance for Sheridan Road (Starsense Demonstration Site)

5.2.2.3 TEMF

CLTC conducted photometric measurements of the existing 400 W HPS shoebox-style luminaires located at the TEMF. Existing luminaires deliver an average of 4.19 fc at grade. Figure 13 shows the existing photometric conditions at the TEMF. Lamps were not new, and measurements represent current conditions. Current lighting uniformity is slightly below IESNA recommended levels; however, the site lighting does meet minimum recommended lighting levels. Values for existing average illuminance and maximum illuminance are provided below. The max-to-minimum uniformity ratio was 10.55.

Illuminance:

Average	4.19 fc
Minimum	0.9 fc
Maximum	9.5 fc
Uniformity	10.55

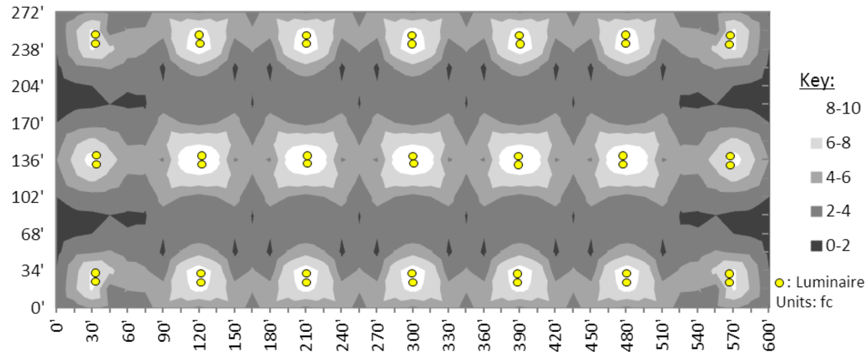


Figure 13: Baseline Illuminance for TEMF (LOD Demonstration Site)

5.3 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

5.3.1 DYNADIMMER SYSTEM

5.3.1.1 SYSTEM DESIGN

A total of 36 fixtures were replaced with 215 W 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 14. Note that the parking lot is divided into two separate zones.

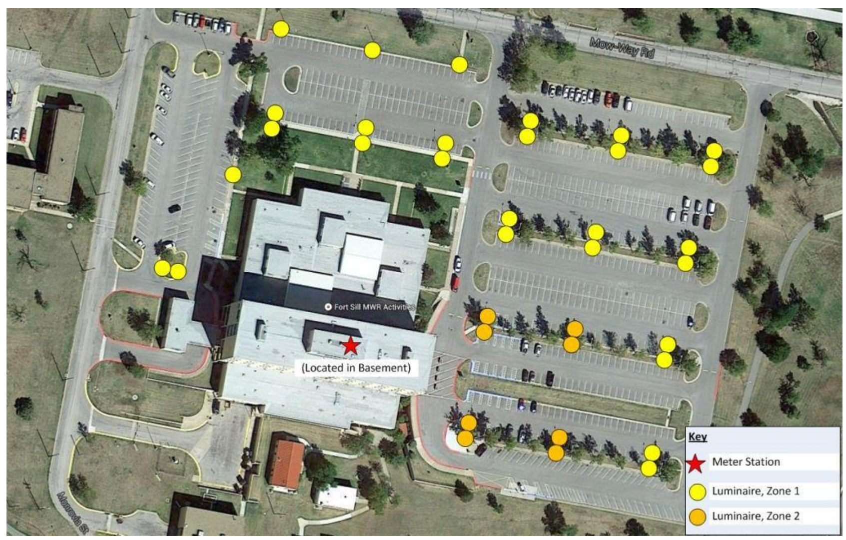


Figure 14: Dynadimmer System at B4700 Where the Performance of All Luminaires is Measured from the Electrical Panel Located in the Basement of the Welcome Center Facility

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 15 the dimming schedule is flexible up to five dimming levels and five time periods.

The dimming schedule can be programmed into each individual Dynadimmer with a DALI interface unit and connected via a USB to a laptop. Initial programming is completed at the factory. The initial schedule is derived from the collaboration between DPW and the lighting designer.

Dynadimmer has no internal clock. It uses a midnight point calculation to determine the absolute time. The midnight point is calculated as the middle point between switch on and switch off and moves as the days get longer and shorter due to the season.

Dynadimmer functionality needs three nights to check the consistency of the duration of the current night schedule and length. In the case of Fort Sill Welcome Center Building 4700 parking lot, occupancy statistics collected prior to the deployment for Zone 1 and 2, was used to set an appropriate dimming schedule to ensure illumination levels correspond to the occupancy and activity level within the parking lot. Different dimming schedules were used for both Zone 1 and 2.

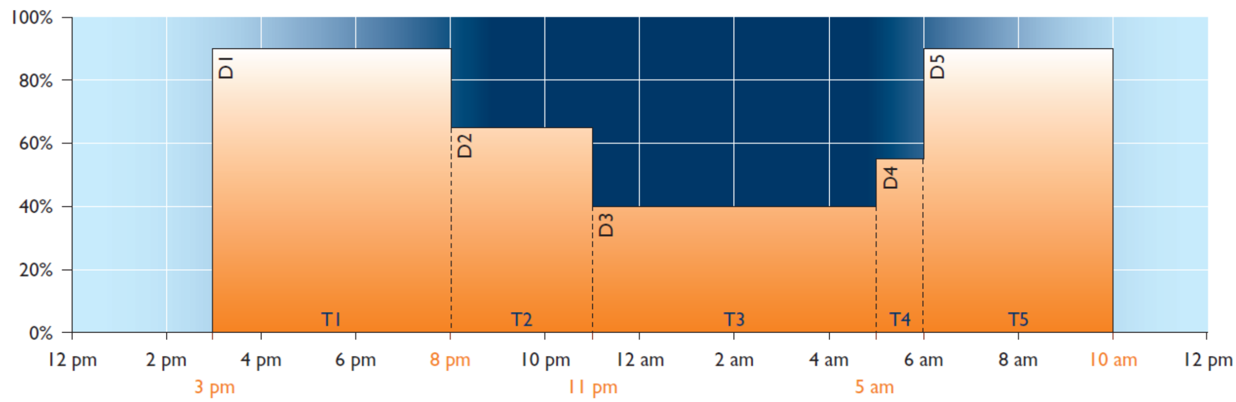


Figure 15: Illustration of Dynadimmer Dimming Profile

5.3.1.2 SYSTEM DEPICTION

The Xitanium driver with Dynadimmer functionality has been built into each 215 W luminaire. The wiring diagram is shown in Figure 16. Current traditional light sources (HPS, QMH and CMH) depreciate in light output during the life of the product.

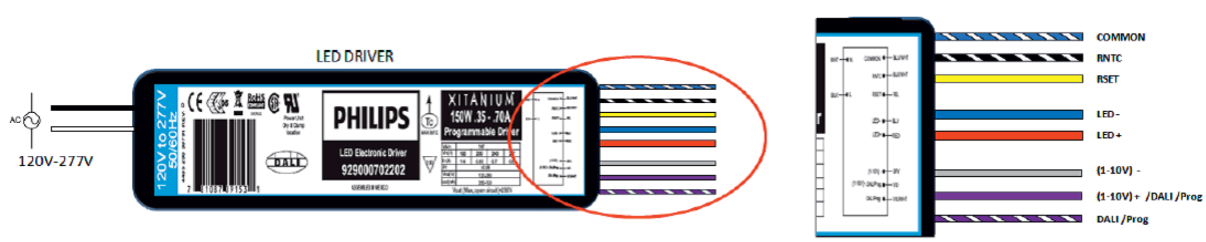


Figure 16: Xitanium Driver Wiring Diagram

The CLO feature of the driver enables OEMs to create solutions with LEDs that deliver constant lumens through the life of the product. Based on the type of LEDs used, heat sinking and driver current, OEMs can estimate the depreciation of light output for specific LEDs and this information can be entered into the driver using the 16 point CLO interface. The driver counts the number of "LED module working hours."

As shown in Figure 17 at the left, each data point represents the LED module working hours threshold and the corresponding driver CLO percentage. The driver will increase current based on this input to enable CLO. When the CLO feature is enabled, the driver nominal output current will be limited by the CLO percentage as shown by the relation below: Driver target nominal output current = CLO percentage X Adjustable Output Current (AOC).

Dynadimmer software (shown in Figure 17): This allows configuration of the dimming schedules and also provides an estimated forecast of energy savings based on the parameters set by the user.

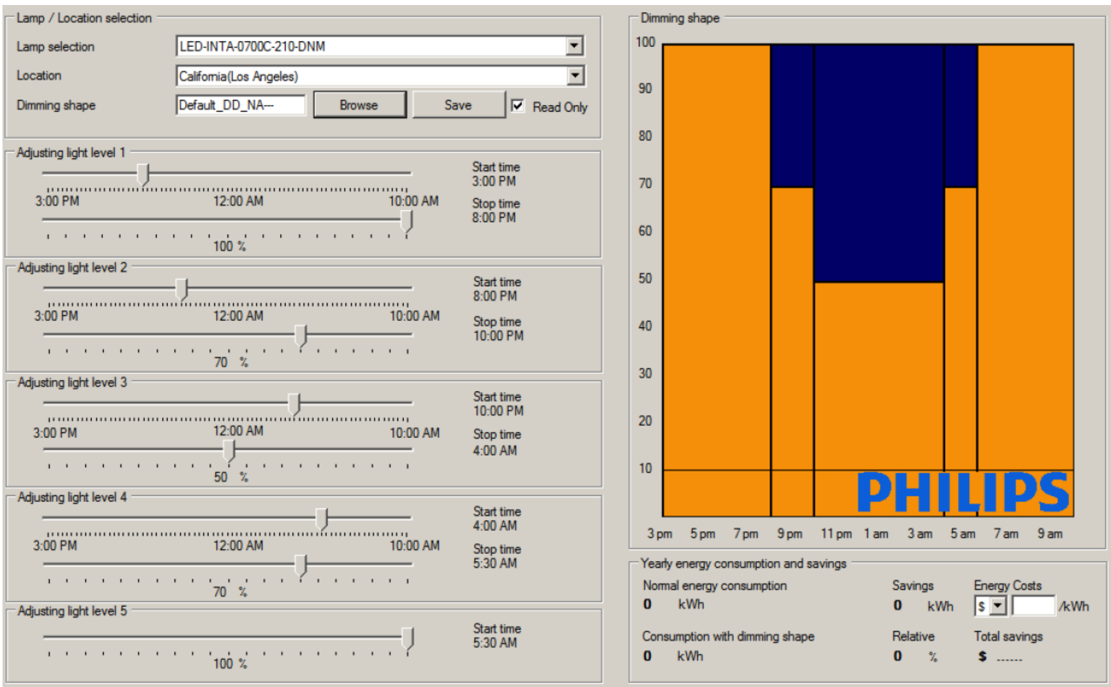


Figure 17: Dynadimmer Programming Software

5.3.1.3 COMPONENTS OF THE SYSTEM

The system deployed at the Fort Sill Welcome Center building 4700 parking lot include 215W LED luminaires which are controlled using the Dynadimmer enable function in the driver. The components and are listed as follows:

The Lumec RoadView Luminaire illustrated in Figure 18 has been used for the project. It maximizes energy savings and provides uniform and comfortable white light. The low copper, die cast aluminum housing has a traditional cobra-head style and low profile. The long lasting design is a complete Philips solution and is environmentally sustainable. Fixtures for Fort Sill include

LED luminaire

Figure 18: Lumec RoadView Luminaire Model with Xitanium Driver System

a pipe adapter option that slip fit onto the existing pole tennon arm.

5.3.1.4 SYSTEM INTEGRATION

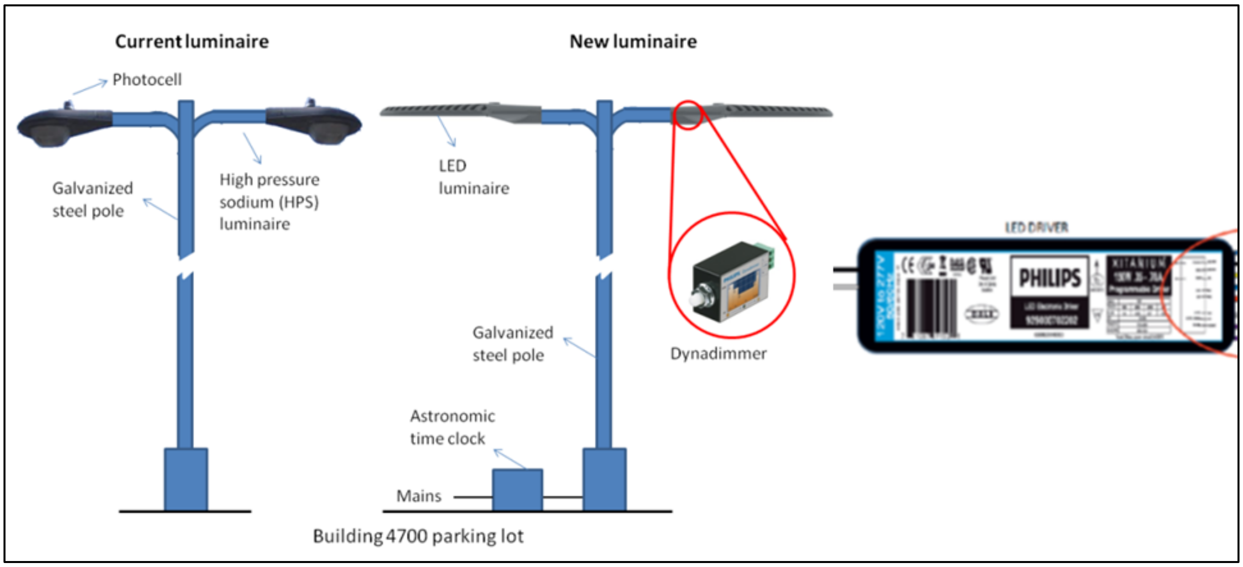


Figure 19: System Integration for Dynadimmer System Deployment

Figure 19 shows the Dynadimmer system integration for deployment. The HPS luminaires are replaced by LED luminaires equipped with the Xitanium intelligent driver system. The poles will not be replaced. A total failure of the internal Dynadimmer functionality will not render the fixture nonoperational. It will only cause the luminaire to lose its dimming capability. The luminaire will then be controlled directly by whichever external controller is present, e.g. a timer, photocell or occupancy sensor. Thus illumination capability will not be compromised. In addition, the failure of the Dynadimmer unit in a particular luminaire, the effect is localized, i.e. other sections of the LED plate (other ½) in the luminaires are not affected by the failed single driver.

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 20.

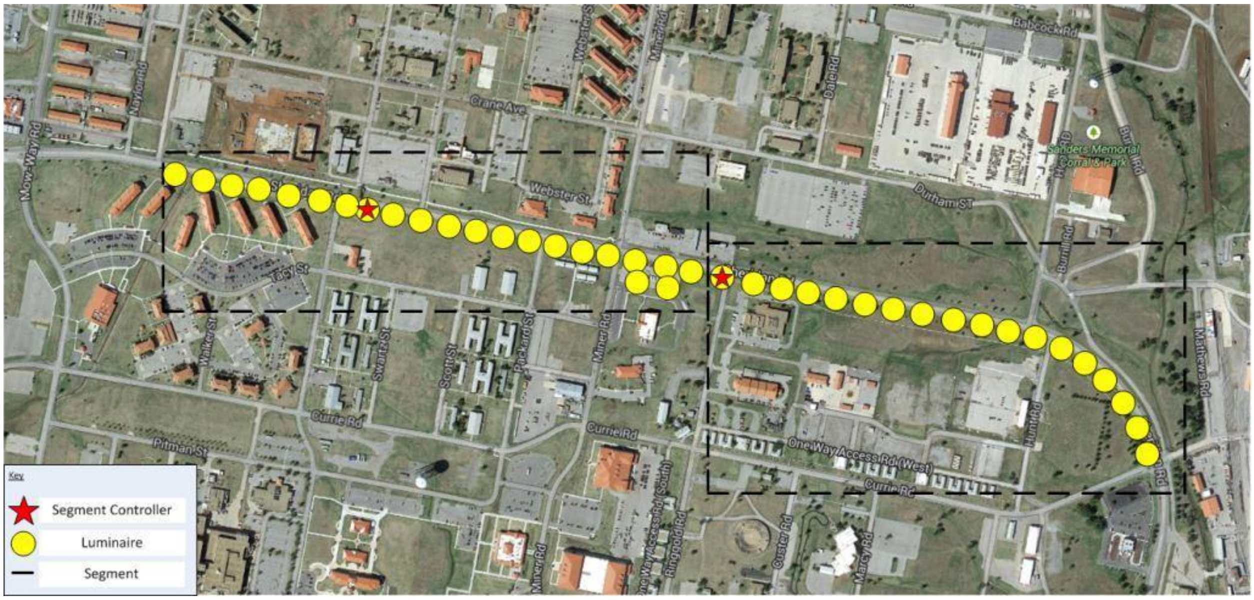


Figure 20: Starsense System Installed on Sheridan Road Includes Two Segment Controllers, Which Control the North (Right Dashed-Box) and South (Left Dashed-Box) Halves of the Demonstration Luminaires

5.3.2.1 SYSTEM DESIGN

Starsense has a scalable architecture (see Figure 21) in which each luminaire, equipped with an RF Outdoor Lighting Controller (OLC) is associated with a segment controller (SC). The SC is also equipped with a similar RF module, but provides an additional interface to connect to the remote management station through a cellular interface. The RF modules are compliant with the IEEE 802.15.4 standard [4] and transmit in the 915 MHz band approved for unlicensed operation (according to FCC 47 CFR Section 15.247). They form a self-healing wireless mesh network that provides reliable connectivity to and from the SC, and back-end management station including a database.

5.3.2.2 SYSTEM DEPICTION

Figure 21 illustrates a system overview of the Starsense system.

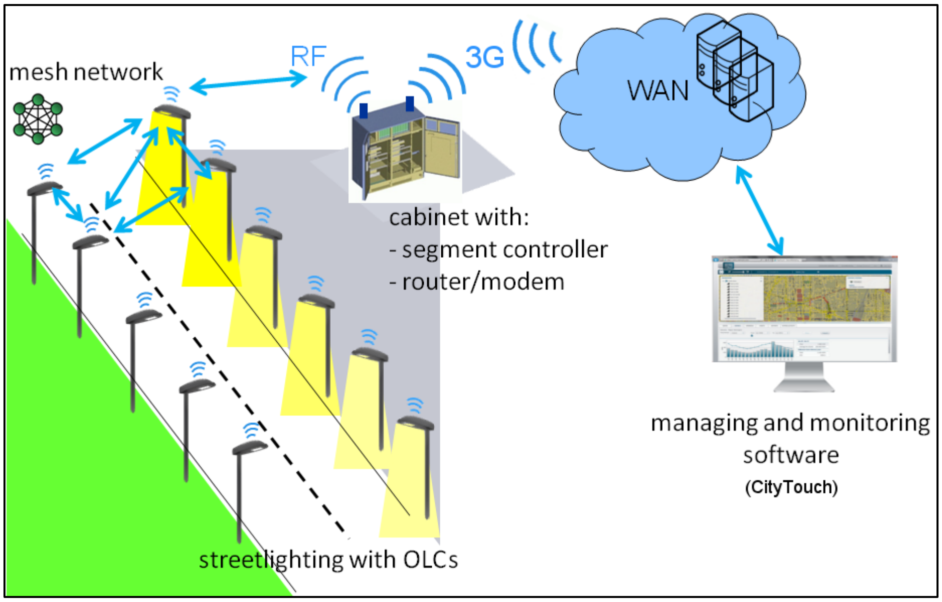


Figure 21: System Depiction of Starsense

5.3.2.3 COMPONENTS OF THE SYSTEM

Figure 22 describes the components of the Starsense system.

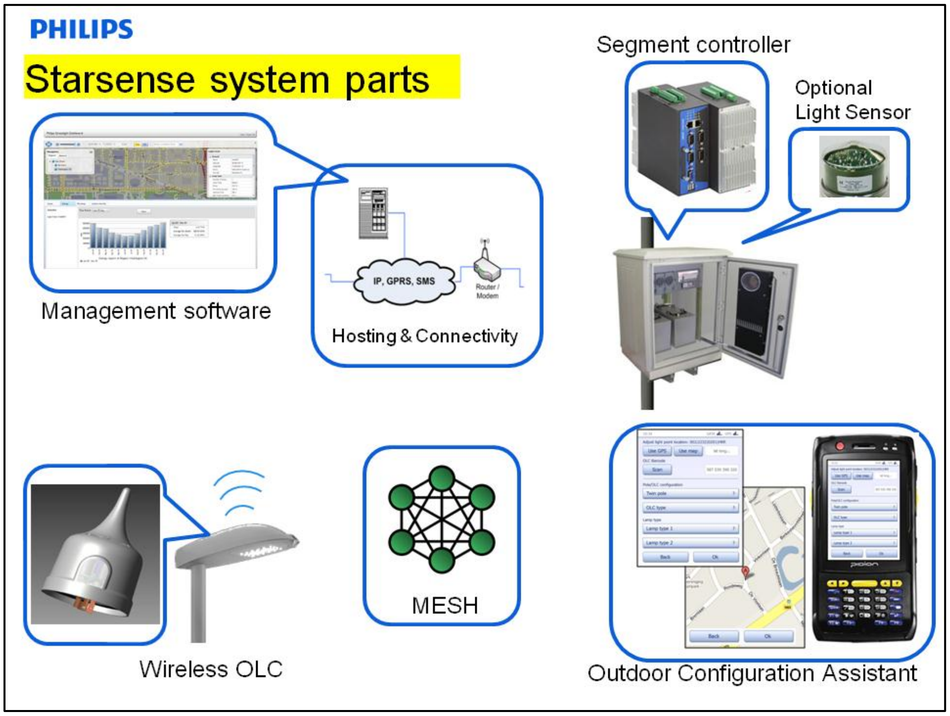


Figure 22: Components of Starsense System

1) LED Luminaire (Figure 23)

The RoadView was created to help those responsible for lighting our streets and highways succeed in their lighting design goals. Powered by the Philips LEDGINE LED platform, and featuring innovative thermal management design, the RoadView offers exceptional performance and value. This versatile luminaire can be tailored to the unique specifications of each project by offering multiple LED boards and wattage options. Utilizing Philips Xitanium LED drivers, and Philips Luxeon LEDs, the RoadView provides exceptional energy efficiency. This luminaire is manufactured with fully recyclable aluminum castings and extrusions that help to protect our environment for years to come. Energy efficiency is enhanced with optional dimming, programmable drivers, and outdoor control systems.

Figure 23: Philips Lumec RoadView Luminaire

2) OLC (Outdoor Lighting Controller, shown in Figure 24)

The OLC is fixed on the top of a LED luminaire. It switches the lamp, adjusts the lighting level and detects lamp and system failures. The OLC communicates to the Segment Controller wirelessly and securely, by RF signals, over a distance of up to 300 meters. It uses a 1-10 V or DALI dimming signal to interface with the electronic ballast and a relay to switch it on and off. It also registers burning hours and offers accurate metering of real energy consumption. Its on-board software can be upgraded over the air.

Figure 24: Starsense Outdoor Lighting Controller (OLC)

3) SC (Segment Controller, shown in Figure 25)

The Segment Controller (SC) controls a number of OLCs and gathers data from them. This information is then sent securely, when required, to the remote backend server over a 3G cellular connection. Mounted on a DIN rail in a cabinet attached to the light pole or on the ground, the SC can be used to interface with other devices in the cabinet, such as traffic counters or weather sensors. The Starsense wireless network is scalable: each Segment Controller can control up to 1,500 light points. Here too, the on-board software can be upgraded remotely.

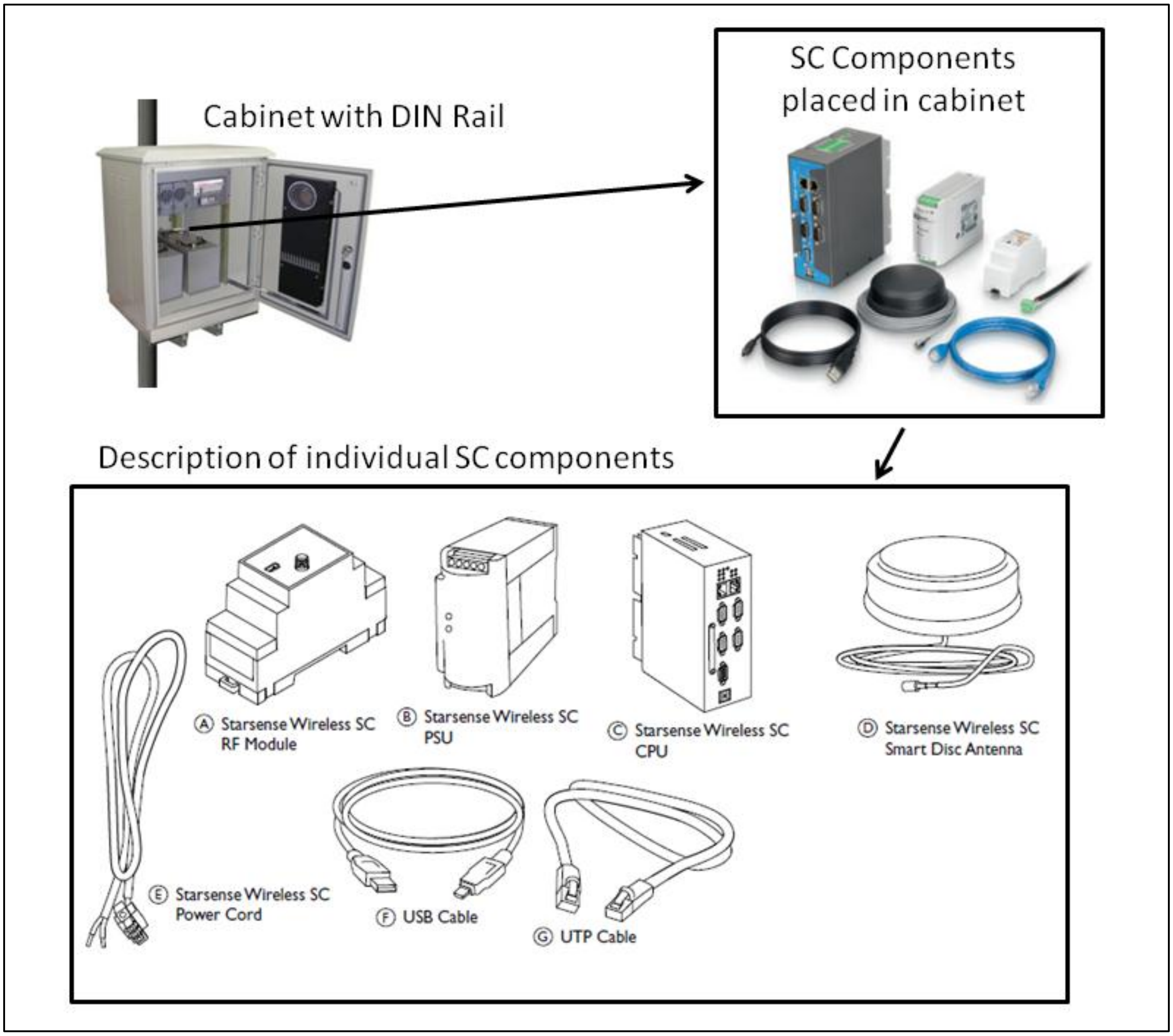


Figure 25: Starsense Segment Controller (SC)

The SC Kit consists of the following key components:

- RF Module
- Power Supply Unit (PSU)
- Central Processing Unit (CPU)
- Smart Disc Antenna
- Cables : USB, UTP, Power cord

4) CityTouch backend management software (shown in Figure 26)

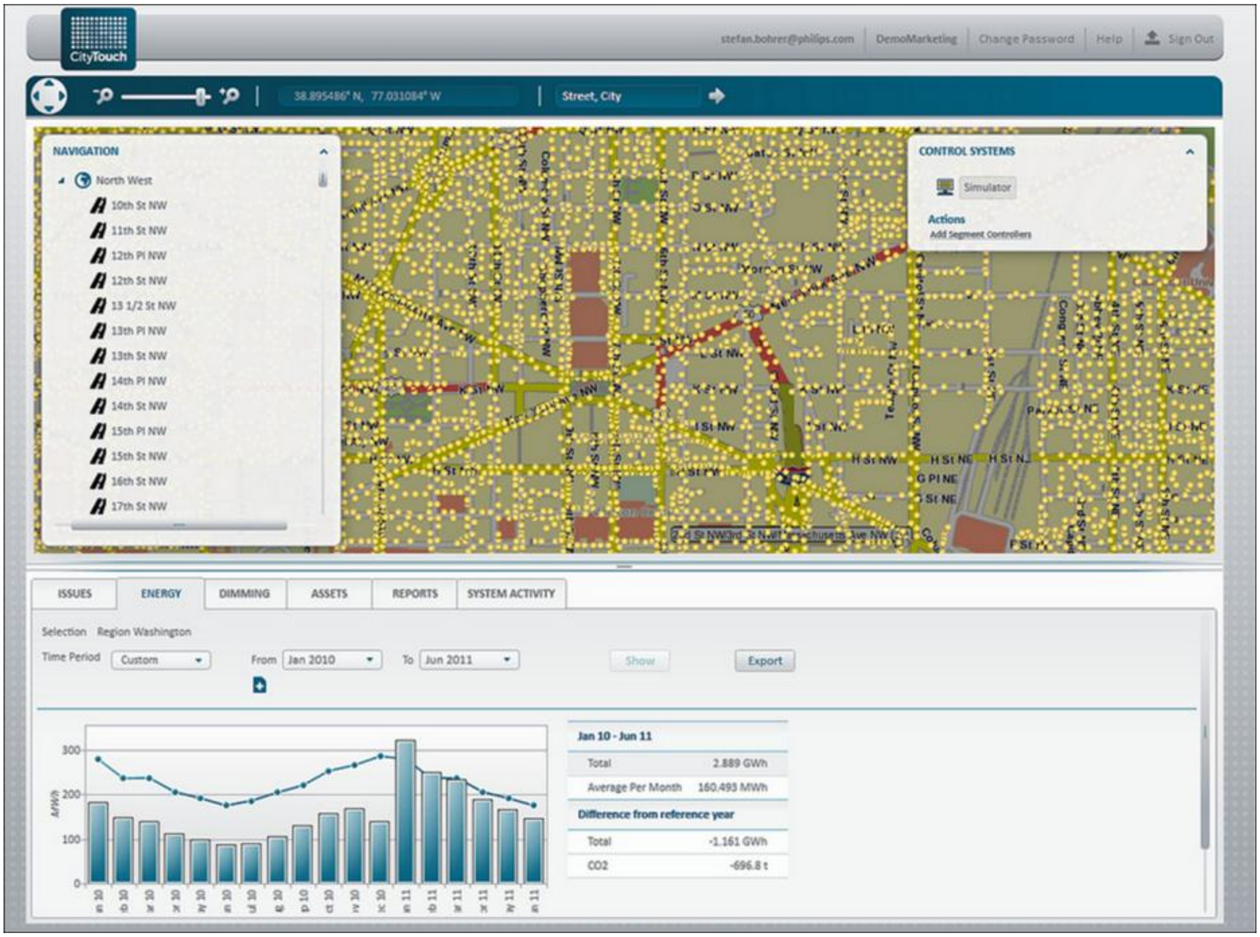


Figure 26: CityTouch Backend Management Software

CityTouch enables its users to manage all the lighting systems for an entire city from a single, intuitive online interface. It provides easy, streamlined maintenance and oversight with real-time status reports for every individual light point. That way, lighting operators can track the consumption and output of every part of their system and can fine-tune lighting levels to meet local needs. Furthermore, CityTouch helps cities face the double challenge of cutting costs and preserving the environment. By making it possible to dim light points throughout the city outside of peak hours, to detect failures and to provide smart lighting workflow support, the system significantly reduces operating costs and energy usage – leading to lower energy bills, lower carbon emissions and less light pollution.

