Bi-Level Demand-Sensitive LED Street Lighting Systems (EW 201017)

Dr. Saifur Rahman

Virginia Tech – Advanced Research Institute

Project Outbrief

September 5, 2013

Project Team

- Dr. Saifur Rahman (PI), Virginia Tech
- Dr. Manisa Pipattanasomporn (co-PI), Virginia Tech
- Dr. Isaac Flory (co-PI), Old Dominion University

Technical Objectives

- To design, develop and demonstrate an energy efficient bi-level demand-sensitive LED street lighting system

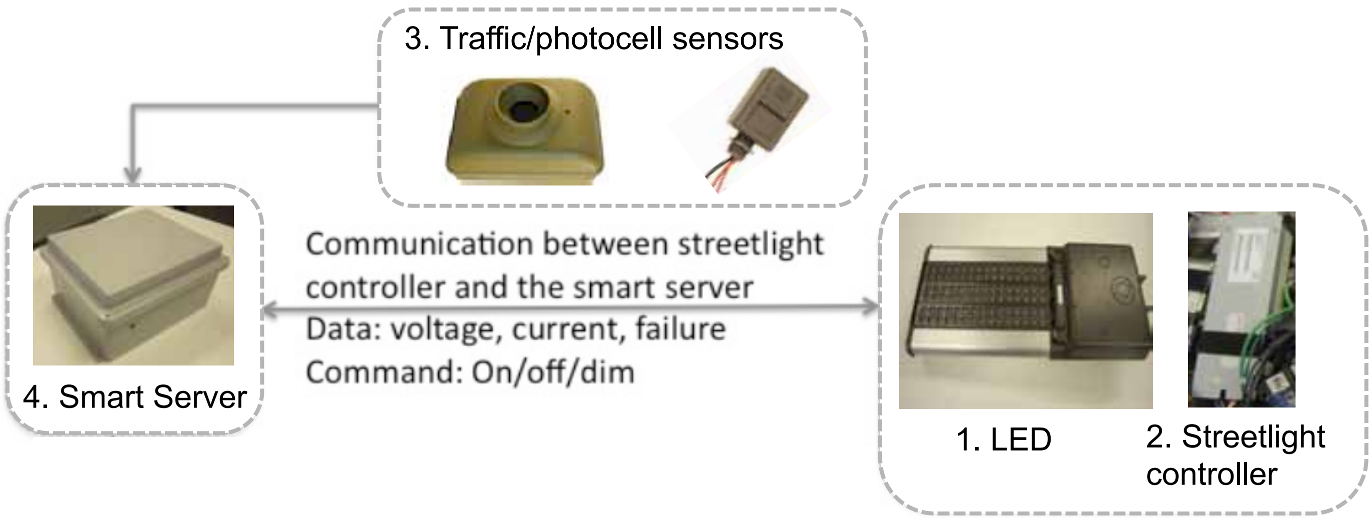
Returned to full intensity when traffic is detected.

The streetlight will be dimmed at night

Deliverables:

- Validation of the expected operational and economic benefits
- Evaluation of technology acceptance and end-user feedback
- Development of guidelines and field experience data to replicate this pilot installation in other DoD facilities

Technology Description



<u>Technology components:</u>

1. LEDs
2. Streetlight controllers
3. Traffic/light sensors
4. Smart server

Uniqueness of the Work

- LEDs:
  - Higher efficacy — lower energy consumption
  - Higher color rendering index (CRI) — lower light pollution
  - Higher life (50,000+ hrs) — lower maintenance costs
  - Instantaneous warm-up, no re-strike time delay — fully dimmable
  - Mercury free — reduction in waste management
  - Wide range of voltage inputs — lower infrastructure costs
- Incorporation of control components to allow:
  - Light intensity reduction at night (streetlight controller)
  - Movement detection (traffic sensor)
  - Smart fail-safe day/night operation (photocell and smart server)
  - Integration of an ability to control the lights ON/OFF (smart server)

