Advanced Street Lighting Technologies Assessment Project - City of San Diego

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This project is sponsored by San Diego Gas & Electric (SDG&E) with Jerine Ahmed as project manager. Tom Cartier with the City of San Diego (City of SD) was the City contact and project manager. Daryl DeJean of Emerging Technologies Associates, Inc. provided initial project setup, coordinated efforts with the City of SD, Department of Energy, International Dark Sky Association, the energy and in situ light characteristics evaluation, and is the primary author and source of information for the Economic Analysis: Sections 3.1 and 3.2. Michael Mutmansky of Clanton & Associates, Inc. of Boulder, Colorado developed and executed the survey portion of the project with the support of Todd Givler, Jessica Garcia and Nancy Clanton. Dr. Ron Gibbons and Chris Edwards of the Virginia Tech Transportation Institute developed, performed, reported the visibility 'performance' tests described in this report and are the primary authors for the Objective Analysis: Sections 3.6, 3.7, 4.6 and Appendix E.

Disclaimer

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Abbreviations and Acronyms

AASHTO	American Association of State Highway & Transportation Officials
ANOVA	Analysis of Variance
ASC	Adaptive Streetlighting Controls
CAN	Controller Area Network
City of SD	City of San Diego
CCT	Correlated Color Temperature in degrees Kelvin
CRI	Color Rendering Index
CW	Cool White
DEER	Database for Energy Efficient Resources
ESD	Environmental Services Department
ET	Emerging Technologies
FC	Footcandles
GHG	Green House Gas
HID	High Intensity Discharge
HPS	High Pressure Sodium
IESNA	Illuminating Engineering Society of North America
IND	Induction
LCC	Life Cycle Cost
LED	Light Emitting Diode
LIT	Lighting & Infrastructure Technology Group
LPS	Low Pressure Sodium
MH	Metal Halide
PG&E	Pacific Gas & Electric
RLMMS	Roadway Lighting Mobile Measurement System
SAS	Statistical Analysis Software
SDG&E	San Diego Gas & Electric
SNK	Student Newman-Keuls
S/P	Scotopic/Photopic
SSL	Solid State Lighting
STV	Small Target Visibility
VTTI	Virginia Tech Transportation Institute
W	Watts
WW	Warm White

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Executive Summary

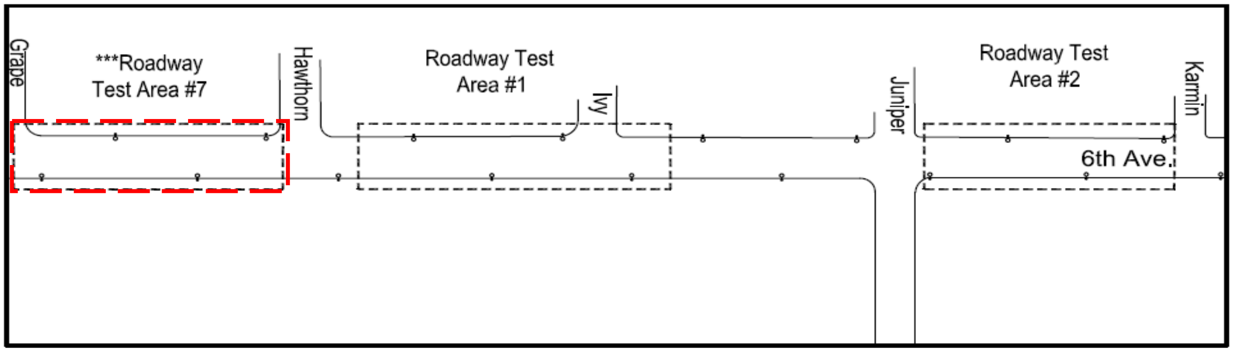
Project Description

The San Diego Gas & Electric (SDG&E) service territory encompasses 145,000 streetlights. Of those streetlights, 105,000 are maintained by municipalities. The street lighting system operates continuously throughout the night for a total energy consumption of 58 GWh per year on the LS-2 rate schedule. Given the potential for considerable energy and demand savings through more efficient and effective street lighting design, an energy efficiency and lighting characteristic assessment was conducted for advanced street light technologies. Particularly, broad spectrum lighting was examined provided by LED and induction light sources.

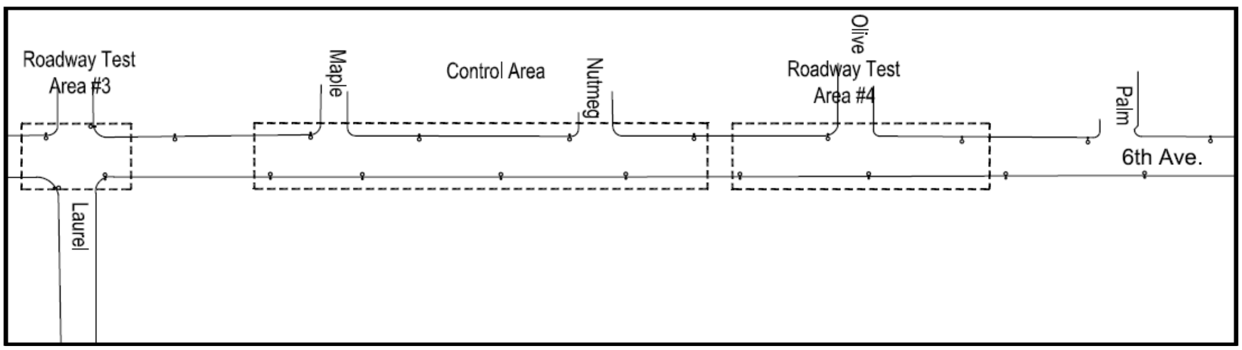
The primary intent of the advanced street lighting assessment project was to determine viable energy-saving options for the existing street lighting system in the City of San Diego (City of SD). This was performed through an experiment in which existing street lighting technology was compared alongside more efficient street lighting technologies utilizing broad spectrum lighting. The goal of the project was to evaluate the energy saving potential of the advanced street lighting technologies and to assess light performance characteristics of the technologies in order to determine the suitability of these technologies for street lighting applications in the City of SD.

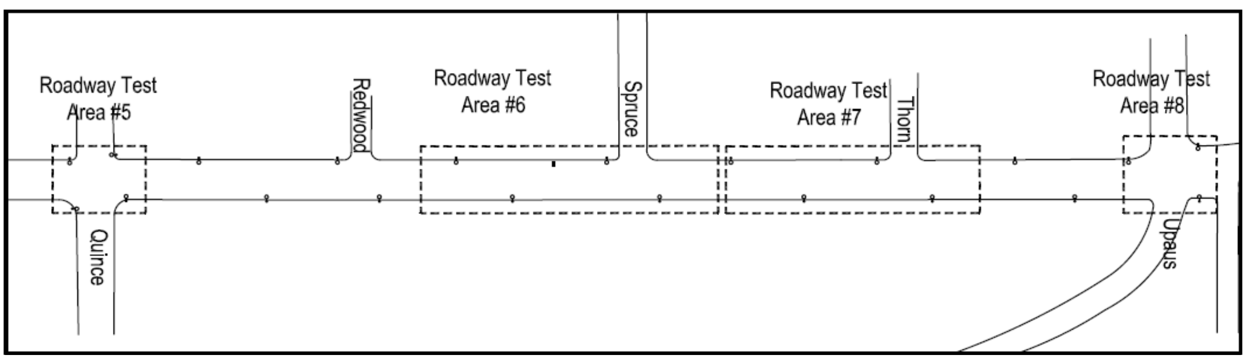
The City of SD requires specific lamp characteristics for the street lighting due to its arrangement with the local astronomers at Palomar Observatory: "For consistency with the City's position with the local astronomers, consideration should be given to **only 3000K** as the color temperature for any street light medium." SDG&E honored the City's request to evaluate the potential energy savings of broad spectrum lighting technologies, specifically induction and LED, at the requested 3000K correlated color temperature (CCT). The **reduced energy efficiency gains** due to a **lower CCT** for LED street lighting were **fully understood by SDG&E**. The project continued in accordance with customer requirements (City of SD). Additionally, it was understood that due to the reduced energy efficiency gains, **the economic implications would be different than those indicated in other similar street light assessment projects** to date in which the CCT was not a factor or permitted to be a higher value.

The project consists of eight different test areas. All of the areas are located along one street which is classified as a commercial/collector. While there are some residences on one side of the street, it is within the downtown area with mixed uses. Each area consists of four luminaires with a different light source and luminaire manufacturer. Three areas use LED technology, three areas use induction lamp technology, and two areas use the existing High Pressure Sodium (HPS) technology as a baseline comparison. Each technology area includes an intersection test area as well as two roadway test areas. Quantitative light and electrical power measurements, photographs, a subjective lighting survey, and object visibility detection, 'performance', tests were administered.



*Note Test Area *7 (outlined in red). The scotopic and photopic measurements were recorded at this location. The detection distance calculations (STV) were performed at Test Area 7, identified in* Figure 3.





Test Area	Technology	Watts/Lamp	Watts/Luminaire
1	Induction	165W	165W
2	Induction	150W	160W
3	Induction	165W	165W
4	LED	-	198W
5	LED	-	146W
6	LED	-	94W
7	Existing HPS (roadway)	250W	288W
8	Existing HPS (intersection)	150W	180W

Project Results

The results of this technology assessment project indicate a change in street light technology from the current High Pressure Sodium (HPS) to an advanced street light technology using broad spectrum lighting may result in a number of benefits. These include:

- Reduced energy consumption (up to 40%)
- Reduced Green House Gas (GHG) emissions (graph in Appendix G: City of San Diego Life Cycle Cost Analysis)
- Improved color rendering (a more pleasing appearance within the City of SD)
- Reduced maintenance costs (longer lamp life resulting in fewer lamp replacements).

Other indirect benefits include reductions in light pollution and with careful selection of the replacement luminaires, a reduction in potential human health risks associated with human circadian rhythms and melatonin production.

The results from the subjective lighting survey indicate that there is not a strong preference for or against broad spectrum light sources for the street lighting in the City of SD. This implies that the community will accept a change from HPS light sources (mild yellow-light sources) to another more efficient street lighting technology that is perceived as 'white light'. The results from the objective performance testing indicate that there is not a significant decrease in visual performance with the reduction of light level that is associated with the 'white light' alternative street lighting technologies. This implies that a change in street lighting technology from existing HPS to more efficient broad spectrum may not result in a decrease in actual safety benefits, from a perspective of vehicular performance and detection distances.

Several factors should be considered before a decision is made to change from existing street lighting technologies to advanced street lighting technologies utilizing broad spectrum lighting. While energy efficiency and lighting performance characteristics are important factors to consider, the City of SD must also consider the impact that broad spectrum lighting will have on the local astronomy community. Careful consideration of the potential drawbacks of a street lighting change must be made to ensure that any decision is well planned and all potential problems are known, understood, and resolved before action is taken. By considering all factors, implementation of advanced street light technologies will be more successful and accepted.

The findings of this project intend to convey the viability of the broad spectrum technologies in a street lighting application. The findings do not recommend or endorse a specific technology. Therefore, readers are **recommended to conduct their own in situ**

assessment of broad spectrum street lighting technologies based upon their **specific conditions and requirements as well as economic considerations**.

While not considered as part of this assessment, it may be appropriate to consider other lighting technologies in addition to light sources for any city-wide street light technology replacement project. One opportunity worth consideration is adaptive street lighting controls which adapts the lighting output of individual or system-wide street lighting to its environment by dimming. The implementation of these controls can improve energy savings, reduce maintenance, and reduce light pollution. For the City of SD, adaptive street lighting controls could help reduce the affects of broad spectrum street lighting on the local astronomy community.

1.0 Introduction

The City of SD Advanced Street Lighting Technology Assessment Project intends to provide SDG&E and the City of SD with an evaluation of the energy savings potential of broad spectrum street light provided by both LED and induction light sources, while maintaining critical light characteristics required in a street lighting application. These characteristics include quality of light, aesthetics, maintenance, public safety for pedestrians and motorists and the environmental impact such as GHGs. An additional consideration is the impact on the night sky and the astronomy community due to the proximity of Palomar Observatory.

The specific goals and objectives of the project are:

1. Determine the energy reduction potential of advanced street light technologies, LED and induction, as compared to traditional HPS source.
2. Evaluate the light characteristics of each technology to determine if energy efficiency is possible without a compromise in light performance.
3. Conduct an economic impact analysis (Life Cycle Cost Analysis) on each technology as compared to the HPS.
4. Identify alternate lighting technologies that are suitable substitutions for high pressure sodium technologies.
5. Collect and analyze target detection distance data under the test area light sources to assist in the understanding of the visual performance of various street lighting technologies and the impact (positive or adverse) on public safety.
6. Evaluate subjective opinions of citizens toward various light sources that may be suitable candidates for selection as replacement luminaires for the City of SD street lighting.
7. Identify parameters or characteristics of proposed technologies that may be critical in the technology evaluation process.