5.3.2.4 SYSTEM INTEGRATION

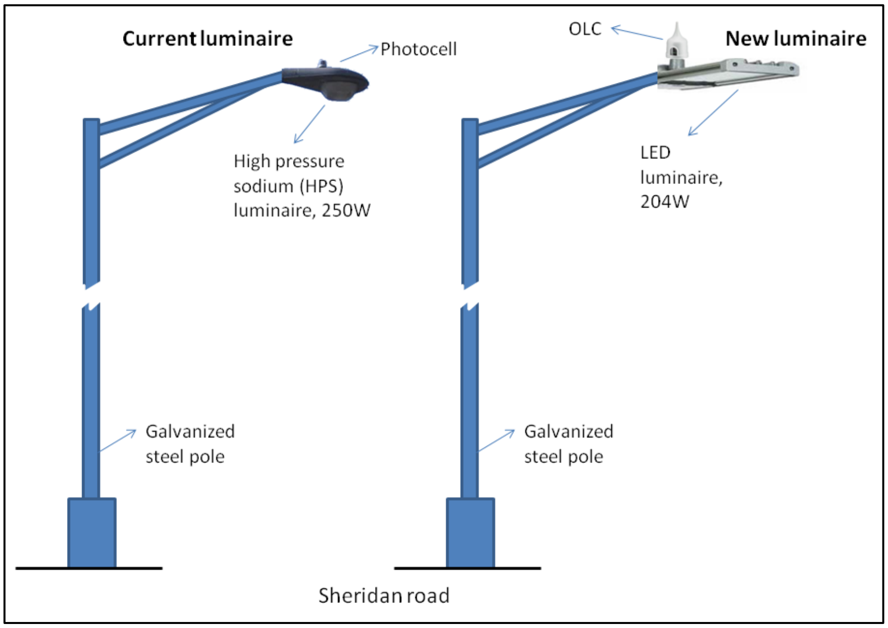


Figure 27: Installation of Luminaire and OLC for Starsense System

The system is integrated as shown in Figure 21. The installation of luminaire and OLC is illustrated in Figure 27.

5.3.2.5 SYSTEM CONTROLS

Figure 28 shows the system control of Starsense. Using CityTouch, it is possible to define and upload dimming schedules for individual or groups of luminaires. The schedules can be defined for different periods within a single day and also over different days within a month. In addition, the system can be placed in override mode to disable the schedules in case of any unexpected events.

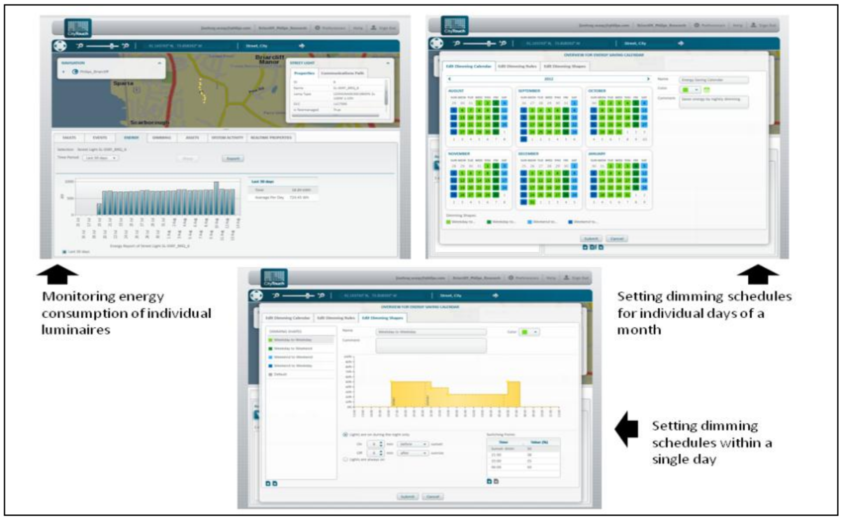


Figure 28: System Control of Starsense

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 29.

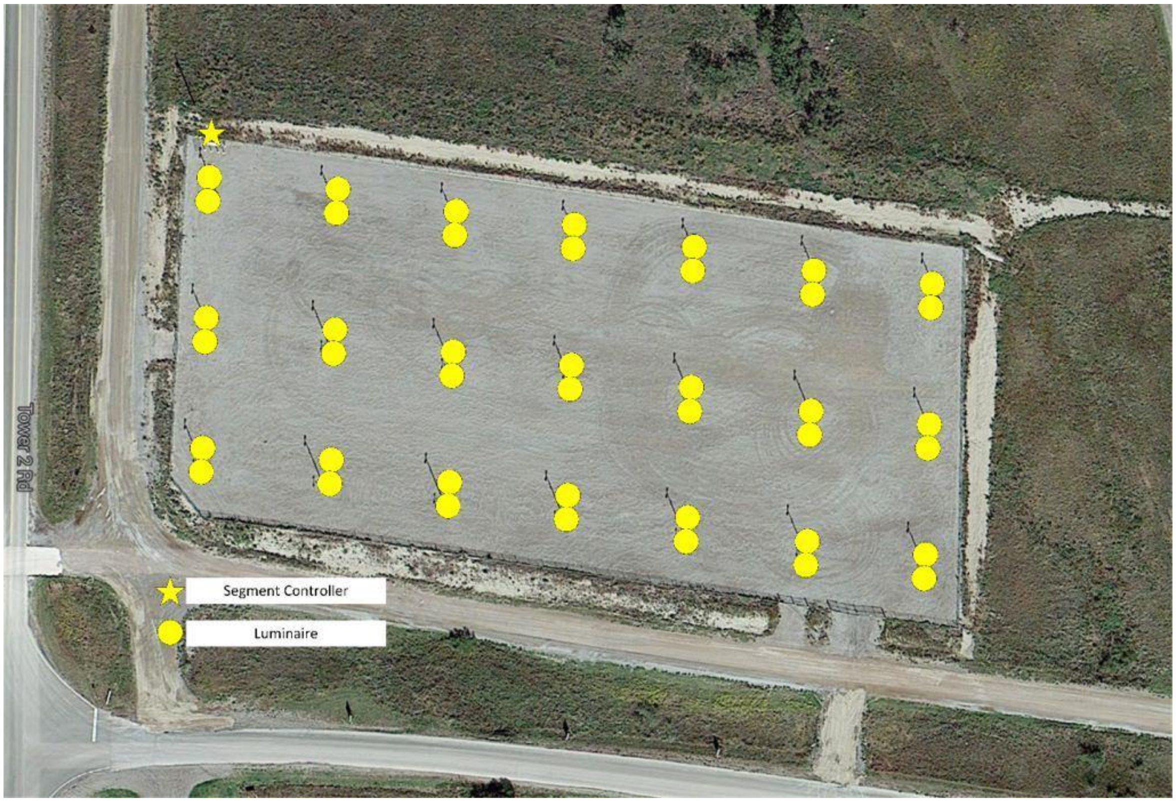


Figure 29: The LOD System Installed at the TEMF Includes a Single Segment Controller Which Communicates Wirelessly with 42 LED Luminaires and 42 Camera Sensors

5.3.3.1 SYSTEM DESIGN

Figure 30 shows the system architecture with intelligent sensors that can detect pedestrians, vehicles and other moving objects, and provide event detection information to neighboring luminaires via RF communication through outdoor lighting controllers (OLC). The RF modules operate in the 915 MHz band approved for unlicensed operation (according to FCC 47 CFR Section 15.247) and implement the IEEE 802.15.4 standard. LOD is a scalable system with flexible placement of sensors and flexible association of sensors with luminaires to form lighting control zone based on presence as well as schedule. For experimental purpose this demonstration project implementation has sensors for each luminaire. In actual deployments there will be fewer sensors to control the entire area. Based on the actual results and the use pattern we found that two sensors are sufficient for this implementation.

5.3.3.2 SYSTEM DEPICTION

Figure 30 illustrates a system overview of the LOD system.

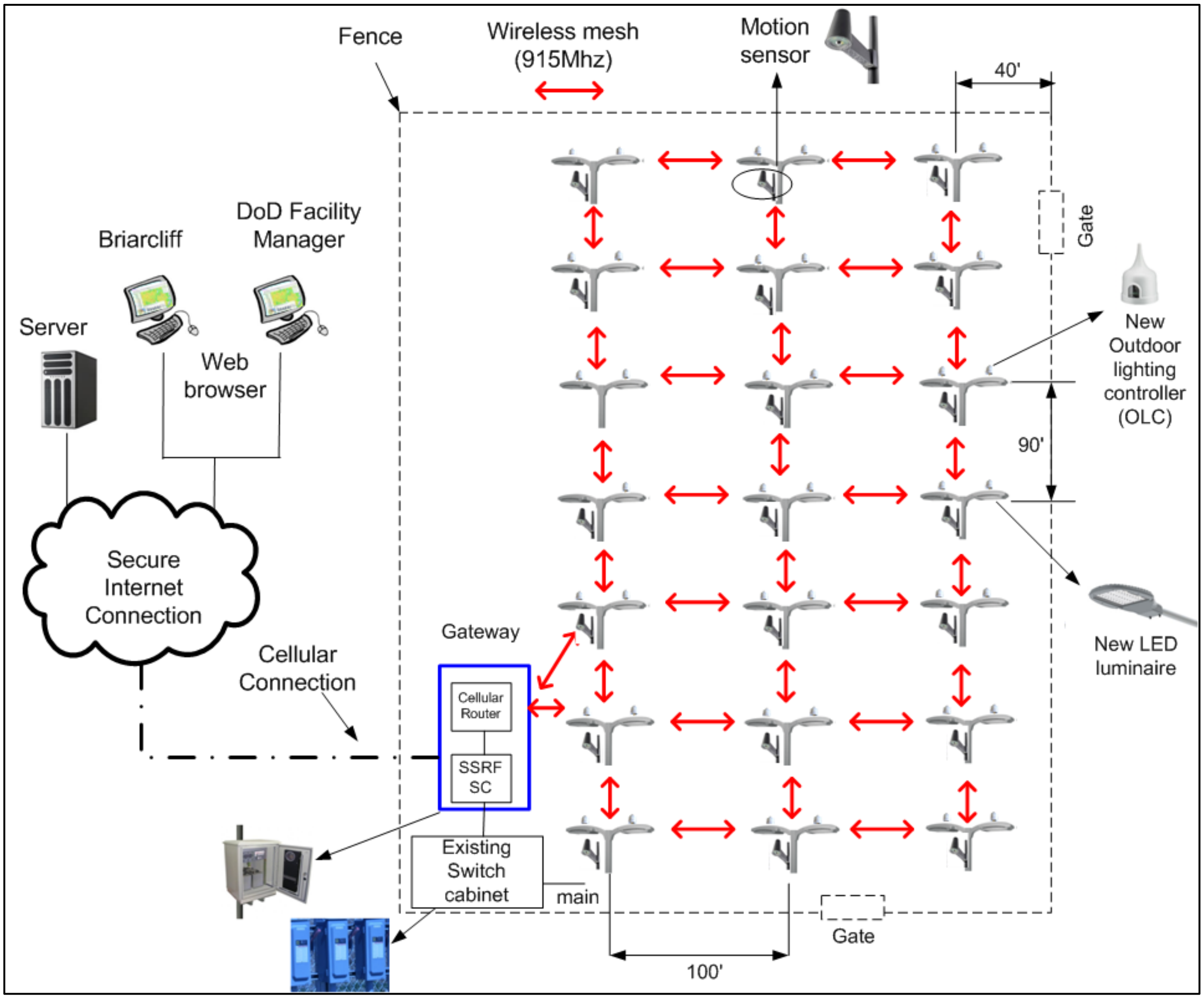


Figure 30: System Architecture of LOD System for Deployment

5.3.3.3 COMONENTS OF THE SYSTEM

The LOD system consists of the following components:

1) LED luminaire (shown in Figure 31)

The Hadco RX2160 luminaire (280W) has been used. It maximizes energy savings and provides uniform and comfortable white light. The low copper, die cast aluminum housing has a traditional cobra-head style and low profile. The long lasting design is a complete Philips Hadco solution and is environmentally sustainable.

Figure 31: Philips Hadco RX2160 Luminaire for LOD System

2) Motion sensor (shown in Figure 32)

The motion sensor is attached beneath the luminaire on the pole. It is able to detect the presence of persons and/or vehicles even in low light conditions. Any detection event is wirelessly transmitted to the relevant OLCs in order to provide the required levels of illumination.

Figure 32: Motion Sensor for LOD System

3) OLC (Outdoor Lighting Controller, shown in Figure 33)

The OLC is fixed on the top of a LED luminaire. It switches the lamp, adjusts the lighting level and detects lamp and system failures. The OLC communicates to the Segment Controller wirelessly and securely, by RF signals, over a distance of up to 300 meters. It uses a 1-10 V or DALI dimming signal to interface with the electronic ballast and a relay to switch it on and off. It also registers burning hours and offers accurate metering of real energy consumption. Its on-board software can be upgraded over the air.

Figure 33: Outdoor Lighting Controller (OLC) for LOD System

4) SC (Segment Controller, shown in Figure 34)

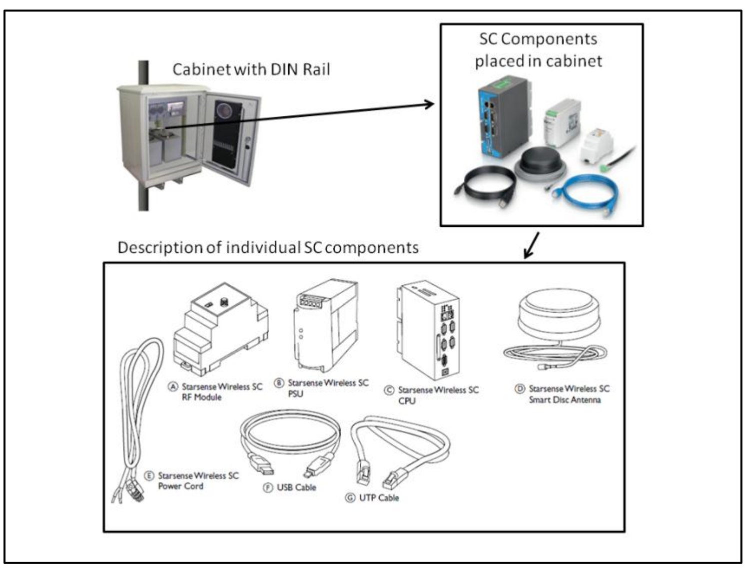


Figure 34: Segment Controller (SC) for LOD System

The Segment Controller (SC) controls a number of OLCs and gathers data from them. This information is then sent securely, when required, to the remote backend server over a 3G cellular connection. Mounted on a DIN rail in a cabinet attached to the light pole or on the ground, the SC can be used to interface with other devices in the cabinet, such as traffic counters or weather sensors. The LOD wireless network which uses the Starsense network as the base is scalable: each Segment Controller can control up to 1,500 light points. Here too, the on-board software can be upgraded remotely.

The SC Kit consists of the following key components:

- RF Module
- Power Supply Unit (PSU)
- Central Processing Unit (CPU)
- Smart Disc Antenna
- Cables : USB and UTP

5) Backend management software (shown in Figure 35)

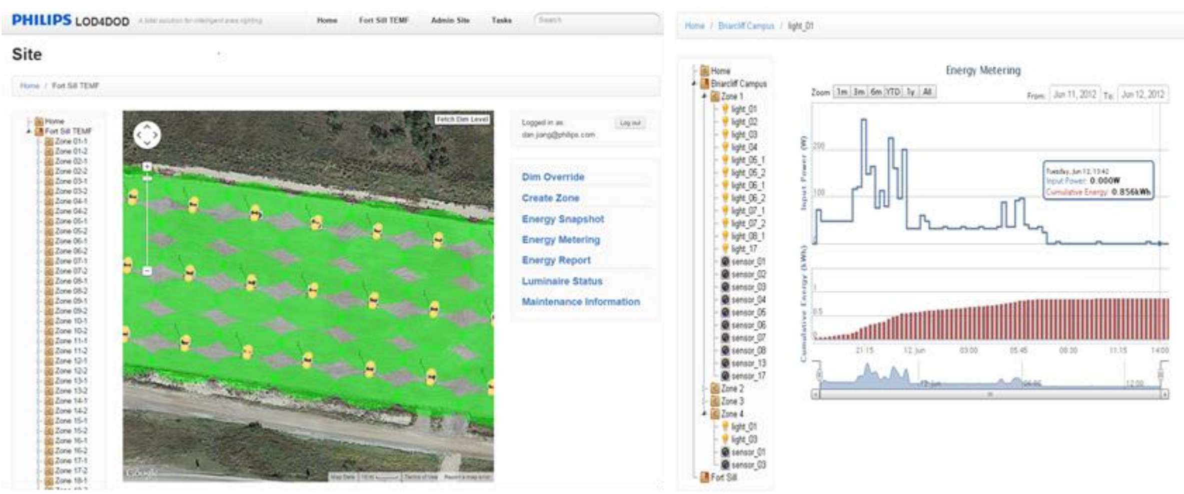


Figure 35: Backend Management Software for LOD System

The backend software is used to monitor the status of the luminaries and control them if necessary. The system also provides visualization tools to monitor energy consumption of all the luminaires based on the data gathered from all the luminaires connected to the system.

5.3.3.4 SYSTEM INTEGRATION

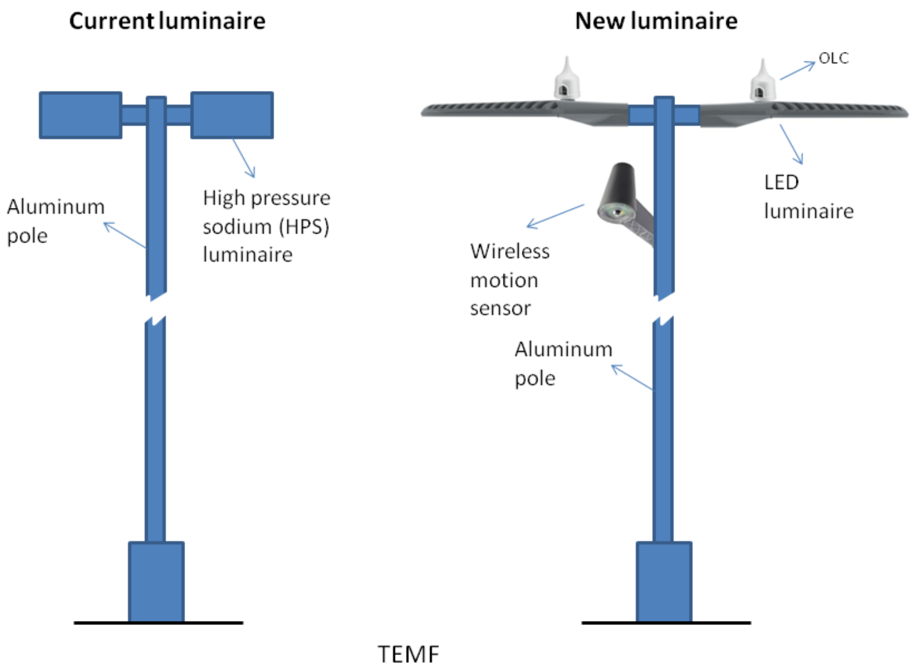


Figure 36: Installation of Luminaire, OLC and Wireless Motion Sensor

The installation of Luminaire, OLC and wireless motion sensor is illustrated in Figure 36.

5.3.3.5 SYSTEM CONTROLS

The wireless communication model allows a luminaire to communicate with other luminaires that are within transmission range. This capability allows the luminaires to provide higher levels of illumination at the point of interest while areas further away can be illuminated at lower levels. This concept is illustrated in Figure 37.

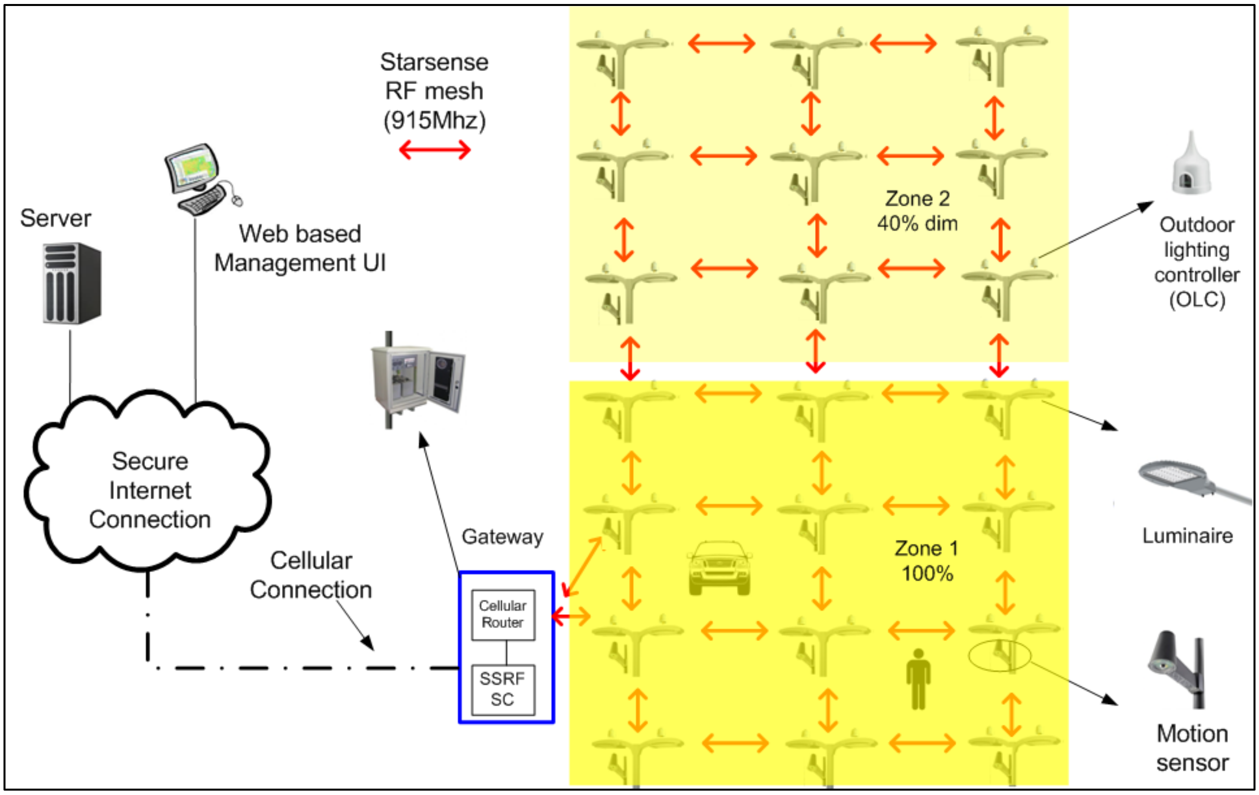


Figure 37: Concept of System Control for LOD System

5.4 OPERATIONAL TESTING

This section elaborates on the operational testing procedures which have been used to validate the system's performance after installation and commissioning.

5.4.1 OPERATIONAL TESTING OF PERFORMANCE

The activities involved in the operational testing phase are described in greater detail below.

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

Table 7 - Table 9 show the test matrix that a technician uses to conduct the demonstrations and verify the performance. It is worth noting that all three systems (Dynadimmer, Starsense and LOD) will undergo a different set of tests.

5.4.1.1 DYNADIMMER

Table 7: Dynadimmer Test Procedures

System Start-Up		
Test procedure	**Acceptable outcome**	**Result**
Load dimming schedule to all luminaires	Dimming at luminaires occurs according to the loaded schedule after 3 days (verify with recording ammeter connected for 3 days.	Yes/No
Steady State		
Test procedure	**Acceptable outcome**	**Result**
Check the light level before and after switching time points	Light dimmed according to defined dimming schedule	Yes/No
Check energy consumption log	Compare the energy consumption with dimming schedule and see if it reflects the dimming schedule	Yes/No

5.4.1.2 STARSENSE

Table 8: Starsense Test Procedures

System Start-Up		
Test procedure	**Acceptable outcome**	**Result**
Load dimming schedule to all luminaires	Dimming at luminaires occurs according to the loaded schedule. Luminaires acknowledge receiving schedules.	Yes/No
Test Override mode	Luminaires are set to the specified override dim value.	Yes/No
Steady State		
Test procedure	**Acceptable outcome**	**Result**
Check the light level before and after switching time points	Light dimmed according to defined dimming schedule	Yes/No
Receive energy logs from all luminaires at regular hourly intervals.	Energy logs are received at the SC from all OLCs every hour	Yes/No
Check energy consumption log of every luminaire against central meter	Metering accuracy should be greater than 95%	Yes/No

5.4.1.3 LOD

Table 9: LOD Test Procedures

System Start-Up		
Test procedure	**Acceptable outcome**	**Result**
Load dimming schedule to all luminaires	Dimming at luminaires occurs according to the loaded schedule. Luminaires acknowledge receiving schedules.	Yes/No

Test Override mode	Luminaire is set to the specified override dim value.	Yes/No
Configure motion sensor	Sensor detects person and vehicle properly	Yes/No
Steady State		
Test procedure	**Acceptable outcome**	**Result**
Receive energy logs from all luminaires at regular hourly intervals.	Energy logs are received at the SC from all OLCs every hour	Yes/No
Check energy consumption log of every luminaire against central meter	Metering accuracy should be greater than 95%	Yes/No
Check that luminaire reacts to people within area of interests	Luminaire should dim up when people walk around its area of interests	Yes/No
Check that luminaire reacts to cars within area of interests	Luminaire should dim up when cars move in the area of interests	Yes/No
Check that luminaires do not react to people or cars outside the area of interests	Illumination level of luminaires should not be affected	Yes/No

5.4.2 COMMUNICATION RELIABILITY TEST OF LOD SYSTEM

LOD system uses the same Starsense wireless mesh network for the sensor based lighting control, which shares the same Starsense hardware and RF stack for the communication in the field. In addition, LOD system provides a web based API for the debugging and diagnostics of the system. This being an advanced research prototype, flexibility with design and reliability test of the communication between nodes in the system is helpful. Figure 38 shows the parameter polling experiment between SC and OLC to test the communication reliability.

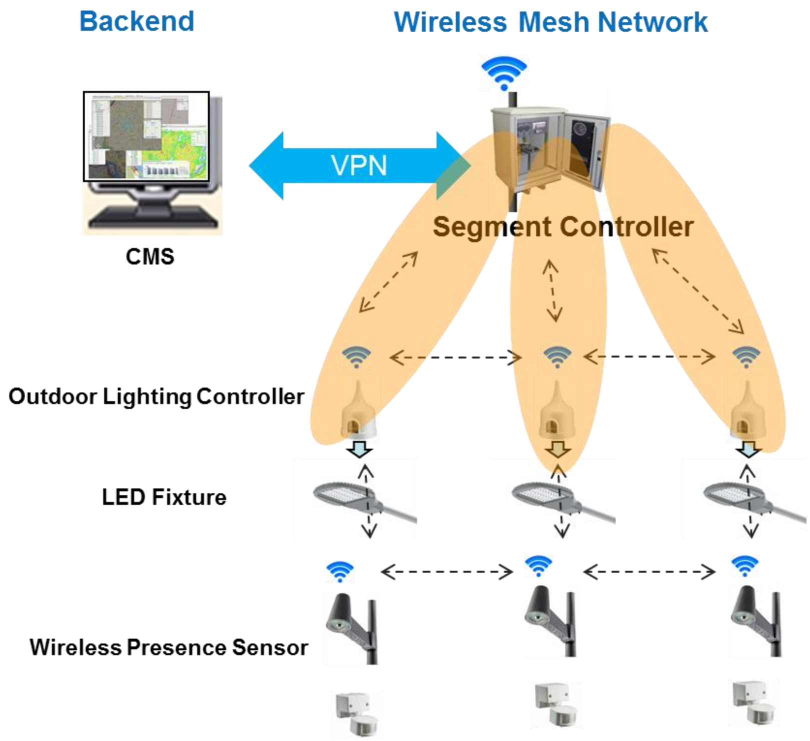


Figure 38: Communication Reliability Test by Polling OLC from SC

In the experiment, SC initiates a query of the sensor control zone parameter of every OLC. Upon receipt of the request, OLC should respond immediately if the communication is reliable. As shown in Figure 39, SC will poll all 42 OLCs in the field in each test, and record the time the request is sent, the time the response is received and the parameter value. The test repeats after a random waiting time. The experiment runs a period of time until significant amount of test data is collected. The collected test data is be analyzed to get the communication reliability performance statistics of the system in the experiment period.

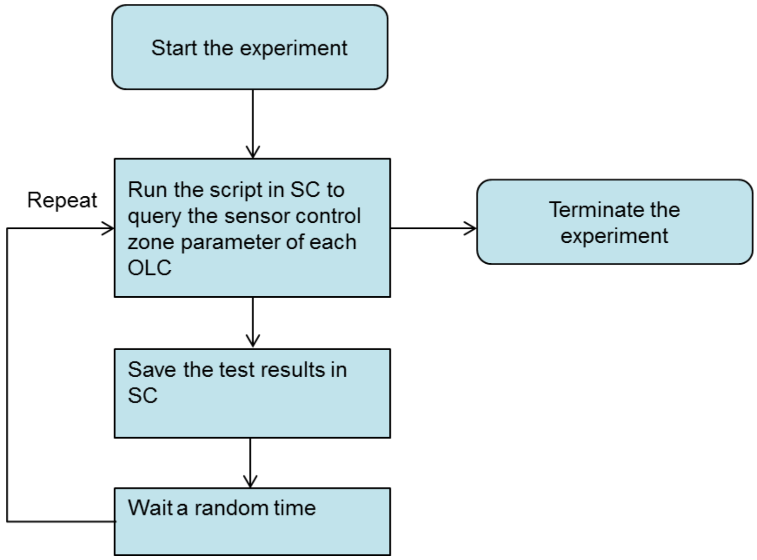


Figure 39: Communication Reliability Experiment Procedure

5.4.3 MODELING AND SIMULATION

AGi32 has been used to carry out accurate photometric predictions. It is a technical tool that can compute illuminance in any situation, assist in luminaire placement and aiming, and validate adherence to any number of lighting criterion. The tool is an industrial standard in accurate photometric predictions.

To address the System Economics Performance Objective, we applied the NIST Building Life Cycle Cost (BLCC) model to evaluate the cost and benefits of energy conservation. http://www1.eere.energy.gov/femp/information/download_blcc.html#blcc

5.4.4 TIMELINE

The operational phases of the demonstration are elaborated below.

Initial conditions: incumbent technology – The existing High Pressure Sodium (HPS) luminaires were initially in place and operating. Baseline evaluation was conducted: one-time power measurements were taken to verify specifications. Current Vs time was recorded at the B4700 Welcome Center to assess the HOU. Photometric measurements were taken at each site.

1. **Installation & Commissioning** – The new LED lighting technology and control systems were installed at each of the three demonstration sites. The independent energy logging equipment was installed. The initial dimming schedule at each site was programmed and executed. The M&V equipment was calibrated. Diagnostics were conducted of the demonstration and M&V systems. This phase lasted approximately three months, from October – December 2013.
2. **Operation** – The Dynadimmer and LOD systems were deployed with the final dimming schedules. The Starsense system was enabled with the initial dimming schedules. Traffic data and many one-time-measurements were collected to inform the final dimming schedules for the Starsense system. The final dimming schedules of Starsense system was implemented on June 24, 2014. We continuously collected the one-year total energy use (kWh per year) data during this period. Testing and occasional diagnostic activities occasionally interrupted the pre-programmed schedule on only isolated occasions. The post-retrofit illuminance characterizations were conducted. This phase lasted approximately twelve months, from January– December 2014.
3. **Postmortem (decommissioning)** – To complete the project, the demonstration systems were processed for transfer or removal, as per the contract agreement. The independent M&V systems were removed. Final training sessions and support were provided to base personnel regarding the remaining equipment. Final survey or interview responses were collected. The project report was prepared and submitted. This phase lasted approximately four months, from January – March 2015.

5.4.5 TECHNOLOGY TRANSFER OR DECOMMISSIONING

The Luminaires replacing existing ones will stay after demonstration. We plan to transfer control technologies to DoD after installations based upon the agreement with DoD Fort Sill DPW. The specific terms of agreement will be negotiated after demonstration is nearly close to complete, which allows Fort Sill DPW to have sufficient time and evidence to evaluate the control technologies. If Fort Sill decides to not maintain the control technologies after demo is completed, we may decommission the system and revert the control technologies to photocell control which is used by original installations. Otherwise, the project team will handover smoothly the control technologies to DPW personnel, which includes providing training and assistance of the operation and maintenance of the system as agreed between DPW and the project team.

Current plan regarding the disposition of the three systems is as follows:

- The Dynadimmer systems installed in B4700 building parking lot will be left as is since it is a released product and fully operational requiring little maintenance compared to that of the pre-retrofit lamps alone.
- The Starsense system on Sheridan Road will need to be upgraded to a product release version in coordination with Fort Sill management as there are discussions going on regarding deployment of this system more broadly in the base.
- The LOD system in TEMF, off Miner Road will be decommissioned since this is a research prototype and will not be supported in its current version. Philips is working on systems to address these types of applications.

This plan is being discussed with Fort Sill DPW management (Mr. Hieu Dang, Chief CIV USARMY IMCOM Central) and a written consent will be provided.