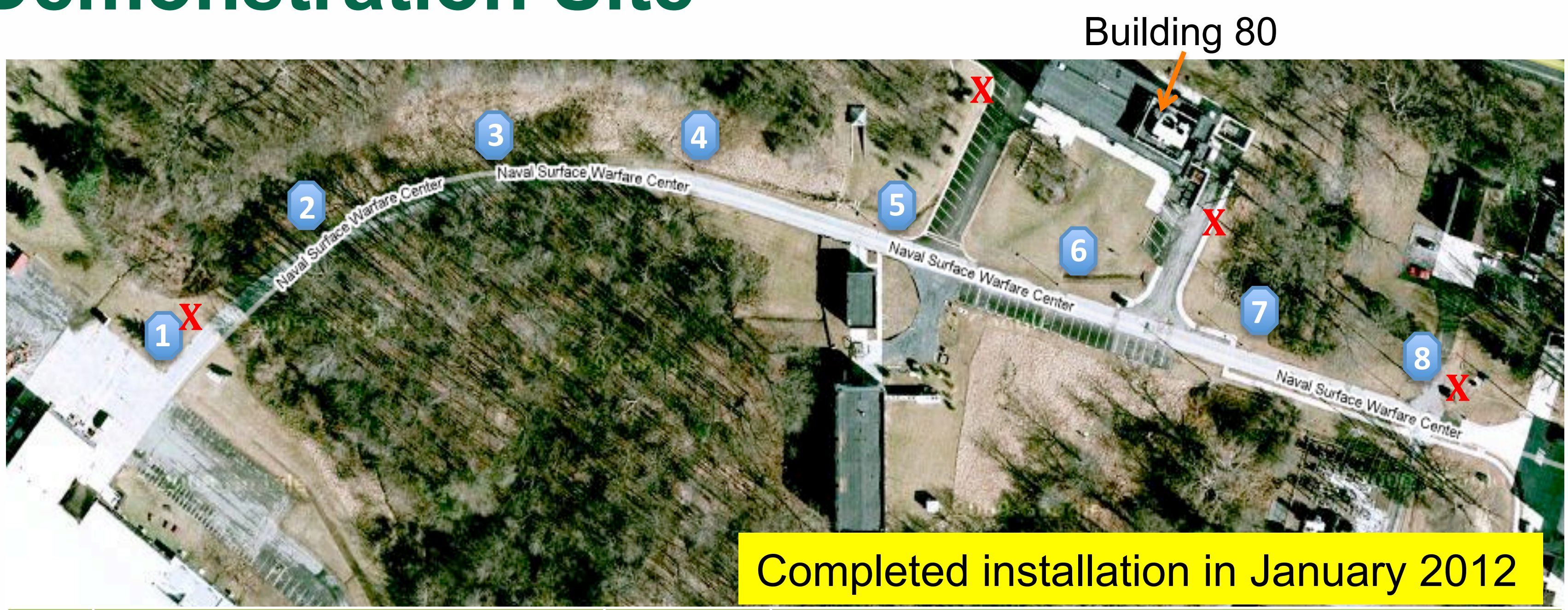
Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
1. Quantitative Performance Objectives				
Reduction in Electricity usage (kWh)	- Electricity saving (kWh)	Power measurements (V, A, kW, kVAR, PF)	> 50% electricity saving	~ 74% electricity savings
Reduction in Carbon foot print (lbs of CO_2)	- CO_2 emission (lbs)	Annual electricity consumption (kWh) and emission rate (lbs/kWh)	> 50% reduction in carbon footprint	~ 74% CO_2 emission reduction
Lower cost of ownership over the life time	- Net present value (NPV) - Savings to inv ratio (SIR) - Payback period - Adjusted internal rate of return (AIRR)	Capital costs and O&M costs	- $NPV_{LED} < NPV_{HPS}$ - SIR >= 1.5 - Payback <= 7 yrs - AIRR >= 5%	- $NPV_{LED} < NPV_{HPS}$ - SIR = 2.02 - Payback = 6 yrs - AIRR = 9.19%
Illumination levels	- Illumination levels (fc)	Illumination measurements (fc)	Average luminance >= 0.8 fc	1.40 fc @ 100% 0.86 fc @ 60%
Color temperature performance	Correlated color temperature (CCT in °K)	Color temperature measurements (°K)	CCT of 4000°K compared to existing CCT of 1600-2100°K	> 4000°K
Reduction in mercury waste	Amount of mercury saving (mg)	Amount of mercury in existing lamps (mg)	100% reduction in mercury disposal requirements	100% reduction

Performance Objectives (cont'd)

Performance Objective	Metric	Data Requirements	Success Criteria	Results
2. Qualitative Performance Objectives				
User acceptance and light quality	- Survey and feedback - Color photographs	Feedback from individuals, including level of comfort, light quality, retrofit ability; Color photographs before and after the installation	Positive feedback and high level of user satisfaction	Positive feedback; high level of user satisfaction; better light quality and lower light pollution
3. Operational Performance Objectives				
System availability	The amount of time the system is operational or ready to operate	System logs that record LED output performance	> 95% availability	100% availability
System reliability	The amount of time the system performs as designed	System logs that record LED output performance	> 95% reliability	100% reliability

Demonstration Site

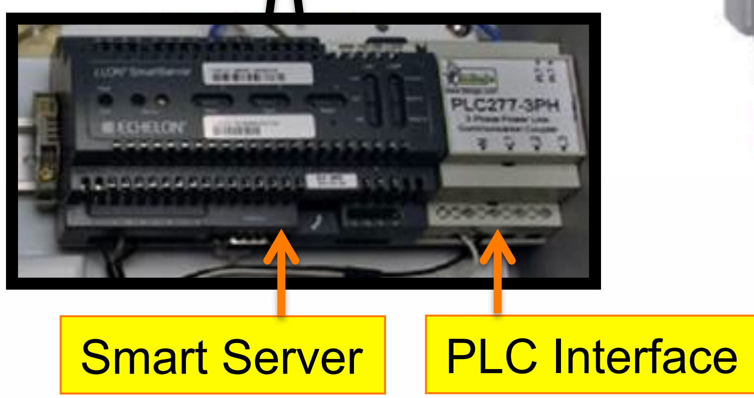


	Technology components	QTY	Locations
1	LED light fixtures	8	Installed at existing light poles
2	Streetlight controllers	8	Installed inside the LED fixtures
3	Traffic sensors	4	Installed at the locations marked by X
4	Smart server	1	Building 80
5	Network mgnt center	1	Building 80

Technology Integration and Controller Development

Outdoor Light Controller (OLC)
For controlling the ON/OFF and dimming of LED fixture