1.1 History and Background

The City of SD, Environmental Services Department (ESD) has been performing energy improvements in various existing City facilities. During lighting fixture conversions to new state-of-the-art florescent type lighting, it was discovered that the broad-spectrum light, ‘white light’ enhances visual acuity. The City of SD sought to expand the application of broad spectrum lighting to determine what advantages it may offer for outdoor lighting, including street lights in the right-of-way.

To evaluate various types of broad spectrum street light technology, the City of SD and SDG&E collaborated on a project to identify and evaluate advanced street light technology which can benefit the public. In a collaborative effort with SDG&E’s Emerging Technologies (ET), Local Government Partnership programs, and the City of SD a conscience decision was made to conduct a side-by-side field test of advanced street light technologies utilizing broad spectrum light sources such as induction and Solid State Lighting (SSL) LEDs to assess their benefits.

This decision was based upon the fact that current lighting research suggests that the human eye can better perceive objects in low light levels when the source spectrum is broad with both short and long wavelength light, commonly perceived as ‘white light’. Metal halide, induction, and LED technologies with a color rendering index (CRI) of 65 or greater can more closely reproduce ‘white light’ than a typical HPS lamp (with a CRI of approximately 20), or the low pressure sodium (LPS) lamps used near the observatories (with a CRI of approximately 5). In previous research (Lewin, 2000), broad spectrum light sources have been found to improve perception-reaction time by providing roadway users better peripheral vision. Multiple technologies generate white light with somewhat different efficiencies and overall visual results.

This project builds upon the experience and lessons learned from previous broad spectrum street lighting conversion studies conducted in Alaska, Michigan and Northern California. The project is unique because it includes both public input and lighting evaluations using sophisticated data collection equipment to compare the efficacy of two competing technologies, LED and induction, versus the base case, existing HPS lighting. The test results will be part of a data set that will help evaluate the role of lamp spectral distribution and visibility under mesopic lighting conditions. These results will be used in the revision of IESNA TM-12-06 'Spectral Effects of Lighting on Visual Performance at Mesopic Light Levels'. The project will also validate manufacturer claims regarding energy savings, light levels, and light characteristics. The project could be used by other cities and agencies across the USA to make informed decision on their choice of new energy efficient street lighting technology.

It is important to note that the results of this project are for a specific set of field conditions: two-lane roadway (meaning two traffic lanes in each direction) with existing 250W HPS fixtures with specific pole spacing and fixture mounting heights. **The specified replacement requires a CCT of 3000K**. In addition, the economic analysis is based on assumptions such as energy cost, maintenance costs, and luminaire costs that are specific to the City of SD. **Readers are advised to use their own cost estimates and assumptions when possible.**

1.2 Technology and Market Overview

New street lighting technologies have the potential benefits of improved efficiency, better maintenance characteristics and improved control capabilities that can reduce the energy consumption and maintenance costs for an overall net gain for the City of SD and its citizens. White light technologies also have the potential for improved visual performance and preferred visual aesthetics that can result in an uncalculated but appreciable benefit as well.

The information gathered through this project will provide direction to the City of SD for future street lighting applications. Further, other municipalities are contemplating similar street lighting systems and the results of this project can inform them of the performance issues related to white light. The publication of this project can provide insight for planning departments into public perception and nighttime visibility variables worth considering.

This project represents early results in the research into the 'white light' impact on street and roadway lighting. This research is part of a bellwether body of knowledge that can impact the Illuminating Engineering Society of North America (IESNA) recommendations for roadway lighting, and ultimately greatly impact the design practices of the lighting engineering community as a whole.

1.3 Prior Work

Previous studies of LED luminaires have been conducted in Oakland and San Francisco by Pacific Gas & Electric's (PG&E) Emerging Technologies Program, with the support of the Department of Energy. These studies evaluated a smaller number of lower wattage LED luminaires in residential neighborhoods and focused primarily on energy consumption and economic performance. There was not a parameter in place for these studies regarding the CCT of the light source.

The Oakland study contacted residents to see if they noticed the new lighting and if so, residents were asked to provide preference feedback from them. The study did not take a set number of people through the test site at the same time. Neither the study in Oakland nor San Francisco included the objective visibility component of the assessment in San Diego to simulate driving and study target detection performance.

Clanton & Associates and the Virginia Tech Transportation Institute (VTTI) performed two similar subjective and objective performance surveys recently for the Municipality of

Anchorage. These studies included the evaluation of luminaires at two different light outputs in an effort to test the proof of concept for Adaptive Street Lighting Control.

2.0 Project Methodology

The project consisted of an energy evaluation, a subjective survey, and an objective 'performance' survey to collect quantitative data. The energy evaluation is performed by evaluating power measurements of the street lighting systems and multiplying the hours of operation to generate typical energy use totals for the year. The subjective survey portion is meant to determine community acceptance of broad spectrum light sources. The objective portion is meant to determine visibility measures for the broad spectrum sources through the use of Small Target Visibility (STV) style targets. Both the subjective and objective portions combined are meant to provide insight into the function visibility provided by various lighting systems and the public preferences for these technologies.

2.1 Overall Project Setup

The test location consists of a four lane roadway in a low-rise residential and high-rise residential area along 6th Avenue in the City of SD. Sixth Avenue is a uniform stretch of roadway oriented North-South, with a uniform width of approximately 62' and a typical cross-section of a parking lane on the East, two drives lanes to the North, two drive lanes to the South, and a parking lane on the West side. There are several segments where the width decreases and there is only parking on the East side, or the parking is taken to provide a left-turn lane, however, the number of drive lanes remains constant. The roadway is relatively flat for the majority of the testing areas (approximately 14 blocks). There is a slight slope downhill beginning at Laurel Street and continuing on to Grape Street. The area is classified as a commercial/collector. While there are some residences on one side of the street, 6th Avenue is within the downtown area with mixed uses.
The road borders Balboa Park on the East side and there is a detached sidewalk the entire length of the test area. On the West side, there is an attached/detached sidewalk, depending on the conditions. The West side also has numerous buildings, from smaller row homes to larger high-rise residential properties and some commercial buildings. There is a mixture of trees on both sides of the road (including Palm trees), but none obstruct the street lighting system in a substantial manner.

The route includes a number of alternative lighting sections in addition to current roadway lighting technologies. Eight different lighting test areas were evaluated in this experiment. The eight different test areas evaluated in the project are indicated in Table 1.

Test Area	Technology	Watts/Lamp	Watts/Luminaire
1	Induction	165W	165W
2	Induction	150W	160W
3	Induction	165W	165W
4	LED	-	198W
5	LED	-	146W
6	LED	-	94W
7	Existing HPS (roadway)	250W	288W
8	Existing HPS (intersection)	150W	180W

Table 1: Lighting System Power Consumption

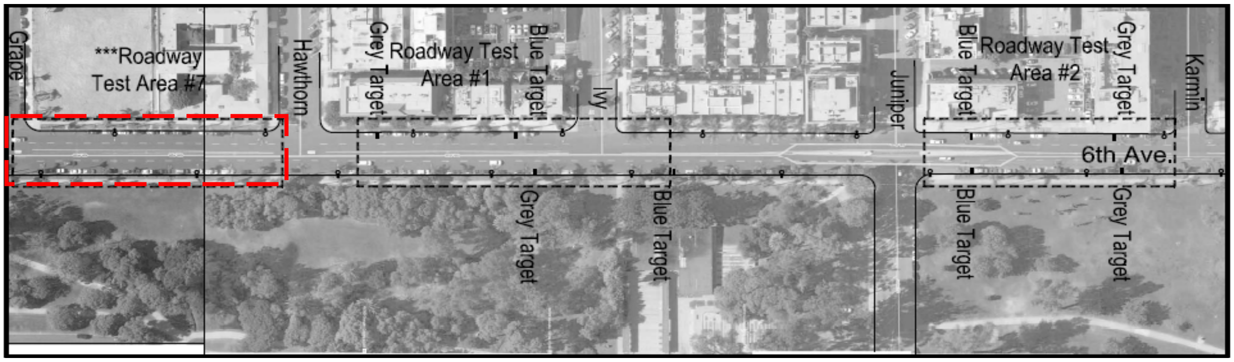


Figure 1: Experiment Location and Set-Up for Test Areas *7, 1, 2.

*Note Test Area *7 (outlined in red). The scotopic and photopic measurements were recorded at this location. The detection distance calculations (STV) were performed at Test Area 7, identified in* Figure 3*.*

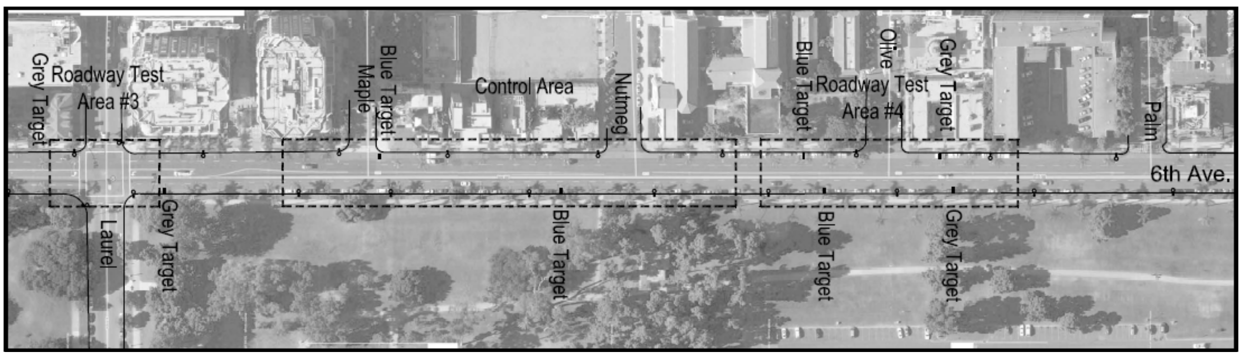


Figure 2: Experiment Location and Set-Up for Test Areas 3 and 4.

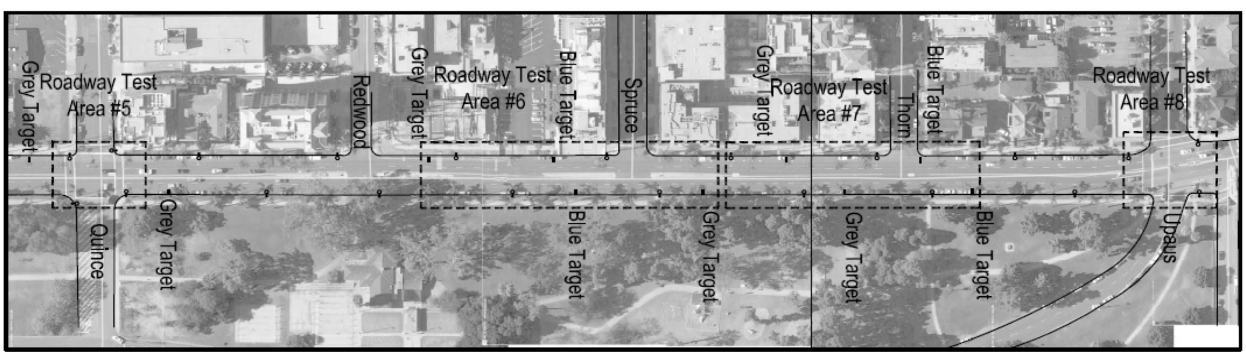


Figure 3: Experiment Location and Set-Up for Test Area 5, 6, 7, 8.

The poles are spaced approximately 100’ apart (to the next pole) in a staggered arrangement. The poles are 25’ high and the arm is 8’ long with an additional 3’ rise in the arm, resulting in a 28’ mounting height for the luminaire.

2.2 Light Sources

This assessment evaluated different light source technologies. Light sources are commonly characterized by their color temperature and color rendering ability. CCT, stated in Kelvin, identifies the 'warmness' or 'coolness' of the light color. A CCT of 2700K represents a warm incandescent looking light. As the temperature increases, it represents a cooler light. For example, a source rated at 5500K or 6500K appears very blue compared to a 2700K source. Normal noon day sunlight has a typical CCT of 5000K. Northern blue sky has a CCT of 10,000 – 20,000K.

The color rendering index (CRI) describes a different characteristic of the light source – not how the source itself appears, but rather how well object colors appear under that light source. The rating ranges from 1-100 where the higher score represents a better color rendering. Noonday daylight has a rating of 100.

The sources considered for this test vary considerably in both of these characteristics. In general, HPS produces a low CCT and a very low CRI. The LED, induction, and other broad spectrum 'white light' sources are typically much cooler in color temperature (many are 4000K and higher), but have much better color rendering near 80 CRI or even better.

Test Area	Technology	Color Temperature (CCT)	Color Rendering Index (CRI)
1	Induction	3000K	80
2	Induction	3000K	85
3	Induction	4000K	80
4	LED	3500K	>70
5	LED	3500K	Unknown
6	LED	3500K	Unknown
7	Existing HPS (roadway)	2100K	20
8	Existing HPS (intersection)	2100K	20

Table 2: Light Source Color Characteristics

2.3 On Site and Laboratory Measurements

The luminaires were tested in field conditions for the CCT of the light sources and the results are shown compared to the manufacturer's stated CCT in Table 3.