5.5 SAMPLING PROTOCOL

The sampling protocol addresses energy, photometric, and survey data. 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 consisted of:

- Current Transformers (CTs)
- Watt-hour Transducer
- Data Logger

Energy logging equipment operation: The watt-hour transducer processes current (from the CTs) and voltage (from voltage taps) and computes energy (Wh per time unit). The transducer has a pulsed output (i.e. one low-voltage signal pulse is generated when one watt-hour of energy has passed through the conductor). The data logger records the number of pulses per time interval. The time interval is user configurable, and was set between 30 seconds and 5 min. The data logger uploaded data to a webserver via cellular GSM modem at regular intervals, between once per hour and once per day.

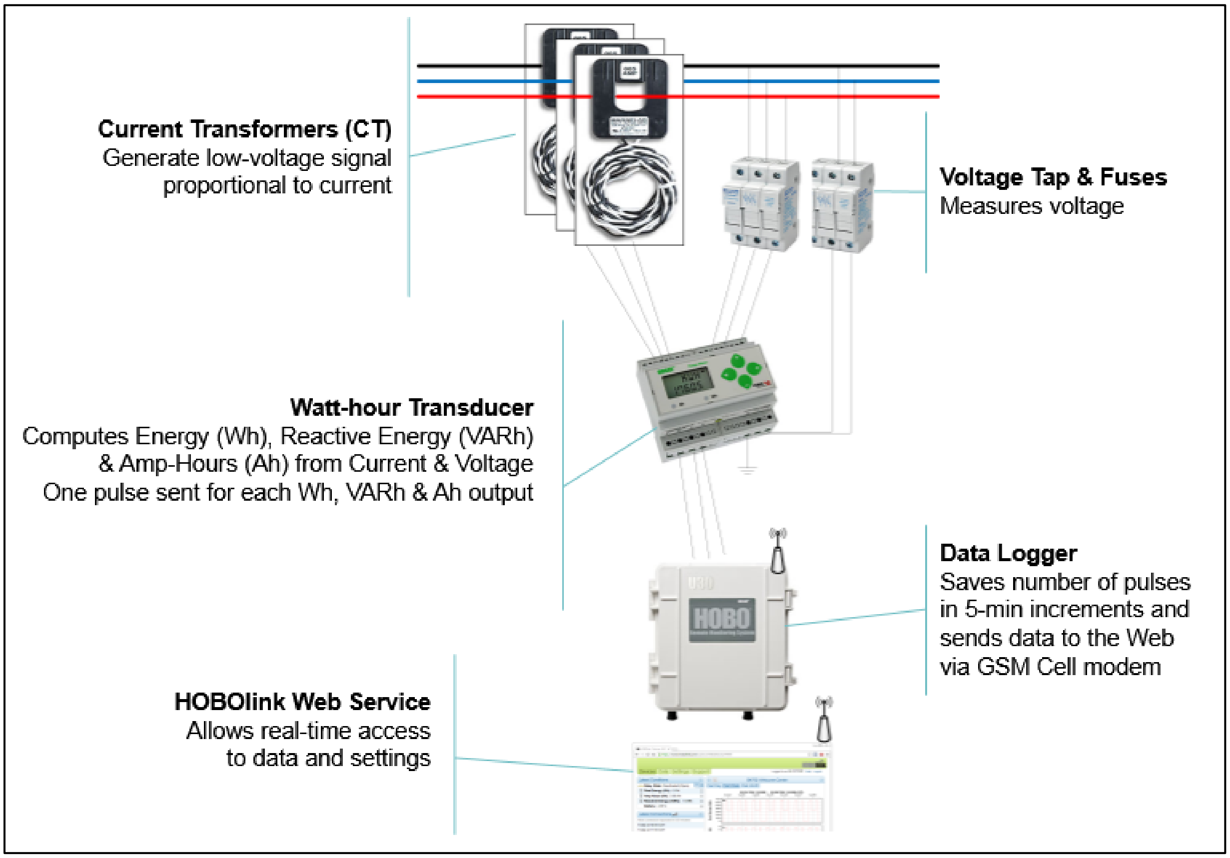


Figure 40: Energy Logging Equipment System Diagram

Timeline of sampling: The energy logging equipment was installed October 2014 – January 2014, with an effective start date of January 24, 2014. The data loggers operated continuously until removal.

Location of energy logging equipment: The energy logging equipment was installed alongside the segment controllers. See section 0 for the locations within each demonstration site where the energy logging equipment (and/or segment controllers) was installed.

The following figures provide detail of the energy logging equipment installed at each demonstration site.

Note that B4700 and TEMF each received a single equipment set, and Sheridan Road received two due to the configuration of the site wiring, where an "equipment set" consists of a watt-hour transducer, a data logger, and assorted CTs, fuses, and conductor.

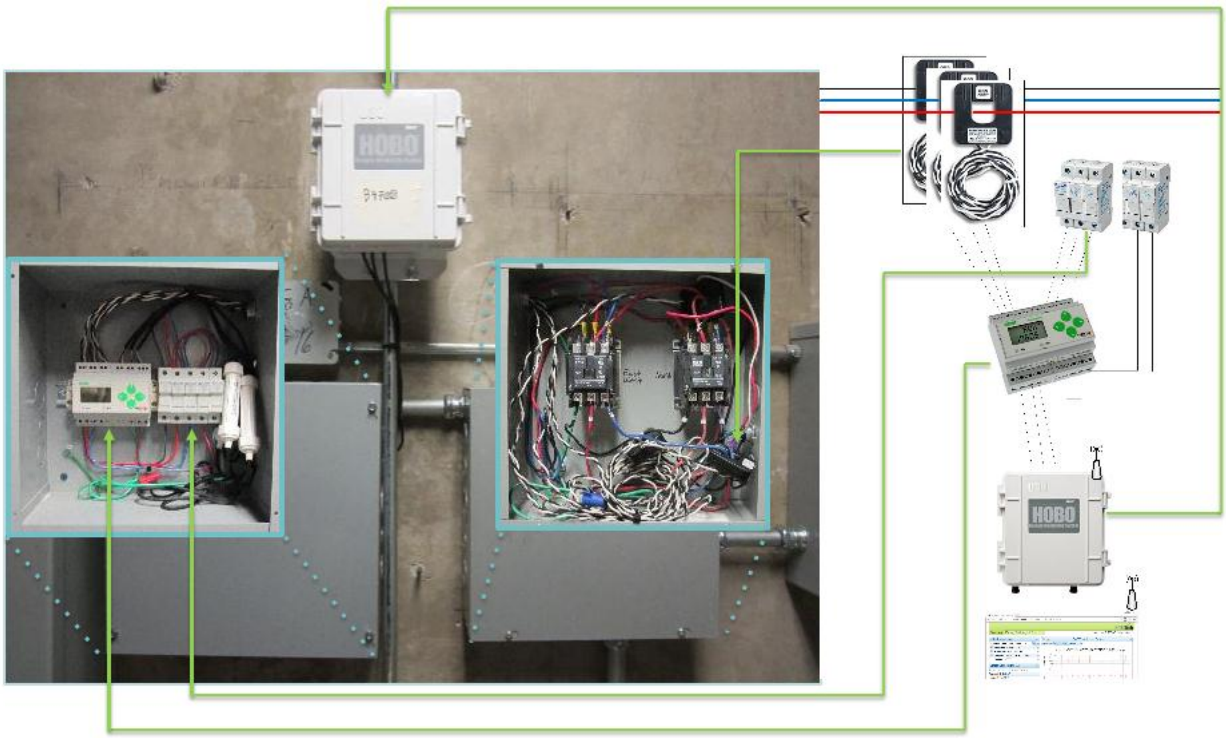


Figure 41: B4700 Energy Logging Equipment System Overview

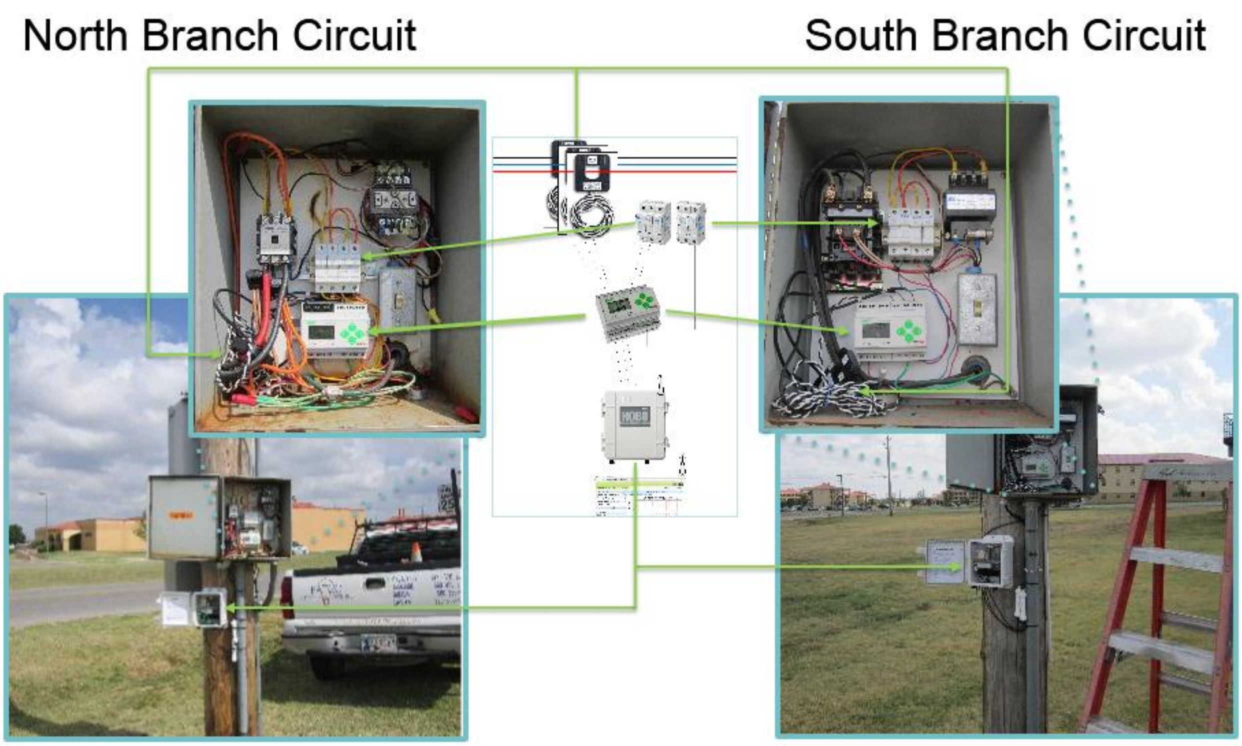


Figure 42: Sheridan Road Energy Logging Equipment System Overview

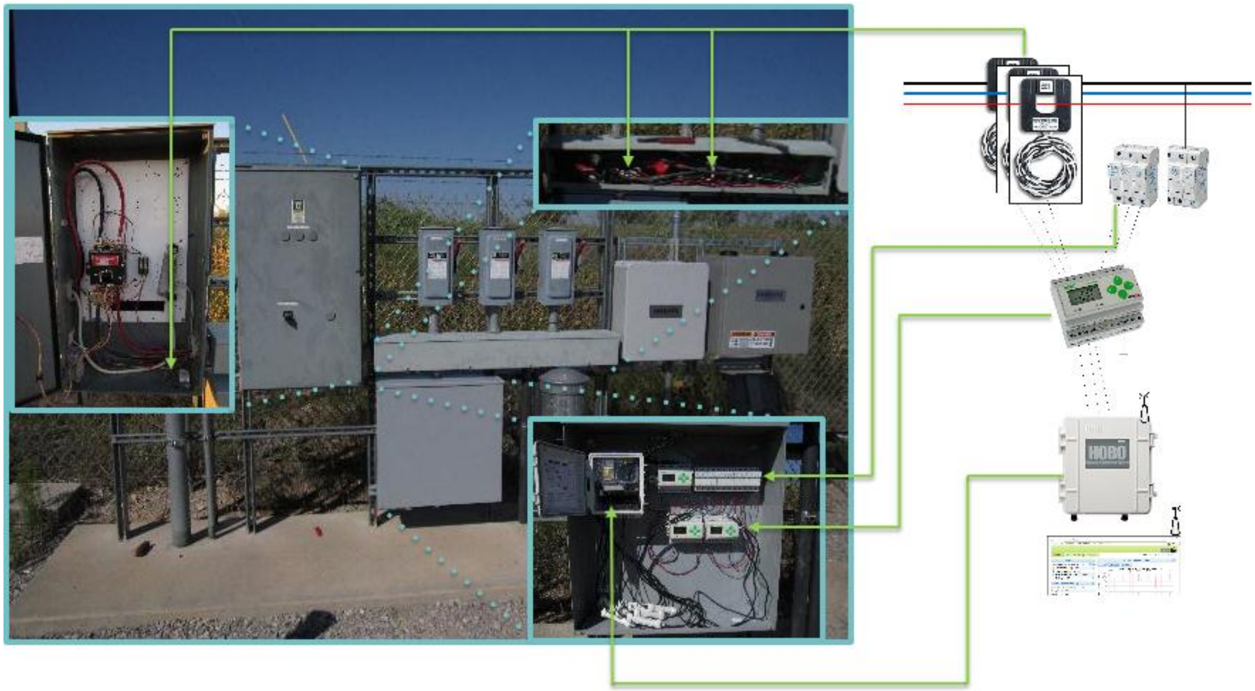


Figure 43: TEMF Energy Logging Equipment System Overview

5.5.2 PHOTOMETRIC

We characterized the optical performance of the lighting technologies with the illuminance, the correlated color temperature (CCT), and the lighting conditions performance objectives.

In order to meaningfully compare 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.

Illuminance is expressed in terms of the minimum maintained average illuminance and the average-minimum uniformity ratio. These metrics are used by the Illuminating Engineering Society (IES) to provide recommendations for different space types or applications. Calculating both of these metrics requires taking a grid of measurements to capture the light distribution.

The CCT was evaluated based on laboratory data commissioned by the product manufacturer. No colorimetric data was collected as part of this demonstration.

The lighting conditions performance objective was assessed via site inspections, feedback from user surveys, and before and after photos.

Illuminance: The Illuminating Engineering Society (IES) has this to say about illuminance:

> *Illuminance is the amount of light striking or "incident upon" a surface. The lighting community has chosen to represent this concept with the italic abbreviation E.*

Illuminance is typically expressed in luminous flux (lumens) per some "unit area" – namely, lumens per square foot or lumens per square meter. Imagine a lighted candle. Now imagine placing it inside a sphere that has a radius of one foot. The luminous flux from the candle flame radiates outward in all directions, eventually striking a surface where it is reflected, transmitted, or absorbed. We reason that there must be a relationship between the total luminous flux (lumens) and the area of the surface being struck (square feet or square meters).

When one candle flame producing one lumen of light radiates that light onto a surface of one square foot, one foot away, we quantify that incident light as one footcandle (fc). When that same candle flame produces one lumen of light and radiates onto a surface of one square meter, one meter away, we call it one lux (lx). For practical purposes, 1 footcandle = 10 lux. Footcandles and lux are both measured by using illuminance meters, or "light meters."-IES Course materials: Fundamentals of Lighting FOL-09.

The industry recommended light levels for roadways are maintained by the IES publication Recommended Practice for Roadway Lighting (RP-8). RP-8 provides recommendations which consist of a pair of metrics: the average illuminance and the uniformity ratio. We calculated these two metrics for each of the three demonstrations. The calculation requires a grid of in-situ illuminance (fc) measurements taken on site with a light meter. The light meter sampling protocol is described below.

A grid of measurement locations, called a test grid, was developed for each demonstration site. The test grids cover only a small portion of each site, typically about one luminaire cycle. The areas to be evaluated were selected so as to capture all space types (i.e. roadway VS intersection) and to minimize light pollution from nearby light sources which were not part of the technology demonstration. Once an area was selected, the location and spacing of measurement points in the test grid was determined according to IESNA LM-50.

A description of the LM-50 instructions for roadways follows. This approach was adapted for use with the parking lot demonstration site as well.

The roadway is marked off in longitudinal and transverse roadway lines. The transverse points are at the quarter points of each lane. The longitudinal points are equally spaced along one luminaire cycle with a minimum of 10 points and a maximum distance between points of 16.5 ft. (5 meters). This grid is documented with a diagram showing test stations and dimensions. Horizontal illuminance readings are taken at each of the grid points and these are used to evaluate system characteristics such as average illuminance, maximum value, minimum value, and system ratios. Other measurements may be taken at points of special significance.

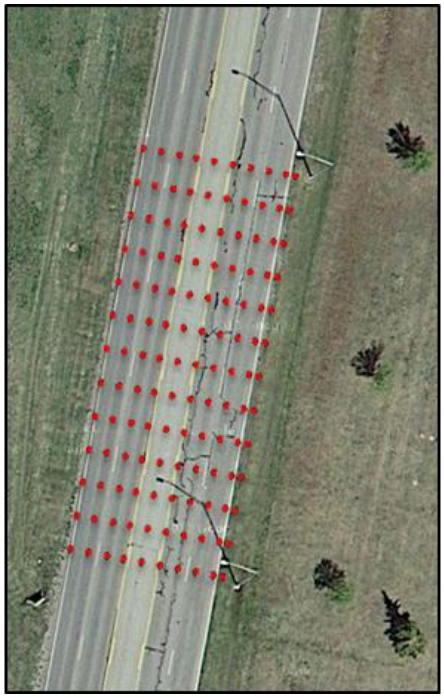


Figure 44: Example Illuminance Measurement Grid

This 11 × 13 grid was used on Sheridan Road. The first column of measurements was located in 10' increments at the roadway edge on luminaire-side of the roadway. The remaining columns were located at ¼ and ¾ positions across the roadway

Illuminance data was collected in ten conditions, resulting in ten illuminance distributions containing between 32 and 156 measurements each. The post-retrofit illuminance characterization was repeated at several dim levels. The summary table shows the location, operational phase (baseline or post-retrofit), and luminaire power (dim level) of each illuminance distribution recorded. The size of the test grid is shown in parentheses (i.e. a 16x5 grid contains 80 measurements). The spacing between measurement points was determined for each case according to IES LM-70, and is approximately ten feet between measurements.

Table 10: Overview of Illuminance Data

	Luminaire Power (%)	B4700	Sheridan	TEMF
Baseline	100%	Yes (16x5)	Yes (11x12)	Yes (9x15)
Post-Retrofit	10%			Yes (12x13)
	40%		Yes (13x10)	
	65%		Yes* (4x8)	
	80%		Yes (13x10)	
	90%		Yes* (4x8)	
	100%	Yes (14x8)		Yes (12x13)

**Intersection illuminance measurements.*

Illuminance contour plots are provided for each site.

The contour plot shows the banded illuminance values overlaid on an aerial image of the site. These contour plots show the location and orientation of the illuminance measurement grids. All illuminance grids for each site were recorded at the locations shown in these figures.

5.5.2.1 TEMF – POST-RETROFIT ILLUMINANCE AT 100%

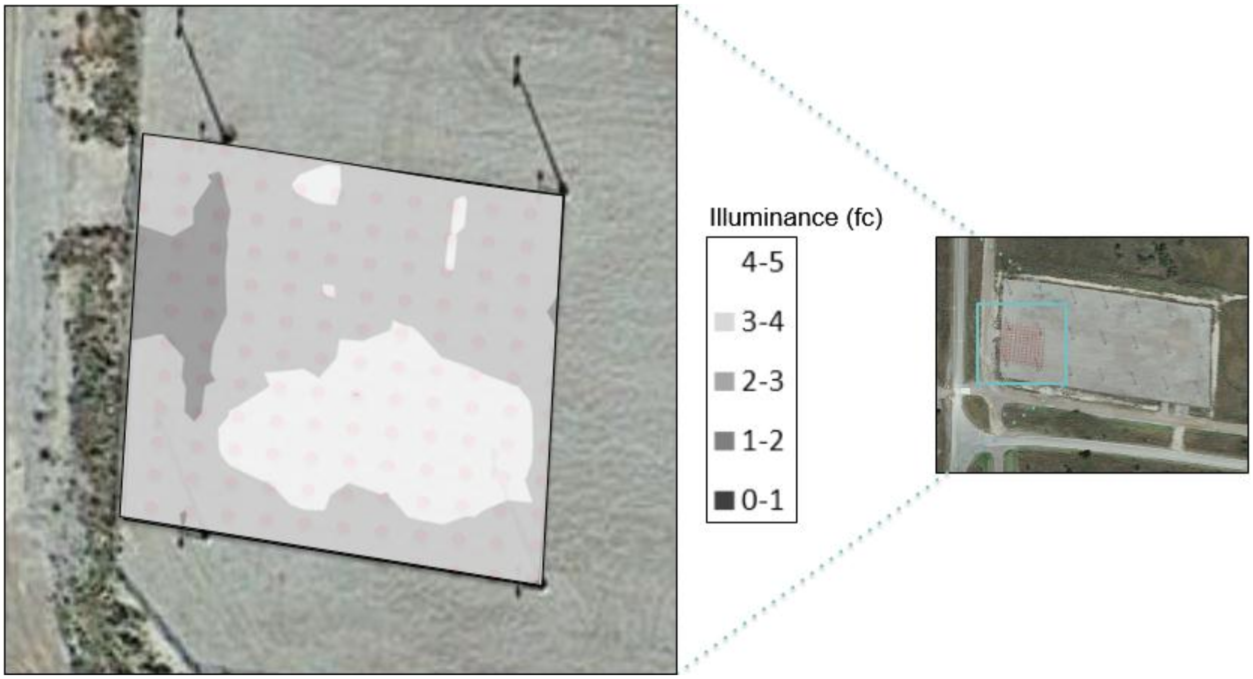


Figure 45: TEMF Post-Retrofit Illuminance with Luminaires at 100% Power Showing the Measurement Locations (Red Dots) and Contour Visualization

The post-retrofit illuminance measurements are shown in Figure 45 and Figure 46. Measurements were taken over a representative section of the parking lot (Figure 45) and replicated to reflect the entire parking lot (Figure 46).

The TEMF demonstration site was generally observed as being well lit, with an even appearance and few dark spots. The illuminance distribution contour plot shows an asymmetric distribution, where the brightest regions were in between the luminaires as opposed to directly under luminaires as would be expected intuitively. This distribution pattern was observed at 10% power as well, which indicates that this distribution was not an artifact of the data collection. The asymmetric distribution might be the result of asymmetric luminaire lenses, interaction with adjacent luminaires, or non-level installation of the luminaires.

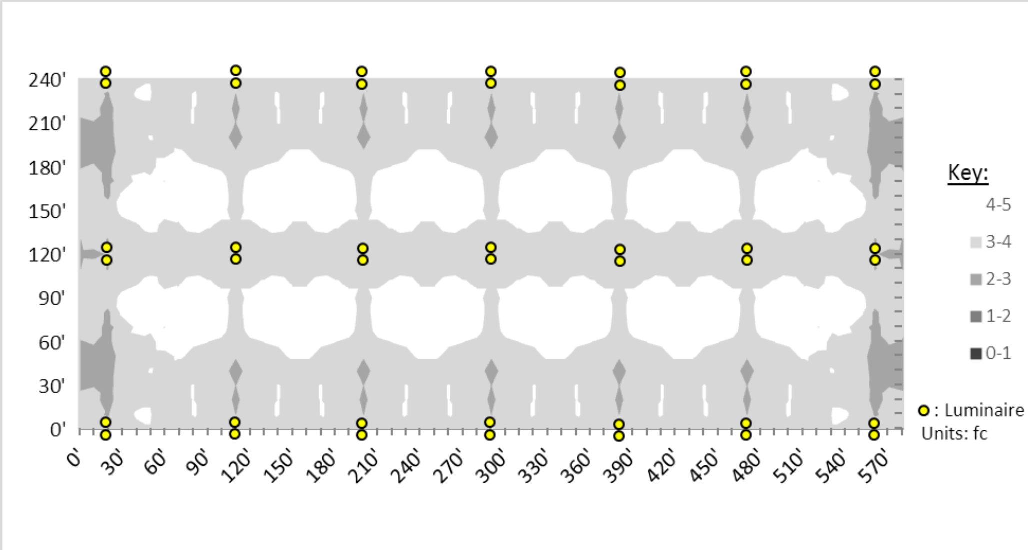


Figure 46: TEMF (LOD Demo Site) Post-Retrofit Illuminance Replicated to Represent the Entire Facility

5.5.2.2 B4700 – POST-RETROFIT ILLUMINANCE AT 100%

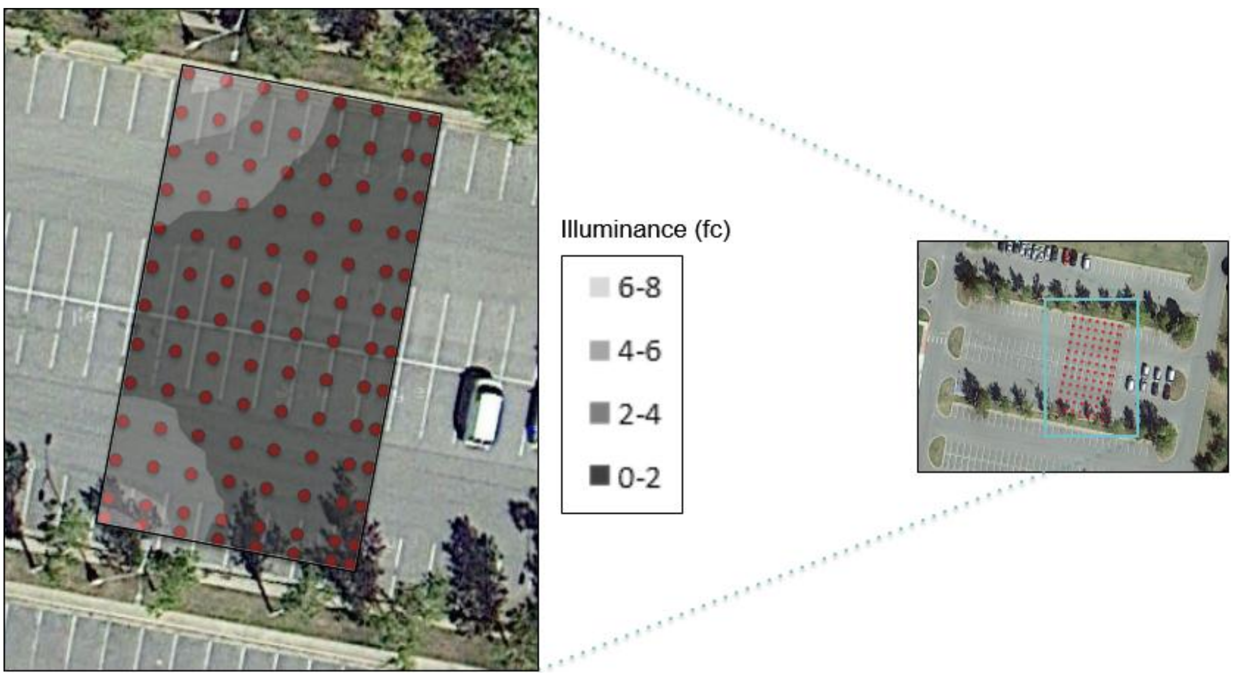


Figure 47**: B4700 Post-Retrofit Illuminance with Luminaires at 100%, Showing the Location of Measurements (Red Dots)**

5.5.2.3 SHERIDAN ROAD – POST-RETROFIT ILLUMINANCE AT 80% (ROADWAY) AND 90% (INTERSECTION)

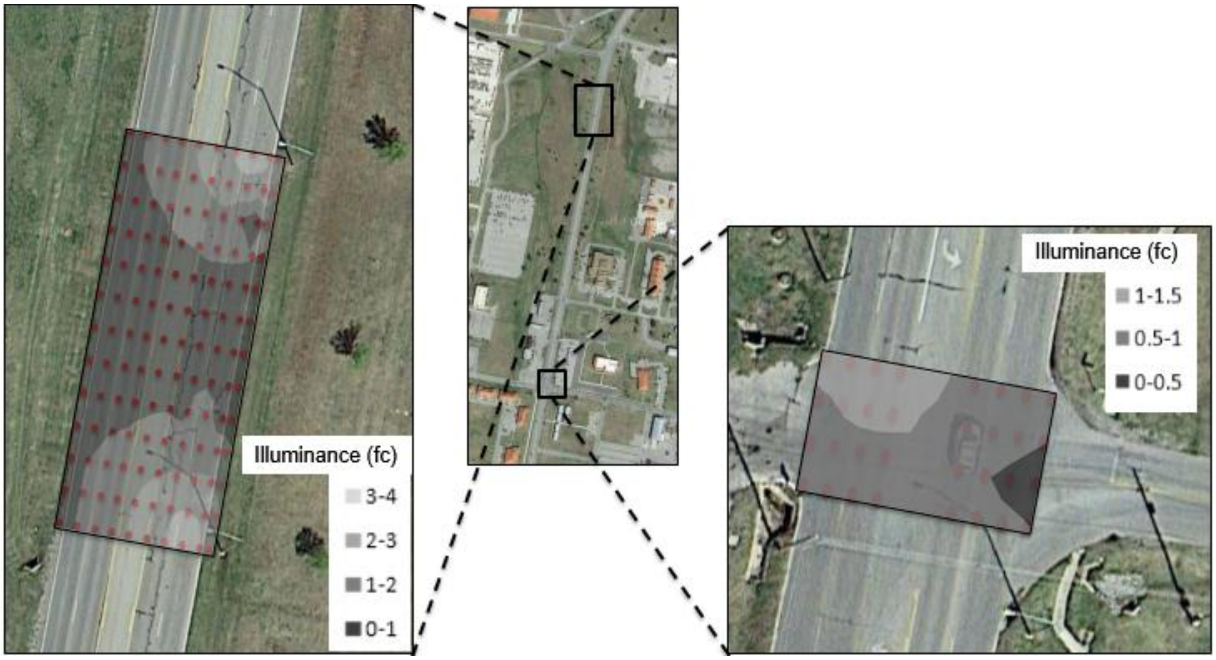


Figure 48: Sheridan Road Post-Retrofit Illuminance with Roadway Luminaires at 80% (Left) and Intersection Luminaires at 90% (Right), Showing the Location of Measurements (Red Dots)

5.5.3 SURVEY SUMMARY

Nine surveys were developed with 10-13 questions each. There were three surveys for each site for separate audiences: 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 the Table 11, 22 surveys have been returned from eight total responders reflecting at least seven responses for each demonstration site.

Table 11: Number of Survey Responses by Demonstration Site Survey Category

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

5.6 SAMPLING RESULTS

Sampling results are listed in Appendices D-F, including daily energy logging results, illuminance distribution measurement results and user survey results.

6 PERFORMANCE ASSESSMENT

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

6.1 SUMMARY OF DATA ANALYSIS

An overview of the data analysis activities contained in section 3.1 of this report is provided in Table 12. Additional discussion of the data analysis activities is provided below.

Table 12: Summary of Data Analysis Activities

Performance Objective	Summary of Analysis	Success Criteria	Result
PO1: Energy Performance	Compared demonstration energy use intensity (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 IES illuminance recommendations	Pass: demonstration technology met IES 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

Performance Objective	Summary of Analysis	Success Criteria	Result
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 operation and Maintenance	Survey facility personnel regarding O&M	Improved O&M experience	Pass: Survey results and anecdotal comments indicate improved satisfaction with demonstration technology.

Traditional lighting system performance is characterized by photometric performance and energy consumption. For adaptive exterior lighting systems, energy performance is also tied to dimming level. Dimming levels are dependent on area occupancy. More light, and therefore higher energy consumption, are required for areas with greater pedestrian and traffic volume. Therefore, performance analysis for baseline and demonstration technologies will consist of three components: annual system energy use, site level occupancy profiles, and photometric performance.

Annual energy use was calculated to determine overall financial and environmental impacts. Occupancy profiles were developed to support the energy analysis. The occupancy data was used to support the development of dimming profiles for adaptive technologies. Periods of lower occupancy received reduced light levels (i.e. curfew dimming), which increased energy savings.

Photometric performance is necessary to demonstrate lighting designs meet site level lighting requirements. Systems must deliver adequate light to the intended target and provide appropriate lighting distribution and uniformity. Pre- and post-retrofit measurements are necessary to demonstrate new systems meet or exceed existing conditions.

User acceptance was assessed with surveys. Areas of user acceptance assessed included lighting quality, ease of installation, and satisfaction with operation and maintenance.

6.2 PERFORMANCE ASSESSMENT

This section contains a sub-section for each performance objective. Each PO follows the same format. The subsections begin with a table containing the performance objective metric, data requirements, and success criteria. A discussion of the data analysis approach is provided. The data analysis is presented under the heading “Procedure”. Finally, the results of the analysis are discussed under the heading “Conclusions”.