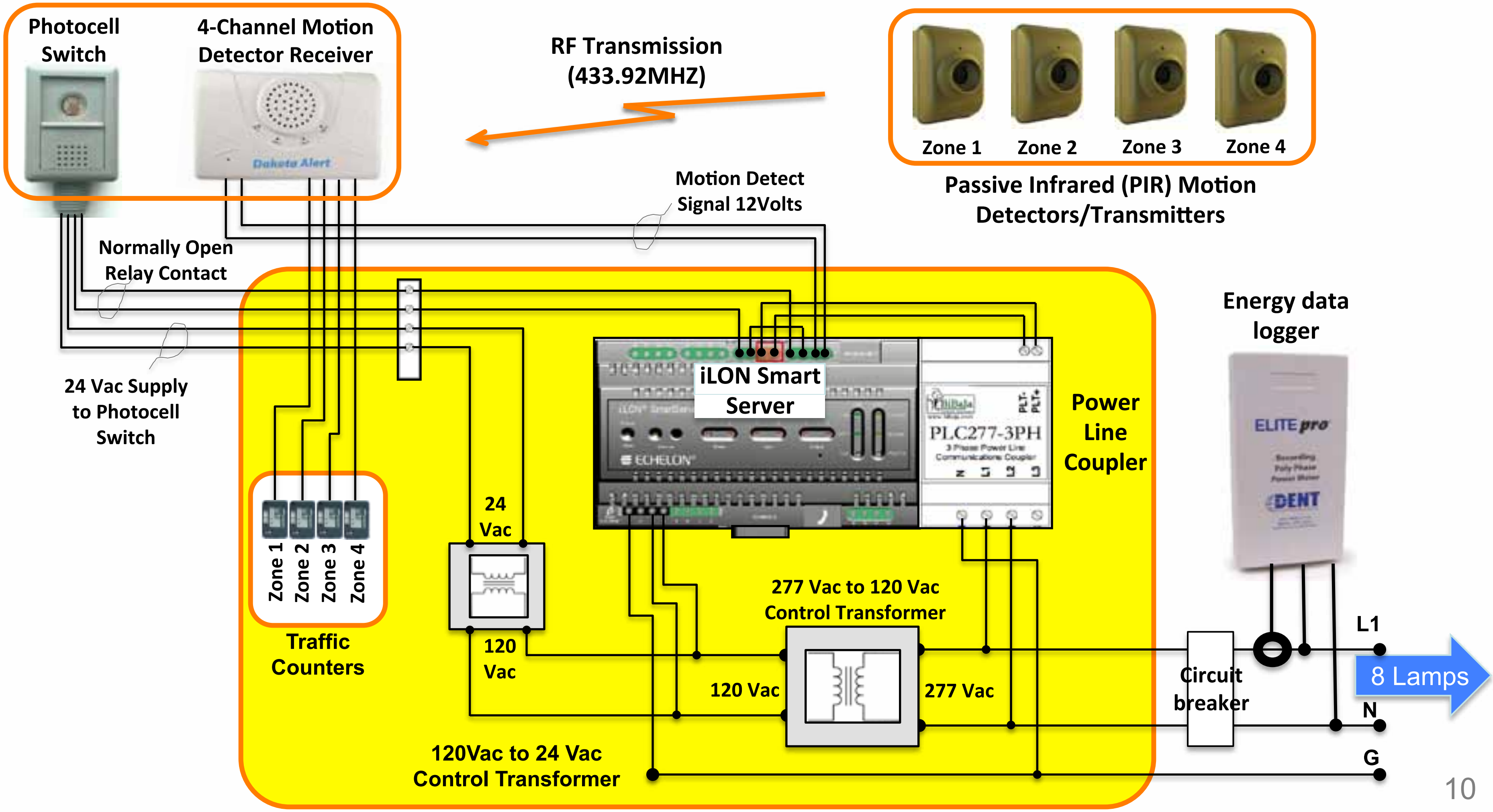
SmartServer/ PLC Interface
For managing the LED street lighting system



Traffic Sensor
For detecting foot/vehicle traffic

Photocell Sensor
For detecting ambient light level

Technology Integration and Controller Development (Cont'd)