There are minor differences in the actual vs. manufacturer's stated CCT; however, there are several important aspects of these differences that are important to understand in the context of a subjective/objective survey regimen as was completed in this project. The first is the subjective perception of light, and how color temperature affects this perception. At low light levels, humans have increased perception with increased levels of blue wavelengths. In the case of CCT, the sources with higher blue wavelengths have higher CCT.

All of the luminaires were planned to have a CCT of approximately 3000K as an attempt to reduce the variability of color temperature in the tests, which is important to avoid the possibility that the subjective surveys will show a preference for a particular product due to the CCT rather than the performance of the fixture in terms of glare, light distribution, and general 'feel' the light makes on the street.

One LED fixture stands out as the one product that does not appear to closely match the manufactured stated CCT and the measured CCT. The cause of this deviation is currently under inquiry.

Test Area	Technology	Manuf. Stated Color Temp.	Measured Color Temp.
1	Induction	3000K	2930K
2	Induction	3000K	3250K
3	Induction	4000K	3625K
4	LED	3500K	3475K
5	LED	3500K	3500K
6	LED	3500K	4560K
7	Existing HPS (roadway)	2100K	Not measured
8	Existing HPS (intersection)	2100K	Not measured

Table 3: Manufacturer's Stated CCT vs. Measured CCT

Illuminance measurements were taken once the luminaires were installed on the streetscape. Scotopic and photopic illuminance readings were taken with a Solar Light Company SL-3101 Dual Scotopic/Photopic (S/P) light meter and pavement luminance at the same location.

Figure 4: S/P Light Meter (Solar Light Company).

The S/P and the luminance readings were made on a 5 foot by 10 foot grid in the road between poles to follow, as closely as possible, the IESNA guidance on photometric measurements of street lighting systems. Since poles are staggered on the street, it is difficult to establish a measurement grid that will work for every condition, but the grids started approximately 2.5' into the road from the head of the luminaire and 5' to the side of the head of the luminaire, in an attempt to standardize the results for comparison purposes. The test areas in the roadway (Areas 1, 2, 4, 6, and 7) were measured in this manner, but the intersection poles were not.

The measured data is included in Appendix C: Site Calculations. Figures of the measured photopic readings for Test Area 4 and Test Area 6 are included in the 'Results' section (Section 3).

2.4 Survey Approach

The project subjectively and objectively evaluated eight different luminaire systems, including two systems that represent the existing lighting conditions in the test area.

Subjective Evaluation:

1. Two groups of participants evaluated each test area filling out a thirteen-statement survey.
2. Statements were rated to evaluate the perception of safety of the lighting system, the preference for the 'color' of the light, and other general impressions of the lighting system.
3. The results were analyzed for statistically significant differences in response among the various test areas.

Objective 'Performance' Evaluation:

1. Some of the participants from the subjective survey groups rode in a vehicle that traveled through each test area (three participants at a time).
2. Participants pushed a 'detection' button when they identified a target along the side of the road.
3. Equipment on the car recorded its location, the target location, the luminous scene at the time the target was recognized, as well as the illuminance and luminance conditions along the roadway.
4. These results were analyzed to establish the average detection distance to the target under each of the lighting systems.

The results of the two different evaluations were then compared to find correlations between how people view the different lighting conditions and how these same conditions are rated with current visibility criteria, specifically, detection distance.

2.5 Subjective Survey

The subjective lighting survey consists of thirteen statements which the participants rated on a 1-5 scale (strongly disagree to strongly agree, respectively). The survey was administered to two groups of individuals comprised of two sub-groups each. The groups evaluated the street lighting in eight different areas. The two groups contained 26 and 30 individuals. The surveys were completed as the individuals rotated through the eight areas in a specific order. Within each group, one sub-group started with Test Area 1 and proceeded in order: 1, 2, 3, 4, 5, 6, 7, 8 while the other sub-group started with Test Area 4 and proceeded in order: 5, 6, 7, 8, 1, 2, 3, 4. Both groups rotated through the lighting order until returning to the test area they began with.

The following list of statements comprised the survey. See Appendix A: Subjective Lighting Survey Form for survey forms typical for each area.

1. **'It would be safe to walk here, alone, during daylight hours'**
2. **'It would be safe to walk here, alone, during darkness hours'**
3. **'The lighting is comfortable'**
4. **'There is too much light on the street'**
5. **'There is not enough light on the street'**
6. **'The light is uneven (patchy)'**
7. **'The light sources are glaring'**
8. **'It would be safe to walk on the sidewalk here, alone, during darkness hours'**

9. **'I cannot tell the colors of things due to the lighting'**
10. **'The lighting permits safe navigation.'**
11. **'I like the color of the light.'**
12. **'I would like this style lighting on my city streets.'**
13. **'How does the lighting in this area compare with the lighting of similar city streets at night?'**

2.6 Objective 'Performance' Visibility Test

An objective assessment of the alternative lighting technologies required both human factor components in addition to lighting metrics. To evaluate these components, the experimental design incorporated a response metric, in this case object detection distance, and illuminance and luminance metrics. The data collection was made possible by using an enhanced version of the Virginia Tech Transportation Institute Lighting and Infrastructure Technology groups' roadway lighting mobile measurement system (RLMMS). The combined data capturing capability allowed the research team to continuously collect response data from participants in addition to lighting metrics.

2.7 Experimental Design

The experimental design incorporated eight lighting systems, six of which were alternative light sources installed for this evaluation session. An existing HPS installation was used as a control and comparison section. The section where the lighting was installed was also defined into two specific locations: typical roadway and typical intersection. Visual target types also varied, with small targets placed at all locations and pedestrians placed at intersections. Additional experimental variables included lighting level, which was obtained by manipulating the target position under each lighting section (e.g., high and low illuminance) and a color comparison using two specific colors of targets (e.g., blue and grey). Details of each variable are shown in Table 4.

Variable	Description
Lighting	6 alternative light sources (3 induction and 3 LED), and the existing condition (HPS 250W)
Lighting Level	High (4.5-6.3 fc) and Low (2.1-3.1 fc) Illuminance (target position)
Color	Grey (18% reflectance) or Blue target (6.2% reflectance)
Target Type	STV Target or Pedestrian
Section	Roadway or Intersection

Table 4: Objective Testing Experimental Variable Descriptions

2.8 Methods for Objective Testing

2.8.1 Participants

Thirty-four participants volunteered to be passengers for the objective portion of the project which took place in the data collection vehicle. The participants were recruited from participants in the subjective evaluation portion of the project. The participant pool contained both males and females aged 18 and older. It should be noted that gender and age were not controlled for this project, thus were not analyzed. A single trip through the all of the test areas contained up to three passengers who detected visibility targets from their respective positions in the front or back seat of the vehicle.

2.8.2 Equipment

Beyond the lighting installations on the street, two specific pieces of equipment were required for the objective 'performance' experiment. The first is a complex measurement system developed for measuring roadway lighting installations. The second were visibility targets used to allow objects to be detected by the project participants.

2.8.3 Equipment - Roadway Lighting Mobile Measurement System (RLMMS)

The data collection equipment used during the experiment contained a variety of elements for collecting illuminance, luminance, color temperature and participant response data. The RLMMS was created by the Lighting and Infrastructure Technology Group (LIT) at the VTTI as a method for collecting roadway lighting data in addition to participant response data.

A specially designed "Spider" apparatus that contained four waterproof Minolta illuminance detector heads were mounted horizontally onto the vehicle roof in such a way that two meters were positioned over the right and left wheel paths and the other two meters were placed along the centerline of the vehicle. An additional vertically mounted illuminance meter was positioned in the vehicle windshield as a method to measure glare from the lighting installations. The waterproof detector heads and windshield mounted Minolta head were connected to separate Minolta T10 bodies that sent data to the data collection PC positioned in the trunk of the vehicle.

A NovaTel Global Positioning Device (GPS) was positioned at the center of the four roof mounted illuminance meters and attached to the "Spider" apparatus. The GPS device was connected to the data collection box via USB and the vehicle latitude and longitude position data was incorporated into the overall data file.

Two separate video cameras were mounted on the vehicle windshield, one collected color images of the forward driving luminous scene and the second camera collected luminance information of the forward driving scene. Each camera was connected to a standalone PC computer that was then connected to the data collection PC. The data collection PC was responsible for collecting illuminance, human response (reaction times), and GPS data and synchronized the camera PC images with a common timestamp. Additional equipment inside the vehicle consisted of individual input boxes for participant entered responses and a Controller Area Network (CAN) reader to collect vehicle network information.

Each component of the RLMMS is controlled by a specialized software program created in LabVIEW™. The entire hardware suite is synchronized through the software program and data collection rates are set at 20Hz. Video image capture rate was set at 3.75 frames per second (fps). The final output file used during the analysis contained a synchronization stamp, GPS information (e.g., Latitude, Longitude), input box presses, individual images from each of the cameras inside the vehicle, vehicle speed, vehicle distance, and the illuminance meter data from each of the Minolta T-10s (4 total).

Figure 5 below shows the test vehicle used for this project. Figure 6 shows the experimental vehicle and the "Spider" apparatus with incorporated Minolta waterproof heads in addition to the GPS unit and cameras mounted inside the vehicle.

Figure 5: Experimental Vehicle with RLMMS Components.

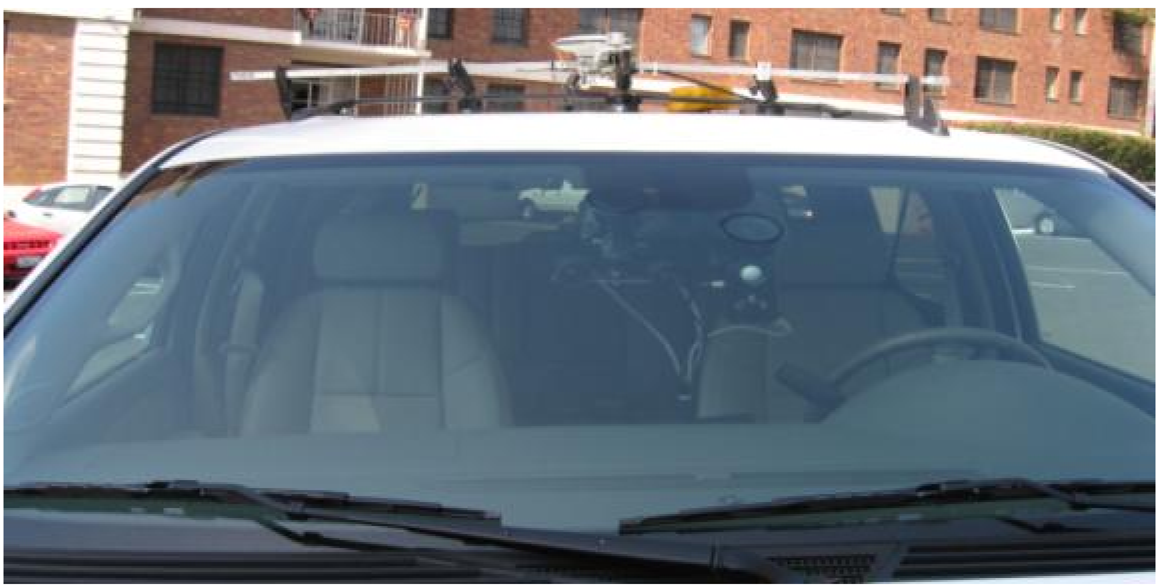


Figure 6: RLMMS Components Mounted on and Inside a Vehicle

2.8.4 Equipment - Visibility Targets

Research has established a relationship between certain visibility metrics and the detection and avoidance of a small object on a roadway. Research has also established a correlation between these visibility metrics and the frequency of vehicular accidents at night. The calculation of Small Target Visibility (STV) is a method to calculate this relationship.

The STV method (as defined by IESNA RP-8) is used to determine the visibility level of an array of targets along the roadway when considering certain factors such as: the luminance of the targets, the luminance of the immediate background, the adaptation level of the adjacent surroundings, and the disability glare. The weighted average of the visibility level of these targets results in the STV value.

Two types of visibility targets were used in the performance testing. The first target is an STV style targets made from wooden squares. The second type is pedestrians. These objects were located along the roadway and were used as the objects of interest in the performance portion of the project. Pedestrians were positioned in intersections at crosswalks, while the other targets were positioned along the roadway.

The STV style targets are flat vertical targets, which measure 7 inches on each side. On one side, a tab is also located. This tab measures 2.375 inches by 2.375 inches. The targets are pictured in Figure 7. There were two potential target colors, grey or blue. Note that the target bases (shown as unfinished wood in the photos below) were painted to be similar to the road surface.