6.2.1 PO1: ENERGY PERFORMANCE

Metric:	Annual Energy Use Intensity (EUI) per luminaire expressed as kWh/yr/lum
Data Requirements:	Metered data on electricity usage before and after the installation of new lighting systems.
Success Criteria:	>50% reduction in annual EUI per luminaire over metered baseline
Results:	All three sites met the success criteria of >50% reduction in annual EUI over the baseline.

The purpose of this analysis was to determine if the annual energy use intensity (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.

The HPS EUI was the product of the luminaire power and the hours of darkness during the effective logging period.

The LED EUI was derived from approx. one year of measured energy data. Energy use was logged for all fixtures at each site. To determine the LED-EUI we took the total energy consumed by all of the fixtures during the effective logging period and divided by the number of luminaires. The effective logging period represents the period during which each site operated with all controls enabled and the independent logging system was functioning normally.

The technology would be considered a success if the LED-EUI was 50% or less than the HPS-EUI.

The procedure section is a step-by-step walkthrough of this analysis, which follows these four steps:

1. The purpose of this analysis was to determine if the annual energy use intensity (EUI) per luminaire decreased by at least 50%. The percent reduction in EUI calculation for a site was related to the baseline and post-retrofit Energy Use Intensity (EUI) according to the equation presented in this step.
2. The baseline EUI was calculated for each site by taking the product of the luminaire power and the effective annual hours of use (HOU).
3. The post-retrofit EUI was calculated for each site from the total energy use measured for all luminaires during the effective logging period.
4. Finally, we calculated the change in percent change EUI and check if the percent reduction meets or exceeds the success criteria target of 50% reduction.

Procedure:

1. **The percent reduction in EUI calculation for a site was related to the pre- and post-retrofit Energy Use Intensity (EUI):**

$$PR = 1 - EUI_{After} / EUI_{Before} \tag{1}$$

Where,

PR is the percent reduction in EUI;

EUI_After is the EUI after retrofit; and

EUI_Before is the baseline EUI or the EUI before retrofit.

Thus, to calculate the PR, we first evaluate the baseline and post-retrofit EUI.

2. **The baseline EUI was calculated for each site by taking the product of the luminaire power and the effective annual hours of use (HOU).**

$$EUI = P \cdot HOU \tag{2}$$

Where,

EUI is the energy use intensity (kWh/yr/lum);

P is the baseline luminaire power per site (kW); and

HOU is the hours of use per year (hr/yr).

Baseline Luminaire Power: Of the three test locations, the same incumbent luminaire type was used at both the B4700 Welcome Center and at the TEMF demonstration sites: a 400-watt nominal high pressure sodium luminaire. A 400-watt nominal HPS luminaire with standard ballast will draw approximately 450 watts during normal operation. One-time current measurements were taken at the TEMF to verify the actual luminaire power (Table 13). The baseline (HPS) luminaire power was calculated from the one-time current measurements using the nominal voltage, 240 Vac. The baseline luminaire power for both B4700 and the TEMF was 453.6 watts per luminaire.

Table 13: Baseline One-Time Measurements Recorded at TEMF

Location	Nominal Voltage (RMS volts)	Current (amps)	Power (watts)	Watts/Fixture
Pole #1	240	3.77	904.80	452.40
Pole #2	240	3.79	909.60	454.80
Average			907.20	453.60

The Sheridan Road test location utilized a 250 W HPS luminaire as opposed to the 400 W luminaires. The Sheridan Road luminaire power was calculated assuming a power factor of 0.83, resulting in the luminaire power: 295 watts per luminaire.

The three sites originally had high pressure sodium (HPS) luminaires with a nominal rating of either 400 or 250 watts. The baseline luminaire powers are shown in Table 14.

Table 14: Baseline Luminaire Powers

Site	Incumbent Luminaire	Baseline Luminaire Power
B4700	400 W HPS	453.6 W
Sheridan Road	250 W HPS	295.0 W
TEMF	400 W HPS	453.6 W

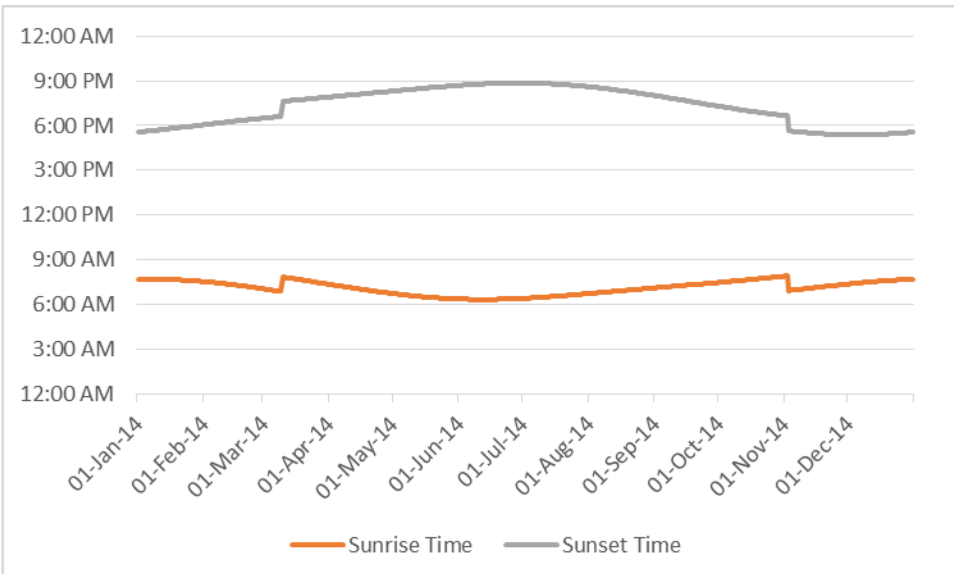


Figure 49: Sunrise/Sunset Times for 2014 in Fort Sill, OK

Post-retrofit measured data was collected for approximately one year. We used the NOAA sunrise/sunset times shown in Figure 49 to calculate hours of use for the baseline EUI. The effective monitoring period was the period of independent logging when the demonstration technology was installed and commissioned with all controls fully deployed. The effective monitoring period differed from the actual logging period only for Sheridan Road, where a curfew dimming schedule was implemented approximately halfway through the actual monitoring period. Table 15 shows the effective date ranges, number of days, and the corresponding hours of darkness according to NOAA sunrise/sunset times for Fort Sill, OK in 2014.

Table 15: Baseline Hours of Use According to Effective Monitoring Period

Site	Effective Start Date	Effective End Date	No. of Days	Baseline "annual" hours of use.
B4700	24 January 2014	13 January 2015	355	4175.2
Sheridan Rd	21 June 2014	6 December 2014	169	1963.0
TEMF	24 January 2014	1 December 2014	312	3568.9

Baseline EUI: The baseline EUI for each site was the product of the baseline luminaire power and the effective annual hours of use (Table 16).

Table 16: Baseline Energy Use Intensity (EUI)

Site	Baseline Luminaire Power (Watt)	Hours of Use (hr/yr)	Baseline Energy Use Intensity* (kWh/lum)
B4700	453.6	4175.2	1893.9
Sheridan Rd	295.0	1963.0	579.1
TEMF	453.6	3568.9	1618.9

**This is the effective EUI, not the true EUI. The Effective EUI (kWh/yr/lum) is calculated here for the effective monitoring period, which was less than one year.*

3. The post-retrofit EUI was calculated for each site from the total energy use measured for all luminaires during the logging period.

The following section discusses the daily energy data before proceeding with the energy use analysis.

The following graphs show the energy use per day (red line) collected from each of the three demonstration sites by the independent energy logging equipment. The annual energy use will be calculated below by taking the sum of these daily energy values. The following section provides a brief discussion of the daily energy data represented by these graphs, explaining the various peaks and fluctuations we observed at each site. Finally, the analysis will continue by calculating the annual energy use.

In addition to the measured data, each graph shows two computed values for comparison:

- "HPS Baseline" (orange dashed line) and
- "LED w/o Controls" (green dashed line).

Both of these are calculated rather than measured values, denoted by the dashed line. These lines also represent total daily energy (kWh/day). They were calculated by taking the product of site power and hours of use per day. In both cases, the hours of use were calculated by assuming the lights were on only at night, and then using NOAA sunrise/sunset times to calculate the duration of darkness per day throughout the year. The power values used in each case are discussed in the following sections.

The "effective luminaire power" was the nominal power plus a correction factor. The effective luminaire powers for the incumbent (HPS) technology were discussed in the previous section. For the post-retrofit effective luminaire powers, we applied a 0 W adjustment. Each of the demonstration sites was retrofitted with LED luminaires. The site TEMF received nominal 280 W LED luminaires. B4700 and Sheridan Road both received nominal 215 W LED luminaires. We did not have to apply any adjustment factor to arrive at the effective luminaire power (Table 17). This power represents the actual power one luminaire would draw while operating at full power (i.e. with no dimming).

Table 17: Post-Retrofit Nominal and Effective Luminaire Power

Site	Post-Retrofit Luminaire	Adjustment	Effective Luminaire Power
B4700	215 W LED	0 W	215 W/lum
Sheridan Rd	215 W LED	0 W	215 W/lum
TEMF	280 W LED	0 W	280 W/lum

The "site-power" is equal to the "effective luminaire power" multiplied by the number of luminaires at each site. The site-power for the HPS Baseline line (orange dashed line) was equal to the effective baseline luminaire power multiplied by the number of luminaires at each site. The LED w/o controls (green dashed line) site power was equal to the effective LED power value, times the number of luminaires at each site.

The same quantity of luminaires were used for both the pre- and post-retrofit assessment (Table 18). In the following graphs, the green dashed line represents the maximum energy we predict the demonstration site can consume in a day if the luminaires operate from dawn to dusk (i.e. the energy use per day with no dimming).

Table 18: Site-Power Values

Operational Phase	Site	QTY (lum)	Effective Luminaire Power (watt)	Site-Power (kW)
Pre-Retrofit	B4700	36	453.6	16.3
	Sheridan Rd	40	295.0	11.8
	TEMF	42	453.6	19.1
Post-Retrofit	B4700	36	215.0	8.8
	Sheridan Rd	40	215.0	9.8
	TEMF	42	280.0	11.8

B4700

The energy use results for the B4700 Welcome Center site are shown in Figure 50. The daily energy use for B4700 was typically about 25 kWh/day less than that predicted for LED without controls (red VS green-dashed). This differenced 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.

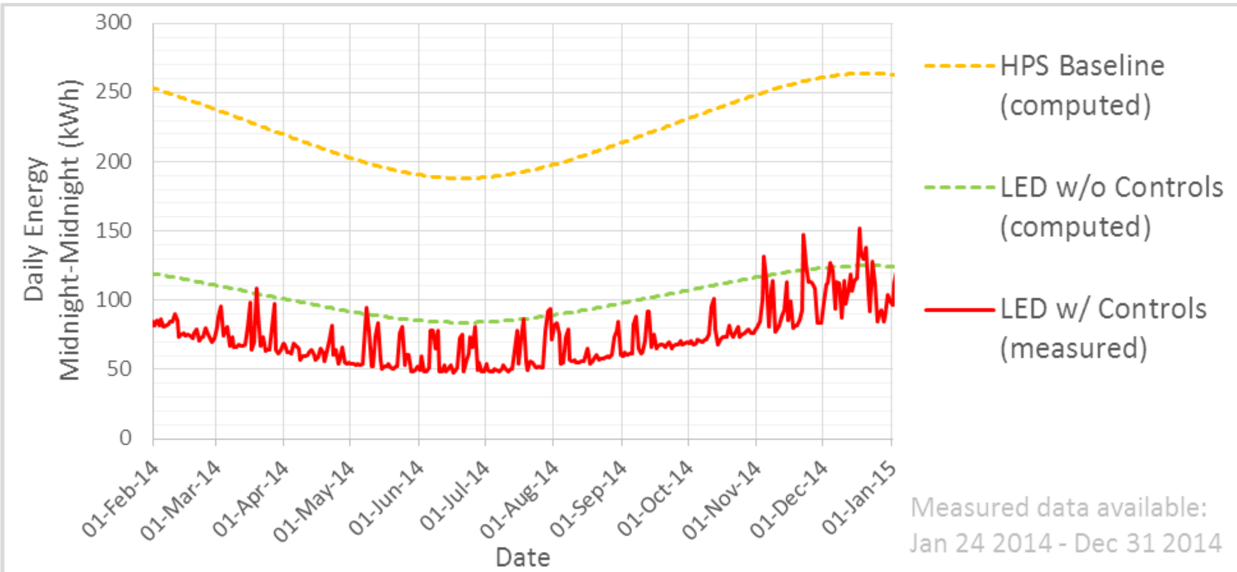


Figure 50: B4700 Energy Use Results

How or why would the measured energy exceed the predicted (red peaks which exceed green-dashed line)? The measured energy results from luminaires at B4700 programmed with a curfew dimming schedule, while the predicted energy assumes there is no dimming. Therefore, the measured energy would be less than the predicted daily energy use by an amount proportional to the degree of dimming applied. However, over the course of logging the luminaires reset many times. The luminaires might reset in response to a variety of circumstances, such as a power failure on site. When the luminaires reset, the curfew dimming would be temporarily disabled. Under these circumstances, the luminaires would revert to ON/OFF operation (i.e. with no dimming), and were turned on or off by a photocell.

When this occurs, the daily energy use would deviate from normal operation for two reasons: 1) the site-wide connected load increased because the luminaires fail to dim; 2) the hours of operation may increase because weather conditions that day cause the photocell to turn the luminaires on during the day. These circumstances appear as spikes in the measured data (red line). Disabling the curfew dimming alone results in energy use spikes that were quite close to the LED-without-controls prediction for that day (green-dashed line). Spikes that exceed the predicted value occurred when both the dimming was disabled and the luminaires operated for longer than normal (i.e. during part of the day).

Sheridan Road

The energy use results for the Sheridan Road site are shown in Figure 51. 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 24th 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 IES RP-8 recommended illuminance levels, pneumatic tube traffic counters which 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 schedule with lower light levels for non-intersection-adjacent luminaires. The fluctuation observed in March corresponds with diagnostic activities performed by the project team.

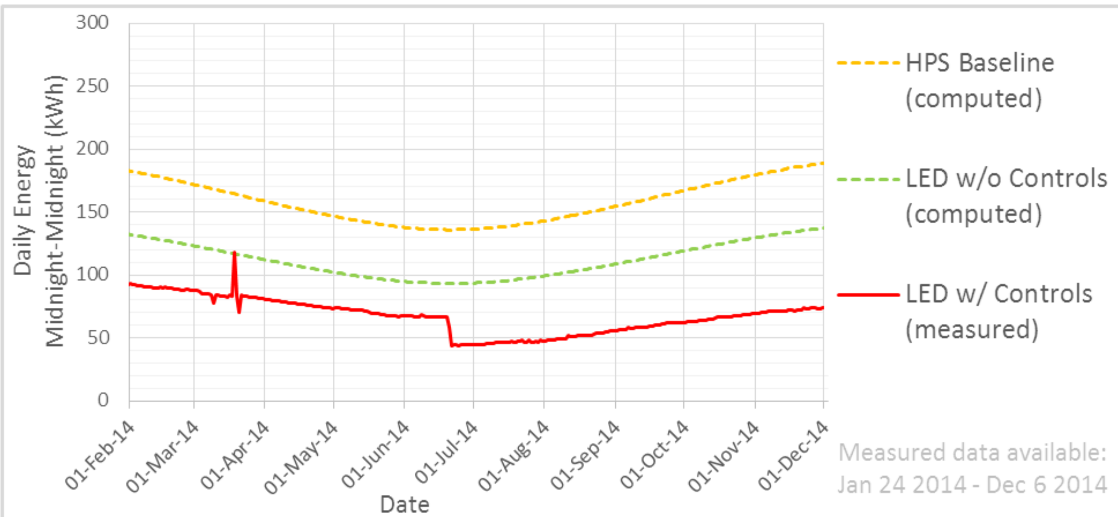


Figure 51: Sheridan Road Energy Use Results

TEMF

The energy use results for the TEMF site are shown in Figure 52. 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. The site was commissioned for maximum energy savings by limiting the occupancy sensor zonal control groups to one pole per zone (i.e. each pole received an occupancy sensor, when that sensor detected motion, that pole was switched to HIGH mode. All other poles remained at LOW mode). There were 21 poles with two luminaires each.

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 corresponds 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.

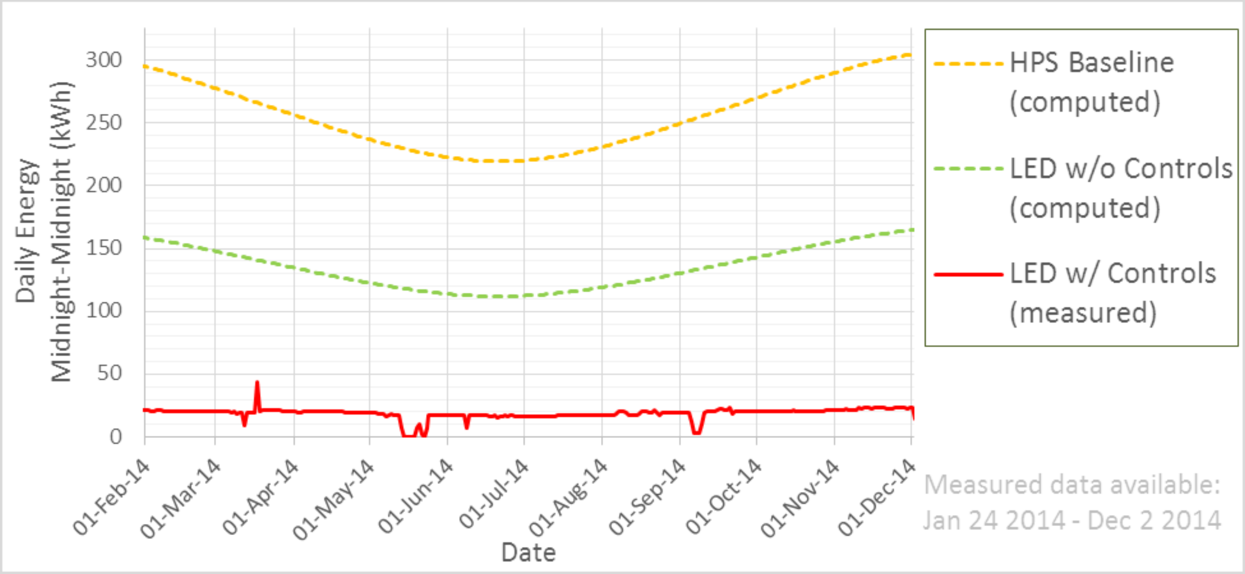


Figure 52: TEMF Energy Use Results

Measured Energy Analysis

The measured annual energy use (EAnnual) was the sum of the measured energy during the effective monitoring period.

$$E_{Annual} = \sum_{i=1}^{d} E_i \tag{3}$$

Where,

> E_{Annual} is the annual energy use (kWh/yr);
>
> d is the total number of days of measured energy (days);
>
> Ei is the measured daily energy use on day i.

The annual energy use for B4700 was the sum of the daily energy use reported by the independent logging system from January 24, 2014 to January 13, 2015. The annual energy use was 26.5 MWh. The monitoring period was 355 days.

The annual energy use results for all three sites are shown in Table 19.

Table 19: Extrapolated Annual Energy Use

Site	Metered Energy use (MWh)	No. of days	Effective Start Date	Effective End Date
B4700	26.50	355	24 January 2014	13 January 2015
Sheridan Rd	9.90	169	21 June 2014	6 December 2014
TEMF	5.84	312	24 January 2014	1 December 2014

The post-retrofit EUI for each site was calculated from the annual energy use and the number of luminaires at each site. The final result is shown in Table 20.

Table 20: Post-Retrofit Energy Use Intensity (EUI)

Site	Energy Use (MWh)	QTY per Site (lum)	Energy Use Intensity (kWh/lum)
B4700	26.50	36	736.1
Sheridan Rd	9.90	40	235.8
TEMF	5.84	42	145.9

Calculate the change in EUI. Check if the percent reduction meets or exceeds the success criteria target of 50%.

To determine if each site passed the success criteria, we calculated the percent reduction in EUI for each site, and assessed whether the reduction was greater than 50%. The results are shown in Table 21.

Table 21: 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 Rd	579.1	235.8	59.3%	Pass
TEMF	1618.9	145.9	91.0%	Pass

Conclusions:

All three sites met the success criteria of >50% reduction in annual EUI over the baseline.

6.2.2 PO2: MAINTENANCE IMPLICATIONS

Metric:	Annual maintenance cost savings ($US) per luminaire
Data Requirements:	Luminaire service cycle estimates based on product specifications for old and new systems.
Success Criteria:	>40% reduction in maintenance costs per luminaire per year over baseline
Results:	Annual maintenance costs reduced by at least 78%, from $45 USD to $10 USD per year per luminaire.

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 about every 4 years. The re-lamp cost including labor and materials is about 55 USD. As a result, the annual maintenance cost of HPS based lighting system is high, and the nominal cost is about 45 USD 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. This poses great benefits to adopt LED based luminaire, and the estimated annual maintenance cost is about 10 USD per luminaire.

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 the above will upgrade the traditional maintenance workflow greatly, and save base-wide maintenance cost in total.

6.2.3 PO3A: LIGHTING PERFORMANCE

Metric:	Illuminance and uniformity metrics including % of Grid Points Illuminated and average illuminance, coefficient of variation, average-to-min uniformity ratio, and max-to-min uniformity ratio.
Data Requirements:	Photopic and scotopic illuminance measurements before and after installation.
Success Criteria:	Dynamic lumen output with improved lighting distribution while meeting standards.
Results:	All three LED demonstration sites passed by met industry recommendations for illuminance and delivering dynamic lighting performance.

A demonstration site received a pass if ALL of the following criteria were met:

1. Minimum Maintained Average Illuminance (EAvg) and Uniformity ratio meet or exceed RP-8 recommendations for both incumbent and LED solutions.
2. The uniformity ratio of the retrofit solution is less than for the incumbent system by at least 0.1 (EAvg/EMin, unit-less) or 10%, whichever is greater.

3. The retrofit (LED) solution demonstrates dynamic light level operation, such as curfew dimming or occupancy controls.

Each of these criteria is discussed here in detail:

Criteria #1: Lighting recommendations are provided by the Illuminating Engineering Society (IES) for roadways in the publication RP-8. Both the incumbent and retrofit lighting solutions should meet RP-8 recommendations. The recommendations consist of two metrics: minimum maintained average illuminance, and uniformity ratio. In both the incumbent and retrofit cases, exceeding RP-8 indicates excessive lighting and wasted energy, while lighting performance that falls below RP-8 indicates under-lit spaces. If the incumbent was below RP-8, then the energy savings would be under-represented because the baseline energy use did not reflect adequate lighting conditions (i.e. the baseline would have been higher, resulting in larger energy savings switching to LED, if the space had been adequately illuminated by the incumbent technology). This criteria checks the lighting was adequate in the test spaces, which ensures that the energy demand reduction is not exaggerated by changes in lighting quality.

Criteria #2: The "uniformity ratio" (unless stated otherwise) is the ratio of the average illuminance to the minimum illuminance. In the previous criteria, uniformity is checked against RP-8. In this criteria, post-retrofit uniformity is checked against baseline uniformity. The uniformity describes the light distribution in a space. Generally, more even lighting is desirable because it improves user experience and visual acuity while optimizing energy use. The uniformity of a space is dictated by the luminaire spacing and luminaire distributions in that space. A grid of approx. 100 measurements was defined for each site according to the IES standard practice LM-70 in order to calculate the average and minimum illuminance. This criteria checks that the light distribution was improved by the retrofitting the spaces with new lighting sources.

Criteria #3: Dynamic light level operation implies that the dim level of the luminaires changes over time. Lighting controls maximize the energy savings in space by tailoring the dim level to meet the needs of a particular site's occupants. Dynamic light level operation can be achieved in multiple ways, such as by curfew dimming (i.e. a pre-configured dimming schedule) or motion sensors. This criteria checks that each system was capable of dynamic light level operation.

Procedure

1. **Determine illuminance recommendations from IES publications that apply to each demonstration site.**

<u>B4700 and TEMF</u>

Both of these sites are parking lots with illuminance recommendations provided by the IES publication RP-20-98: Lighting for Parking Facilities.

The recommendations in RP-20 are given in the form of a minimum horizontal illuminance, and a maximum-to-minimum uniformity ratio. Two sets of recommendations are in RP-20: Basic and Enhanced Security. The Basic conditions were used for this analysis. The RP-20 recommendations are provided in Table 22.

Table 22: Recommended Illuminance Values for Parking Lots

	Basic	**unit**
Minimum Horizontal Illuminance	0.2	fc
Uniformity Ratio, Max to Min	20:1	

Source: IES RP-20-98, Table 1, pg. 3

Sheridan Road

The Sheridan Road site is a section of roadway which includes intersections. Again, the illuminance recommendations are provided in the form of two values: a minimum maintained average illuminance and a uniformity ratio. However, where the parking lot illuminance ratio was the ratio of maximum-to-minimum, the uniformity ratio for roadways is the average-to-minimum illuminance. The roadway illuminance recommendations are maintained in the IES publication RP-8-00. Separate recommendations are provided for each of the following three conditions: 1) roadway type, including expressway, major, collector, and local; 2) Pedestrian conflict area, including high, medium, and low; and 3) pavement classification, including R1, R2-or-R3, and R4. An excerpt of the recommendations from RP-8 is provided here in Table 23.

Table 23: IES Recommended Illuminance Values for Roadways

Road and Pedestrian Conflict Area		Pavement Classification (Minimum Maintained Average Values)			**Uniformity Ratio (E_avg / E_min)**
Road	Pedestrian Conflict Area	R1	R2 & R3	R4	N/A
Expressway	High	1.0	1.4	1.3	3.0
	Medium	0.8	1.2	1.0	3.0
	Low	0.6	0.9	0.8	3.0
Major	High	1.2	1.7	1.5	3.0
	Medium	0.9	1.3	1.1	3.0
	Low	0.6	0.9	0.8	3.0
Collector	High	0.8	1.2	1.0	4.0
	Medium	0.6	0.9	0.8	4.0
	Low	0.4	0.6	0.5	4.0
Local	High	0.6	0.9	0.8	6.0
	Medium	0.5	0.7	0.6	6.0
	Low	0.3	0.4	0.4	6.0

Source: IES RP-8-00, Table 2, pg. 8

In order to identify the illuminance recommendations for Sheridan Road, we identified the classification of Sheridan Rd for each of the three conditions. The resulting classifications are shown in Table 24.

Table 24: Roadway Classification for Sheridan Road Demonstration Site

Condition	Classification
Road	Collector/Local
Pedestrian Conflict Area	Low
Pavement Classification	R3

Sheridan Road was classified as a collector roadway, which intersects multiple local class roadways. The nighttime pedestrian conflict was low. The pavement was typical R3 pavement following the CIE pavement reflectance classifications.

RP-8 describes these classifications as follows:

- **Road – Collector:** Roadways servicing traffic between major and local streets. These are streets used mainly for traffic movements within residential, commercial and industrial areas. They do not handle long, through trips. Collector streets may be used for truck or bus movements and give direct service to abutting properties.
- **Road – Local:** Local streets are used primarily for direct access to residential, commercial, industrial, or other abutting property. They make up a large percentage of the total street system, but carry a small proportion of vehicular traffic.
- **Pedestrian Conflict Area – Low:** Areas with very low volumes of night pedestrian usage. These can occur in any of the cited roadway classifications but may be typified by suburban single family streets, very low density residential developments, and rural or semi-rural areas.
- **Pavement Classification – R3:** Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways). Mode of reflectance: Slightly Specular.

The roadway illuminance recommendations for Sheridan Road are shown in Table 25. Recommendations are provided for both collector and local roadways because Sheridan Road, which was a collector road, intersected several local class roadways.

Table 25: IES Recommendations for Roadway Portions of Sheridan Road

		IES Recommendations	
	Road Classification	Minimum Maintained Average Illuminance (fc)	Uniformity
Sheridan Road	Collector	0.6	4:1 (Avg:Min)
	Local	0.4	4:1 (Avg:Min)

The IES recommendations for intersections are derived from the roadway recommendations. The recommended minimum maintained average illuminance for an intersection is equal to the sum of the minimum maintained average illuminance recommended for each of the intersecting roadways. The recommended uniformity ratio for an intersection is equal to the smallest uniformity ratio of the intersecting roadways. The resulting intersection illuminance recommendations are provided in Table 26.

Table 26: IES Recommendations for Intersection Portions of Sheridan Road

	IES Recommendation		
	Minimum Maintained Average Illuminance (fc)	**Uniformity**	**Classification**
Sheridan Road Intersection	1	4:1 (Avg:Min)	Collector / Local Intersection

2. Calculate illuminance metrics for each site

A grid of measurements is required to calculate the maintained average illuminance and uniformity ratios of a space. The illuminance measurements consisted of grids of about 100 points each. A light meter was used to manually record horizontal illuminance at each grid point. The grids were evaluated several times, including once with the incumbent (HPS) lighting technology, and one or more times with the demonstration technology at different dim levels. The grid layouts, resulting data, and a selection of data visualizations (contour plots) are provided in section 5.

The results are shown in the following tables:

Table 27: Pre-Retrofit Illuminance Results

		HPS Illuminance				
Location	**Power**	**Max**	**Min**	**Average**	**Uniformity**	
B4700 – Parking Lot	100%	8.4	0.2	1.8	42.0	Max:Min
Sheridan – Roadway + Intersection	100%	2.1	0.0	0.45	N/A	Avg:Min
TEMF – Parking Lot	100%	9.5	0.9	4.19	10.6	Max:Min

Table 28: Post-Retrofit Illuminance Results

		LED Illuminance				
Location	**Power**	**Max**	**Min**	**Average**	**Uniformity**	
B4700 – Parking Lot	100%	7.4	1.0	2.0	7.4	Max:Min
Sheridan Road – Roadway	40%	1.8	0.2	0.7	3.0	Avg:Min
Sheridan Road – Intersection	80%	3.4	0.3	1.2	3.7	Avg:Min
TEMF – Parking Lot	100%	4.7	2.4	3.8	2.0	Max:Min

3. Determine if the Minimum Maintained Average Illuminance (EAvg) and Uniformity ratio meet recommendations for both incumbent and LED solutions.

Table 29: Illuminance Results Compared to IES Recommendations

	Location	Illuminance Results			IES Recommendation			Pass/Fail?	
		Avg (fc)	Uniformity		Avg (fc)	Uniformity		Average	Uniformity
HPS	B4700 – Parking Lot	1.9	42.0	Max:Min	0.2	20:1	Max:Min	Pass	0.2
	Sheridan – Roadway	0.5	N/A	Avg:Min	0.6	4:1	Avg:Min	Fail	0.6
	Sheridan – Intersection	0.5	N/A	Avg:Min	1.0	4:1	Avg:Min	Fail	1.0
	TEMF – Parking Lot	4.2	10.6	Max:Min	0.2	20:1	Max:Min	Pass	0.2
LED	B4700 – Parking Lot	2.0	7.4	Max:Min	0.2	20:1	Max:Min	Pass	0.2
	Sheridan – Roadway	0.7	3.0	Avg:Min	0.6	4:1	Avg:Min	Pass	0.6
	Sheridan – Intersection	1.2	3.7	Avg:Min	1.0	4:1	Avg:Min	Pass	1.0
	TEMF – Parking Lot	3.8	2.0	Max:Min	0.2	20:1	Max:Min	Pass	0.2

Conclusions

All of the post-retrofit LED demonstration sites met the IES illuminance recommendations. In some cases, the space was possibly over-lit: TEMF and B4700 both exceeded IES 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 IES recommendations. Sheridan Road was likely under-lit by the incumbent technology.

These comments are summarized in Table 30. Each space has a color and an arrow.

The color indicates weather the IES recommendations were met;

- Green = both criteria passed;
- Yellow = one criteria passed;
- Red = both criteria failed.

The arrows indicate the light level relative to the IES recommendations:

- Up-arrow = the space was well above IES recommendations (i.e. over-lit);
- No arrow = the space was very close to IES recommendations;
- Down-arrow = the space was well below IES recommendations (i.e. under-lit).