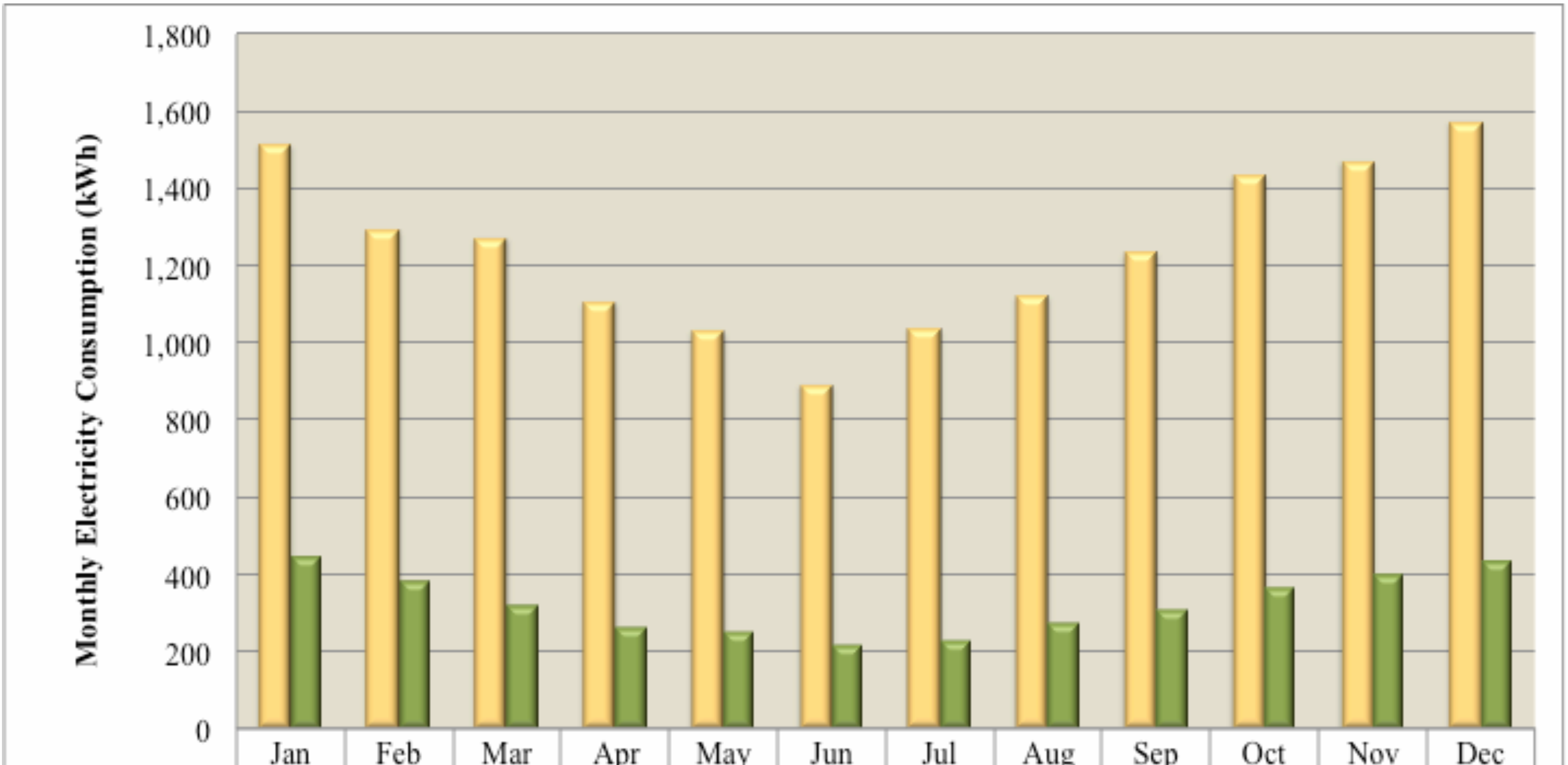


Demonstration Results

1. Electricity savings
2. CO_2 emission savings
3. Illumination levels
4. Color temperature performance
5. Reduction in mercury waste
6. User acceptance and light quality
7. System availability
8. System reliability
9. Cost of ownership

1. Electricity Savings

Average electricity **savings of 75%** was experienced after the installation.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
HPS (2011)	1,514	1,290	1,270	1,103	1,030	890	1,034	1,119	1,232	1,431	1,468	1,572
LED (2012)	444	385	319	264	253	218	232	275	309	364	397	433

Total
14,953 kWh
3,893 kWh

Annual savings = 11,060 kWh

2. CO_2 Savings

Average **<u>CO_2 savings of 75%</u>** was experienced after the installation.

	HPS	LED	Annual savings
Annual Electricity Consumption	14,953 kWh	3,893 kWh	11,060 kWh (~74% savings)
Annual CO2 emission	21,742 lbs	5,660 lbs	16,081 lbs (~74% savings)

CO2 conversion factor for Maryland of 1.454 lbs/kWh was used.

3. Illumination Assessment

HPS

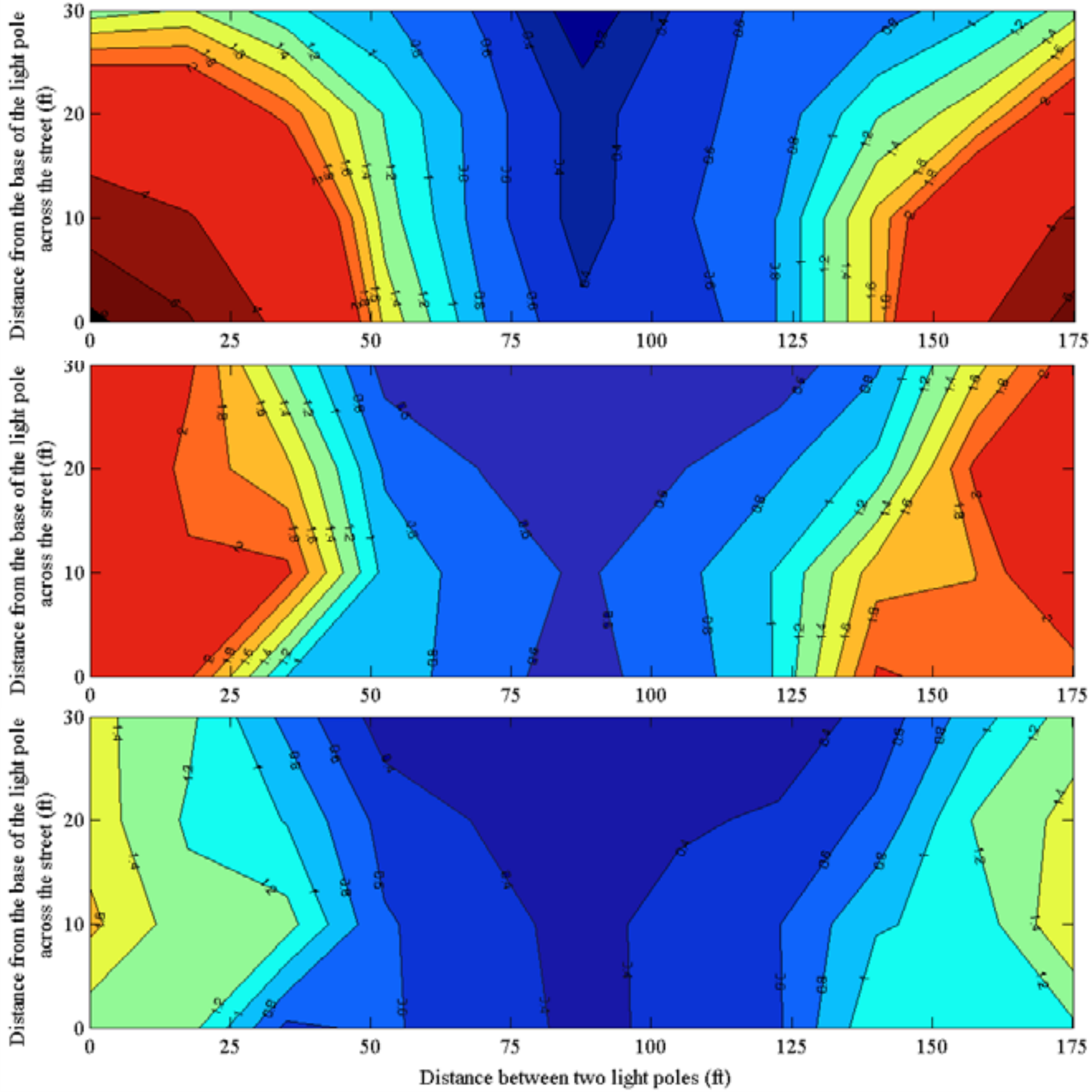
Min: 0.32 fc
Max: 8.5 fc

LED @ 100%

Min: 0.53 fc
Max: 2.74 fc

LED @ 60%

Min: 0.32 fc
Max: 1.65 fc



HPS vs LED
Illumination Measurement (foot candle)