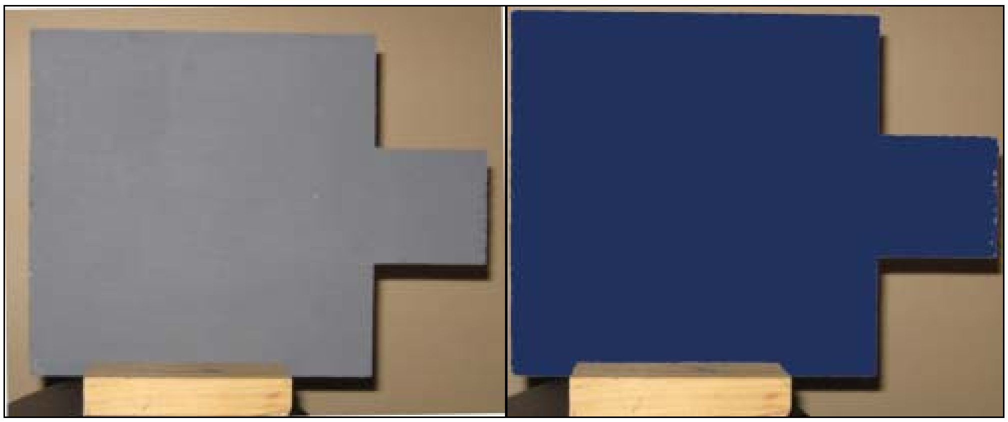


Figure 7: Example of Detection Targets along Experimental Route

Targets of each color were positioned within each of the test areas. The targets were positioned such that two levels of vertical illuminance levels were achieved. In the northbound lanes, a high illuminance level was achieved by target placement and in the southbound lanes; a low level of vertical illuminance was achieved. Before the experiment, specific locations where target illuminance matched within each of the northbound and southbound directions were also selected.

The targets were placed in the edge lane of the roadway in such a way as not to be struck by the participant vehicle. As the roadway allowed shoulder parking, the objects were located at the edge of the lane allowing for a parked car in the edge lane. Figure 8 below shows locations of the STV style targets near Test Area 4.

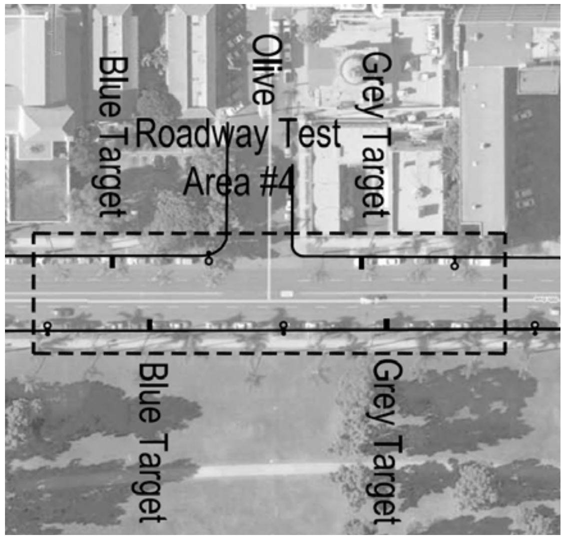


Figure 8: Experiment Location and Set-Up for Test Area 4.

In addition to the small targets, participants were asked to identify pedestrians at the intersections of interest. The pedestrians were wearing hardhats of a specific color (yellow or white). The pedestrians were located in the approach side crosswalk at each intersection, which is the crosswalk closest to the approach of the vehicle. The pedestrians appeared at intersections for both the northbound and southbound vehicle travel. A group of local University students were used as assistants and acted as the pedestrians and monitored the targets within each test area.

It should be noted that at the Laurel Street and at the Upas Street intersections, significant roadway signage and traffic control personnel were present due to the roadway lane closures.

The entire route containing each of the lighting sections was roughly 1.0 mi (1.6 km) in length. The roadway and intersection installations contained the same number of luminaires and the length of each section was comparable across section type (roadway or intersection).

2.9 Survey Night Site Conditions

The weather on the night of the survey was overcast, 55° Fahrenheit and 70% relative humidity. The mild overcast cloud condition provided some sky luminance over the test areas, although the buildings and streets have considerably higher apparent luminance, therefore, the cloud luminance is not considered to be a factor to reject survey data.

The pavement was dry and clear. The road was closed before the first survey and remained closed through the final survey group. Participants were able to enter the roadway to make the assessments. Most participants answered the survey statements from the road or the curb rather than the setback sidewalk.

2.10 Photos

The team took photos of the experiment area on the night of the survey.

Figure 9: Photo of Road Closure Sign.

Figure 10: Nighttime Photo of Survey Group under HPS Lighting.

Note the sky luminance behind the survey group (looking toward the South and the downtown district)

Figure 11: Nighttime Photo of Survey Group under White Lighting.

2.11 Procedure

Participants were introduced to the subjective and objective project at the San Diego War Memorial Building. Once the orientation and overview of the evening was complete, the first group of participants was taken by bus to the first test area situated on 6th Avenue. There, the (experimental) vehicle driver then recruited the first three participants for the objective 'performance' portion of the project. The participants chose amongst them who was would sit in the front versus the back. Once finalized, the participants were asked to enter the vehicle and review the tasks involved in this portion of the project.

While sitting in the stationary experimental vehicle, the experiment was reviewed by the experimenter, also the driver. The experimenter pointed out the surveyor input boxes that were positioned both in the front and rear seats of the vehicle that enabled participant input when a visibility target was detected. After the input boxes introduced, the participants were shown an example target.

Participants were instructed only to press a response button upon detecting either of the two visibility targets. The participants were requested to notify the experimenter if a button had been pressed accidently during the experimental run.

Prior to beginning the experimental drive, the participants in the back seat were also asked to move to where they could comfortably see the forward view of the roadway and thus detect targets out of the front windshield (rather than the side windows). Each participant was asked not to converse or hint to the other participants when they had seen a target in order to minimize influencing detection distances. Prior to starting the experimental run, the experimenter asked if the participants had any questions or concerns' regarding the detection task or what was being asked of them.

When all questions had been addressed, the experimenter then opened a data-file on the data collection machine and started recording. If a target was present at the starting location (or near the starting location), the experimenter advised participants to ignore the target and begin searching after the vehicle was in motion. The starting location of the experimental vehicle varied during the testing sessions and was dependent on the location of the subjective evaluation participants.

The vehicle was driven at a maximum speed of 30 mph, which is the designated road speed along 6th Avenue. The experimental vehicle also drove in the far left lane in each direction of travel. In addition to driving the vehicle, the experimenter also recorded the visibility target locations. Along the route, the participants pressed input boxes upon detecting the targets and/or the pedestrians located on the side of the roadway or in the crosswalks of the intersections. The total testing time lasted approximately 8 minutes. This was broken down by having the participants review the experiment (2 min) and then participate in the detection task as they were driven along the route (~ 6 min). A total of 12 runs were made through the entire testing route. At the end of the route, the vehicle returned the surveyors and picked up a new set of participants. At the end of the evening, testing participants were returned to the Memorial Building and thanked for their assistance with the project.

2.12 Data Analysis

Two separate data analyses were performed for visibility data and illuminance sensor data. For the objective visibility analysis, an initial data cleaning was performed where targets were located via GPS coordinates, responses were verified and matched to each target section, and additional data anomalies (outliers) were removed from the data. For example all data that exceed three standard deviations away from the mean were excluded. This resulted in values approximately 100 meters or greater being removed from the data set. An additional data check was then performed to look for any other outliers and to check the images associated with the data file. These were performed by checking the data in Arc Map and verifying the image information.

Then the entire data file including the input box and space bar presses, latitude and longitude information, the respective image names from the color and luminance cameras were imported into a Statistical Analysis Software (SAS) for review and analysis. For example, the distance calculation was obtained by calculating the distance from using latitude and longitude coordinates for each button and space bar press.

This was rechecked using the distance calculation obtained from the vehicle network data. When the distance calculations were completed the dataset underwent an additional data check for outliers and anomalous data and corrections were made as required (e.g., either deletions for false button presses, frame corrections, or deletions for anomalous data). Analysis of Variance (ANOVA) was used as the statistical tool to investigate differences among lighting type, lighting location, and target variables such as target color for targets, helmet color for pedestrians, and vertical illuminance level.

The objective illuminance data for the lighting sections underwent the same data cleaning process as the visibility (or detection distance) data. The entire data file was checked for anomalies and sections were verified with GPS information. Additional spot checks were performed using the color images collected during the drive to verify section location and starting/ending points.

The cleaned data file was then imported into SAS for review and analysis. The illuminance data gave an approximation of the light intensity reaching the road surface, which gave a further understanding of the performance of the different lighting sections.

3.0 Results

The following sections provide information on the results of the subjective and performance surveys, energy and cost implications, lighting field measurements, and lighting calculations.

3.1 Electrical Demand and Energy Savings

Numerous spot readings over the course of several evenings was required to gather data on the power characteristics for the HPS and advanced street light technologies. No significant variations in power consumption were noted in the spot readings.

The base case HPS luminaire consumed an average of 288 watts per luminaire. Based upon 4165 annual operating hours, the estimated annual energy consumption for the HPS luminaire is 1200 kWh.

The average power consumption for the advanced street light technologies is 198 watts for the LED luminaires and 163 watts for the induction luminaires. The annual energy consumption for the LED is 824 kWh and induction is 679 kWh. The potential energy savings is 375 kWh (31%) for the LED and 521 kWh (43%) for induction.

Luminaire Type	Power (W)	Power Savings (W)	Estimated Annual Energy Consumption (4165 hr/yr, kWh)	Estimated Annual Savings (4165 hr/yr, kWh, %)
250W HPS Type III full cutoff (base case)	288	-	1200	-
LED	198	90	825	375 (31%)
Induction (avg)	163	125	679	521 (43%)

Table 5: Potential Demand and Energy Savings

The road width throughout the testing areas was reasonably uniform; therefore, the power for each system is dependent on the wattage of the luminaire and the spacing of the luminaires within each test area.

The linear power density for a typical roadway cross-section is calculated in Figure 12 below. This represents a composite of the pole spacing found in the test areas, (100 foot spacing pole to opposite pole).

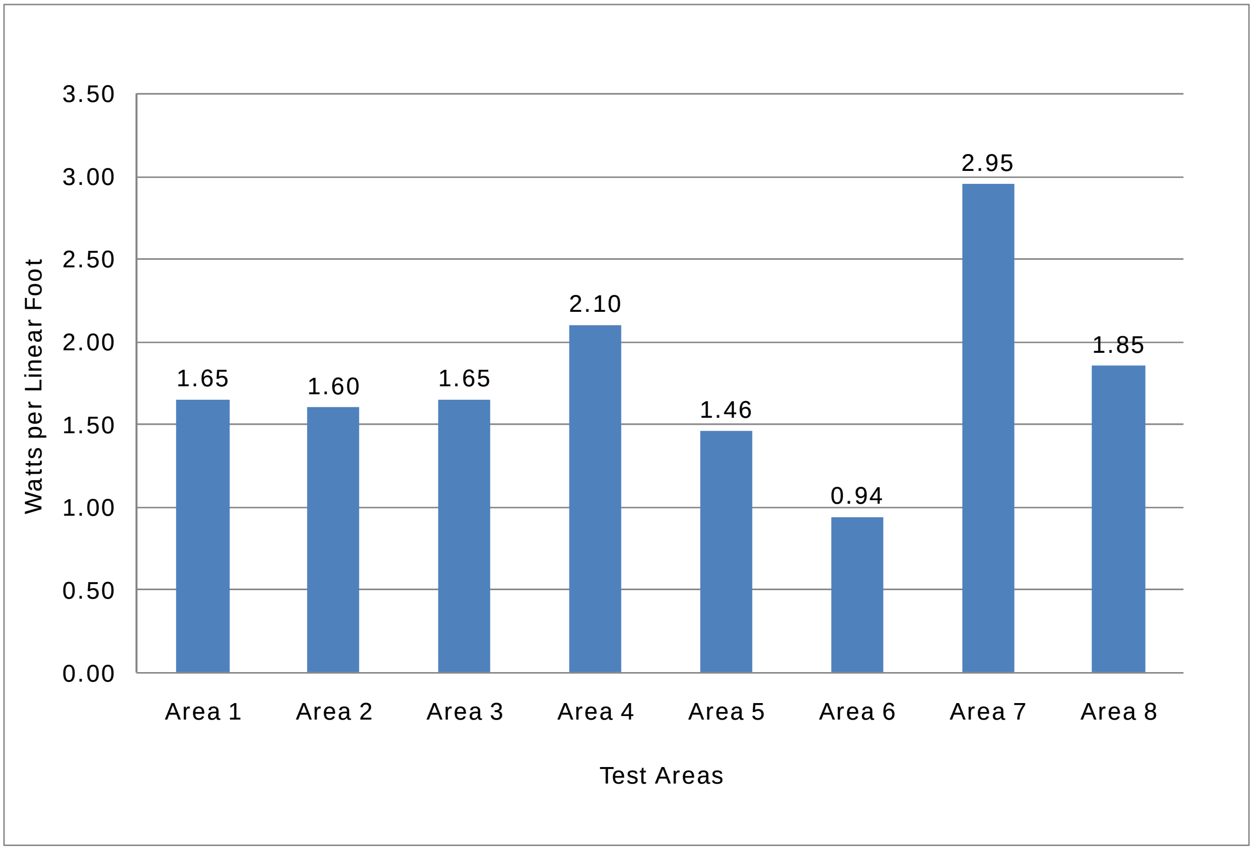


Figure 12: Power Consumption Comparison for Each Lighting System Based on a Standard 100-foot Pole-to-Pole Staggered Spacing (200-feet Pole-to-Pole per side).