Table 30: Summary of Illuminance Results

Site	HPS	LED
TEMF	↑	↑
B4700	↑	↑
Sheridan – Roadway	↓	
Sheridan – Intersection	↓	

Viewing the illuminance results in this context suggests several conclusions:

- The energy savings at the TEMF should be representative of what one would expect for similar spaces because the lighting quality did not change substantially between pre- and post-retrofit.
- The energy at the TEMF could be reduced by reducing the light level. This space was over-lit both in pre- and post-retrofit conditions
- The B4700 retrofit improved the lighting distribution without substantially changing the overall brightness
- Sheridan road energy savings should be greater than reported. The baseline case was not adequately illuminating this space. Therefore, the baseline case should have consumed more energy than reported. If the baseline had met IES recommendations, the baseline energy use would have been greater, which would have increased the reported energy savings.
- The Sheridan road retrofit greatly improved the lighting quality. The LED lighting solution on Sheridan road met the IES recommendations without being too bright.

6.2.4 PO3B: LIGHTING PERFORMANCE

Metric:	Correlated Color Temperature in Kelvin – CCT(K)
Data Requirements:	Measurements using a Chroma meter under the luminaires to calculate CCT(K)
Success Criteria:	Meet user acceptance in the 4000 to 6000K range.
Results:	User feedback approved of the color temperature, which was found to be 4430 K.

The correlated color temperature (CCT) describes the color appearance of a light source. The purpose of this performance objective was to assess the CCT of the demonstration technology, and assess whether the CCT was appropriate for the application.

Procedure

1. Verify that the demonstration lighting technologies fall within the desired CCT range.

The Illuminating Engineering Society (IES) describes correlated Color Temperature (CCT) as follows:

The "color temperature" of a light source is a numerical measurement of its color appearance. It is based on the principle that any object will emit light if it is heated to a high enough temperature, and that the color of that light will shift in a predictable manner as the temperature is increased.

…

In actual practice, blackbody radiators… are used to assign color temperature. The blackbody radiator is theoretical. With increased temperature, the blackbody would shift gradually from red to orange to yellow to white and, finally, to blue-white. A light source's color temperature, then, is the temperature, measured in degrees kelvin, expressed in kelvin (K), at which the color of the blackbody would exactly match the color of the light source. For many light sources, an exact match cannot be achieved. In such cases, the closest possible match is made, and the color is described as correlated color temperature….

Correlated Color Temperature (CCT) can be measured in-situ or under lab conditions. If the CCT is measured in-situ, the measurement will be affected by the environment. Lab measurements of CCT are standard practice for evaluating CCT.

Lighting manufacturers including Philips conduct laboratory assessments of their lighting products. A colorimetric luminaire assessment to meet IES guidelines must be conducted by a qualified lab. The qualified lab will generate a report meeting a standard format designed by the IES.

Philips submitted one luminaire from the unnamed "RX2" product series for colorimetric testing to the independent lab: Intertek. Intertek found a CCT of 4430 K for this luminaire. The lab report is included as an appendix to this report, and is currently available online:

http://www.hadco.com/Hadco/Public/ProductDetail.aspx?pid=4095

The demonstration at Fort Sill used multiple luminaire types, especially 1) the RoadView "RVM" series, and 2) the unnamed "RX2" series. Both of these product families utilize the same "LEDGINE" LED module with Philips "Xitanium" LED drivers. Therefore, the CCT of 4430 K found by Intertek is representative of the luminaires used at all three sites at Fort Sill for technology demonstration because the same LED module was used in all luminaires.

Finally, we conclude that the CCT of 4430 K does fall within the desired CCT range of 4000-6000 K.

2. Verify user acceptance.

Surveys were distributed and the results are shown in section 5 of this report.
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" (Figure 53).

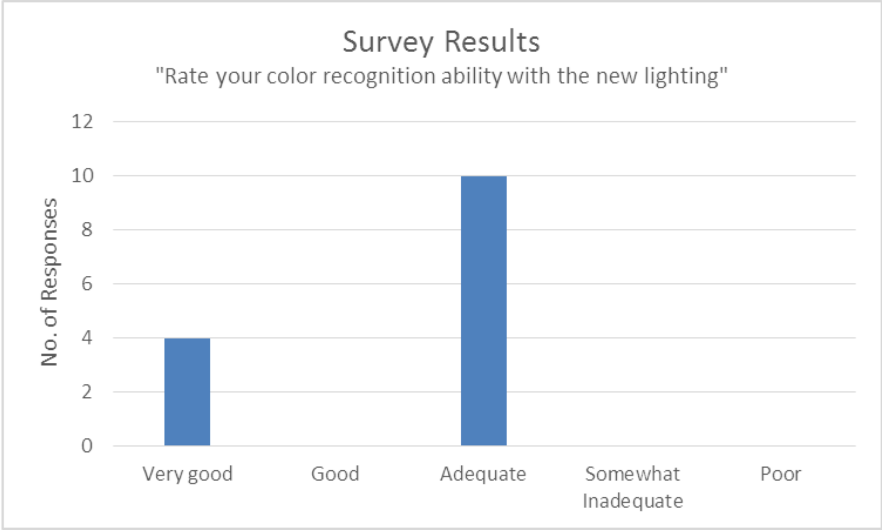


Figure 53: Color recognition survey responses

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.

Conclusions

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 PO4A: COST EFFECTIVENESS OF DYNADIMMER SYSTEM

Metric:	- Savings/Investment Ratio (SIR) - Simple Payback Period
Data Requirements:	Capital costs, historical energy cost, energy usage, installation, commissioning, operating and maintenance costs
Success Criteria:	SIR (10 years) > 1.0 SIR (20 years) > 2.0 Payback < 7 years
Results	SIR (10 years) 1.99 > 1.0 SIR (20 years) 3.49 > 2.0 Payback 4.29 years < 7 years

The Dynadimmer system is a standalone lighting control system with integrated Dynadimmer function in the LED driver. The system’s cost performance is naturally extendable in terms of the scale of deployment. According to the cost analysis elaborated in section 6, the simple payback period is 4.29 years, and SIR in 10 years and 20 years are 1.99 and 3.49 respectively. The performance can be extended to any scale of deployments because Dynadimmer is fixture integrated lighting control solution.

6.2.6 PO4B: COST EFFECTIVENESS OF STARSENSE SYSTEM

Metric:	- Savings/Investment Ratio (SIR) - Simple Payback Period
Data Requirements:	Capital costs, historical energy cost, energy usage, installation, commissioning, operating and maintenance costs
Success Criteria:	SIR (10 years) > 1.0 SIR (20 years) > 2.0 Payback < 7 years
Results (Sheridan Rd demo site)	SIR (10 years) 0.83 > 1.0 SIR (20 years) 1.45 > 2.0 Payback 10.28 years < 7 years
Results (projected deployment with 1400 light points)	SIR (10 years) 1.12 > 1.0 SIR (20 years) 1.96 < 2.0 Payback 7.59 years > 7 years

The Starsense system is the networked lighting control system, and the cost of the system is much dependent on the scale of the deployment. The table above shows the cost figures of the Sheridan Road deployment in Fort Sill with 40 light points as well as a projected typical deployment with 1,400 light points.

According to the cost analysis elaborated in section 6, although the 40-light-point demonstration deployment in Fort Sill's payback period is not very attractive, the typical large scale deployment can be largely improved to meet the targeted performance objective. In addition, the lighting performance of the demonstration site in Fort Sill is greatly improved in terms of uniformity. Currently only a moderate dimming schedule is applied which can be further dimmed down to achieve more energy saving, therefore achieving improved payback period.

6.2.7 PO4C: COST EFFECTIVENESS OF LOD SYSTEM

Metric:	- Savings/Investment Ratio (SIR) - Simple Payback Period
Data Requirements:	Capital costs, historical energy cost, energy usage, installation, commissioning, operating and maintenance costs
Success Criteria:	SIR (10 years) > 1.0 SIR (20 years) > 2.0 Payback < 7 years
Results (TEMF demo site)	SIR (10 years) 1.75 > 1.0 SIR (20 years) 3.08 > 2.0 Payback 4.89 years < 7 years

Results (projected deployment with 200 light points and 20 camera sensors)	SIR (10 years) 2.10 > 1.0 SIR (20 years) 3.69 > 2.0 Payback 4.08 years < 7 years

The LOD system is the networked lighting control system as well with more energy saving capability due to the advanced motion sensor based lighting control technology. In the demonstration in Fort Sill, each luminaire is associated with one camera sensor for the thorough study of the deployment. However, this configuration is not necessary for the deployment in practice. With the smart commissioning and configuration algorithm, only a few motion sensors are required to be placed in strategically important location in the site, such as entrance and exit, and one motion sensor can control a group of light fixtures for the optimized energy saving and performance balance. The table above shows the cost figures of the TEMF deployment in Fort Sill with 42 light points and 2 camera sensors as well as a projected typical deployment with 200 light points and 20 camera sensors.

The simple payback period and SIR in both 10 years and 20 years for both deployments are very attractive. The key bottleneck in terms of cost of networked lighting control system is how to reduce the cost of SC and associated management software, which is one direction more effort can be put on for further cost performance improvement.

6.2.8 PO5A: SYSTEM RELIABILITY

Metric:	Success rate of control system data delivery
Data Requirements:	Message delivery failure log
Success Criteria:	> 99.9% data delivery success rate
Results:	100% data delivery success rate achieved in the test period

According to the communication reliability test design in section 5.xx, a series of experiments were performed over the period of January 12 –22, 2015. 160 rounds of experiments were performed to inquire 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.

6.2.9 PO5B: SYSTEM RELIABILITY

Metric:	Metering accuracy
Data Requirements:	Metering data log and independent measurements
Success Criteria:	>95% accuracy of metering functions
Results:	Starsense: average accuracy = 97.56% > 95% accuracy of metering functions

Dynadimmer system doesn’t have the metering function and therefore we don’t evaluate the accuracy in the report.

Starsense system has the metering function built into the OLC. We compared the metered energy consumption by the Starsense system to the reference meter installed by CLTC on a monthly basis from February to July 2014. Table 31 and Figure 54 show the metered energy consumption values in the two systems during the test period. The average accuracy of metering function of Starsense system is 97.56% compared to the reference.

Table 31: Metering Accuracy Evaluation of Starsense Deployment

	Reference Meter (kWh)	Starsense (kWh)	% Difference
February	2515.1	2637.3	4.74%
March	2609.2	2690.0	3.05%
April	2310.4	2380.6	2.99%
May	2180.6	2229.5	2.22%
June	1774.7	1785.4	0.60%
July	1436.9	1452.1	1.05%

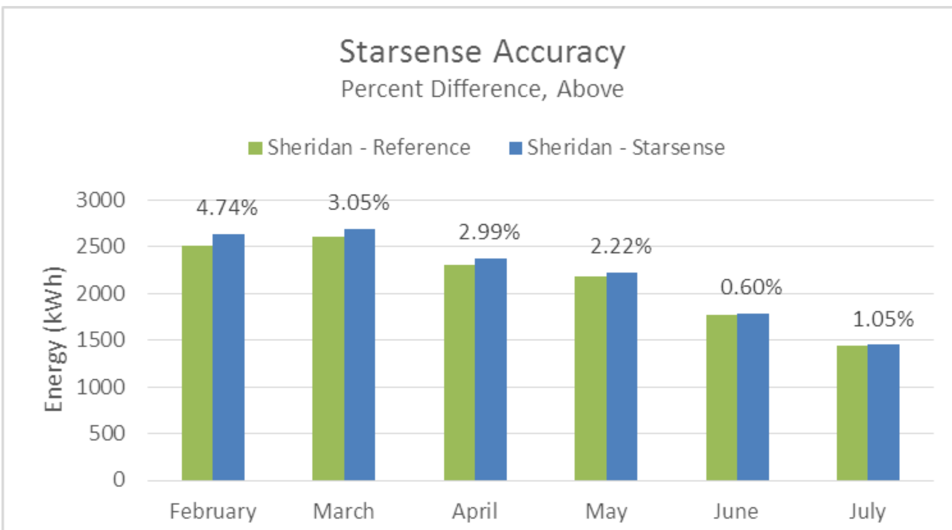


Figure 54: Metering Accuracy of Starsense System Compared to the Reference

LOD system has the metering function built into the OLC as well. However, the camera sensor doesn't have the metering function due to its advanced research 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, we measured the power consumption of one camera sensor in the lab for a period of time, and the average daily energy consumption is 3.2256 kWh. Then we added the calibrated energy consumption of all camera sensors to the metered value from LOD system and compared the results to the reference shown in Table 32 and Figure 55. The average metering accuracy of the system is 93.62%. The main reason why the system doesn't pass the performance objective is camera sensor's energy consumption in the field might differ from what we measured in the lab, and sometimes the entire site's electricity was shut down such as what we observed on a few days in May 2014 however we still counted the camera's consumption in the projected energy consumption which is 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 we need to improve in the next stage of development.

Table 32: Metering Accuracy Evaluation of LOD Deployment

	Reference Meter (kWh)	LOD Projected w/ camera sensor (kWh)	% Difference
February	628.7	653.4	3.86%
March	687.3	721.1	4.80%
April	593.3	628.9	5.83%
May	383.2	418.3	8.77%
June	486.6	525.1	7.61%
July	515.8	555.4	7.40%

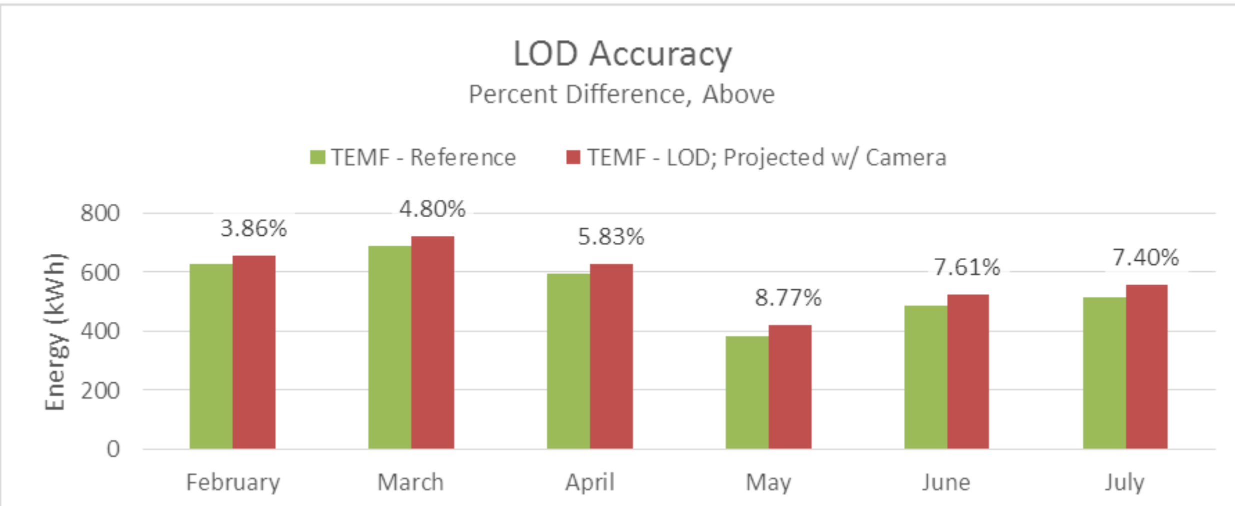


Figure 55: Metering Accuracy of LOD System Compared to the Reference

6.2.10 PO6A: ENHANCED LIGHTING CONDITIONS

Metric:	Photographic comparisons
Data Requirements:	Ground level and overhead photographs will be taken to give qualitative indication of lighting performance
Success Criteria:	Positive subjective evaluation of increased visual clarity, color perception and lighting uniformity.
Results:	Lighting quality improved at all three demonstration sites.

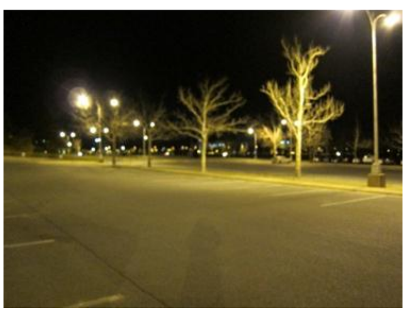
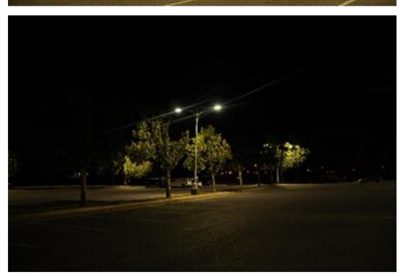
A subjective assessment of lighting quality by a lighting professional provides valuable insight into the true performance of a lighting installation. The response of the human eye at low light level conditions is not easily modeled due to the dynamic response of mesopic vision. The lighting industry is currently expanding analysis techniques to better capture the true response of the human eye in low light level conditions. One such technique includes high dynamic range (HDR) photography. Photography allows the lighting conditions to be assessed by a lighting professional without visiting the site. Photography techniques were employed at each site with mixed results.

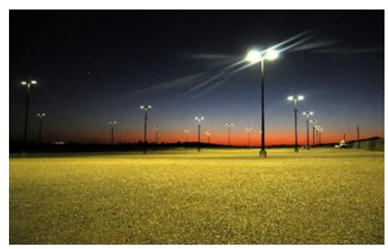
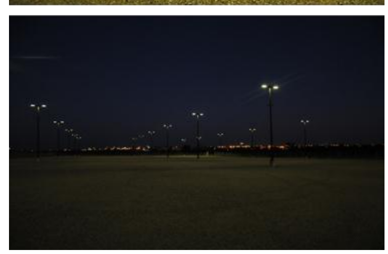
The project team included lighting professionals with the University of California, California Lighting Technology Center. The project team subjectively assessed the lighting conditions of both the pre- and post-retrofit lighting systems in person. The results of this assessment are provided here. Photos of each site are provided where available.

Procedure

1. Examine the lighting conditions of each demonstration site.

Table 33: Nighttime Photos of Lighting at Fort Sill Demonstration Sites

	Pre-Retrofit	**Post-Retrofit**
B4700	 	  

	Pre-Retrofit	**Post-Retrofit**
Sheridan		  
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 of the lighting in each site. This subjective comparison focused 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 which is affected by the color and uniformity. The relative brightness was not assessed because we assume that both pre- and post-retrofit should meet IES recommendations and therefore be about equally bright.

Table 34: Subjective Assessment of Change in Lighting Conditions

Demo Site	B4700	Sheridan Rd	TEMF
Color Perception Improved?	Yes	Yes	Yes
Lighting Uniformity Improved?	Yes	Yes	Yes
Visual Acuity Improved?	Yes	Yes	Yes
Test Result	Pass	Pass	Pass

Conclusions

The project team concluded that by subjective assessment the lighting conditions improved significantly in all respects with the demonstration technology compared to the existing conditions at all three sites.

6.2.11 PO6B: ENHANCED LIGHTING CONDITIONS

Metric:	User acceptance
Data Requirements:	Feedback from facility personal (through surveys) on the overall satisfaction with the lighting performance and control features
Success Criteria:	User opinion surveys indicate improved lighting conditions, and overall satisfaction
Results:	User feedback indicated acceptance of the demonstration technology.

Nine surveys were administered, one for each of three audiences – General, Security, and Maintenance – for each of the three sites. All nine surveys asked to rate overall preference between the old and new lighting technology. The purpose of this performance objective was to assess the overall preference of occupants between the incumbent and LED lighting technologies.

Procedure

1. **Aggregate survey responses.**

   Surveys were administered to three audience groups for each of the three Fort Sill demonstration sites. The survey responses are included in section 5 of this report. Everyone surveyed was asked to rate their overall preference between the old and new lighting technology. A total of 17 responses were received to this question, with nine preferring the new lighting and eight expressing no preference (Figure 56).

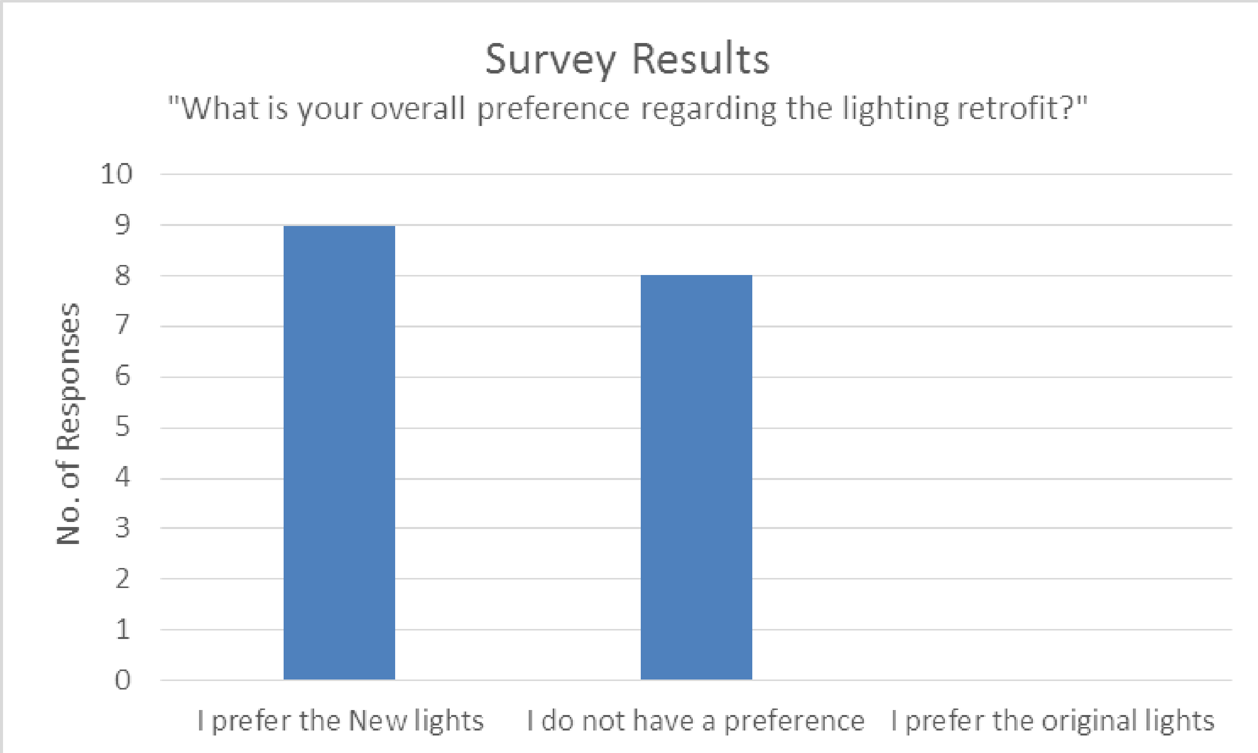


Figure 56: Overall Preference Survey Responses

Conclusion

We concluded that the survey responses indicate overall satisfaction with the demonstration technology.

6.2.12 PO7: EASE OF INSTALLATION AND COMMISSIONING

Metric:	Ability of installers to quickly install and commission the system
Data Requirements:	Feedback from installers on time required to install and commission system
Success Criteria:	Installation and commissioning with minimal training
Results:	Fairly easy installation and commissioning

Dynadimmer system is a standalone lighting control system. The current Philips Xitanium LED driver has integrated the function into the driver. All drivers can be pre-loaded with the dimming schedules suitable for the typical deployment. Therefore, installation and commissioning of the system is hassle-free for electrical service contractor.

Starsense system and LOD system are advanced lighting control systems with versatile commissioning tools to enable easy installation. The contractor only needs to plug the OLC into the NEMA socket on top of the luminaire, strip off the barcode on the OLC and OCA tool provided can be used to scan the barcode and upload the commissioning information to the backend, which completes the installation and commissioning process. The TEMF retrofit was originally planned to be a two-week project, and the actual deployment only took four days many due to the easy installation and commissioning feature of the system.

6.2.13 PO8: SATISFACTION WITH OPERATION AND MAINTENANCE

Metric:	Level of satisfaction of facility personnel with operation, monitoring and maintenance of the systems
Data Requirements:	Feedback from base operations personnel on operation and maintenance functionalities
Success Criteria:	Systems perform reliably. Mgmt. tools improve operations and maintenance.
Results	Facility personnel indicated overall satisfaction with the demonstration technology.

The purpose of this performance objective was to assess the level of satisfaction of facility personnel with the new lighting technology. We assessed the level of satisfaction of facility personnel by administering surveys. The surveys and Reponses are in section 5 of this report.

Procedure

1. **Aggregate survey responses.**

   We developed survey questionnaires for each demonstration site specifically for maintenance personnel and for security personnel. The survey was administered by the base liaison. Nineteen responses were received among the questionnaires for the question, “How does the lighting retrofit affect your job?”. The results are shown in Figure 57.

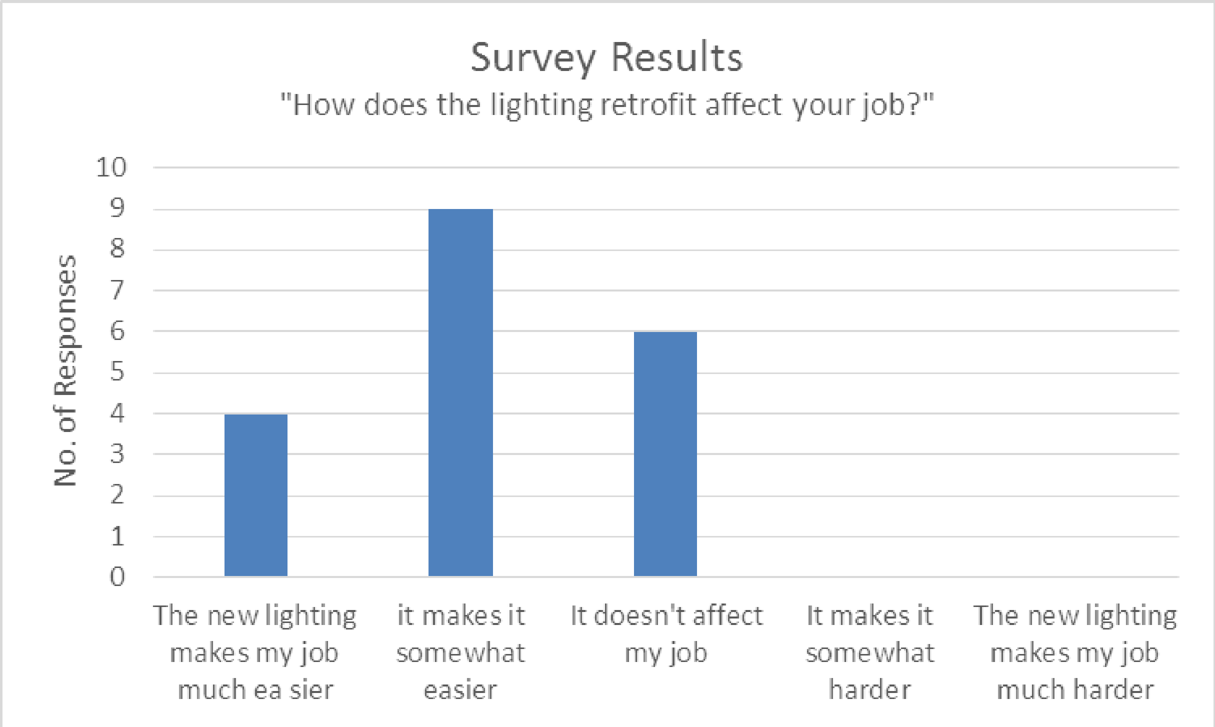


Figure 57: Facility Personnel Survey Results

Several additional anecdotal comments were written in by survey responders. In response to the question: "What are the biggest challenges to lighting maintenance on the base?" maintenance staff commented:

- *All different kinds of ballasts and bulbs and fixtures*
- *Bulbs going out often, having to get around cars to get access*
- *Getting around cars in parking lots*
- *Understanding the motion sensors and where it is located, having to explain the function to every new soldier that has a problem with it*
- *[The new lighting is] harder to diagnose because I'm not trained on how to fix*

These comments illustrate the impact of bulb replacement on lighting operation and maintenance activities, and the need for training. The demonstration lighting technology addresses both of these issues with by increased product lifespan. LED luminaires do not require bulb replacements, so regular bulb replacement activities, including navigating around parked vehicles and other obstacles, are eliminated. Longer product lifespans translate into reduced training because there are fewer product changes.

Conclusions

We concluded that the survey responses from facility personnel indicate overall satisfaction with the demonstration technology. This conclusion is supported by anecdotal comments which specifically identified frequent bulb replacements as a key issue which was resolved by the demonstration technology.

7 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.

- **NIST 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 35 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 35: 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 vs. 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

Hardware capital costs: The major hardware components of three demonstrated technologies consist of LED luminaires, LED drivers, outdoor lighting controllers, camera sensors as well as Segment Controller for the backend connectivity and remote tele-management. The cost of LED luminaires has been coming down continuously over the past years. The cost of hardware components as well as management software for lighting controls can be amortized by the collectively managed light points, which depends on the scale of the deployment.

Installation costs: The cost of labor and material required to install the three demonstrated technologies varies with the region where the technologies are deployed. Fort Sill, OK is a representative site for DoD wide deployment.

Facility operational costs: The demonstrated LED based lighting solutions have shown significant energy savings from the deployment in Fort Sill, and nation-wide deployment will help DoD reduce the electricity bill greatly and contribute to achieving its energy independence goal. In addition, the tele-management capability of networked lighting control systems can be offered as a lighting service to the military bases and the operation of lighting facilities can be automated and hassle-free for the facility managers of the base.

Maintenance: The longevity of LED based light sources will reduce the daily maintenance work much easier. The LED light source doesn’t have to be re-lamped as the High Pressure Sodium (HPS) based light source in a short period of time (about every 4 years). In addition, the advanced remote diagnostics capability provided by the networked lighting control system will make the maintenance more prepared and optimized, which is expected to save the maintenance cost for the base as well.

Hardware lifetime: According to DOE [12], the useful time (L70) for White-light LED is expected 35,000 – 50,000 hours, and could be greater than 100,000 hours depending on drive current, operating temperature, etc. Philips has lifetime test of the light sources that we use for demo [13]. The estimate of hardware lifetime based on components degradation during demonstration is difficult due to the limited demo time. LM-80-08 [10] and LM-79-08[9] require the test data after 6,000 hours of operation for measuring lumen maintenance of LED light sources and the photometric measurements of Solid State Lighting products, respectively.

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 as well as Outdoor Lighting Controllers and sensors. Figure 58 shows the estimated price down trend of LED luminaires from Q4 2013 onward forecasted by DoE’s CALiPER (Commercially Available LED Product Evaluation and Reporting) program.

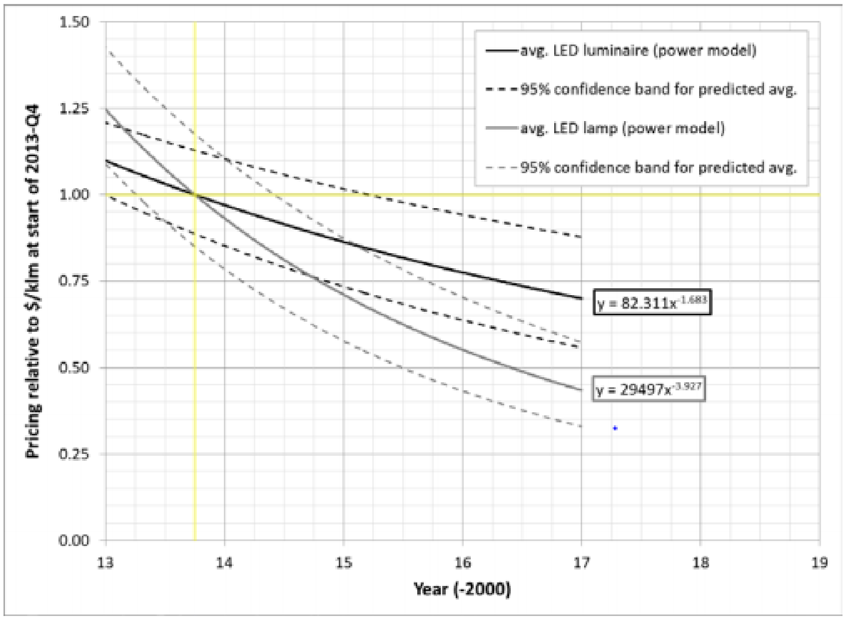


Figure 58: LED Lamp (CALiPER) and LED Luminaire (CALiPER and SCL) Pricing Trends Merged and Normalized for Equal Value at Start of 2013-Q4

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, of which one 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. In this report, nation-wide average of 10 cents per kWh is used. Appendix H has more discussion on the electricity rate.

7.3 DERIVING THE COST OF COMMERCIAL VERSIONS

This section derives the cost of the three demonstrated technologies at Fort Sill. The baseline technology of all the three demonstration sites is HPS based light fixtures and photo cell based on/off control. Photo cell will track the sunset and sunrise time every day although the light might be turned on a little bit earlier in the evening and be turned off a little later in the morning due to cloudy, rainy and snowy weather. In the calculation below, sunrise/sunset times from

National Oceanic and Atmospheric Administration (NOAA) as shown in Figure 59 are used to obtain the operation hours of every light fixture, which is 4,313hours in total annually.