	MIN	MAX	AVE	AVE/MIN	MAX/MIN
HPS	0.32	8.50	2.24	7.00	26.56
LED @ 100%	0.53	2.74	1.40	2.64	5.17
LED @ 60%	0.32	1.65	0.86	2.68	5.16

Much better light level

Much better light uniformity

- The newly installed LED street lighting system meets:
  - ✓ Recommended AVE maintained luminance values for collector roads in commercial areas of 0.8 fc*
  - ✓ Recommended AVE to MIN value of 4 to 1*
  - ✓ Recommended MAX to MIN value of 8 to 1*

  * based on the Illuminating Engineering Society of North America (IESNA) measurement guideline LM-50-99.

- This implies:
  - ✓ LED provides better illumination and luminance uniformity as compared to the existing HPS lamps.

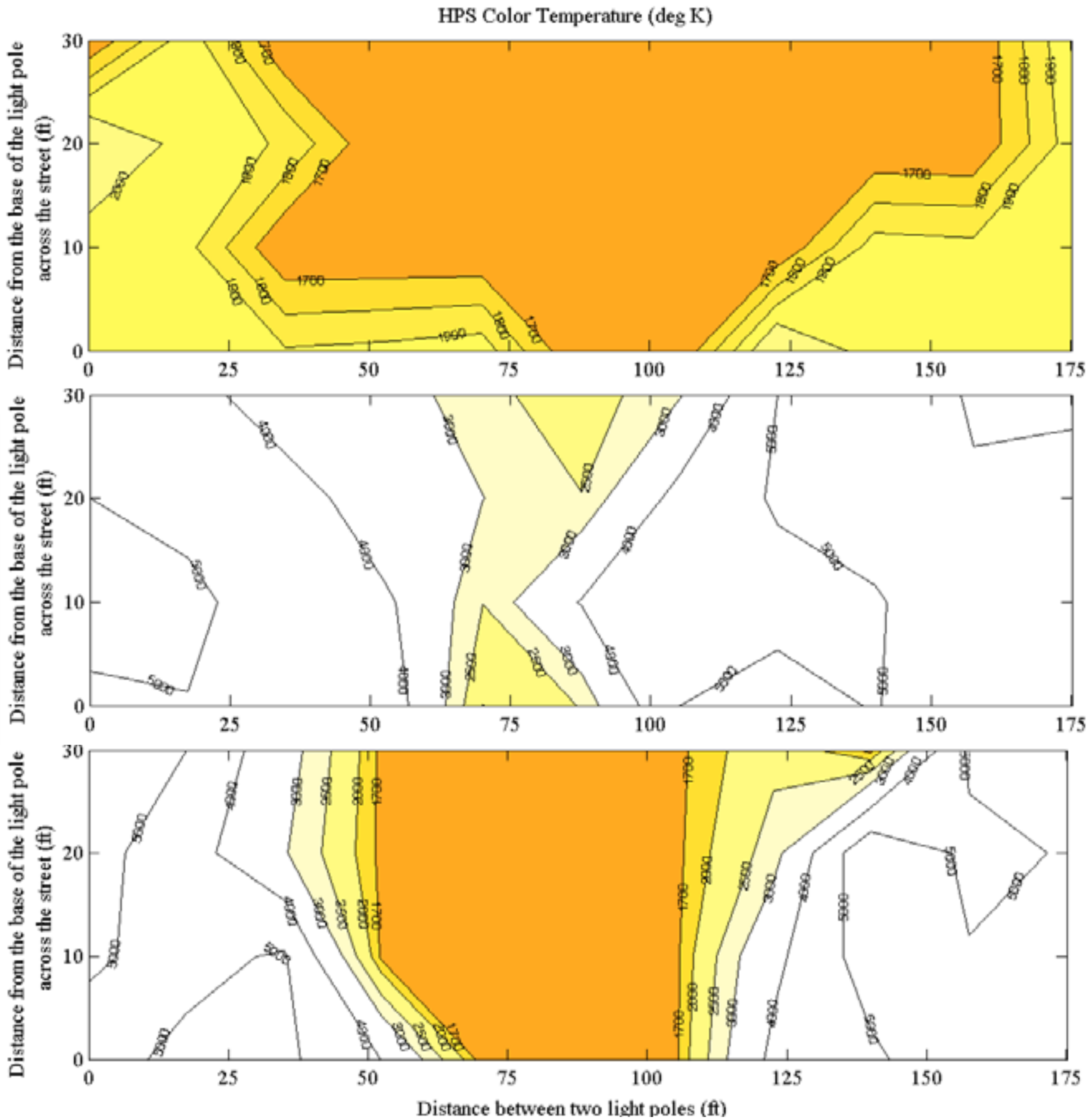
4. Color Temperature Performance

ESTCP

HPS

LED @ 100%

LED @ 60%



Min: 1600°K
Max: 2140°K
Area with no light pollution:
1600°K-2140°K

Min: 2510°K*
Max: 5800°K
Area with no light pollution:
4300°K-5800°K

Min: 1600°K*
Max: 5850°K
Area with no light pollution:
4700°K-5850°K

* Due to light pollution from the HPS unit at Building A

5. Reduction in Mercury Waste (mg)

100% mercury waste reduction is observed as LED does not contain mercury

	Base case (HPS)	Alternative (LED)	Savings from Alternative
Amount of mercury/bulb	11-30 mg	0 mg	11-30 mg/lamp
Amount of mercury during the study period of 12 years	8 bulbs every 3 years = 32 bulbs	-	352-960 mg

6. User Acceptance and Light Quality

A survey was conducted during the week of April 9-16, 2013.