3.2 Economic Implications

This section is based upon the City of SD cost and savings estimates to evaluate economic performance of the base case HPS luminaire and the LED and induction luminaires assessed in this project. The City of SD calculated both the simple payback as well as a life cycle cost of each technology based upon a 20 year economic life cycle.

Economic estimates are sensitive to site-specific variables such as maintenance and energy costs, and to luminaire cost. Of particular note, estimates are also dependent upon assumptions for luminaire lifetime, which is a function of the life of all parts of the luminaire (light sources, power supply, housing, coating, etc.). Manufacturers' claims for luminaire lifetimes are highly variable. Additionally, the testing was based on head replacements at existing pole locations. All systems were not designed for precise equivalence of performance. Readers are advised to use their own specific cost estimates and assumptions.

The cost and equipment assumptions made in this section apply only to the City of SD. The City of SD required luminaires to be 3000K. Therefore, readers should consider their specific variables such as maintenance, energy and luminaire costs before drawing any conclusions about the cost effectiveness of LED or induction luminaires. LED luminaire lifetime is a function of all the manufacturer's components of the luminaire (LEDs, driver, housing, coatings, etc.), electrical and thermal properties. Therefore manufacture claims are highly variable. The assumptions for LED life expectancy in this project are based upon 50,000 hours as per the Department of Energy (U.S. DOE, 2009).

This section is based upon the City of SD cost and savings estimates to evaluate economic performance of the base case HPS luminaire and the advance street light technologies, LED, and induction luminaires, assessed in this project. The City of SD calculated both simple payback as well as life cycle cost of each technology based upon a 20 year economic life cycle.

The lower CCT affected the overall energy savings potential of the LED luminaire. Lowering the color temperature of a given chip is typically achieved by increasing the number of phosphors contained in the encapsulant, with the result that a greater percentage of lumens emitted by the chip itself are absorbed before exiting the LED. Lowering the color temperature has a negative impact on chip efficacy (fewer lumens produced for a given power consumption). The specification of a low CCT resulted in the LED losing approximately 25-40% of the energy savings potential compared to a typical high CCT LED source (with a 5500K CCT). The paybacks for this project are longer than projects where CCT was not a key consideration.

The energy cost for each luminaire is based upon the SDG&E LS-2 rate schedule as of July 2009 (see Appendix F: SDG&E LS-2 Rate Schedule). Under this rate schedule, streetlights are billed a monthly set rate based on the type and wattage of the lamp assuming 4165 annual operating hours. This project focused on the replacement of HPS luminaires with both LED and induction technology. Table 6 provides the charges for the street lights based upon the wattages in the City of SD.

SDG&E Commodity Rates					
(Updated with July 09 Rates)					
Lamp		**Total Monthly**			**Equivalent Lumen Output**
Type	**Wattage**	**UDC**	**Energy Rate**	**Total Mo LS-2 Rate**	
HPS	150	$ 3.14	$ 4.95	***$ 8.09***	16,000
	250	$ 5.14	$ 8.02	***$ 13.16***	27,000
Induction	85	$ 1.22	$ 2.18	***$ 3.40***	6,000
	165	$ 2.36	$ 4.23	***$ 6.59***	12,000
LED	109	$ 1.56	$ 2.80	***$ 4.36***	4,995
	198	$ 2.83	$ 5.08	***$ 7.91***	8,325

Table 6: SDG&E Commodity Rate Schedule

The simple payback calculations consider the total investment cost and energy savings for both the LED and induction luminaire. Again, it is important to understand that this assessment was performed utilizing a lower CCT for the LED luminaires. In previous assessments, the simple payback ranged from 7.4 to 20.4 years using a higher CCT LED luminaire (PG&E 0714, PG&E 0727). For the induction luminaire, the CCT did not have significant impact on the energy savings but more on the lamp characteristic performance since the generator requires 163W regardless of the CCT of the vessel (lamp). For this assessment, the LED luminaire simple payback is 17.6 years and the induction luminaire is 7.0 years.

Luminaire Type	Initial Investment	Installation Cost	Total Investment	Energy Cost (current)	Energy Savings	Simple Payback (yrs)
HPS 250 W	-	-	-	$157.92	-	-
LED	$1,071	$39	$1,110	$94.92	$63.00	17.6
Induction	$515	$39	$554	$79.08	$78.84	7.0

Table 7: Simple Payback Based Upon Energy Savings Only

Note the initial investment cost does not reflect potential bulk or discounted pricing which impacts payback calculations.

3.2.1 Economic Implications

The City of SD performs streetlight maintenance when lamps burn out and as group re-lamping scenarios. To determine the maintenance cost it is assumed that LEDs would experience a very fractional failure rate of 10% (USDOE & PG&E, 2008). It is assumed that the induction would experience a 10% failure rate before 100,000 hours. Due to the novelty of LED technology, the failure rates are considered equivalent. Additionally, the L_{70} for the LED is assumed to be 50,000 hours while that of induction is 80,000 plus hours. **Each reader should make their own assumptions of the potential failure rate of ANY technology to determine the maintenance costs associated with the technology.** The rate structure for such maintenance is shown in Table 8 below. The table includes estimated costs for the boom truck and provides time for establishing traffic control.

Re-Lamping Labor Rates (Loaded)				
	1 Hour	**15 Min**	**20 Min**	**30 Min**
Labor	$ 59.52	$ 14.88	$ 19.84	$ 29.76
Truck	$ 10.00	$ 2.50	$ 3.33	$ 5.00
Total	***$ 69.52***	***$ 17.38***	***$ 23.17***	***$ 34.76***

Table 8: City of SD Re-Lamping Rates

The advanced street light technologies experience a different maintenance cycle than the existing HPS technology. In existing technology, when the lamp burns out, a new lamp can simply be exchanged for the old one. With the LED street light technologies, when the lamp burns out, the entire luminaire may need to be replaced. The rate structure to perform this scenario as well as current total HPS luminaire replacement is shown in Table 9 below.

Electrician Labor Rates (Loaded)				
	1 Hour	**15 Min**	**20 Min**	**30 Min**
Labor	$ 68.49	$ 17.12	$ 22.83	$ 34.25
Truck	$ 10.00	$ 2.50	$ 3.33	$ 5.00
Total	***$ 78.49***	***$ 19.62***	***$ 26.16***	***$ 39.25***

Table 9: City of SD Electrician Labor Rates

The manufacturers of the LED luminaires assessed in this project claim life expectancies from 50,000 to 89,000 hours (approximately 12-21 years at 4165 operating hours per year). This assessment uses 50,000 hours for the LED life expectancy. The base case 250W HPS lamp has an expected life of 24,000 hours (approximately 6 years). The induction lamp has a stated life of 100,000 hours (approximately 24 years). For both the LED and induction technology, a properly designed fixture is required, both electrically and thermally, to achieve full life expectancy. If the fixture has poor electrical or thermal design, the light source life is adversely affected resulting in a much shorter life.

In estimating maintenance costs, it was assumed that inspection, photocell and routine cleaning are consistent among all luminaires. Therefore, these were not considered in the maintenance savings calculations.

Based on the City of SD's data and assumptions, the end of useful life in hours for each technology (for this particular assessment) is as follows: HPS – 24,000; LED – 50,000 induction – 100,000. The induction life is based upon proven life in a properly designed luminaire, both electrically and thermally. The Database for Energy Efficient Resources states a 65,000 hour life for LEDs (DEER, 2008). The LED life is based on the longest life provided by a manufacturer at this time.

To properly illustrate a range of cost and savings information, two tables (Table 10 and Table 11) were created based upon a 100,000 hour (24 year) cycle due to the induction's life expectancy. Table 10 assumes the 50,000 hour (12 year) LED life while Table 11 assumes the CA DEER LED life of 65,600 hours (16 years).

Luminaire Type	Maintenance Cost	Maintenance Savings	Energy Cost (current)	Energy Savings	Total Cost	Total Savings	Savings	Payback
HPS 250 W	$7.36	-	$157.92	-	$165.28	-	-	-
LED	$11.79	-$4.43	$94.92	$63.00	$106.71	$58.57	35%	19.0
Induction	$4.31	$3.05	$79.08	$78.84	$83.39	$81.89	50%	6.8

Table 10: Estimated Annual Cost and Savings per Technology (50,000 hour LED life)

Luminaire Type	Maintenance Cost	Maintenance Savings	Energy Cost (current)	Energy Savings	Total Cost	Total Savings	Savings	Payback
HPS 250 W	$7.36	-	$157.92	-	$165.28	-	-	-
LED	$8.84	-$1.48	$94.92	$63.00	$103.76	$61.52	37%	18.0
Induction	$4.31	$3.05	$79.08	$78.84	$83.39	$81.89	50%	6.8

Table 11: Estimated Annual Cost and Savings per Technology (65,600 hour LED life)

City estimated costs for each input to determine annualized maintenance cost:

- Labor: $23 for all replacements
- Lamp cost:
    - HPS - $17.50 per lamp
    - LED (10% failure) - $111.00
    - Induction (10% failure) - $55.40
- Disposal fee:
    - HPS - $4.50
    - LED - $7.50
    - Induction - $25.00

To illustrate how the annualized maintenance cost is calculated, the LED luminaire is used from Table 10. The total cost of a lamp replacement in the 50,000 hour or 12 year life equals the sum of the labor ($23), lamp cost ($111) and the disposal fee ($7.50). This calculation results in a total cost of $141.59 which is then divided by the 12 year life expectancy yielding an annualized maintenance cost of $11.79 per year. Due to the inability to accurately pinpoint actual factors, this maintenance cost calculation does not take into consideration an inflation factor, escalating energy cost, or the future cost of the LEDs which is expected to be much less in 10 years. It is assumed that inspection, photocell and routine cleaning are consistent among all luminaires. Therefore, these other maintenance issues were not considered in the maintenance savings calculations.

The City of SD calculated the payback using a 20 year economic life cycle analysis. The economic analysis was based upon the future value of costs and savings and current product costs. Due to uncertainty of the future product cost, especially for LED technology, the City of SD used a very conservative approach. The results of the analysis showed by including an inflation factor of 2.5% per year for the energy and maintenance labor costs, the paybacks for LED and induction became 35.5 and 6.5 years, respectively. Appendix G: City of San Diego Life Cycle Cost Analysis contains the spreadsheet showing the calculations and assumptions made to achieve these paybacks. In general, when maintenance costs are considered, the LED payback is longer than the simple payback whereas the induction payback slightly improves by 6 months.

3.3 Measured Lighting Levels

The measured light levels for two testing areas (Areas 4 and 6) are show in false-color diagrams below. The diagrams for Test Areas 1, 2, and 7 can be found Appendix B: Site Measurements.

The false-color diagrams are represented in an approximate logarithmic scale to provide greater visual separation in the values near the bottom of the scale (below 1.0 footcandles). The scale is the same for all diagrams, therefore relative comparisons of the light levels on the street may be made with a reasonable measure of accuracy.

These graphs are important to provide a reasonable visual representation of the illuminance on the road surface *based on actual measurements*. The actual performance is also useful to corroborate the calculated values for the roadway segments. This distinction will be explained in further detail in Section 13.4 Calculated Lighting Values.

0	0.1	0.2	0.3	0.4	0.6	0.8	1.0	2.0	3.0	4.0	6.0	8.0

Figure 13: False Color Rendering Scale (fc).

Figure 14: Nighttime and Daytime Photos of Test Area 4

Note the distribution extends slightly beyond the parking lane of traffic and does not cross the full width of the roadway.

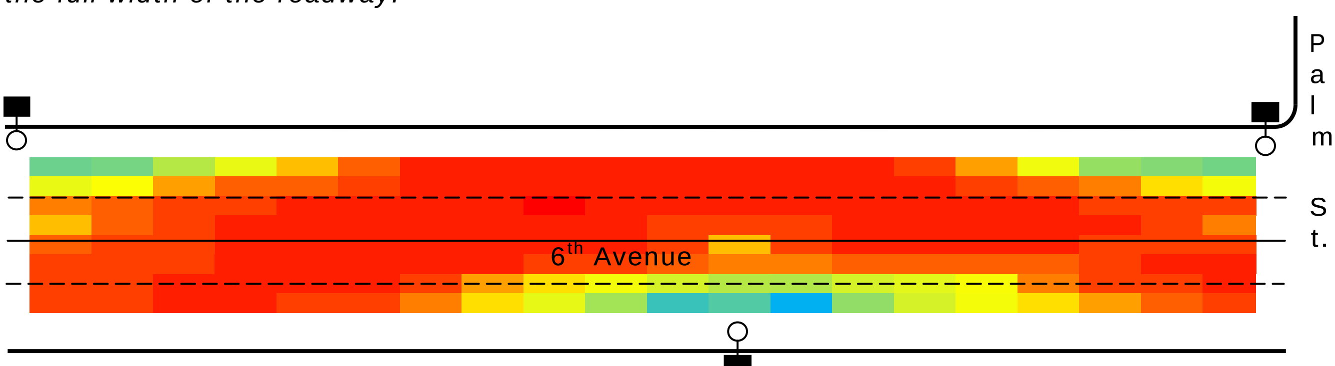


Figure 15: Test Area 4; Measured Photopic False Color Rendering.