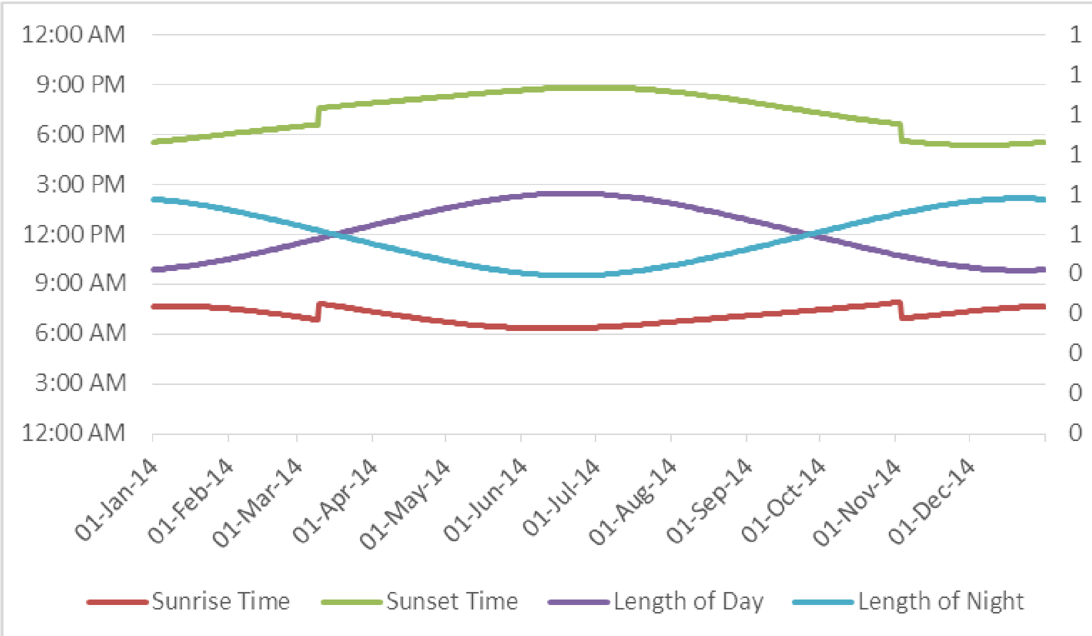


Figure 59: Annual Sunrise/Sunset Time and Associated Length of Day and Night

Table 36 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, we assume the total investment costs of the project include total costs of hardware capital costs, software costs and installation costs as well as SIOH (Supervision, Inspection and Overhead) and design costs, which is about 6% and 10% of the total costs.

Table 36: Cost Figures of Dynadimmer Demonstration – Parking Lot Lighting

	Dynadimmer – Building 4700	
	Baseline	**Demonstration**
Number of fixtures per site		36
Hardware capital costs incl. software (USD)	11,400	17,064
Installation costs (USD)	3,312	4,824
Total investment costs (USD)	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 (USD)		0.10
Annual energy cost (USD)	7,049	2,397
Annual energy savings (USD)		4,652

Annual maintenance cost (USD)	1,620	360
Annual maintenance cost savings (USD)		1,260
Simple payback in years (total investment/first-year savings)		4.29
Savings to Investment Ratio (SIR) in 10 years		1.99
Savings to Investment Ratio (SIR) in 20 years		3.49

The Dynadimmer system is a standalone lighting control system, and is naturally extendable to any scale of deployment regardless of the deployment size.

Table 37 summarizes the breakdown of the commercial cost that reflects the actual cost of the Starsense demonstration project deployed at Sheridan Road in Fort Sill.

Table 37: Cost Figures of Starsense Demonstration – Street Lighting

	Starsense – Sheridan Road	
	Baseline	**Demonstration**
Number of fixtures per site		40
Hardware capital costs incl. software (USD)	11,670	30,620
Installation costs (USD)	3,680	8,400
Total investment costs (USD)	17,806	45, 263
Energy savings percentage of the demonstration system		59%
Annual hours operation per pole	4,313	4,313
Utility price per kWh (USD)		0.10
Annual energy cost (USD)	5,089	2,087
Annual energy savings (USD)		3,002
Annual maintenance cost (USD)	1,800	400
Annual maintenance cost savings (USD)		1,400
Simple payback in years (total investment/first-year savings)		10.28
Savings to Investment Ratio (SIR) in 10 years		0.83
Savings to Investment Ratio (SIR) in 20 years		1.45

Since the size of ESTCP demonstration project is very small for the pilot purpose only, of which 40 nodes share the cost of Segment Controller 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 shown in Table 38.

Table 38: Projected Cost figures of Starsense in Practical Scale

	Starsense	
	Baseline	**Demonstration**
Number of fixtures per site		1,400
Hardware capital costs incl. software (USD)	376,150	714,700
Installation costs (USD)	128,800	294,000
Total investment costs (USD)	585,742	1,170,092
Energy savings percentage of the demonstration system		59%
Annual hours operation per pole	4,313	4,313
Utility price per kWh (USD)		0.10
Annual energy cost (USD)	178,127	73,032
Annual energy savings (USD)		105,095
Annual maintenance cost (USD)	63,000	14,000
Annual maintenance cost savings (USD)		49,000
Simple payback in years (total investment/first-year savings)		7.59
Savings to Investment Ratio (SIR) in 10 years		1.12
Savings to Investment Ratio (SIR) in 20 years		1.96

Table 39 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, we assume 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.

Table 39: Cost Figures of LOD Demonstration – Maintenance Facility Lighting

	LOD – TEMF	
	Baseline	**Demonstration**
Number of fixtures per site		42
Hardware capital costs incl. software (USD)	20,690	35,356
Installation costs (USD)	3,864	9,450
Total investment costs (USD)	28,482	51,975
Energy savings percentage of the demonstration system		92%
Annual hours operation per pole	4,313	4,313
Utility price per kWh (USD)		0.10
Annual energy cost (USD)	9,965	797
Annual energy savings (USD)		9,168
Annual maintenance cost (USD)	1,892	420
Annual maintenance cost savings (USD)		1,470
Simple payback in years (total investment/first-year savings)		4.89
Savings to Investment Ratio (SIR) in 10 years		1.75
Savings to Investment Ratio (SIR) in 20 years		3.08

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 Segment Controller and the management software. The cost figures of another deployment with 200 nodes are projected in Table 40. In this calculation, we assume one camera sensor will be deployed per 10 fixtures, and therefore 20 camera sensors are used in total.

Table 40: Projected Cost Figures of LOD in Practical Scale

	LOD – TEMF	
	Baseline	**Demonstration**
Number of fixtures per site		200
Hardware capital costs incl. software (USD)	94,950	133,000
Installation costs (USD)	18,400	45,000
Total investment costs (USD)	585,742	206,480
Energy savings percentage of the demonstration system		92%
Annual hours operation per pole	4,313	4,313
Utility price per kWh (USD)		0.10
Annual energy cost (USD)	47,452	3,796
Annual energy savings (USD)		43,656
Annual maintenance cost (USD)	9,000	2,000
Annual maintenance cost savings (USD)		7,000
Simple payback in years (total investment/first-year savings)		4.08
Savings to Investment Ratio (SIR) in 10 years		2.10
Savings to Investment Ratio (SIR) in 20 years		3.69

The above projected cost figures of larger deployment for the LOD system is even more attractive. Table 41 summarizes the overall cost performance of the systems under different considerations mentioned above.

Table 41: 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 :1400 nodes	7.59	1.96
LOD demonstration project	4.89	3.08
LOD practical scale : 200 nodes	4.08	3.69

8 IMPLMENTATION ISSUES

The formal project start was delayed by several months due to contractual formalities; however, we began engineering design and site preparatory work in anticipation of the contractual completion. These 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 our systems as they employ wireless communication using FCC certified ISM bands (IEEE 802.15.4). We conducted a wide range of tests using our 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 therefore 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 w a short term experiment thereby providing fewer approval formalities such as DIACAP. Also, it was found that we had much more latitude as long as we kept our networks 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 DIACAP 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 the installations and troubleshooting quickly and without interruption. An example of the benefit in using local contractors is:

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 illicit feedback on the change to energy efficient technologies. The surveys not only provided 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. . We were 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 (COTS) 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. We have proven the scalability of our systems which is essential for viable deployment across DoD.

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APPENDICES

Appendix A: HEALTH AND SAFETY PLAN (HASP)

Prior to the start of work each day on a jobsite, evaluate the site for any unsafe conditions at the jobsite and take appropriate steps to eliminate employee exposure.

Prior to the initiation of any work by employees, evaluate the hazards of that work, and instruct the employees as to site and job-specific hazards. As jobs change, site and job-specific instructions shall also change.

Insure that first aid and emergency services are available when required.

Investigate all accidents or near-miss accidents and take appropriate steps to eliminate the cause of the accident before work is resumed

Ensure that all personnel (workers or visitors) wear, as a minimum, the following personal protective equipment (PPE)

- Approved foot protection
- Approved safety glasses with side-shields – ANSI Z87 compliant
- Long pants
- Shirts with sleeves that cover the shoulders, no tank tops or cut-off shirts
- Electrical Arc Flash Protective Equipment as required by NFPA 70E and OSHA

Electrical dangers and improper electrical conditions, when observed, shall be corrected immediately.

Use of the following equipment is prohibited by all personnel:

- Metal ladders used while performing energized electrical work
- Damaged or defective equipment, such as frayed extension cords, missing grounding pins, etc.
- Not using equipment as designed or required by manufacturer such as daisy-chaining of electrical cords, indoor use only component being used outdoors, not protecting cords from physical damage, pinch points, (run through doorways), improperly strung in corridors, etc.

All personnel shall be protected from such electrical hazards:

- Exposed live electrical parts
- Ungrounded electrical equipment (double insulated tools are acceptable)

- Unprotected electrical cords, (ground not continuous).
- Non-GFCI protected equipment

Daily tests and inspections by a qualified person on the following construction equipment shall be made to ensure it is safe, free from defects, and functioning properly, (as intended):

- Lighting and illumination equipment
- Power and Electrical Equipment
- GFCIs
- Portable electric tools and cords
- Extension cords

Immediately tag out and remove all equipment found to be defective for repair or replacement.

Personnel who may accidentally come in contact with energized circuits while working within a Control Zone shall be protected by the following:

- Training in accordance with appropriate procedures
- Lockout and tagout
- A suitable barricade and signs
- Personal protective equipment appropriate for the task

Equipment failure shall be prevented by proper maintenance and inspection of all electrical equipment and other equipment/tools coming into contact with electric equipment/sources.

Appendix B: POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Dr. Jim Galvin	SERDP/ESTCP 901 North Stuart Street, Suite 303 Arlington, VA 22203	(703) 696-2121 (703) 696-2114 James.Galvin@osd.mil	Energy & Water Program Manager
Mr. Peter Knowles	HydroGeoLogic Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	(703) 736-4511 (703) 696-2114 pknowles@hgl.com	Energy & Water Program Manager Assistant
Satyen Mukherjee	Philips Research N. A. 345 Scarborough Road Briarcliff Manor NY 10510	(914) 945-6320 (914)-945-6014 Satyen.mukherjee@philips.com	Principle Investigator
Sree Venkit	Philips Lighting Electronics N.A. 10275 West Higgins Road Rosemont, IL 60018	(847) 390-5070 (847) 390-5264 sree.venkit@philips.com	Co-Principle Investigator
Kosta Papamichael	California Lighting Technology Center University of California, Davis	(530) 747-3834 (530) 747-3812 kpapamichael@ucdavis.edu	Co-Principle Investigator
Hieu Dang, Chief	Directorate of Public Works Building 1950 Barbour Rd. Fort Sill, OK 73503	(580) 442-3608 (580) 442-7307 christopher.a.brown112.civ@mail.mil	Fort Sill Liaison main Contact
John L Rutledge, Engineering Technician	Department of Public Works Building Barbour Road Fort Sill, OK 73503	(580) 704 1699 john.l.rutledge.civ@mail.mil	Fort Sill Contact
Misha Carlisle	Directorate of Public Works Building 1950 Barbour Rd. Fort Sill, OK 73503	(580) 442-3226 (580) 442-7307 misha.carlisle@us.army.mil	Fort Sill Contact
Dan Jiang	Philips Research N. A. 345 Scarborough Road Briarcliff Manor NY 10510	(914) 945-6284 (914) 945-6580 dan.jiang@philips.com	Key Performer

POINT OF CONTACT **Name**	**ORGANIZATION** **Name** **Address**	**Phone** **Fax** **E-mail**	**Role in Project**
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Thomas Patten	California Lighting Technology Center University of California, Davis	(530) 747-3848 (530) 747-3812 twpatten@ucdavis.edu	Performer
Kiran Challapali	Philips Research N. A. 345 Scarborough Road Briarcliff Manor NY 10510	(914) 945-6356 (914) 945-6330 kiran.challapali@philips.com	Advisor

Appendix C: SURVEY QUESTIONNAIRE

SURVEY QUESTIONNAIRE FOR KEY BASE PERSONNEL

SURVEY CATEGORIES

1. Visual Comfort / Glare
2. Light Quantity
3. Color
4. Uniformity/Illuminated Area
5. Safety
6. Overall preference

RATING SCALE

(1 2 3 4 5)
1 = Strongly Disagree
2: Somewhat Disagree
3: I don't know
4: Somewhat agree
5: Strongly agree

QUESTIONS

1. **Visual Comfort / Glare**
   a. The lighting is comfortable.
   (1 2 3 4 5)
   b. The light level is comfortable.
   (1 2 3 4 5)
   c. The light sources are not glaring.
   (1 2 3 4 5)
   d. The new street lights create more glare than the existing street lights.
   (1 2 3 4 5)
2. **Quantity of Light**
   a. There is too much light on the street.
   (1 2 3 4 5)
   b. There is not enough light on the street.
   (1 2 3 4 5)
   c. The new streetlights provide the right amount of light in the area.
   (1 2 3 4 5)
   d. The lights are too bright.
   (1 2 3 4 5)
   e. The lights are not bright enough.

(1 2 3 4 5)

f. The street is too dark.
(1 2 3 4 5)

g. The sidewalk is too dark.
(1 2 3 4 5)

h. The new street lights adequately illuminated the street.
(1 2 3 4 5)

i. The area is well lit.
(1 2 3 4 5)

3. Color

a. I like the color of the light.
(1 2 3 4 5)

b. I can distinguish colors easily, at night, under the new streetlights.
(1 2 3 4 5)

c. The color of the new street lights is noticeable compared to the existing street lights.
(1 2 3 4 5)

d. The color of the existing streetlights is better than the new streetlights.
(1 2 3 4 5)

e. The street lights improve my visibility while driving.
(1 2 3 4 5)

f. The streetlights improve my visibility as a pedestrian.
(1 2 3 4 5)

4. Uniformity

a. The light is uneven (patchy).
(1 2 3 4 5)

b. The lighting coverage is sufficient.
(1 2 3 4 5)

c. The lighting has dark areas.
(1 2 3 4 5)

d. The area is well lit.
(1 2 3 4 5)

5. Safety

a. The lighting makes me feel safe to walk here at night.
(1 2 3 4 5)

b. The lighting enables safer vehicular navigation.
(1 2 3 4 5)

c. The lighting makes me feel safer than areas lit with the existing lighting.
(1 2 3 4 5)

d. The street lights have improved my visibility as a pedestrian.

(1 2 3 4 5)

e. The street lights have improved my visibility as a driver.
   (1 2 3 4 5)
f. I can see objects better under these streetlights.
   (1 2 3 4 5)

6. Overall Preference

a. I support switching all our street lights to these street lights.
   (1 2 3 4 4)
b. I prefer this street lighting over the existing street lighting.
   (1 2 3 4 5)

SURVEY QUESTIONAIRE FOR INSTALLERS

INSTALLER QUESTIONNAIRE

Installer Name: ________________________________ Date of Interview: _________________

Number of persons doing the installation: __________

Did the products arrive in good condition, with all necessary components and installation instructions?
Y N
If no, what was damaged or missing?

____

____

____

Did you require the installation instructions, if provided, to install the luminaires? Y N

Were the instructions clear and accurate? Y N
If no, what was unclear?

____

____

____

Did you encounter any technical challenges during installation? Y N
If yes, what were they?

____

____

____

Have you installed exterior luminaires with controls prior to this job? Y N
If yes, where? What were they?

____

____

____

Have you installed LED luminaires prior to this job? Y N
If yes, where? What were they?

____

____

____

How long does it take to replace a typical luminaire (without controls) from start to finish?

____

____

____

Did the luminaires take longer to install than traditional luminaires used for this application? Y N
If yes, how much longer?

____

____

____

How did the installation time compare with your expectations?

____

____

____

Based on your experience with the installation and after viewing the completed system, would you recommend this type of product? If yes, why? If no, why not?

____

____

____

On a scale of 1-10, how would you rate the installation process? ___________

1 = Went smoothly and on time, no obstacles
10 = Difficult, many unforeseen challenges and obstacles

If you were to do this installation again, what, if anything, would you do differently? (Or advice to give to someone else who was preparing for this installation job.)

____

____

____

Any other comments?

____

____

____

____

____

____

Appendix D: ENERGY RESULTS

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
1/24/2014 Fri	104.60	94.15	21.25
1/25/2014 Sat	78.46	93.72	20.85
1/26/2014 Sun	81.57	93.43	20.45
1/27/2014 Mon	78.82	94.01	10.27
1/28/2014 Tue	82.02	93.46	21.27
1/29/2014 Wed	78.58	93.33	21.09
1/30/2014 Thu	79.82	93.07	20.94
1/31/2014 Fri	84.83	92.77	20.90
2/01/2014 Sat	81.42	92.87	21.02
2/02/2014 Sun	85.04	92.49	20.94
2/03/2014 Mon	81.80	92.08	20.77
2/04/2014 Tue	86.69	91.43	20.86
2/05/2014 Wed	80.87	91.60	21.16
2/06/2014 Thu	81.36	91.18	21.24
2/07/2014 Fri	82.56	90.74	21.01
2/08/2014 Sat	84.91	90.42	20.80
2/09/2014 Sun	84.76	90.36	20.65
2/10/2014 Mon	89.66	90.27	20.70
2/11/2014 Tue	85.76	89.62	20.64
2/12/2014 Wed	73.80	89.69	20.40
2/13/2014 Thu	75.48	89.76	20.35
2/14/2014 Fri	76.03	90.27	20.22
2/15/2014 Sat	74.77	89.95	20.21
2/16/2014 Sun	75.71	90.07	20.08
2/17/2014 Mon	74.11	89.66	19.90
2/18/2014 Tue	72.69	89.32	19.96
2/19/2014 Wed	76.21	89.37	19.85
2/20/2014 Thu	79.23	89.02	19.93
2/21/2014 Fri	70.57	88.37	20.08
2/22/2014 Sat	73.07	88.27	19.97
2/23/2014 Sun	73.66	88.18	20.07
2/24/2014 Mon	80.25	87.96	20.04
2/25/2014 Tue	75.18	88.32	20.15
2/26/2014 Wed	73.66	88.32	20.35
2/27/2014 Thu	69.46	87.96	20.16
2/28/2014 Fri	72.29	87.55	19.90
3/01/2014 Sat	81.20	87.62	20.06
3/02/2014 Sun	88.40	87.66	20.58
3/03/2014 Mon	95.26	86.70	20.33
3/04/2014 Tue	74.22	85.44	19.97
3/05/2014 Wed	78.90	85.24	19.93
3/06/2014 Thu	81.10	84.88	19.87
3/07/2014 Fri	66.63	84.55	19.70

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
3/08/2014 Sat	73.78	84.49	19.91
3/09/2014 Sun	66.27	77.24	18.39
3/10/2014 Mon	66.20	83.96	19.52
3/11/2014 Tue	67.67	83.67	19.41
3/12/2014 Wed	67.44	83.44	8.70
3/13/2014 Thu	66.66	83.01	19.55
3/14/2014 Fri	68.06	82.91	19.43
3/15/2014 Sat	80.48	82.66	19.35
3/16/2014 Sun	98.11	84.01	19.67
3/17/2014 Mon	64.38	82.77	43.75
3/18/2014 Tue	69.39	118.25	20.14
3/19/2014 Wed	108.27	83.15	21.15
3/20/2014 Thu	91.23	70.56	21.42
3/21/2014 Fri	67.32	83.81	21.41
3/22/2014 Sat	73.74	83.55	21.47
3/23/2014 Sun	63.32	83.32	21.65
3/24/2014 Mon	64.38	82.85	21.04
3/25/2014 Tue	64.44	82.57	21.06
3/26/2014 Wed	80.92	82.66	20.98
3/27/2014 Thu	97.58	82.39	20.70
3/28/2014 Fri	64.58	82.00	20.87
3/29/2014 Sat	61.53	81.67	20.83
3/30/2014 Sun	64.53	81.18	20.66
3/31/2014 Mon	69.22	81.03	20.44
4/01/2014 Tue	68.27	80.81	19.89
4/02/2014 Wed	62.05	80.51	19.62
4/03/2014 Thu	62.58	80.29	19.82
4/04/2014 Fri	61.40	79.74	20.05
4/05/2014 Sat	69.21	79.37	19.95
4/06/2014 Sun	66.91	79.26	20.64
4/07/2014 Mon	65.14	79.22	20.35
4/08/2014 Tue	56.67	78.98	20.41
4/09/2014 Wed	59.99	78.54	20.25
4/10/2014 Thu	59.33	78.40	20.20
4/11/2014 Fri	60.35	77.98	20.21
4/12/2014 Sat	61.95	77.99	20.08
4/13/2014 Sun	64.29	77.78	20.20
4/14/2014 Mon	60.22	77.73	20.39
4/15/2014 Tue	57.03	77.03	20.30
4/16/2014 Wed	58.82	76.91	20.18
4/17/2014 Thu	64.73	76.58	20.18
4/18/2014 Fri	62.18	76.28	20.11
4/19/2014 Sat	55.84	76.04	19.97
4/20/2014 Sun	63.52	75.84	19.98
4/21/2014 Mon	71.73	75.63	19.78
4/22/2014 Tue	82.20	75.31	19.72

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
4/23/2014 Wed	60.32	75.12	19.69
4/24/2014 Thu	64.02	74.83	19.70
4/25/2014 Fri	54.19	74.53	19.78
4/26/2014 Sat	57.00	74.40	19.73
4/27/2014 Sun	65.99	74.19	19.63
4/28/2014 Mon	54.68	73.93	19.65
4/29/2014 Tue	54.16	73.68	19.67
4/30/2014 Wed	55.01	73.45	19.78
5/01/2014 Thu	54.12	73.88	19.74
5/02/2014 Fri	54.15	73.65	19.64
5/03/2014 Sat	53.48	73.55	19.55
5/04/2014 Sun	53.69	73.45	17.96
5/05/2014 Mon	53.51	73.26	17.83
5/06/2014 Tue	53.73	73.02	17.86
5/07/2014 Wed	68.07	72.70	16.03
5/08/2014 Thu	94.29	72.33	17.80
5/09/2014 Fri	77.41	71.76	17.83
5/10/2014 Sat	52.46	72.16	17.80
5/11/2014 Sun	52.48	72.22	17.62
5/12/2014 Mon	74.38	72.06	17.56
5/13/2014 Tue	83.76	71.78	7.03
5/14/2014 Wed	57.00	71.36	0.00
5/15/2014 Thu	50.81	71.14	0.00
5/16/2014 Fri	52.10	69.99	0.00
5/17/2014 Sat	52.24	69.43	0.00
5/18/2014 Sun	54.23	69.20	0.00
5/19/2014 Mon	51.11	69.13	6.65
5/20/2014 Tue	50.47	68.94	9.98
5/21/2014 Wed	52.11	68.78	1.95
5/22/2014 Thu	52.40	68.54	0.00
5/23/2014 Fri	76.32	68.21	6.71
5/24/2014 Sat	81.20	67.83	17.25
5/25/2014 Sun	52.71	67.86	17.13
5/26/2014 Mon	60.34	67.75	17.03
5/27/2014 Tue	60.76	67.59	17.04
5/28/2014 Wed	48.68	67.35	17.03
5/29/2014 Thu	48.91	67.03	16.99
5/30/2014 Fri	49.06	67.20	17.03
5/31/2014 Sat	51.78	67.44	17.02
6/01/2014 Sun	49.09	67.44	16.91
6/02/2014 Mon	59.35	67.34	16.85
6/03/2014 Tue	48.93	67.21	17.06
6/04/2014 Wed	48.30	67.15	16.99
6/05/2014 Thu	50.92	67.06	17.03
6/06/2014 Fri	78.34	66.82	17.09
6/07/2014 Sat	77.86	66.71	17.18

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
6/08/2014 Sun	65.59	68.32	7.21
6/09/2014 Mon	78.00	67.85	17.30
6/10/2014 Tue	48.72	67.07	17.24
6/11/2014 Wed	48.31	66.71	17.18
6/12/2014 Thu	52.83	66.71	17.08
6/13/2014 Fri	48.31	66.82	17.10
6/14/2014 Sat	50.23	66.60	16.94
6/15/2014 Sun	53.58	66.70	16.90
6/16/2014 Mon	47.79	66.73	16.80
6/17/2014 Tue	48.27	66.74	16.79
6/18/2014 Wed	51.24	66.81	16.79
6/19/2014 Thu	72.84	66.80	16.86
6/20/2014 Fri	75.06	58.58	15.27
6/21/2014 Sat	48.84	43.95	16.75
6/22/2014 Sun	56.31	44.23	16.70
6/23/2014 Mon	61.35	44.21	17.06
6/24/2014 Tue	73.31	44.09	16.72
6/25/2014 Wed	65.73	44.21	17.46
6/26/2014 Thu	81.16	44.26	17.07
6/27/2014 Fri	49.03	44.32	16.62
6/28/2014 Sat	55.23	44.41	16.61
6/29/2014 Sun	48.41	44.40	16.51
6/30/2014 Mon	48.31	44.51	16.53
7/01/2014 Tue	53.82	44.81	16.61
7/02/2014 Wed	49.84	44.81	16.72
7/03/2014 Thu	48.91	44.79	16.75
7/04/2014 Fri	48.68	44.72	16.69
7/05/2014 Sat	50.75	44.84	16.59
7/06/2014 Sun	49.24	45.09	16.56
7/07/2014 Mon	48.42	45.59	16.61
7/08/2014 Tue	49.96	45.77	16.71
7/09/2014 Wed	53.47	45.87	16.70
7/10/2014 Thu	50.22	46.15	16.66
7/11/2014 Fri	48.49	46.42	16.67
7/12/2014 Sat	50.36	46.00	16.69
7/13/2014 Sun	50.08	46.13	16.71
7/14/2014 Mon	64.07	46.41	16.81
7/15/2014 Tue	78.27	46.69	16.84
7/16/2014 Wed	54.48	46.51	16.91
7/17/2014 Thu	72.74	47.59	16.99
7/18/2014 Fri	86.16	46.45	16.93
7/19/2014 Sat	54.57	46.81	16.85
7/20/2014 Sun	49.71	47.05	16.89
7/21/2014 Mon	55.44	47.27	16.94
7/22/2014 Tue	54.72	48.01	16.89
7/23/2014 Wed	52.40	46.22	16.92

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
7/24/2014 Thu	51.66	46.27	16.91
7/25/2014 Fri	52.10	48.17	17.05
7/26/2014 Sat	51.36	46.70	16.89
7/27/2014 Sun	51.49	46.83	16.97
7/28/2014 Mon	78.26	46.92	17.21
7/29/2014 Tue	92.18	46.61	17.26
7/30/2014 Wed	93.69	47.99	17.32
7/31/2014 Thu	71.93	47.42	17.34
8/01/2014 Fri	81.48	47.53	17.29
8/02/2014 Sat	83.50	47.97	17.26
8/03/2014 Sun	74.92	48.14	17.42
8/04/2014 Mon	54.05	48.28	17.60
8/05/2014 Tue	55.42	48.54	17.57
8/06/2014 Wed	73.62	48.90	18.68
8/07/2014 Thu	79.25	48.93	19.98
8/08/2014 Fri	57.05	49.13	19.91
8/09/2014 Sat	56.13	49.34	20.05
8/10/2014 Sun	57.23	49.38	18.91
8/11/2014 Mon	54.79	51.61	17.47
8/12/2014 Tue	55.19	50.74	17.60
8/13/2014 Wed	55.72	50.99	17.59
8/14/2014 Thu	56.22	51.49	17.60
8/15/2014 Fri	58.60	51.61	18.59
8/16/2014 Sat	64.95	51.64	20.05
8/17/2014 Sun	54.25	51.76	20.40
8/18/2014 Mon	55.93	51.54	20.74
8/19/2014 Tue	57.52	51.86	19.82
8/20/2014 Wed	60.09	52.24	19.07
8/21/2014 Thu	56.96	52.24	21.07
8/22/2014 Fri	57.70	52.66	19.68
8/23/2014 Sat	57.81	53.58	17.78
8/24/2014 Sun	58.91	53.80	19.12
8/25/2014 Mon	59.81	53.98	19.12
8/26/2014 Tue	58.52	54.14	19.16
8/27/2014 Wed	60.78	54.37	19.27
8/28/2014 Thu	73.69	54.30	19.45
8/29/2014 Fri	77.86	55.51	19.40
8/30/2014 Sat	84.85	55.82	19.29
8/31/2014 Sun	60.16	55.95	19.26
9/01/2014 Mon	59.94	56.08	19.30
9/02/2014 Tue	62.13	56.18	19.30
9/03/2014 Wed	60.34	56.33	19.32
9/04/2014 Thu	61.07	56.46	19.32
9/05/2014 Fri	61.57	56.66	12.55
9/06/2014 Sat	82.53	58.15	3.12
9/07/2014 Sun	88.51	57.38	3.06

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
9/08/2014 Mon	65.11	57.78	3.09
9/09/2014 Tue	61.08	57.97	9.75
9/10/2014 Wed	62.75	58.28	19.75
9/11/2014 Thu	70.30	58.62	20.09
9/12/2014 Fri	91.63	58.74	20.18
9/13/2014 Sat	91.50	58.17	20.26
9/14/2014 Sun	65.84	58.57	20.08
9/15/2014 Mon	75.28	59.17	21.28
9/16/2014 Tue	64.71	59.37	22.90
9/17/2014 Wed	67.07	59.58	22.86
9/18/2014 Thu	67.76	59.77	21.74
9/19/2014 Fri	68.26	60.07	21.29
9/20/2014 Sat	66.10	60.55	22.96
9/21/2014 Sun	67.94	60.70	18.31
9/22/2014 Mon	69.97	61.13	19.95
9/23/2014 Tue	65.07	61.61	19.95
9/24/2014 Wed	67.26	61.75	19.93
9/25/2014 Thu	68.13	61.76	19.93
9/26/2014 Fri	67.52	61.89	19.93
9/27/2014 Sat	70.60	61.99	19.89
9/28/2014 Sun	68.16	62.38	19.87
9/29/2014 Mon	68.72	62.44	20.03
9/30/2014 Tue	69.99	62.13	20.02
10/01/2014 Wed	69.21	62.35	19.94
10/02/2014 Thu	70.81	62.65	20.07
10/03/2014 Fri	67.50	62.70	20.30
10/04/2014 Sat	69.10	62.84	20.28
10/05/2014 Sun	71.16	63.03	20.10
10/06/2014 Mon	70.88	63.42	20.00
10/07/2014 Tue	69.63	63.71	20.03
10/08/2014 Wed	71.60	63.99	20.05
10/09/2014 Thu	71.56	64.24	20.03
10/10/2014 Fri	75.38	64.33	20.11
10/11/2014 Sat	95.43	64.38	20.32
10/12/2014 Sun	101.16	64.43	20.39
10/13/2014 Mon	79.00	64.98	20.52
10/14/2014 Tue	67.78	66.07	20.81
10/15/2014 Wed	72.04	66.29	20.90
10/16/2014 Thu	73.09	66.35	20.77
10/17/2014 Fri	73.70	66.53	20.74
10/18/2014 Sat	73.62	66.64	20.80
10/19/2014 Sun	81.99	66.70	20.48
10/20/2014 Mon	76.91	66.82	20.51
10/21/2014 Tue	73.43	67.03	20.48
10/22/2014 Wed	77.42	67.33	20.55
10/23/2014 Thu	80.93	67.74	20.56

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
10/24/2014 Fri	73.19	67.79	20.53
10/25/2014 Sat	75.20	68.01	20.29
10/26/2014 Sun	76.04	68.19	20.61
10/27/2014 Mon	78.33	68.41	20.81
10/28/2014 Tue	78.68	68.61	21.00
10/29/2014 Wed	76.60	68.72	21.06
10/30/2014 Thu	76.68	69.00	21.04
10/31/2014 Fri	77.64	69.39	21.17
11/01/2014 Sat	80.80	69.42	21.19
11/02/2014 Sun	84.47	69.73	21.08
11/03/2014 Mon	100.35	69.90	20.97
11/04/2014 Tue	131.39	70.46	21.39
11/05/2014 Wed	114.50	69.88	22.58
11/06/2014 Thu	81.00	70.80	21.13
11/07/2014 Fri	108.96	70.81	21.05
11/08/2014 Sat	113.68	71.00	21.07
11/09/2014 Sun	76.89	71.04	21.72
11/10/2014 Mon	80.26	71.24	23.57
11/11/2014 Tue	81.86	71.45	22.85
11/12/2014 Wed	88.07	71.55	23.27
11/13/2014 Thu	93.28	71.61	23.20
11/14/2014 Fri	112.92	71.59	23.08
11/15/2014 Sat	85.82	71.86	22.90
11/16/2014 Sun	98.92	72.02	23.01
11/17/2014 Mon	79.65	72.06	23.23
11/18/2014 Tue	82.19	71.63	23.19
11/19/2014 Wed	82.10	72.22	23.06
11/20/2014 Thu	85.01	72.40	22.93
11/21/2014 Fri	92.74	72.40	22.72
11/22/2014 Sat	147.27	73.68	22.68
11/23/2014 Sun	125.85	73.13	22.85
11/24/2014 Mon	113.06	73.32	23.09
11/25/2014 Tue	112.84	73.61	23.11
11/26/2014 Wed	112.38	73.82	23.11
11/27/2014 Thu	108.14	73.56	23.19
11/28/2014 Fri	83.49	73.37	23.01
11/29/2014 Sat	83.46	73.41	22.89
11/30/2014 Sun	84.05	73.60	23.08
12/01/2014 Mon	98.78	73.80	23.54
12/02/2014 Tue	111.60	73.87	13.77
12/03/2014 Wed	112.08	74.25	
12/04/2014 Thu	126.92	74.06	
12/05/2014 Fri	121.44	73.95	
12/06/2014 Sat	93.54	74.12	
12/07/2014 Sun	112.97		
12/08/2014 Mon	111.85		

	Measured Energy (kWh)		
Date	**B4700**	**Sheridan Road**	**TEMF**
12/09/2014 Tue	87.37		
12/10/2014 Wed	114.06		
12/11/2014 Thu	97.83		
12/12/2014 Fri	106.20		
12/13/2014 Sat	118.80		
12/14/2014 Sun	107.15		
12/15/2014 Mon	113.81		
12/16/2014 Tue	115.54		
12/17/2014 Wed	151.88		
12/18/2014 Thu	133.91		
12/19/2014 Fri	129.38		
12/20/2014 Sat	138.34		
12/21/2014 Sun	105.17		
12/22/2014 Mon	92.38		
12/23/2014 Tue	127.94		
12/24/2014 Wed	112.05		
12/25/2014 Thu	84.41		
12/26/2014 Fri	89.36		
12/27/2014 Sat	93.00		
12/28/2014 Sun	84.97		
12/29/2014 Mon	89.47		
12/30/2014 Tue	104.11		
12/31/2014 Wed	98.91		
1/01/2015 Thu	96.47		
1/02/2015 Fri	111.89		
1/03/2015 Sat	121.84		
1/04/2015 Sun	86.50		
1/05/2015 Mon	114.12		
1/06/2015 Tue	110.27		
1/07/2015 Wed	85.47		
1/08/2015 Thu	84.66		
1/09/2015 Fri	86.62		
1/10/2015 Sat	95.70		
1/11/2015 Sun	130.33		
1/12/2015 Mon	132.18		
1/13/2015 Tue	126.56		
End of Tabulated Energy Data			

Appendix E: ILLUMINANCE RESULTS

Units: Illuminance measurements were taken in a grid. The grid spacing is given here in feet in the following tables. The values in the tables are the illuminance values recorded at each grid point. The illuminance values are given here in footcandles.