1. How satisfied are you with the overall performance of LED lighting?

100% very satisfied

2. How satisfied are you with the visibility improvement offered by the LED streetlights for you as a driver?

100% very satisfied

3. How satisfied are you with the visibility improvement offered by the LED streetlights for you as a pedestrian?

100% very satisfied

4. Do you feel that the new streetlights give off the right amount of light, or are they too bright or too dim?

100% Right amount of light

7. System Availability

The availability of the overall system was derived from the availability of each component.

All system components (LED luminaires, streetlight controllers, SmartServer and traffic/photocell sensors) demonstrated no failure during the post-installation monitoring.

This implies 100% system availability.

8. System Reliability

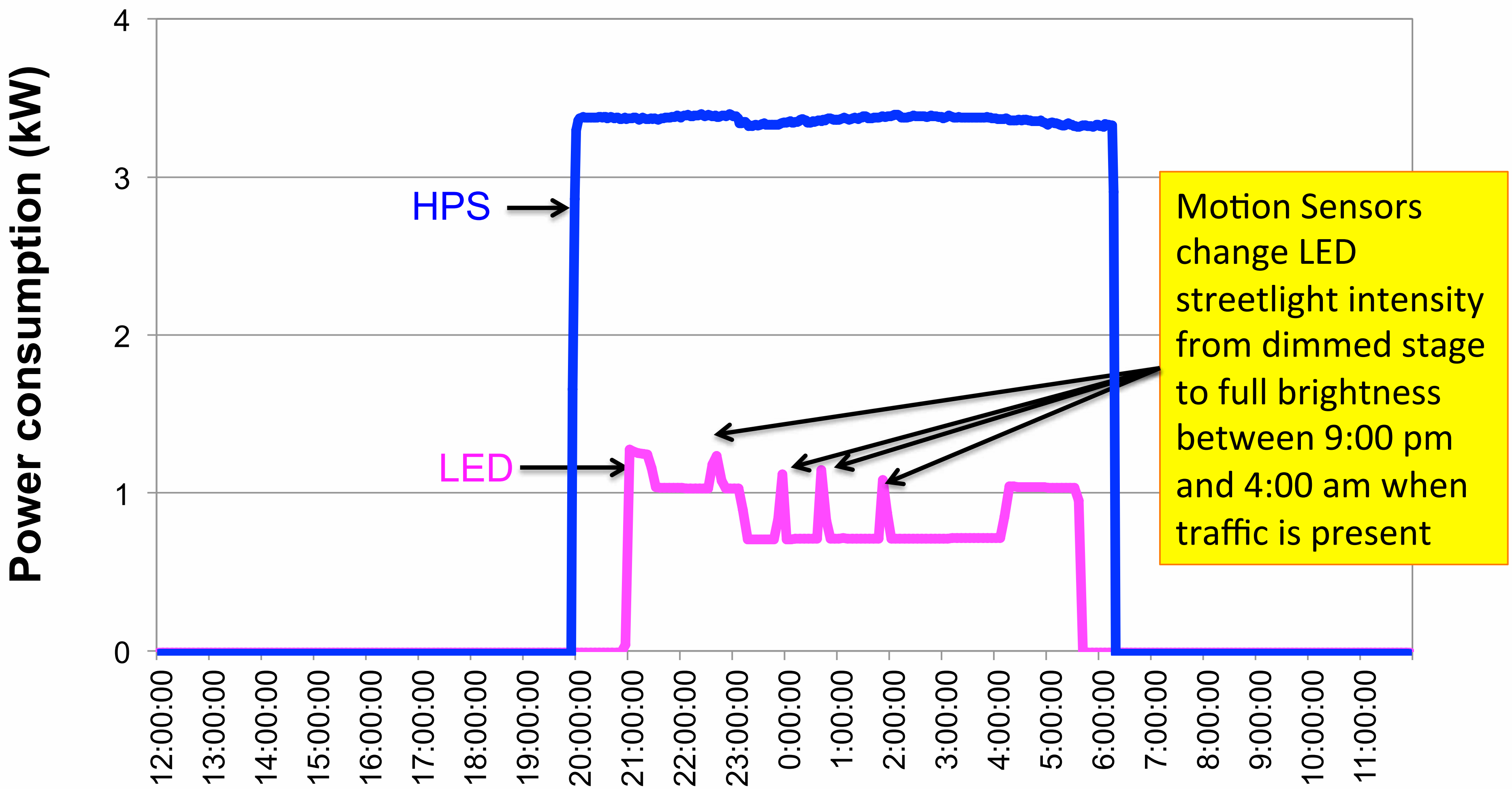
System reliability was measured by the amount of time the system performs as designed.

Recorded data indicate that:

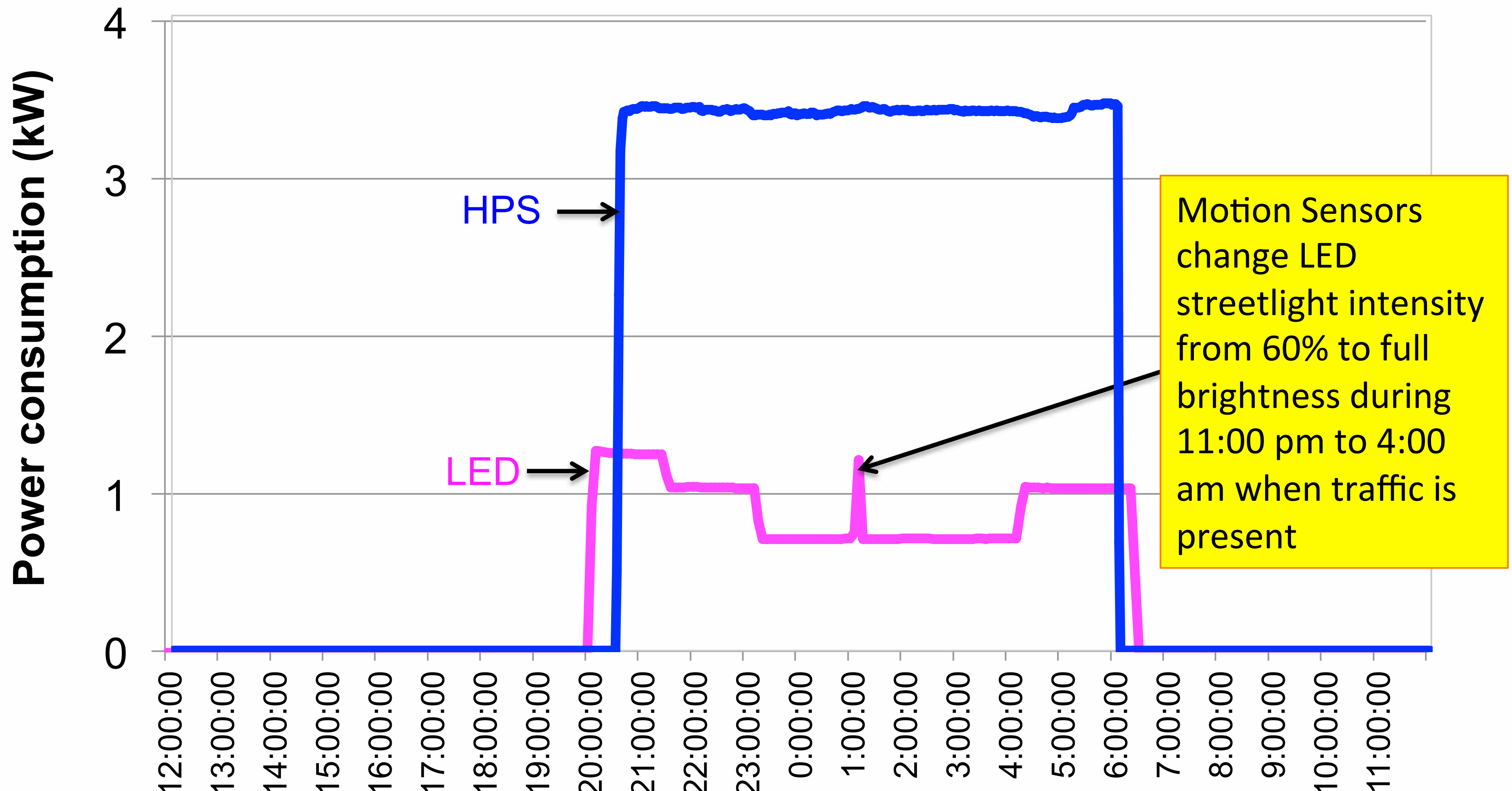
- LED luminaires were switched ON at sunset;
- LED luminaires were switched OFF at sunrise;
- LED luminaires were dimmed at pre-selected times;
- LED luminaires increased their intensity to 100% when foot/vehicle traffic was detected; and their intensity was gradually decreased to the previous level after a pre-set time.
- The system was also function as expected during rain and snow.

This implies 100% system reliability.

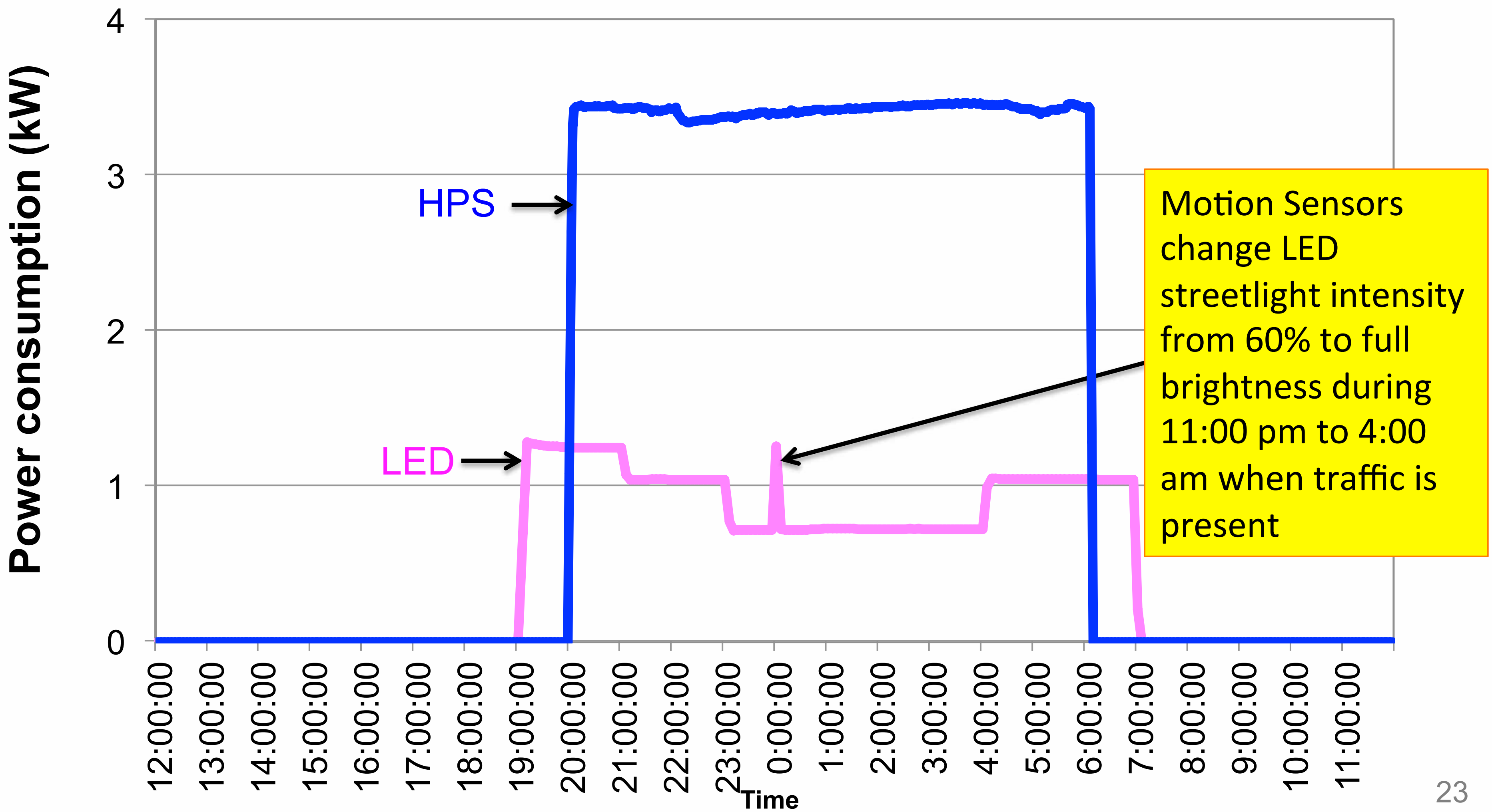
Operation of HPS vs LED (As of June 2012)