Figure 16: Nighttime and Daytime Photos of Test Area 6

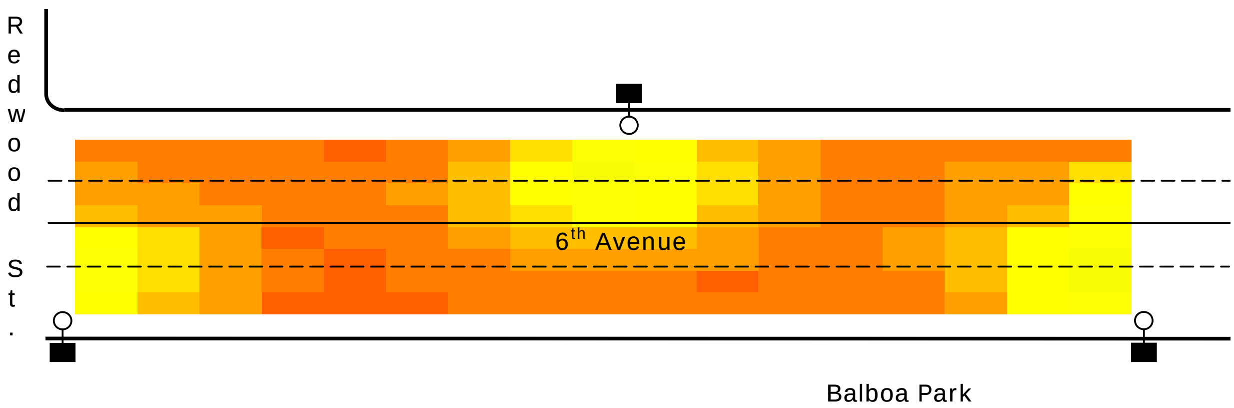


Figure 17: Test Area 6; Measured Photopic False Color Rendering.

	Measured Photopic Illuminance at Grade (fc)				
Test Area	Avg.	Max	Min.	Avg/Min	Max/Min
1	0.9	3.2	0.2	4.3	16.0
2	0.7	3.3	0.1	7.2	33.0
4	0.7	8.0	0.0	-	-
6	0.5	1.0	0.3	1.8	3.3
7	1.7	7.6	0.6	2.9	12.7

Table 12: Experimental Data Collected from Test Areas

The diagrams above provide context for the light levels that are delivered by the different lighting systems tested with the use of colors instead of values. The distribution of the light to each side of the luminaire and across the road is reasonably well represented with these diagrams, and the distribution from the high point to the low points can be understood as well.

For example, consider the information presented in Figure 15 and Figure 17 above: Test Area 4 shows much lower 'low' values, and much higher 'high' values compared to Test Area 6, so the uniformity is going to be worse. While the average light level on the street sections is not directly shown in the diagrams, it is clear the Test Area 4 has a lower average due to the preponderance of the lower (more red) values throughout the measurement area.

The light distribution from the two test areas is also quite different. Test Area 4 has a linear output that does not distribute across the road very much, whereas the light in Test Area 6 crosses the road much further, more effectively putting light on both sides of the road. The luminaire in Test Area 4 is intended for very narrow streets and pedestrian walkways primarily and these measurements indicate that the luminaire does have a wide, but very narrow distribution that makes it unsuitable for a street of this width.

A comparison of Test Area 6 (Figure 17) and Test Area 4 (Figure 15) show that Test Area 6 has considerably better localized uniformity on the street (compare the relative size of the high illuminance areas below the luminaires in each test area) and the overall uniformity is considerably better in Test Area 6 as well. This test area has the best overall uniformity of all the test areas, and the illustrations reflect this diagrammatically.

3.4 Calculated Lighting Values

Table 13 shows calculations of the lighting for all the streets areas, normalized to 100' spacing pole-to-pole. This provides the possibility to compare the performance of the lighting systems on a level playing field, and shows additional information that is not possible to obtain in the field.

Roadway luminance calculations are included, which are not possible to derive from basic illuminance or luminance measurements from the field. Veiling Luminance and Small Target Visibility (STV) are also calculated, because luminance is very geometry specific and is a statistical sampling done in roadway calculations.

	Luminance (cd/m^2)					Illuminance at Grade (lux)					Veiling Luminance	STV
Test Area	Avg.	Max.	Min.	Avg./ Min.	Max/ Min	Avg.	Max.	Min.	Avg./ Min.	Max/ Min	Lv_{max}/L_{avg}	
1	0.49	0.92	0.29	1.69	3.17	9.34	17.3	4.56	2.05	3.8	0.17	2.09
2	0.4	0.85	0.24	1.67	3.54	8.41	23.2	3.11	2.7	7.45	0.17	1.97
3	0.4	0.58	0.28	1.43	2.07	8.78	16.8	3.2	2.74	5.24	0.11	1.85
4	0.34	1.27	0.07	4.86	18.1	9.21	40.1	1.36	6.77	29.5	0.1	1.61
5	0.71	1.15	0.47	1.51	2.45	8.67	10.9	7.1	1.22	1.54	0.24	2.15
6	0.25	0.43	0.18	1.39	2.39	3.85	5.22	2.68	1.44	1.95	0.23	1.16
7	2	2.98	1.19	1.68	2.5	33.3	52.8	17.8	1.87	2.96	0.2	3.85
8	1.24	2.46	0.79	1.57	3.11	18.7	25.1	13.6	1.38	1.84	0.26	2.84

Table 13: Lighting Systems Calculations

Note Test Area 6 once again. It shows some of the lowest ('best') illuminance uniformity values of all the test areas, with an average:minimum value of 1.44 and a maximum:minimum value of 1.95. That far exceeds the uniformity requirements of every IESNA Illuminance Criteria recommendation in Table 16 (Appendix C: Site Calculations). Compare those values to Test Area 4 and the difference in uniformity performance that is discussed above regarding the field measurements becomes apparent once again.

The performance of these systems correlates to various levels of criteria in the IESNA RP-8: Recommended Practice for Roadway Lighting (IESNA, 2005). There are three current methods of lighting design within RP-8, including the *'Illuminance'* method, the *'Luminance'* method, and the *'Small Target Visibility'* method. Similarly, the American Association of State Highway and Transportation Officials (AASHTO) uses the '*Illuminance'* method and the '*Luminance'* method within their documents for design criteria, referencing the methods and specific criteria limits from the IESNA RP-8 document.

For this test, the lighting is being compared using IESNA calculation methods and generally accepted light output modifiers to produce a 'maintained' lighting calculation that is necessary for design verification. The lighting calculation methods used for this criteria selection are the '*Illuminance*' method and '*Luminance*' method. The IESNA guideline criteria levels along with the IESNA performance level met by the Test Area calculations can be found in Appendix C: Site Calculations.

Let it be noted that IESNA is leading authority on lighting standards. While many municipalities may have their own lighting standards, many derive or refer to IESNA standards.

3.5 Subjective Survey

The results for the subjective survey showed statistically significantly differences occurred in responses between systems in nine of the thirteen statements:

2. 'It would be safe to walk here, alone, during darkness hours'

5. 'There is not enough light on the street'

6. 'The light is uneven (patchy)'

8. 'It would be safe to walk on the sidewalk here, alone, during darkness hours'

9. 'I cannot tell the colors of things due to the lighting'

10. 'The lighting permits safe navigation.'

11. 'I like the color of the light.'

12. 'I would like this style lighting on my city streets.'

13. 'How does the lighting in this area compare with the lighting of similar city streets at night?'

The survey respondents showed no strong preference for the alternate lighting systems. While this is a change from previous research results (*Anchorage Residential Report, 2008 and Anchorage Commercial Report, 2009*), there are significant differences in the testing procedures, luminaire and light source selection, and site conditions that make direct comparisons difficult.

- **Statement 1 (safe to walk during the day)** resulted in most participants feeling safe in the testing areas. There were no real differences between the testing areas. Though, for **Statement 2 (safe to walk, along, during darkness)**, the white light source from Test Area 4 was rated the highest (participants felt safer in this Test

Area than any other). Both existing light sources in Test Areas 7 and 8 were rated nearly the same and the white light source in Test Area 1 was ranked the lowest.

- **Statement 8 (safe to walk on sidewalk, alone, during darkness)**, the white light source from Test Area 4 was ranked the highest and the white light source from Test Area 6 was ranked the lowest. The existing light sources in Test Areas 7 and 8 were ranked nearly the same towards the middle of the spread.
- **Statement 9 (cannot tell colors)**, the white light source in Test Area 6 was ranked the lowest (colors were accurately rendered) and the existing light sources in Test Areas 7 and 8 were ranked the highest (colors were not accurately rendered). Statement 11 asked participants to if they liked the color of the light. The white light source in Test Area 6 was ranked the highest and the existing light sources in Test Areas 7 and 8 were ranked the lowest.
- **Statement 12 (like the style of lighting for their city streets)**, participants ranked the white light style of lighting in Test Area 6 as the highest. The existing style of lighting in Test Area 8 was ranked as the lowest.
- **Statement 13 (compare the lighting in each of the test areas to existing street lighting)**, participants ranked Test Area 6 better than existing light sources.

3.6 Objective Visibility Detection Distance

An Analysis Of Variance (ANOVA) was conducted on the detection distance data to identify if and what differences occurred between the lighting sections. Follow-up statistical Student Newman-Keuls (SNK) was used to identify where these differences occurred. The Results of the ANOVA are shown in Table 14.

Source	F value	P value	Significant
Lighting Type	3.03	0.0037	*
Lighting Location	1.39	0.238	
Lighting Type * Illuminance Level	2.68	0.0139	*
Target Color (Roadway targets)	36.68	0.001	*
Lighting Type * Target Color	1.57	0.1962	

Table 14: Lighting Sections, Lighting Levels (Target Placement), and Target Color ANOVA Results

The initial analysis compared lighting type and the lighting location (street or intersection). Significant differences occurred for lighting type and pair wise comparisons of the results were performed using a SNK analysis. The results are shown in the Figure 18.

The letters at the top of the columns show the results of the SNK analysis: similar letters indicate groupings, which show no statistical differences. Those columns containing the same letters are not significantly different from one another.

For example, Test Area 4 had the highest mean detection distance; however, it was not significantly different from Test Area 1, Test Area 2, Test Area 7, or the majority of the intersection lighting excluding Test Area 3 as these lighting types also has the same letter 'A'.

Comparing only within groups (roadway vs. intersection), the roadway sections had similar results, however, Test Area 4 had significantly longer detection distances (M = 41.1 meters) than Test Area 6 (*M* = 32.2 meters). Practically speaking at 30 mph (13.4 m/s) the 9-meter difference between these two is less than a second for a driver.

A significant difference also occurred across lighting sections where Test Area 4 had a significantly longer detection distance than the Test Area 3 intersection (*M* = 32.5 meters). Staying within sections and looking specifically at intersections, Test Area 3 had significantly lower detection distances than Test Area 8 (*M* = 36.8 meters) or Test Area 5 (*M* = 40.2 meters).

Overall, across lighting sections and lighting groups, the alternative lighting technologies did not significantly differ in detection distances compared to the existing roadway lighting or intersection lighting. These results show comparable detection distances across lighting system types, with lower detection distances for Test Area 6 and Test Area 3 should be noted however, that lighting level (or target placement) was collapsed across groups for this specific analysis and is investigated in the next comparison.

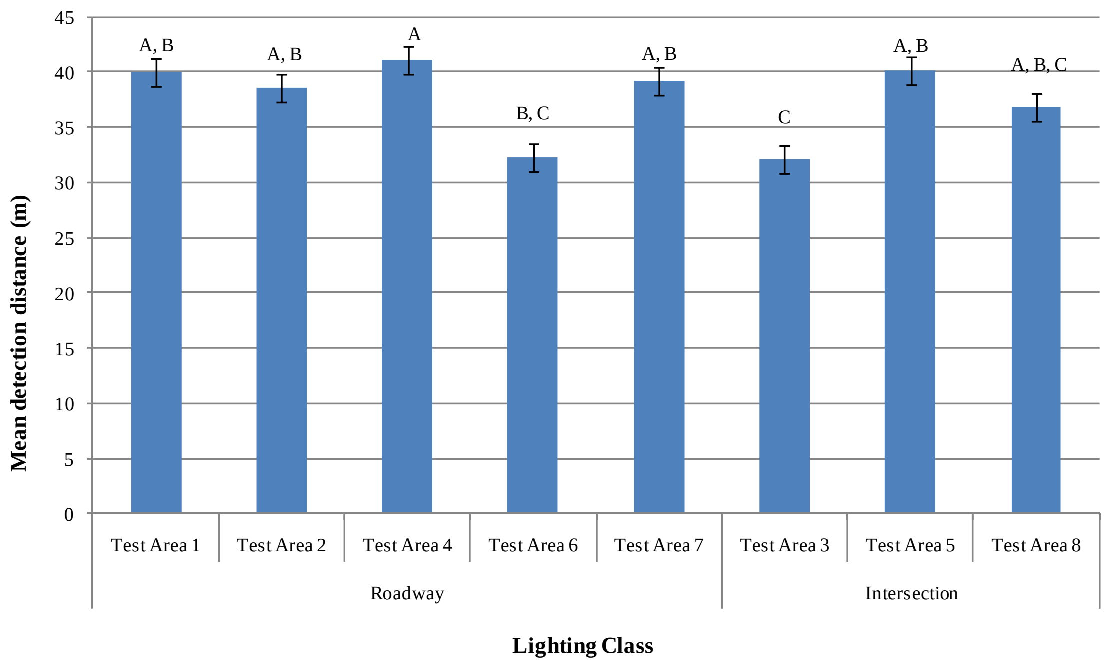


Figure 18: Lighting Type and Lighting Location Comparisons.