TEMF – Incumbent:

(ft.)	0	11 3/7	22 6/7	34 2/7	45 5/7	57 1/7	68 4/7	80	91 3/7	102 6/7	114 2/7	125 5/7	137 1/7	148 4/7	160
0	1.9	3.0	4.3	3.6	2.5	3.1	5.3	4.5	3.7	3.1	1.9	1.5	1.3	1.6	1.5
17 1/2	2.2	5.6	8.3	3.1	4.1	4.2	4.8	7.3	8.6	5.5	3.4	2.8	3.1	4.0	3.7
35	2.0	5.2	8.3	6.5	4.7	4.2	2.9	7.5	9.1	5.8	3.9	3.4	4.1	6.1	5.6
52 1/2	1.5	3.4	3.8	4.2	3.3	3.2	1.7	4.2	5.4	4.2	3.2	3.1	3.3	4.5	4.4
70	1.0	1.7	2.0	2.3	2.1	2.1	2.1	2.1	2.6	2.3	2.1	1.9	1.9	2.1	2.4
87 1/2	0.9	1.6	1.7	2.0	1.8	1.9	3.3	2.2	2.0	1.8	1.6	1.4	1.5	1.2	1.1
105	2.0	2.8	3.2	3.1	2.7	2.3	4.8	4.0	3.4	2.8	2.2	1.7	1.5	1.4	1.4
122 1/2	3.0	5.4	6.6	5.3	3.7	3.8	5.4	7.4	7.7	5.3	3.5	2.8	2.7	2.7	2.3
140	3.9	6.5	9.0	6.8	5.0	4.6	3.8	8.6	9.5	7.0	4.8	3.8	3.4	4.4	4.1

TEMF – Post-Retrofit at 10%:

(ft.)	0	10	20	30	40	50	60	70	80	90	100	110	120
0	0.43	0.41	0.44	0.38	0.39	0.36	0.40	0.41	0.47	0.44	0.43	0.39	0.39
10	0.45	0.44	0.43	0.40	0.40	0.37	0.41	0.43	0.49	0.48	0.44	0.43	0.38
20	0.48	0.42	0.40	0.35	0.36	0.33	0.38	0.38	0.48	0.48	0.45	0.37	0.44
30	0.53	0.53	0.54	0.50	0.48	0.48	0.52	0.54	0.59	0.52	0.51	0.50	0.47
40	0.56	0.54	0.38	0.52	0.52	0.51	0.52	0.56	0.59	0.57	0.44	0.50	0.48
50	0.43	0.55	0.39	0.52	0.55	0.46	0.54	0.55	0.58	0.59	0.56	0.53	0.47
60	0.51	0.51	0.45	0.52	0.52	0.55	0.57	0.57	0.58	0.54	0.51	0.50	0.49
70	0.49	0.50	0.47	0.52	0.52	0.57	0.57	0.58	0.62	0.58	0.57	0.52	0.52
80	0.50	0.53	0.55	0.55	0.52	0.55	0.56	0.61	0.66	0.63	0.55	0.54	0.50
90	0.55	0.54	0.50	0.54	0.52	0.55	0.55	0.62	0.64	0.64	0.60	0.49	0.50
100	0.52	0.53	0.52	0.51	0.48	0.54	0.53	0.61	0.61	0.58	0.51	0.47	0.44
110	0.56	0.48	0.37	0.41	0.44	0.43	0.44	0.48	0.51	0.51	0.50	0.37	0.39

TEMF – Post-Retrofit at 100%:

(ft.)	0	10	20	30	40	50	60	70	80	90	100	110	120
0	3.16	3.02	3.29	2.82	2.84	2.70	2.95	3.09	3.52	3.28	3.35	2.97	2.90
10	3.32	3.23	3.43	2.95	2.93	2.77	3.06	3.37	3.64	3.54	3.28	3.26	2.87
20	3.53	2.91	2.46	2.55	2.56	2.43	2.73	2.73	2.77	3.63	3.37	2.96	3.04
30	3.81	3.89	3.87	3.69	3.57	3.47	3.72	3.36	4.23	4.17	3.79	3.72	3.38
40	3.95	4.02	3.95	3.80	3.80	3.72	3.80	4.17	4.40	4.27	3.95	3.71	3.45
50	3.99	4.02	3.98	3.82	4.03	3.87	3.89	4.07	4.38	4.15	4.20	3.82	3.56
60	3.33	3.75	3.70	3.81	3.86	3.88	4.18	3.99	4.22	4.21	3.86	3.78	3.49
70	3.25	3.76	3.71	3.87	3.72	4.06	4.17	4.30	4.35	4.13	3.96	3.75	3.60
80	3.62	4.02	4.02	4.02	3.71	3.91	4.05	4.51	4.69	4.56	4.19	3.81	3.56
90	3.90	3.94	3.68	3.80	3.72	3.83	4.01	4.52	4.74	4.71	4.23	3.28	3.66
100	3.48	3.85	3.56	3.16	3.43	3.71	3.84	4.40	4.50	4.51	3.72	3.22	3.32
110	4.05	2.98	2.78	2.98	2.60	3.08	3.16	3.42	3.52	3.23	3.71	3.56	2.91

B4700 – Incumbent at 100%:

(ft.)	50	25	0	25	50
0	0.30	0.30	0.30	0.20	0.30
10	0.60	0.70	0.60	0.60	0.60
20	1.20	1.30	1.20	0.20	1.60
30	1.00	1.60	2.90	1.10	2.90
40	1.70	2.50	3.60	3.50	4.10
50	0.30	0.30	1.10	5.90	7.80
60	1.40	2.10	3.40	5.00	5.60
70	1.00	2.20	2.20	8.40	3.00
80	1.10	1.20	1.30	3.30	1.50
90	0.30	0.70	0.60	1.60	0.70
100	0.40	0.40	0.50	0.50	0.40
110	0.60	0.60	0.70	0.00	0.20
120	1.10	1.30	1.20	0.20	1.10
130	1.70	1.60	2.60	1.70	2.90
140	2.30	1.90	3.90	6.50	4.60
150	1.30	0.20	2.10	5.20	0.70

B4700 – Post-Retrofit at 100%:

(ft.)	0	10	20	30	40	50	60	65
0	7.45	6.50	4.05	1.79	1.82	1.58	1.36	1.23
10	4.22	4.05	3.11	2.16	1.51	1.32	1.24	1.20
20	3.03	3.03	2.40	1.74	1.44	1.34	1.08	1.06
30	2.31	2.37	1.83	1.58	1.42	1.23	1.09	1.11
40	1.80	1.79	1.64	1.45	1.34	1.17	1.13	1.19
50	1.43	1.43	1.40	1.33	1.25	1.13	1.16	1.18
60	1.37	1.29	1.34	1.24	1.17	1.13	1.16	1.16
70	1.58	1.01	1.38	1.24	1.19	1.13	1.21	1.18
80	1.81	1.64	1.55	1.39	1.28	1.16	1.27	1.22
90	2.25	1.92	1.77	1.62	1.45	1.20	1.33	1.28
100	3.32	2.80	2.41	1.96	1.56	1.25	1.37	1.33
110	4.29	3.65	2.85	2.17	1.67	1.30	1.41	1.37
120	5.74	5.31	3.82	2.72	1.95	1.34	1.36	1.40
125	5.71	6.60	4.35	2.81	2.05	1.58	1.36	1.39

Sheridan Road – Incumbent at 100%:

(ft.)	0	3	9	15	21	27	33	39	45	51	57	60
0	1.1	1.3	1.6	2.1	1.9	0.7	0.5	0.7	0.5	0.4	0.4	0.2
15	0.6	0.8	1.1	0.9	1.9	0.7	0.3	0.5	0.4	0.3	0.3	0.2
30	0.4	0.4	0.7	0.3	1.2	0.4	0.2	0.3	0.3	0.3	0.2	0.1
45	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.3	0.2	0.3	0.2	0.1
60	0.2	0.3	0.0	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1
75	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1
90	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.1	0.1
105	0.4	0.5	0.6	0.4	0.6	0.5	0.5	0.3	0.3	0.2	0.2	0.1
120	0.5	0.5	0.7	0.5	0.7	0.7	0.6	0.4	0.3	0.2	0.2	0.1
135	0.7	0.8	1.0	1.0	1.0	0.9	0.7	0.6	0.3	0.3	0.2	0.1
150	1.0	1.1	1.3	1.2	1.3	0.8	0.6	0.6	0.5	0.3	0.2	0.1

Sheridan Road – Post-Retrofit at 80%:

(ft.)	0	3	9	15	21	27	33	39	45	51
0	2.59	3.27	3.39	3.02	2.53	2.00	1.52	1.21	0.95	0.72
15	2.15	2.73	2.82	2.59	2.13	1.72	1.32	1.11	0.93	0.73
30	1.41	0.37	1.17	1.73	1.47	1.26	1.05	0.93	0.80	0.68
45	0.90	1.09	1.14	1.15	1.03	0.96	0.83	0.74	0.67	0.58
60	0.48	0.72	0.77	0.77	0.74	0.70	0.67	0.62	0.60	0.55
75	0.41	0.54	0.58	0.62	0.61	0.60	0.58	0.56	0.55	0.52
90	0.38	0.51	0.56	0.57	0.61	0.59	0.57	0.56	0.54	0.52
105	0.33	0.60	0.91	0.68	0.72	0.70	0.66	0.63	0.56	0.55
120	0.69	0.78	1.46	0.84	0.98	0.90	0.80	0.75	0.66	0.59
135	1.10	1.38	1.43	1.43	1.40	1.23	1.07	0.97	0.78	0.69
150	1.64	2.27	2.23	2.15	1.98	1.67	1.35	1.19	0.97	0.77
165	2.19	2.95	3.16	2.86	2.48	1.97	1.51	1.23	0.97	0.79
175	2.29	3.21	3.31	2.98	2.52	1.96	1.50	1.22	0.98	0.77

Sheridan Road – Post-Retrofit at 40%:

(ft.)	0	3	9	15	21	27	33	39	45	51
0	1.41	1.74	1.78	1.58	1.30	1.07	0.80	0.67	0.51	0.40
15	1.13	1.38	1.42	1.34	1.10	0.93	0.76	0.60	0.47	0.38
30	0.70	0.87	0.93	0.91	0.78	0.69	0.58	0.51	0.41	0.36
45	0.46	0.55	0.58	0.60	0.55	0.52	0.46	0.41	0.34	0.28
60	0.29	0.35	0.39	0.41	0.39	0.38	0.34	0.35	0.31	0.29
75	0.22	0.28	0.31	0.31	0.33	0.32	0.31	0.30	0.29	0.28
90	0.22	0.28	0.29	0.31	0.32	0.32	0.31	0.30	0.29	0.28
105	0.26	0.34	0.33	0.38	0.39	0.37	0.34	0.32	0.32	0.29
120	0.39	0.48	0.46	0.62	0.52	0.48	0.44	0.42	0.37	0.32
135	0.59	0.78	0.72	0.78	0.74	0.65	0.59	0.49	0.43	0.32
150	0.98	1.21	1.15	1.19	1.03	0.88	0.73	0.59	0.53	0.43
165	1.31	1.63	1.62	1.54	1.29	1.05	0.79	0.63	0.51	0.41
175	1.35	1.70	1.74	1.58	1.30	1.04	0.80	0.63	0.51	0.39

Sheridan Road – Post-Retrofit Intersection at 90%:

(ft.)	0	6	12	18	32	38	44	50
0	1.22	1.36	1.39	1.36	0.96	0.84	0.68	0.56
6	0.92	1.06	1.07	1.05	0.77	0.66	0.59	0.51
12	0.72	0.87	0.93	0.91	0.68	0.55	0.46	0.38
18	0.52	0.50	0.76	0.77	0.66	0.61	0.56	0.52

Sheridan Road – Post-Retrofit Intersection at 65%:

(ft.)	0	6	12	18	32	38	44	50
0	0.94	0.99	1.02	0.99	0.73	0.62	0.54	0.46
6	0.70	0.81	0.85	0.82	0.62	0.55	0.49	0.42
12	0.60	0.69	0.72	0.73	0.57	0.41	0.40	0.34
18	0.30	0.37	0.52	0.51	0.50	0.44	0.41	0.39

Appendix F: SURVEY RESULTS

RESPONSES TO MAINTENANCE SURVEYS

Maintenance Questionnaire.		**Responder 1**	
		"Maintenance staff.PDF"	
Sheridan			
1	Did you notice the changes to the lighting?	A	Yes
2	How does the lighting affect your job?	B	Somewhat easier
3	Did you notice the dimming?	B	No
4	Does the dimming functionality affect your job?	B	Somewhat easier
5	How long did lighting maintenance take?	n/a	30 min
6	Have you encountered maintenance issues with the old lighting?	A	Yes. Changed bulbs regularly
7	Have you encountered maintenance issues with the new lighting?	A	Yes. Harder to diagnose because I'm not trained on how to fix
8	Rate your level of experience with outdoor lighting maintenance?	A	Very experienced
9	Rate your level of experience with LEDs?	B	Experienced
10	What is the best reason for lighting retrofit?	B	Energy Savings
11	What are the biggest challenges to lighting maintenance on the base?	n/a	All different kinds of ballasts and bulbs and fixtures
12	What is your overall preference?	A	Prefer new lights
13	Other comments	n/a	No Comment
B4700			
1	Did you notice the changes to the lighting?	A	Yes
2	How does the lighting affect your job?	B	Somewhat Easier
3	Did you notice the dimming?	B	No
4	Does the dimming functionality affect your job?	C	Doesn't affect my job
5	How long did lighting maintenance take?	n/a	30 min
6	Have you encountered maintenance issues with the old lighting?	A	Yes. "Bulbs going out often, having to get around cars to get access"
7	Have you encountered maintenance issues with the new lighting?	B	No

Maintenance Questionnaire.		**Responder 1**	
		"Maintenance staff.PDF"	
B4700			
8	Rate your level of experience with outdoor lighting maintenance?	B	Experienced
9	Rate your level of experience with LEDs?	B	Experienced
10	What is the best reason for lighting retrofit?	B	Energy Savings
11	What are the biggest challenges to lighting maintenance on the base?	n/a	Getting around cars in parking lots
12	What is your overall preference?	A	I prefer new the new lights
13	Other comments	n/a	No comment
TEMF			
1	Did you notice the changes to the lighting?	A	Yes
2	How does the lighting affect your job?	B	Somewhat easier
3	Did you notice the dimming?	B	No
4	Does the dimming functionality affect your job?	D	Somewhat harder
5	How long did lighting maintenance take?	n/a	15 min
6	Have you encountered maintenance issues with the old lighting?	A	Yes. "Bulbs going out on a regular basis"
7	Have you encountered maintenance issues with the new lighting?	B	No
8	Rate your level of experience with outdoor lighting maintenance?	B	Experienced
9	Rate your level of experience with LEDs?	B	Experienced
10	What is the best reason for lighting retrofit?	B	Energy Savings
11	What are the biggest challenges to lighting maintenance on the base?	n/a	"Understanding the motion sensors and where it is located, having to explain the function to every new soldier that has a problem with it"
12	What is your overall preference?	A	I prefer the new lights
13	Other comments	n/a	No comment

RESPONSES TO SECURITY SURVEYS (RESPONDERS 1-4)

		Responder 1		Responder 2		Responder 3		Responder 4	
Security Questionnaire		**"Security staff 1.pdf"**		**"Security staff 2.pdf"**		**"Security staff 3.pdf"**		**"Security staff 4.pdf"**	
Sheridan									
1	How important is street, parking, and outdoor area lighting to your ability to perform your job?		No Response	B	Somewhat important	A	Very important	A	Very important
2	How does the lighting retrofit affect your job?		No Response	B	Somewhat easier	B	somewhat easier	B	somewhat easier
3	Did you notice the changes to the lighting before receiving this survey?		No Response	B	No	A	Yes	B	No
4	Did you notice that the new lighting dims down to lower light levels at certain times?		No Response	B	No	B	No	B	No
5	How does the dimming functionality of the new lighting affect your job?		No Response	C	No Effect	C	No effect	C	No effect
6	Rate the brightness of the new lighting:		No Response	C	A little dim	B	Comfortably bright	B	Comfortably bright
7	Rate your color recognition ability with the new lighting:		No Response	C	Adequate		No response		no response
8	Rate your object recognition ability with the new lighting:		No Response	C	Adequate		No response		no response
9	What is your overall preference regarding the lighting retrofit?		No Response	C	No preference		No response		no response
10	Please provide any additional comments…	n/a		n/a	no comment	n/a	No response		no response

Security Questionnaire		**Responder 1** "Security staff 1.pdf"		**Responder 2** "Security staff 2.pdf"		**Responder 3** "Security staff 3.pdf"		**Responder 4** "Security staff 4.pdf"	
B4700									
1	How important is street, parking, and outdoor area lighting to your ability to perform your job?		No Response	B	Somewhat important	C	Neither important nor unimportant		no response
2	How does the lighting retrofit affect your job?		No Response	C	No effect	C	No effect		no response
3	Did you notice the changes to the lighting before receiving this survey?		No Response	B	No	B	No		no response
4	Did you notice that the new lighting dims down to lower light levels at certain times?		No Response	B	No		No response		no response
5	How does the dimming functionality of the new lighting affect your job?		No Response	B	Somewhat easier	A	Much easier		no response
6	Rate the brightness of the new lighting:		No Response	B	Comfortably bright	A	Too bright		no response
7	Rate your color recognition ability with the new lighting:		No Response	C	Adequate		No response	A	Very good
8	Rate your object recognition ability with the new lighting:		No Response	C	Adequate		No response	A	Very good
9	What is your overall preference regarding the lighting retrofit?		No Response	C	No preference		No response	A	I prefer the new lights
10	Please provide any additional comments…	n/a		n/a	no comment		No response	n/a	no comment

Security Questionnaire		**Responder 1**		**Responder 2**		**Responder 3**		**Responder 4**	
		"Security staff 1.pdf"		**"Security staff 2.pdf"**		**"Security staff 3.pdf"**		**"Security staff 4.pdf"**	
TEMF									
1	How important is street, parking, and outdoor area lighting to your ability to perform your job?	A	Very Important	C	Neither important nor unimportant	A	Very important		no response
2	How does the lighting retrofit affect your job?	B	It makes it somewhat easier	C	No effect	A	Much easier		no response
3	Did you notice the changes to the lighting before receiving this survey?	A	Yes	B	No	A	Yes		no response
4	Did you notice that now the light level at the TEMF parking lot responds to motion?	A	Yes	B	No	A	Yes		no response
5	How does the dimming functionality of the new lighting affect your job?	C	No effect	D	Makes it somewhat harder	A	Much easier		no response
6	Rate the brightness of the new lighting when the fixtures are on HIGH:	B	Comfortably bright	C	a little dim	B	Comfortably bright		no response
7	Rate the brightness of the new lighting when the fixtures are on LOW:	C	A little dim	C	a little dim		No response	C	a little dim
8	Rate your color recognition ability with the new lighting:	C	Adequate	C	adequate		No response	C	adequate
9	Rate your object recognition ability with the new lighting:	B	Good	C	adequate		No response	C	adequate
10	What is your overall preference regarding the lighting retrofit?	A	I prefer the new lights	C	No preference		No response	A	I prefer the new lights

Security Questionnaire		**Responder 1** "Security staff 1.pdf"		**Responder 2** "Security staff 2.pdf"		**Responder 3** "Security staff 3.pdf"		**Responder 4** "Security staff 4.pdf"	
11	Please provide any additional comments…	n/a	"The TEMF has not been utilized since I've been assigned to this zone (approx. 1 mo.). However, the lighting even in LOW Mode seems adequate."	n/a	no comment		No response	n/a	No comment

RESPONSES TO SECURITY SURVEYS (RESPONDERS 5-7)

	Security Questionnaire	**Responder 5** "Security staff 5.pdf"		**Responder 6** "Security staff 6.pdf"		**Responder 7** "Security staff 7.pdf"	
Sheridan							
1	How important is street, parking, and outdoor area lighting to your ability to perform your job?	C	Neither important nor unimportant		no response	A	Very important
2	How does the lighting retrofit affect your job?	C	No effect		no response	A	Much easier
3	Did you notice the changes to the lighting before receiving this survey?	B	No		no response	B	No
4	Did you notice that the new lighting dims down to lower light levels at certain times?	B	No		no response	B	No
5	How does the dimming functionality of the new lighting affect your job?	C	No effect		no response	A	Much easier
6	Rate the brightness of the new lighting:	C	A little dim		no response	B	Comfortably bright
7	Rate your color recognition ability with the new lighting:	C	Adequate		no response	A	Very good
8	Rate your object recognition ability with the new lighting:	C	Adequate		no response	A	Very good
9	What is your overall preference regarding the lighting retrofit?	C	No preference		no response	A	I prefer the new lights
10	Please provide any additional comments…	n/a	no comment		no response	n/a	no comment

Security Questionnaire		**Responder 5**		**Responder 6**		**Responder 7**	
		"Security staff 5.pdf"		**"Security staff 6.pdf"**		**"Security staff 7.pdf"**	
B4700							
1	How important is street, parking, and outdoor area lighting to your ability to perform your job?	C	Neither important nor unimportant	A	Very important	A	Very important
2	How does the lighting retrofit affect your job?	B	somewhat easier	C	No effect	A	Much easier
3	Did you notice the changes to the lighting before receiving this survey?	B	No		no response		no response
4	Did you notice that the new lighting dims down to lower light levels at certain times?	B	No	B	No	B	No
5	How does the dimming functionality of the new lighting affect your job?	C	No effect	C	No effect	A	Much easier
6	Rate the brightness of the new lighting:	C	A little dim	C	A little dim	B	Comfortably bright
7	Rate your color recognition ability with the new lighting:	C	Adequate	C	Adequate	A	Very good
8	Rate your object recognition ability with the new lighting:	C	Adequate	C	Adequate	A	Very good
9	What is your overall preference regarding the lighting retrofit?	C	No preference	C	No preference	A	I prefer the new lights
10	Please provide any additional comments…	n/a	no comment	n/a	no comment	n/a	no comment

Security Questionnaire		**Responder 5** "Security staff 5.pdf"		**Responder 6** "Security staff 6.pdf"		**Responder 7** "Security staff 7.pdf"	
TEMF							
1	How important is street, parking, and outdoor area lighting to your ability to perform your job?	B	Somewhat important	B	Somewhat important	A	Very important
2	How does the lighting retrofit affect your job?	B	somewhat easier	C	No effect	A	Much easier
3	Did you notice the changes to the lighting before receiving this survey?	B	No	B	No	B	No
4	Did you notice that now the light level at the TEMF parking lot responds to motion?	B	No	B	No	B	No
5	How does the dimming functionality of the new lighting affect your job?	C	No effect	C	No effect	A	Much easier
6	Rate the brightness of the new lighting when the fixtures are on HIGH:	C	a little dim	C	a little dim	B	Comfortably bright
7	Rate the brightness of the new lighting when the fixtures are on LOW:	C	a little dim	C	a little dim	B	Comfortably bright
8	Rate your **color recognition** ability with the new lighting:	C	adequate	C	adequate	A	Very good
9	Rate your **object recognition** ability with the new lighting:	C	adequate	C	adequate	A	Very good
10	What is your overall preference regarding the lighting retrofit?	C	No preference	C	No preference	A	No preference
11	Please provide any additional comments…	n/a	no comment	n/a	no comment	n/a	no comment

Appendix G: SHORTCOMINGS OF CURRENT LIGHTING METRICS & UNITS

Shortcomings of Current Lighting Metrics & Units

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February 1, 2015

Introduction

The main lighting metric used to determine the appropriateness of illumination has traditionally been the amount of light per unit area at points of interest, usually work surfaces. This metric is called *Illuminance* and is measured in *Lumens* (the photometric equivalent to Watt) per area. If area is expressed in square feet, then the illuminance unit is called *Foot-Candle*; if it is measured in square meters it is called *Lux*. Both Illuminance (the metric) and Lumen (the unit) have major shortcomings, as neither represents what the human eye sees, which is the distribution of light arriving to it from all surfaces within the human field of view. This white paper is focused on explaining the Illuminance and Lumens shortcomings. Moreover, it includes suggestions for better lighting metrics and units that address the complete effects of light on humans.

Illuminance

Illuminance is a metric of the density of luminous flux arriving at a surface from all possible directions. This provides information about the amount of light reaching a work surface, but not about the directional input of light to the eye, referred to as *Luminance (a.k.a. objective brightness) Distribution*, which is what really matters in determining visual performance.

We have known for the longest time that Illuminance is not really a good metric for lighting performance. The reason that it prevailed is the low cost of illuminance meters (starting at about $10) and the speed of taking measurements (a couple of seconds). In contrast, luminance meters are pretty expensive (stating at about $2,000) and while a single-direction measurement takes the same amount as the illuminance measurement, the time required to determine luminance from all incoming directions to the eye, is extremely long, making it practically impossible with manual methods incoming directions sequentially.

Today we can easily measure luminance distributions using *High Dynamic Range Images* (that can be produced with digital cameras) and software[1]. Unfortunately, most standards are still expressed in terms of illuminance and, even though the original barriers have been removed, luminance distributions are the exception rather than the norm. Hopefully that practice will

[1] Papamichael, K., Fernandes, L., Thanachareonkit, A., "HDR Imaging in Lighting Practice." Lighting Design and Application, Illuminating Engineering Society of North America, Nov. 2010.

change as we learn more about dealing with distributions of numbers, rather than single numbers in determining luminous performance.

Aiming only for illuminance in the areas that we think we need light, e.g., street pavement is very ineffective and potentially inappropriate because focusing only on the street pavement and directing all light to it makes all other surfaces appear much darker. This is because the human eye sees in relative terms. Making some surfaces brighter makes the rest appear dimmer. With new LED lights, we can focus most of the light on the street pavement, which makes all surrounding non-street-pavement areas very dark. Some of the "wasted" light of pre-LED lighting may have been beneficial after all (Figure 60). Proper evaluation should include HDR imaging (and simulations) to really understand visual performance.

Figure 60: High Pressure Sodium (before) vs. LED (after) Street Lighting

Lumen

The lumen accounts only for the combined sensitivity of the three color sensors of the eye, called cones, which peaks in the green-yellow part of the visible spectrum (555 nm) and is called "Photopic" sensitivity (Figure 2).

The majority of cones are in area of the retina called fovea, which corresponds to a 1 degree solid angle in the direction of focus. The rest of the solid angle of the human eye field of view is ignored in the lumen unit. Traditionally, all photometers use the photopic sensitivity to determine lumens from the spectral power distribution of light.

The non-fovea are of the human retina has non-color sensors, called rods, whose sensitivity peaks in the blue-green part of the visible spectrum (495 nm) and is called "Scotopic" sensitivity (Figure 2). Rods are much more sensitive to light than cones and are active at low light levels.

Cones are less sensitive and are active under high light levels. While Scotopic light meters are available, they are pretty expensive, mainly because of very limited use.

In addition to the cones and rods, the human eye also has a third photo sensitive sensor type, called ipRGC (for intrinsically photosensitive Retinal Ganglion Cell), whose sensitivity peaks in the blue are of the visible spectrum (464 nm) (Figure 61).

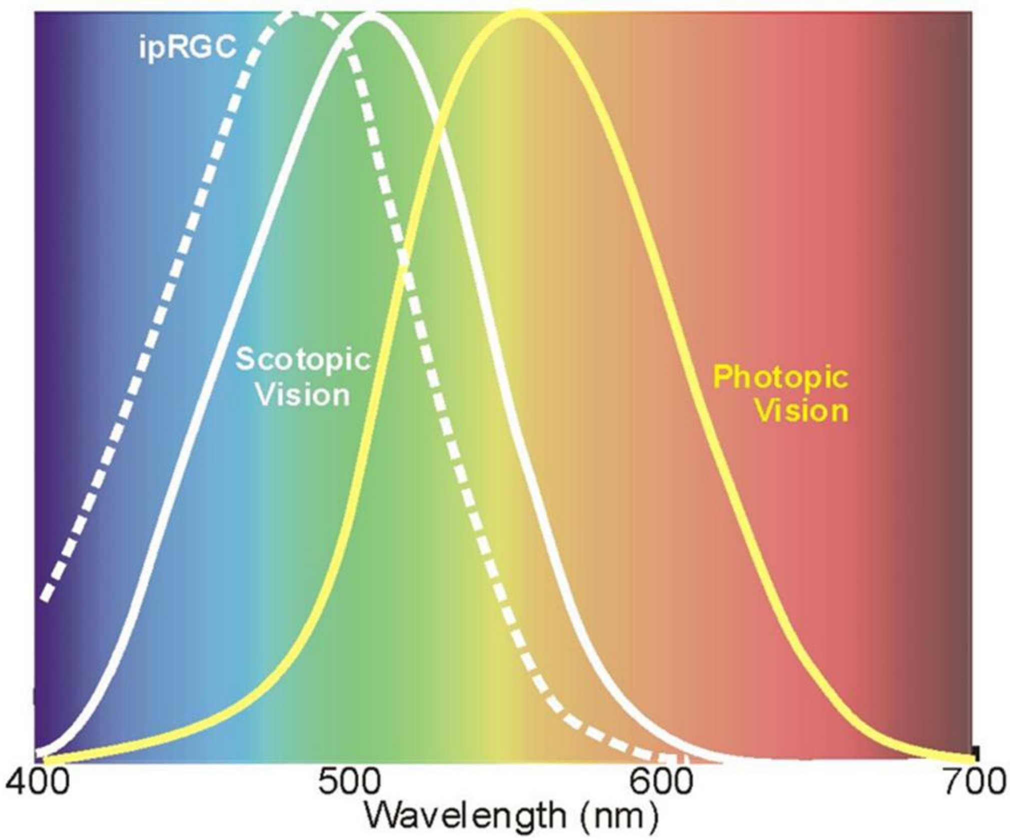

Figure 61: The Photopic, Scotopic and ipRGC Sensitivities

The ipRGC sensors are mostly at the lower part of the retina and their signal is used by the brain for brightness reception and also for adjusting circadian rhythms, i.e., the operation of the body during day and night. As humans we have evolved with very little if any blue light exposure at night. Fire and incandescent lighting have very little blue content and at low intensity. In contrast, fluorescent and LED lights produce significant output in the blue part of the spectrum, which can significantly disrupt circadian rhythms.