Operation of HPS vs LED (As of August 2012)



Operation of HPS vs LED (As of October 2012)



9. HPS vs LED
Life Cycle Cost (LCC) Analysis

- Use NIST Building Life Cycle Cost (BLCC) Program:

	Base Case (HPS)	Alternative (LED)
Initial Capital Cost	- HPS lamp = 8*$400 = $3,200 - Photocell = $100 - Lamp installation: $4,900 - Electrical wiring = $6,150 Total = $14,350	- LED + controller = 8*$1,195 = [illegible] - Photocell = $100 - Smart server = $750 - Lamp installation = $4,900 - Electrical wiring = $6,150 Total = $22,300
Recurring Cost		
(a) Maintenance – replacement cost	Light bulb: $50 every 3 years Ballast: $200 every 6 years Labor: $50/hr Y3: 8 bulb replacement = $400 Labor = 5hrs*$50/hr = $250 Y6: 8 bulb & 8 ballast replacement = $2,000 labor = 8hrs*$50/hr = $400 Y9: same as Y3	Life: assume 12 years No maintenance required
(b) Operation – electricity cost @ 11.83c/kWh	14,953 kWh/year or $1,769/year, 3% inflation	3,893 kWh/year or $460/year, 3% inflation

* From EIA's eGRID 2012

HPS vs LED
Net Present Value Comparison
(Over 12 years)

	Base Case (HPS)	Alternative (LED)	Savings from Alternative
Initial Investment Cost	$14,350	$22,760	-$8,410
Maintenance cost	$3,700	$0	$3,700
Electricity cost	$17,909	$4,663	$13,247
Total Present Value LCC	**$35,959**	**$26,963**	**$8,537**

- Savings-to-Investment Ratio (SIR): 2.02
- Adjusted Internal Rate of Return (AIRR): 9.19%
- Payback period: 6 years
- 12-year electricity savings: 132,690 kWh
- 12-year emissions reduction: 192,955 lbs CO_2

$$\text{SIR} = \frac{(\$13,247+\$3,700)}{(\$22,760-\$14,350)}$$

Contributions to DoD Energy and Water Goals

- We provide a technology demonstration to validate performance and operational costs and benefits of the demand-sensitive LED street lighting systems.
- We evaluate technology acceptance and get the technology ready to be transferred by working with NSWC Carderock Division.
- We provide field experience and implementation models that can be replicable in other DoD installations.

Issues/Lessons Learned (Site Access Permits)

- Restrictions on physical access to the site
  - Visitors must be escorted in the base at all times.
  - For a day-time visit, requests must be made one day in advance.
  - For a night-time visit, requests must be made two weeks in advance.
- Restrictions on wireless communications
  - There are certain restrictions on frequency band and power level to use for wireless communications within the base.
  - Mesh network is not allowed.
- Restrictions on installation contractors
  - Only electrical contractors with security clearance are allowed to perform the work.
- Restrictions on remote access from outside the base to the equipment
  - Remote access from outside the base is not allowed.
  - Data cannot be downloaded remotely.
  - System cannot be monitored/diagnosed remotely.

Issues/Lessons Learned (Technical)

- Light intensity, light quality and uniformity and power consumption
  - ♦ LED gives much better light quality and uniformity than HPS.
  - ♦ LED provides an average saving of 75% of electricity compared to HPS.
- Communications
  - ♦ There are interferences in power lines due to existing loads in the building (i.e., signals received by the controller have low S/N ratio). However, the smart server is designed to handle this issue.
  - ♦ Communication range from traffic sensors (PIR) to the receiver is 2500 feet.
- In-rush current
  - ♦ Streetlight controller exhibited some issues during switching the LEDs ON/OFF (i.e., switching relay inside the controller kept the lights on all the time). A new controller was designed and its use has prevented this problem from occurring.
- Photocell
  - ♦ The client prefers all lamps to be controlled by one photocell to ensure all lamps come ON at the same time. This was provided.

June 11, 2012 @ 8:53pm
100% Intensity

June 11, 2012 @ 9:14pm
80% Intensity

June 11, 2012 @ 9:25pm
80% Intensity

June 11, 2012 @ 9:25pm
80% Intensity

Thank You

Professor Saifur Rahman
Virginia Tech Advanced Research Institute
srahman@vt.edu
www.ari.vt.edu