Figure 19 shows another analysis comparing target vertical illuminance level (high vs. low as controlled by target placement) and lighting location (roadway and intersection). In the majority of cases, the general trend suggests more lighting provides better detection distances across the lighting types.

In a few cases (e.g., Test Area 1 and Test Area 5), the trends appear to be reversed with low illuminance target placement providing higher mean detection distances. This result could have been due to target placement and surrounding clutter. For example, targets placed in the intersection locations could have been obstructed by the pedestrian object. Targets placed on the roadway could have been influenced by the presence or absence of parked cars thus influencing detection distance measures.

Looking specifically within section types, consistent with the initial detection data, Test Area 6 still had the lowest detection distance in either the high or low lighting level. Test Area 3 followed the same trend as the previous result, again with the lowest detection distance despite high or low illuminance levels within the intersections. Overall, the general trend follows an obvious theme with higher illuminance levels providing longer detection distances. Again, these trends were consistent throughout target types, and a specific analysis to review the pedestrian and target information is provided in the next section.

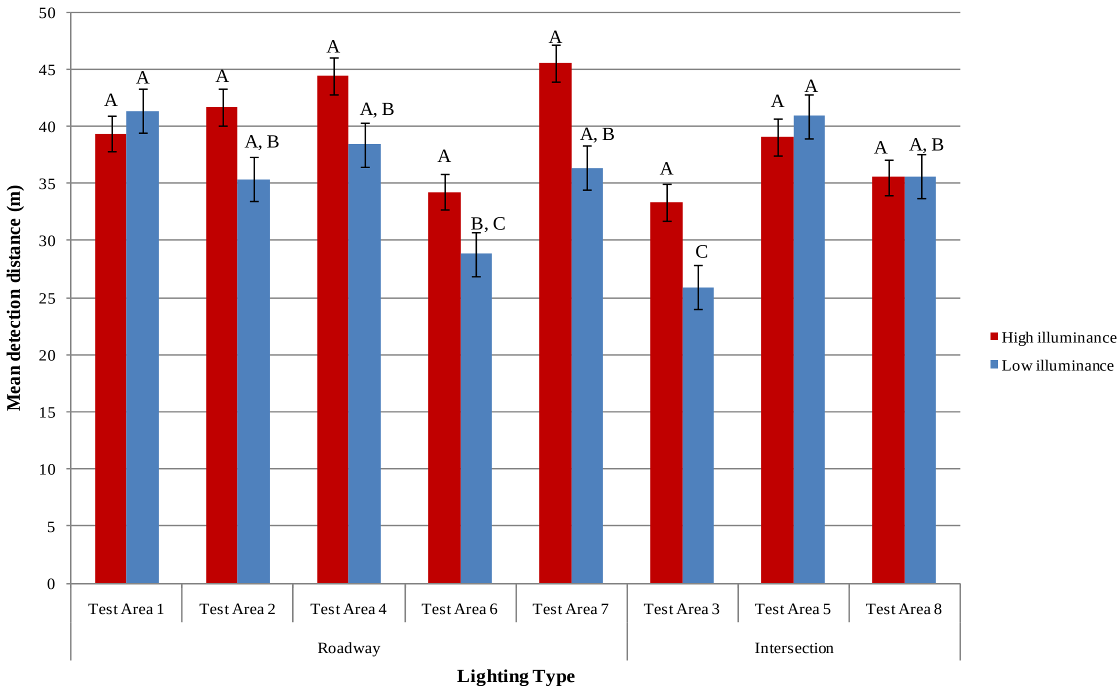


Figure 19: High and Low Lighting Level and Lighting Location.

Figure 20 shows the analysis comparing target types within the test areas. The initial comparison was for pedestrian targets. When collapsed across hardhat color and compared across lighting test area, no significant differences occurred between pedestrian positions. This suggests that no matter the lighting condition (Test Area 3, Test Area 5, or Test Area 8) no significant difference in detection distances occurred.

The results suggest comparable pedestrian detection distances with either alternative lighting configurations or existing. No significant impact was seen with the alternative light technologies; however they appear to be comparable to existing lighting installations.

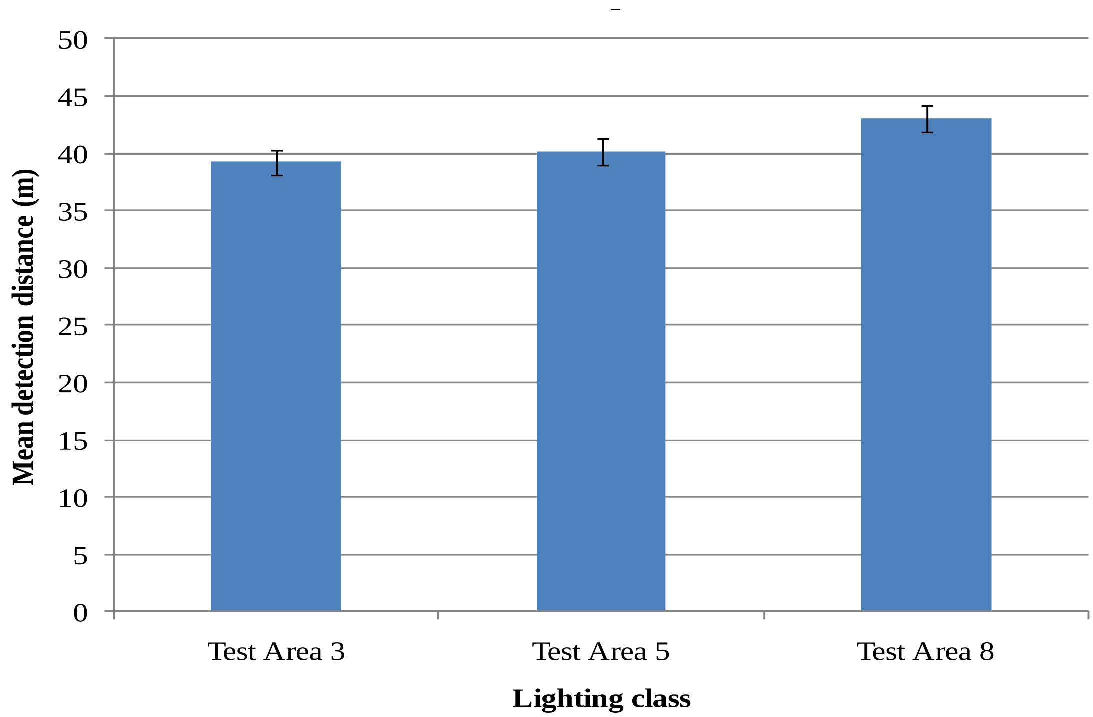


Figure 20: Pedestrian (Hardhat) Performance for Intersection Test Areas

The next comparison is for target color only across the roadway sections which contained both the blue and grey targets. As outlined in Figure 21, the grey target has longer detection distances across the lighting sections compared to the blue target. It is important to note that the blue color used on the visibility target is darker with a lower reflectance, which may have impeded the contrast and thus reduced possible detection of the target across the lighting sections.

When reviewing the comparison across the existing installation, detection distances did not significantly differ between the two target colors. The largest differences occurred with Test Area 1,Test Area 4, and Test Area 6 installations where the detection distance for the grey target was M = 44.8 m, M =47.8 m, M = 40.1 meters respectively, compared to the blue detection distances of M = 29.1m, M = 32.8 m, M =27.8 meters respectively. The blue visibility targets did not appear to benefit from the white lighting at these specific lighting locations.

The results of these comparisons suggested that the lower reflectance of the blue target plays a central role in target detection; however, the contrast evident for each target may have been detrimental for some of the lighting technologies. Further supplemental contrast analyses will be undertaken at a later date.

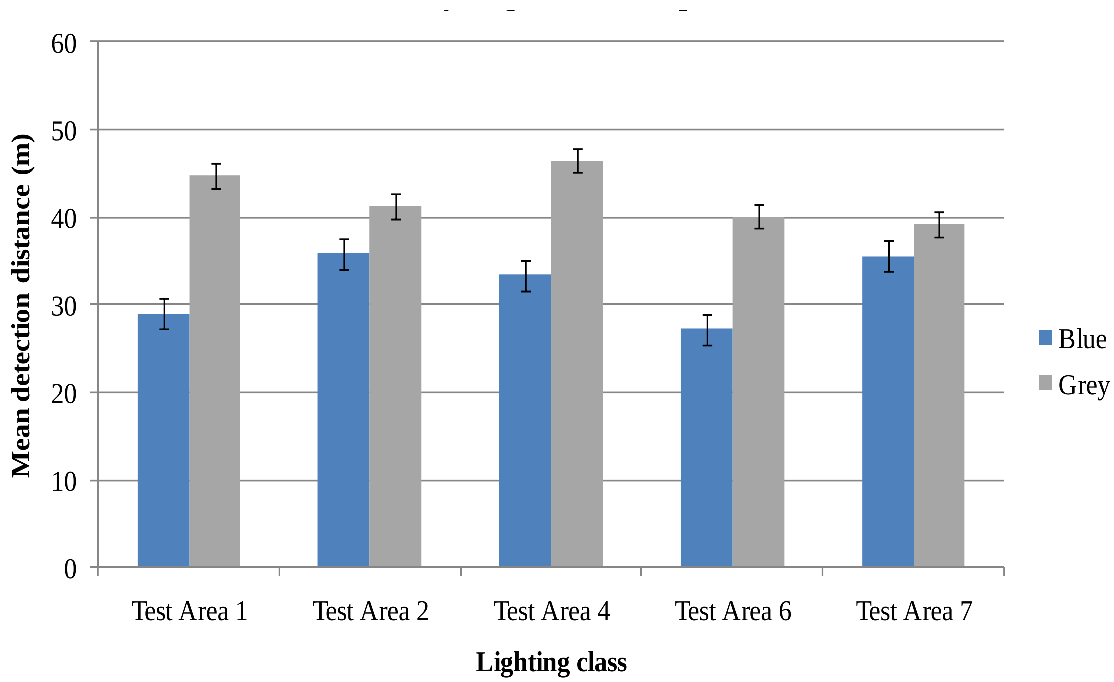


Figure 21: Target Color Comparison across the Roadway Section.

3.7 Objective Visibility Illuminance

The results of the data collected by the four roof mounted illuminance sensors were combined and are presented below. Two sensors were placed along the midline of the vehicle (forward and rear) and two were placed over each of the wheel paths (left and right). Some inconsistences across installations were seen between the front and rear sensor, however these inconsistencies are likely due to data collection anamoloies and thus the illuminance levels were collapsed across sensor location and split into lighting sections.

The Test Area 6 installation provides the roadway segment with reasonably uniformity, but delivers the lowest level of illuminance of all the alternative street lighting systems, which is an expected result due to the power output. The Test Area 4 system has a lower average, but these results can be explained by the non-uniform distribution of the light, and the fact that the illuminance readings were taken in the drive lanes, while the majority of the light from the Test Area 4 system is limited to the parking lane primarily.

For the intersection locations, Test Area 3 had the highest average illuminance compared to the broad spectrum sources. Similar to Test Area 6 installation, Test Area 5 intersection installation had the lowest mean illuminance levels across the runs.