There is plenty of evidence that exposure to blue light at night is bad for our health and well-being and the exposure effects take time before they manifest. The American Medical Association released a statement in November of 2012, officially stating the risks from blue light at night.

When designing and implementing lighting solutions, we should include consideration of all sensitivities of the human eye to ensure that we serve visual as well as the biological needs.

Today we ignore the circadian effects of blue light at night and it seems that it may be causing significant long-term harm. We are also ignoring potential effects of blue light at night on the health of the eye itself, which could be significant as well.

Implementation Issues & Recommendations

While today we can determine not only photopic but also scotopic and ipRGC illuminance and luminance distributions, we do not have effective ways of using them, i.e., performance standards that we can aim for.

Luminance distributions are most important to determine visual comfort in terms of luminance ratios within the field of view and it is relatively straight forward to consider them for determination of luminous performance.

Scotopic sensitivity is being considered mainly through the Scotopic/Photopic (S/P) ratio that can be used to determine "equivalent photopic lumens" for environments with light levels that are between scotopic and photopic conditions, a.k.a. mesopic conditions.

ipRGC sensitivity is important in computing the dosage of light affecting circadian rhythms, as a function of intensity and duration, in addition to timing. However, we do not have generally accepted standards that link dosage to potential effects.

More research work is needed in these areas to help develop performance standards that can be used to more effectively evaluate luminous performance in different environments.

Appendix H: ELECTRICITY RATES

Electricity rate is one of the important cost drivers that directly impacts the payback period of the demonstrated technologies. These rates vary widely from state to state thereby influencing the return on investment (ROI) depending on the location of the DOD bases where they are deployed.

Figure 62 shows all the military bases in the States across the country.

Figure 62: Military Bases in the U.S.

Table 42 below summarizes the electricity rates of the states (published by U.S. Energy Information Administration in January 2015). The rate figures show large variance, from as low as 5.50 cents in the transportation sector in Illinois, to as high as 37.59 cents in the residential sector in Hawaii. Even in the same state, different sectors vary in rate. The nation-wide average electricity rate is about 10 cents for all sectors, which is the baseline rate we have used in this report.

To estimate the level of impact of our technologies in the different regions, Table 43 lists all states where the average electricity rate exceeds is more than 10 cents per kWh. For these states, the expected ROI will be better than the estimated average. Also listed in the table are the number of personnel in DOD bases in the entire state which is assumed to be an indication of the size of the bases. The product of the electricity rate and the number of personnel can be considered as a figure of merit (or impact indicator) for the impact of deployment of these technologies in the respective regions. Table 43 lists the states in decreasing order with respect to the impact indicator. According to this table, California ranks the highest in potential impact potential due to the large number of military personnel and Hawaii ranks second due to its high electricity rate.

Table 42: Average Retail Price of Electricity to Ultimate Customers by End-Use Sector by State, December 2014 and 2013 (Cents per Kilowatthour)

	Residential		Commercial		Industrial		Transportation		All Sectors	
Census Division and State Graph	December 2014	December 2013	December 2014	December 2013	December 2014	December 2013	December 2014	December 2013	December 2014	December 2013
New England Graph	18.83	18.26	14.94	15.36	11.73	12.60	8.85	13.11	16.05	16.02
Connecticut Graph	19.69	17.59	15.70	14.73	13.08	12.53	11.35	12.58	17.23	15.83
Maine Graph	15.71	14.31	NM	12.98	9.10	9.23	--	--	13.20	12.65
Massachusetts Graph	19.66	20.00	14.92	16.42	12.32	13.42	NM	13.45	16.34	17.02
New Hampshire Graph	18.52	16.13	14.68	14.30	11.79	11.97	--	--	15.79	14.71
Rhode Island Graph	17.03	20.17	15.39	16.83	13.53	14.32	17.75	11.24	15.88	17.97
Vermont Graph	16.69	17.03	14.39	14.85	9.96	11.19	--	--	14.21	14.79
Middle Atlantic Graph	15.79	15.24	12.71	12.44	7.14	7.11	12.13	11.52	12.80	12.48
New Jersey Graph	15.56	15.28	12.10	12.23	10.36	10.74	9.86	11.35	13.23	13.28
New York Graph	19.26	18.18	14.87	14.45	6.13	5.97	13.60	12.62	15.40	14.74
Pennsylvania Graph	13.01	12.75	9.54	9.19	6.99	6.99	7.43	7.90	10.13	9.95
East North Central Graph	12.28	11.49	9.75	9.23	6.79	6.47	7.04	5.04	9.71	9.19
Illinois Graph	11.31	9.84	8.52	7.80	6.33	5.68	6.81	4.67	8.84	7.91
Indiana Graph	11.07	10.49	9.85	9.51	6.73	6.68	9.65	9.13	8.95	8.70
Michigan Graph	13.95	14.20	10.61	10.72	7.43	7.50	11.70	11.99	10.87	11.09
Ohio Graph	12.32	11.30	9.89	9.06	6.57	6.11	7.89	6.73	9.83	9.05
Wisconsin Graph	13.41	12.79	10.69	10.05	7.34	6.92	--	--	10.57	10.08
West North Central Graph	10.12	9.96	8.46	8.34	6.29	6.29	8.11	7.82	8.50	8.43
Iowa Graph	10.12	10.33	7.80	8.02	5.22	5.15	--	--	7.58	7.72
Kansas Graph	11.34	10.92	9.31	9.32	7.30	7.22	--	--	9.47	9.33
Minnesota Graph	11.49	11.20	9.02	8.92	6.53	6.85	9.43	9.17	9.14	9.15
Missouri Graph	9.37	9.18	7.99	7.66	5.52	5.60	6.52	6.40	8.18	8.02
Nebraska Graph	9.31	9.18	8.34	8.18	6.75	6.78	--	--	8.22	8.10
North Dakota Graph	8.34	8.56	8.04	8.26	7.90	7.11	--	--	8.10	8.04
South Dakota Graph	10.03	9.66	8.60	8.25	6.88	6.77	--	--	8.89	8.58
South Atlantic Graph	11.30	11.04	9.57	9.39	6.37	6.55	8.80	8.76	9.82	9.70
Delaware Graph	13.11	12.64	10.23	10.44	8.41	8.53	--	--	11.06	11.08
District of Columbia Graph	12.07	12.50	11.87	11.93	10.03	4.63	NM	9.93	11.80	11.83
Florida Graph	11.92	11.31	10.02	9.44	7.94	7.53	9.63	9.08	10.81	10.22
Georgia Graph	10.40	10.41	9.65	9.92	5.79	6.14	5.30	7.55	9.06	9.27
Maryland Graph	13.51	13.43	10.89	10.82	8.42	8.43	9.41	8.58	11.94	11.91
North Carolina Graph	10.48	10.56	8.47	8.86	5.95	6.43	7.64	8.07	9.02	9.30
South Carolina Graph	11.82	11.68	10.16	9.97	5.86	6.37	--	--	9.36	9.51

Census Division and State Graph	Residential December 2014	Residential December 2013	Commercial December 2014	Commercial December 2013	Industrial December 2014	Industrial December 2013	Transportation December 2014	Transportation December 2013	All Sectors December 2014	All Sectors December 2013
Virginia Graph	10.97	10.36	8.45	7.86	7.04	6.56	8.39	8.31	9.41	8.85
West Virginia Graph	9.08	9.08	7.79	7.75	5.70	5.91	10.03	9.93	7.57	7.70
East South Central Graph	10.44	10.02	10.26	9.84	5.60	5.80	8.14	12.49	8.77	8.65
Alabama Graph	11.08	10.50	10.71	10.29	5.70	5.59	--	--	8.83	8.67
Kentucky Graph	9.81	9.52	9.45	8.86	5.02	5.68	--	--	7.86	7.93
Mississippi Graph	11.30	10.54	10.98	10.54	6.43	6.21	--	--	9.53	9.08
Tennessee Graph	10.06	9.79	10.14	9.82	5.67	5.97	8.14	12.49	9.11	9.00
West South Central Graph	10.78	10.34	8.07	8.03	5.99	5.72	5.58	7.47	8.42	8.27
Arkansas Graph	9.07	8.98	7.80	7.96	5.66	5.88	11.03	11.21	7.57	7.67
Louisiana Graph	9.17	8.76	9.12	8.81	5.73	5.58	8.72	8.58	7.80	7.62
Oklahoma Graph	8.91	8.20	7.44	7.35	5.23	5.38	--	--	7.40	7.21
Texas Graph	11.76	11.27	8.00	8.00	6.26	5.79	5.34	5.32	8.86	8.67
Mountain Graph	10.97	10.79	9.09	8.94	6.06	6.09	9.95	10.13	8.81	8.80
Arizona Graph	10.92	10.97	9.33	9.17	5.94	6.18	--	--	9.24	9.37
Colorado Graph	11.44	11.46	9.44	9.50	6.71	6.89	10.27	10.52	9.41	9.51
Idaho Graph	9.41	9.26	7.61	7.37	5.87	5.66	--	--	7.94	7.85
Montana Graph	9.73	9.94	9.41	9.46	5.14	5.51	--	--	8.37	8.63
Nevada Graph	12.95	12.30	9.52	9.43	5.94	5.79	8.73	8.18	9.06	8.93
New Mexico Graph	11.58	10.84	9.96	9.34	5.86	6.10	--	--	9.12	8.80
Utah Graph	10.34	9.98	7.71	7.65	5.58	5.35	9.70	9.95	7.82	7.70
Wyoming Graph	10.49	10.11	8.69	8.37	6.51	6.45	--	--	7.79	7.70
Pacific Contiguous Graph	13.48	12.92	12.39	11.06	7.81	7.33	8.51	8.73	11.89	11.06
California Graph	17.08	16.12	14.09	12.25	10.78	9.61	8.49	8.74	14.54	13.16
Oregon Graph	10.29	9.92	8.65	8.57	5.77	5.56	9.19	8.63	8.80	8.66
Washington Graph	8.22	8.66	7.76	7.91	4.02	4.28	7.78	8.11	6.97	7.33
Pacific Noncontiguous Graph	26.50	27.20	24.26	25.67	24.32	26.22	--	--	24.98	26.32
Alaska Graph	18.45	18.04	16.33	16.70	14.18	16.69	--	--	16.68	17.21
Hawaii Graph	34.59	36.58	32.09	33.68	28.13	29.86	--	--	31.22	33.10
U.S. Total Graph	12.15	11.72	10.34	9.96	6.65	6.63	10.25	10.20	10.13	9.86

Table 43: Ranking of High Impact States Applying the Demonstrated Technologies

State	**Electricity Rate** (cents/kWh)	**Number of DoD Staff** (k)	**Impact Indicator** (electricity rate X number of DOD staff)
California	14.66	213	3122
Hawaii	33.7	45	1516
Florida	10.4	109	1133
New York	14.27	71	1013
Maryland	11.62	57	662
New Jersey	13.13	32	420
Massachusetts	14.31	29	414
Alaska	17.02	24	408
Michigan	10.94	33	361
District of Columbia	12.04	23	276

Wisconsin	10.73	25	268
Connecticut	15.98	16	255
Rhode Island	14.25	10	142
Maine	11.7	10	117
Delaware	11.09	10	110
New Hampshire	14.21	6	85
Vermont	14.65	5	73

Appendix I: BLCC CONFIGURATION DOCUMENTS

1. BLCC CONFIGURATION DOCUMENT FOR DYNADIMMER IN 10-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 Dynadimmer</Name>
  <Comment>Dynadimmer 10-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>11 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>Dynadimmer LED</Name>
          <Duration>0 years 0 months</Duration>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
              <Portions>1.0
              </Portions>
              <Intervals>0 years 0 months
              </Intervals>
            </PhaseIn>
          </PhaseIn>
          <ResaleEscalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </ResaleEscalation>
          <ConstructionCost>21888.0</ConstructionCost>
          <SIOH>1313.28</SIOH>
          <DesignCost>2188.8</DesignCost>
          <RecurringCosts>
            <RecurringCost>
              <Name>maintenance cost</Name>
              <Duration>Remaining</Duration>
              <Amount>1260.0</Amount>
              <Escalation>
                <SimpleEscalation>
                </SimpleEscalation>
              </Escalation>
              <Index>
                <UsageIndex>
```

```
                <Intervals>Remaining
                </Intervals>
                <Values>1.0
                </Values>
              </UsageIndex>
            </Index>
          </RecurringCost>
        </RecurringCosts>
      </CapitalComponent>
    </CapitalComponents>
    <EnergyUsages>
      <EnergyUsage>
        <FuelType>Electricity</FuelType>
        <Name>Electricity</Name>
        <Duration>Remaining</Duration>
        <YearlyUsage>46525.0</YearlyUsage>
        <Units>kWh</Units>
        <UnitCost>0.1</UnitCost>
        <UsageIndex>
          <UsageIndex>
            <Intervals>Remaining
            </Intervals>
            <Values>1.0
            </Values>
          </UsageIndex>
        </UsageIndex>
        <State>Oklahoma</State>
        <RateSchedule>Commercial</RateSchedule>
        <Emissions>Oklahoma</Emissions>
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    </EnergyUsages>
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  </Alternatives>
</Project>
```


2. BLCC CONFIGURATION DOCUMENT FOR DYNADIMMER IN 20-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 Dynadimmer</Name>
  <Comment>Dynadimmer 20-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>21 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
```

```
        <Name>Dynadimmer LED</Name>
        <Duration>0 years 0 months</Duration>
          <Escalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </Escalation>
        <PhaseIn>
          <PhaseIn>
            <Portions>1.0
            </Portions>
            <Intervals>0 years 0 months
            </Intervals>
          </PhaseIn>
        </PhaseIn>
        <ResaleEscalation>
          <SimpleEscalation>
          </SimpleEscalation>
        </ResaleEscalation>
        <ConstructionCost>21888.0</ConstructionCost>
        <SIOH>1313.28</SIOH>
        <DesignCost>2188.8</DesignCost>
        <RecurringCosts>
          <RecurringCost>
            <Name>maintenance cost</Name>
            <Duration>Remaining</Duration>
            <Amount>1260.0</Amount>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
            <Index>
              <UsageIndex>
                <Intervals>Remaining
                </Intervals>
                <Values>1.0
                </Values>
              </UsageIndex>
            </Index>
          </RecurringCost>
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    </CapitalComponents>
    <EnergyUsages>
      <EnergyUsage>
        <FuelType>Electricity</FuelType>
        <Name>Electricity</Name>
        <Duration>Remaining</Duration>
        <YearlyUsage>46525.0</YearlyUsage>
        <Units>kWh</Units>
        <UnitCost>0.1</UnitCost>
        <UsageIndex>
          <UsageIndex>
            <Intervals>Remaining
            </Intervals>
            <Values>1.0
            </Values>
```

```
        </UsageIndex>
      </UsageIndex>
      <State>Oklahoma</State>
      <RateSchedule>Commercial</RateSchedule>
      <Emissions>Oklahoma</Emissions>
    </EnergyUsage>
   </EnergyUsages>
  </Alternative>
 </Alternatives>
</Project>
```


3. BLCC CONFIGURATION DOCUMENT FOR STARSENSE DEMONSTRATION PROJECT IN 10-YEAR SIR EVALUATION


```
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<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 Starsense</Name>
  <Comment>Starsense 10-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>11 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>Starsense LED</Name>
          <Duration>0 years 0 months</Duration>
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              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
              <Portions>1.0
              </Portions>
              <Intervals>0 years 0 months
              </Intervals>
            </PhaseIn>
          </PhaseIn>
          <ResaleEscalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </ResaleEscalation>
          <ConstructionCost>39020.0</ConstructionCost>
          <SIOH>2341.2</SIOH>
          <DesignCost>3902.0</DesignCost>
          <RecurringCosts>
            <RecurringCost>
              <Name>maintenance cost</Name>
```

```
              <Duration>Remaining</Duration>
              <Amount>1400.0</Amount>
              <Escalation>
                <SimpleEscalation>
                </SimpleEscalation>
              </Escalation>
              <Index>
                <UsageIndex>
                  <Intervals>Remaining
                  </Intervals>
                  <Values>1.0
                  </Values>
                </UsageIndex>
              </Index>
            </RecurringCost>
          </RecurringCosts>
        </CapitalComponent>
      </CapitalComponents>
      <EnergyUsages>
        <EnergyUsage>
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          <Name>Electricity</Name>
          <Duration>Remaining</Duration>
          <YearlyUsage>30027.0</YearlyUsage>
          <Units>kWh</Units>
          <UnitCost>0.1</UnitCost>
          <UsageIndex>
            <UsageIndex>
              <Intervals>Remaining
              </Intervals>
              <Values>1.0
              </Values>
            </UsageIndex>
          </UsageIndex>
          <State>Oklahoma</State>
          <RateSchedule>Commercial</RateSchedule>
          <Emissions>Oklahoma</Emissions>
        </EnergyUsage>
      </EnergyUsages>
    </Alternative>
  </Alternatives>
</Project>
```


4. BLCC CONFIGURATION DOCUMENT FOR STARSENSE DEMONSTRATION PROJECT IN 20-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 Starsense</Name>
  <Comment>Starsense 20-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
```

```
<PCPeriod>1 year 0 months</PCPeriod>
<Duration>21 years 0 months</Duration>
<DiscountingMethod>1</DiscountingMethod>
<DiscountRate>0.03</DiscountRate>
<Alternatives>
  <Alternative>
    <CapitalComponents>
      <CapitalComponent>
        <Name>Starsense LED</Name>
        <Duration>0 years 0 months</Duration>
          <Escalation>
            <SimpleEscalation>
            </SimpleEscalation>
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            <Intervals>0 years 0 months
            </Intervals>
          </PhaseIn>
        </PhaseIn>
        <ResaleEscalation>
          <SimpleEscalation>
          </SimpleEscalation>
        </ResaleEscalation>
        <ConstructionCost>39020.0</ConstructionCost>
        <SIOH>2341.2</SIOH>
        <DesignCost>3902.0</DesignCost>
        <RecurringCosts>
          <RecurringCost>
            <Name>maintenance cost</Name>
            <Duration>Remaining</Duration>
            <Amount>1400.0</Amount>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
            <Index>
              <UsageIndex>
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                </Intervals>
                <Values>1.0
                </Values>
              </UsageIndex>
            </Index>
          </RecurringCost>
        </RecurringCosts>
      </CapitalComponent>
    </CapitalComponents>
    <EnergyUsages>
      <EnergyUsage>
        <FuelType>Electricity</FuelType>
        <Name>Electricity</Name>
        <Duration>Remaining</Duration>
        <YearlyUsage>30027.0</YearlyUsage>
```

```
          <Units>kWh</Units>
          <UnitCost>0.1</UnitCost>
          <UsageIndex>
            <UsageIndex>
              <Intervals>Remaining
              </Intervals>
              <Values>1.0
              </Values>
            </UsageIndex>
          </UsageIndex>
          <State>Oklahoma</State>
          <RateSchedule>Commercial</RateSchedule>
          <Emissions>Oklahoma</Emissions>
        </EnergyUsage>
      </EnergyUsages>
    </Alternative>
  </Alternatives>
</Project>
```


5. BLCC CONFIGURATION DOCUMENT FOR STARSENSE PRACTICAL SCALE PROJECT IN 10-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 Starsense</Name>
  <Comment>Starsense 10-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>11 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>Starsense LED</Name>
          <Duration>0 years 0 months</Duration>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
              <Portions>1.0
              </Portions>
              <Intervals>0 years 0 months
              </Intervals>
            </PhaseIn>
          </PhaseIn>
          <ResaleEscalation>
            <SimpleEscalation>
```

```
          </SimpleEscalation>
        </ResaleEscalation>
        <ConstructionCost>1008700.0</ConstructionCost>
        <SIOH>60522.0</SIOH>
        <DesignCost>100870.0</DesignCost>
        <RecurringCosts>
          <RecurringCost>
            <Name>maintenance cost</Name>
            <Duration>Remaining</Duration>
            <Amount>49000.0</Amount>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
            <Index>
              <UsageIndex>
                <Intervals>Remaining
                </Intervals>
                <Values>1.0
                </Values>
              </UsageIndex>
            </Index>
          </RecurringCost>
        </RecurringCosts>
      </CapitalComponent>
    </CapitalComponents>
    <EnergyUsages>
      <EnergyUsage>
        <FuelType>Electricity</FuelType>
        <Name>Electricity</Name>
        <Duration>Remaining</Duration>
        <YearlyUsage>1050949.0</YearlyUsage>
        <Units>kWh</Units>
        <UnitCost>0.1</UnitCost>
        <UsageIndex>
          <UsageIndex>
            <Intervals>Remaining
            </Intervals>
            <Values>1.0
            </Values>
          </UsageIndex>
        </UsageIndex>
        <State>Oklahoma</State>
        <RateSchedule>Commercial</RateSchedule>
        <Emissions>Oklahoma</Emissions>
      </EnergyUsage>
    </EnergyUsages>
  </Alternative>
 </Alternatives>
</Project>
```


6. BLCC CONFIGURATION DOCUMENT FOR STARNSESE PRACTICAL SCALE PROJECT IN 20-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
```

```xml
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 Starsense</Name>
  <Comment>Starsense 20-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>21 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>Starsense LED</Name>
          <Duration>0 years 0 months</Duration>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
              <Portions>1.0
              </Portions>
              <Intervals>0 years 0 months
              </Intervals>
            </PhaseIn>
          </PhaseIn>
          <ResaleEscalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </ResaleEscalation>
          <ConstructionCost>1008700.0</ConstructionCost>
          <SIOH>60522.0</SIOH>
          <DesignCost>100870.0</DesignCost>
          <RecurringCosts>
            <RecurringCost>
              <Name>maintenance cost</Name>
              <Duration>Remaining</Duration>
              <Amount>49000.0</Amount>
              <Escalation>
                <SimpleEscalation>
                </SimpleEscalation>
              </Escalation>
              <Index>
                <UsageIndex>
                  <Intervals>Remaining
                  </Intervals>
                  <Values>1.0
                  </Values>
                </UsageIndex>
              </Index>
            </RecurringCost>
          </RecurringCosts>
```

```
        </CapitalComponent>
      </CapitalComponents>
      <EnergyUsages>
        <EnergyUsage>
          <FuelType>Electricity</FuelType>
          <Name>Electricity</Name>
          <Duration>Remaining</Duration>
          <YearlyUsage>1050949.0</YearlyUsage>
          <Units>kWh</Units>
          <UnitCost>0.1</UnitCost>
          <UsageIndex>
            <UsageIndex>
              <Intervals>Remaining
              </Intervals>
              <Values>1.0
              </Values>
            </UsageIndex>
          </UsageIndex>
          <State>Oklahoma</State>
          <RateSchedule>Commercial</RateSchedule>
          <Emissions>Oklahoma</Emissions>
        </EnergyUsage>
      </EnergyUsages>
    </Alternative>
  </Alternatives>
</Project>
```


7. BLCC CONFIGURATION DOCUMENT FOR LOD DEMONSTRATION PROJECT IN 10-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 LOD</Name>
  <Comment>LOD 10-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>11 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>LOD</Name>
          <Duration>0 years 0 months</Duration>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
```

```
          <Portions>1.0
          </Portions>
          <Intervals>0 years 0 months
          </Intervals>
        </PhaseIn>
      </PhaseIn>
      <ResaleEscalation>
        <SimpleEscalation>
        </SimpleEscalation>
      </ResaleEscalation>
      <ConstructionCost>44806.0</ConstructionCost>
      <SIOH>2688.36</SIOH>
      <DesignCost>4480.6</DesignCost>
      <RecurringCosts>
        <RecurringCost>
          <Name>maintenance cost</Name>
          <Duration>Remaining</Duration>
          <Amount>1470.0</Amount>
          <Escalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </Escalation>
          <Index>
            <UsageIndex>
              <Intervals>Remaining
              </Intervals>
              <Values>1.0
              </Values>
            </UsageIndex>
          </Index>
        </RecurringCost>
      </RecurringCosts>
    </CapitalComponent>
  </CapitalComponents>
  <EnergyUsages>
    <EnergyUsage>
      <FuelType>Electricity</FuelType>
      <Name>Electricity</Name>
      <Duration>Remaining</Duration>
      <YearlyUsage>91677.0</YearlyUsage>
      <Units>kWh</Units>
      <UnitCost>0.1</UnitCost>
      <UsageIndex>
        <UsageIndex>
          <Intervals>Remaining
          </Intervals>
          <Values>1.0
          </Values>
        </UsageIndex>
      </UsageIndex>
      <State>Oklahoma</State>
      <RateSchedule>Commercial</RateSchedule>
      <Emissions>Oklahoma</Emissions>
    </EnergyUsage>
  </EnergyUsages>
</Alternative>
```

```
  </Alternatives>
</Project>
```


8. BLCC CONFIGURATION DOCUMENT FOR LOD DEMONSTRATION PROJECT IN 20-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 LOD</Name>
  <Comment>LOD 20-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>21 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>LOD</Name>
          <Duration>0 years 0 months</Duration>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
              <Portions>1.0
              </Portions>
              <Intervals>0 years 0 months
              </Intervals>
            </PhaseIn>
          </PhaseIn>
          <ResaleEscalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </ResaleEscalation>
          <ConstructionCost>44806.0</ConstructionCost>
          <SIOH>2688.36</SIOH>
          <DesignCost>4480.6</DesignCost>
          <RecurringCosts>
            <RecurringCost>
              <Name>maintenance cost</Name>
              <Duration>Remaining</Duration>
              <Amount>1470.0</Amount>
              <Escalation>
                <SimpleEscalation>
                </SimpleEscalation>
              </Escalation>
              <Index>
                <UsageIndex>
```

```
                <Intervals>Remaining
                </Intervals>
                <Values>1.0
                </Values>
              </UsageIndex>
            </Index>
          </RecurringCost>
        </RecurringCosts>
      </CapitalComponent>
    </CapitalComponents>
    <EnergyUsages>
      <EnergyUsage>
        <FuelType>Electricity</FuelType>
        <Name>Electricity</Name>
        <Duration>Remaining</Duration>
        <YearlyUsage>91677.0</YearlyUsage>
        <Units>kWh</Units>
        <UnitCost>0.1</UnitCost>
        <UsageIndex>
          <UsageIndex>
            <Intervals>Remaining
            </Intervals>
            <Values>1.0
            </Values>
          </UsageIndex>
        </UsageIndex>
        <State>Oklahoma</State>
        <RateSchedule>Commercial</RateSchedule>
        <Emissions>Oklahoma</Emissions>
      </EnergyUsage>
    </EnergyUsages>
  </Alternative>
</Alternatives>
</Project>
```


9. BLCC CONFIGURATION DOCUMENT FOR LOD PRACTICAL SCALE PROJECT IN 10-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 LOD</Name>
  <Comment>LOD 10-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>11 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
```

```
        <Name>LOD</Name>
        <Duration>0 years 0 months</Duration>
          <Escalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </Escalation>
        <PhaseIn>
          <PhaseIn>
            <Portions>1.0
            </Portions>
            <Intervals>0 years 0 months
            </Intervals>
          </PhaseIn>
        </PhaseIn>
        <ResaleEscalation>
          <SimpleEscalation>
          </SimpleEscalation>
        </ResaleEscalation>
        <ConstructionCost>178000.0</ConstructionCost>
        <SIOH>10680.0</SIOH>
        <DesignCost>17800.0</DesignCost>
        <RecurringCosts>
          <RecurringCost>
            <Name>maintenance cost</Name>
            <Duration>Remaining</Duration>
            <Amount>7000.0</Amount>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
            <Index>
              <UsageIndex>
                <Intervals>Remaining
                </Intervals>
                <Values>1.0
                </Values>
              </UsageIndex>
            </Index>
          </RecurringCost>
        </RecurringCosts>
      </CapitalComponent>
    </CapitalComponents>
    <EnergyUsages>
      <EnergyUsage>
        <FuelType>Electricity</FuelType>
        <Name>Electricity</Name>
        <Duration>Remaining</Duration>
        <YearlyUsage>436559.0</YearlyUsage>
        <Units>kWh</Units>
        <UnitCost>0.1</UnitCost>
        <UsageIndex>
          <UsageIndex>
            <Intervals>Remaining
            </Intervals>
            <Values>1.0
            </Values>
```

```
          </UsageIndex>
        </UsageIndex>
        <State>Oklahoma</State>
        <RateSchedule>Commercial</RateSchedule>
        <Emissions>Oklahoma</Emissions>
      </EnergyUsage>
    </EnergyUsages>
  </Alternative>
 </Alternatives>
</Project>
```


10. BLCC CONFIGURATION DOCUMENT FOR LOD PRACTCICAL SCALE PROJECT IN 20-YEAR SIR EVALUATION


```
<?xml version="1.0"?>
<Project>
  <Name>Fort Sill Outdoor Lighting EW201141 LOD</Name>
  <Comment>LOD 20-year SIR</Comment>
  <Location>Oklahoma</Location>
  <Analyst>Satyen Mukherjee</Analyst>
  <AnalysisType>3</AnalysisType>
  <AnalysisPurpose>1</AnalysisPurpose>
  <BaseDate>November 1, 2013</BaseDate>
  <PCPeriod>1 year 0 months</PCPeriod>
  <Duration>21 years 0 months</Duration>
  <DiscountingMethod>1</DiscountingMethod>
  <DiscountRate>0.03</DiscountRate>
  <Alternatives>
    <Alternative>
      <CapitalComponents>
        <CapitalComponent>
          <Name>LOD</Name>
          <Duration>0 years 0 months</Duration>
            <Escalation>
              <SimpleEscalation>
              </SimpleEscalation>
            </Escalation>
          <PhaseIn>
            <PhaseIn>
              <Portions>1.0
              </Portions>
              <Intervals>0 years 0 months
              </Intervals>
            </PhaseIn>
          </PhaseIn>
          <ResaleEscalation>
            <SimpleEscalation>
            </SimpleEscalation>
          </ResaleEscalation>
          <ConstructionCost>178000.0</ConstructionCost>
          <SIOH>10680.0</SIOH>
          <DesignCost>17800.0</DesignCost>
          <RecurringCosts>
            <RecurringCost>
              <Name>maintenance cost</Name>
```

```
              <Duration>Remaining</Duration>
              <Amount>7000.0</Amount>
              <Escalation>
                <SimpleEscalation>
                </SimpleEscalation>
              </Escalation>
              <Index>
                <UsageIndex>
                  <Intervals>Remaining
                  </Intervals>
                  <Values>1.0
                  </Values>
                </UsageIndex>
              </Index>
            </RecurringCost>
          </RecurringCosts>
        </CapitalComponent>
      </CapitalComponents>
      <EnergyUsages>
        <EnergyUsage>
          <FuelType>Electricity</FuelType>
          <Name>Electricity</Name>
          <Duration>Remaining</Duration>
          <YearlyUsage>436559.0</YearlyUsage>
          <Units>kWh</Units>
          <UnitCost>0.1</UnitCost>
          <UsageIndex>
            <UsageIndex>
              <Intervals>Remaining
              </Intervals>
              <Values>1.0
              </Values>
            </UsageIndex>
          </UsageIndex>
          <State>Oklahoma</State>
          <RateSchedule>Commercial</RateSchedule>
          <Emissions>Oklahoma</Emissions>
        </EnergyUsage>
      </EnergyUsages>
    </Alternative>
  </Alternatives>
</Project>
```