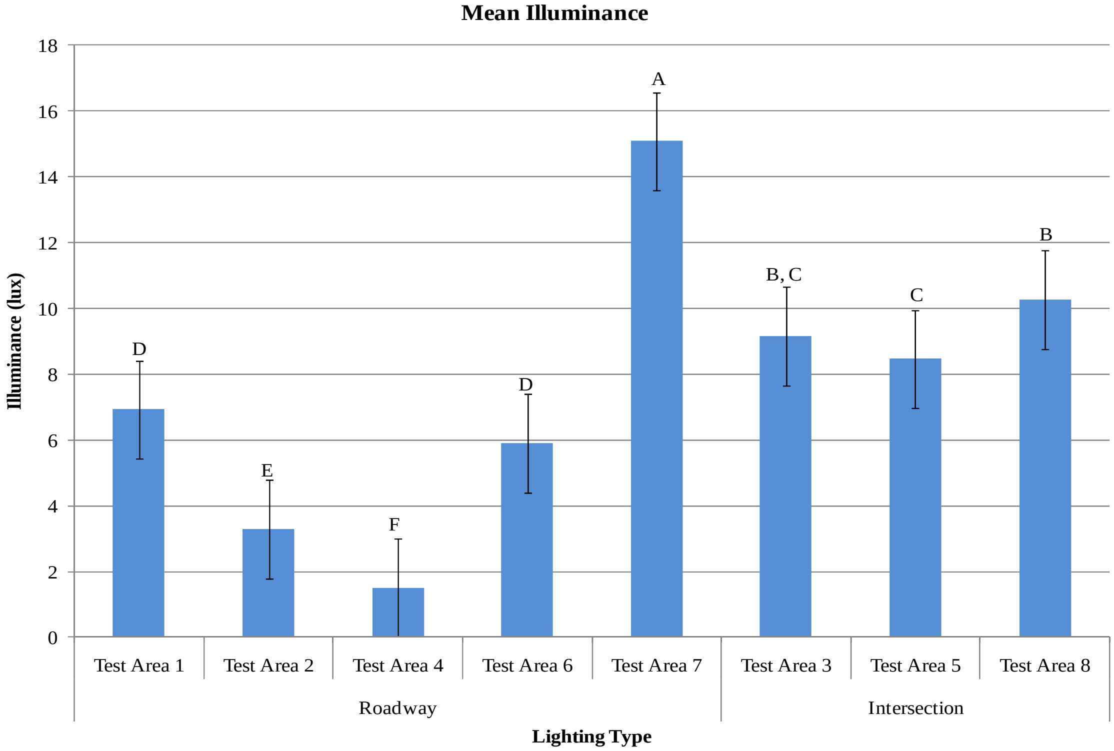


Figure 22: Mean Illuminance Levels Collapsed Across Roof Sensors.

The fifth illuminance meter was located in the vehicle windshield and provided a surrogate measure of the glare experienced while driving through each of the lighting sections. Average illuminance levels were also calculated for each installation based on the 'glare' meter and the results are provided in Figure 23 below. For the street installations (e.g., non-intersection locations) the highest average glare meter reading was obtained for Test Area 1, but no significant differences were seen between Test Area 1 and Test Area 7.

The rest of the alternative roadway lighting installations were generally consistent with the significantly lower reading obtained for Test Area 4. Just reviewing the intersection locations, the highest mean glare reading was obtained for Test Area 3 with no significant differences between Test Area 5 and the existing intersection lighting.

The overall results suggest that despite concerns about glare with the new lighting technologies, the majority of LEDs appear to have less glare consequences or are on par with the current lighting technologies. In this project, the induction installations had higher glare readings than either the existing roadway lighting or LEDs.

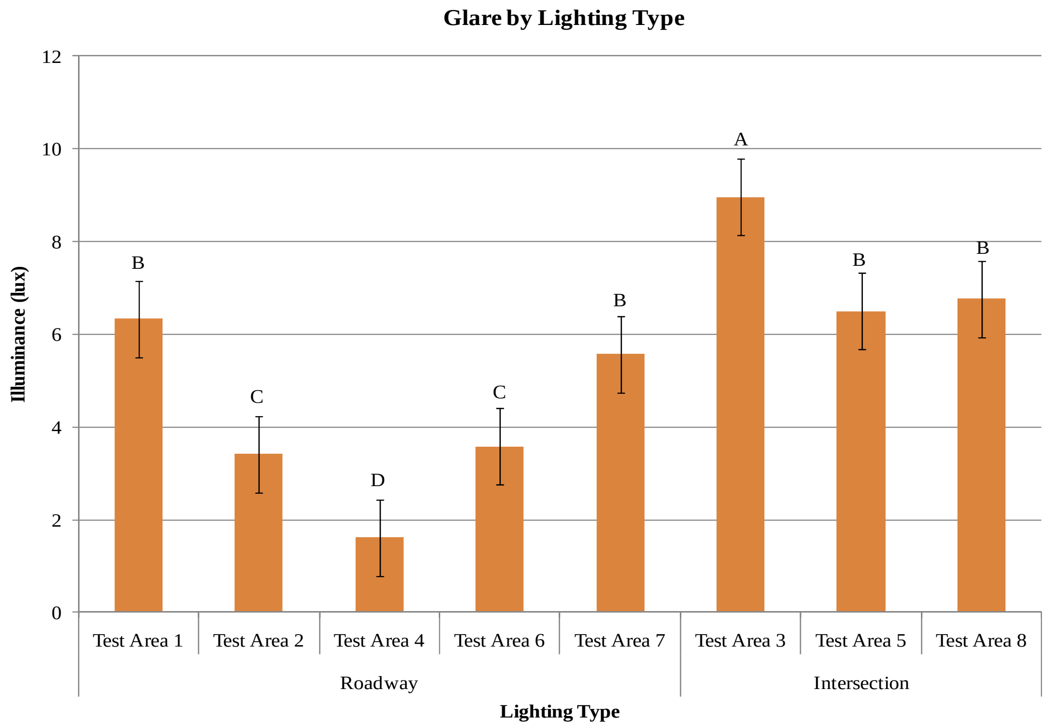


Figure 23: Mean Glare Meter Illuminance Levels by Location.

As a final analysis a series of values were obtained for each of the lighting types within the lighting sections, which included the maximum and minimum illuminance and a uniformity calculation for each of the lighting sections. This information is provided in Table 15 below.

Note that the luminaire in Test Area 4 had a very low illuminance as compared to the other systems. It was observed during the testing that the Test Area 4 luminaire was an inappropriate design for the roadway. The center lane of the roadway was not illuminated to as high a level as the edge lane and this is represented in the data.

Test Area		Minimum Illuminance	Maximum Illuminance	Uniformity Ratio (Max. to Min.)
1	Induction	3.87	14.58	3.75
2	Induction	2.14	8.00	3.74
3	Induction	3.80	20.22	5.32
4	LED	0.77	2.41	3.13
5	LED	2.98	22.68	7.60
6	LED	3.66	9.11	2.49
7	HPS (roadway)	2.84	26.88	9.47
8	HPS (intersection)	2.20	33.64	15.30

Table 15: Rooftop Illuminance Measurements

4.0 Discussion

4.1 Limitations of the Project

The results of this project are inevitably affected by several factors that could not be addressed nor controlled given the constraints of the experiment. It cannot be overstated that locations for all of the luminaires are fixed and designed for the existing condition – a 250W HPS luminaire. In other words, the spacing and mounting height for all of the alternate systems were not optimized for the particular test luminaire, but rather installed in place of the existing HPS luminaire.

The alternate systems evaluated produce significantly less light at a much lower wattage than the existing system. The existing luminaires provide from about 3.5x to 9x the average illuminance and 5x to 8x the luminance of the alternate systems. This is an intentional comparison, regardless of wattage, because the change to a broad spectrum light source alters the entire visual performance of the roadway lighting system.

4.2 Energy and Budget Implications

The energy aspect of this project shows that there are some considerable possibilities to reduce energy consumption (up to 40%) and connected load, while still maintaining a comparable level of visual performance. There is a clear opportunity to reduce energy consumption and municipal tax dollars through a luminaire replacement program that shifts from the current HPS light sources to broad spectrum light sources.

The broad spectrum technologies discussed have considerably improved lamp life expectancy compared to the older MH or HPS technology light sources. This will result in a substantial improvement in maintenance periods, and reduction in overall expenses associated with this maintenance.

Due to the nature of LED light sources, the LED systems tested reflect different energy consumption partially because there are no 'standard' LED lamping packages. This will continue to be the case with LED as the industry advances.

However, one benefit of LED technology is the possibility that the lumen package can be adjusted to meet the needs of the roadway conditions more easily and in smaller increments than the traditional HPS, MH, and induction lamp wattage increments. This may result in the ability for a lighting designer to meet a standard without exceeding it too greatly; which will result in energy savings throughout the life of the lighting design, regardless of any other benefits that may be considered due to broad spectrum nature of the light.

4.3 Street Lighting Controls

The energy savings potential can be greatly increased through the application of an Adaptive Streetlighting Control (ASC) system. This approach is beyond the scope of this project, however, it is an important technology to note. ASC is essentially advanced control for street lights. Each individual pole is given its own address that can be automatically controlled from a remote location. The benefits to considering adaptive lighting in a large scale municipal system of this kind that include:

- Reduced light pollution during the setback time periods.
- Reduced energy consumption.
- Longer lamp life.
- Potential for demand response capability.
- Reduced potential for detrimental light/human health interactions.
- More sophisticated control and system management.

- Improved maintenance information and truck routing.

A combination of both a light technology change and an ASC system could result in reductions of 30% hours of operation and 40% power consumption resulting in a combined 60% reduction in energy use. Savings are increased due to improved information gathering, maintenance, and demand response potential.

4.4 Light Color

The color temperature of the lighting system is a variable that needs careful consideration if a broad spectrum source is considered for adoption by the City of SD and SDG&E. While it is outside the scope of this report, some studies have shown that avoiding short-wavelength light is preferable for flora and fauna and for human impacts as well.

It is possible to have ‘white light’ that has less of the wavelengths that are of concern. This is the reason that attention is being paid to the color temperature of the moon (4125°K). More research will be required to fully understand these interactions, but recent research seems to indicate that this is a solid approach to the question.

There is more to the spectrum than the simple CCT value of the light source, as the frequency distribution of the light is an important aspect of this as well. While the CRI does in some manner provide some insight into this aspect of the light output, it is not a complete picture of the distribution as well. Spectral distribution graphs of the light source output are the best way to begin to fully appreciate the light sources. The value of these graphs is discussed further in Section 4.5 Subjective Survey Analysis.

The LED luminaires in Test Area 6 have a considerably higher CCT than the rest of the tested group. The source of this discrepancy is under investigation; however, the higher blue output of this light source has several impacts on the subjective tests results, and may have a similar impact on the objective test results as well.

First, the higher CCT results in a cooler appearance (but not very strongly cooler compared to the other broad spectrum sources tested here). The difference is subtle from an aesthetic perspective. However, the difference may be very meaningful with respect to the actual perception of the light output from that source, as the increased blue output will increase the perception of light levels to be higher than they are actually. This may have swayed the results for that test area to increase the perception of light level adequacy relative to the other test areas.

Second, the other LED systems are operating under a slight lumen penalty associated with the color temperature restrictions placed on the initial survey parameters. The current LED technology has higher lumen per watt output for higher CCT values. This results in higher energy consumption or increased wattages at 5500K or 6500K by about 25% compared to this project’s target CCT of **3000K**. Since the luminaires in Test Area 6 measure to be about 4500K, they may have a 10% performance advantage that the other tested LED systems do not have. The induction lighting systems do not have this performance penalty with color temperature.

4.5 Subjective Survey Analysis

The results do not indicate a strong preference for white light sources. Both the existing sources and the alternate sources were rated the same on the subjective statement survey. The results indicate that white light sources will be accepted by the community should the City of SD move to one of these alternate light sources.

On survey Statement 8, regarding the feeling of safety at night, the respondents indicated a preference for HPS lighting over some of the ‘white light’ alternates. As noted previously, this preference has not appeared in similar research studies. Some people may indeed prefer the warm color of the HPS light source. Another explanation relates to the urban context of the City of SD. The nearby astronomical community currently requires low pressure sodium (LPS) street lights in the observatory vicinity. Because residents in the San Diego community may be much more used to the very warm, monochromatic orange color of the LPS source, the overall look of an HPS system may feel quite acceptable and not as ‘extreme’ as the whiter sources. HPS certainly feels much more ‘white’ than LPS when solely comparing the two.

These results also highlight the importance of evaluating light sources for individual cities. A system that is preferred in one location may not be the preference in another. Studies performed in Anchorage show a very strong preference for white light. The increased sense of brightness that these white sources might bring to a subjective analysis may not be as noticeable in a southern location such as San Diego where daylight is more consistent year round.

4.6 Objective Visibility Analysis

The results of the visibility portion of the project indicate that equivalent object detection distances were achieved for lower levels of roadway illuminance under white light sources, as compared with higher levels of the illuminance under the HPS source. This is similar to other investigation results. In addition, with the exception of two luminaires, the alternatives were not statistically different from the existing installation.

The LED luminaires in Test Area 6 produced a substantially lower illuminance and also lower detection distance. The induction luminaires in Test Area 3 results at the intersection may have been influenced by other obstacles at the Laurel Street intersection. The LED luminaires in Test Area 4 were not appropriate for this roadway type and yielded a lower illuminance and poor uniformity. The luminaires in Test Area 4 did have the highest performance for detection and it had the lowest value for glare. It is likely that the low glare resulted in longer detection distances. Also, the light from the luminaire is strongly distributed in the parking lanes on the sides of the street, beyond the illuminance meters on the car, but ideally located for the targets.

It should be noted that only four luminaires were used in each test location. This means that the observer was not likely within the test area when they were observing the targets. Adaptation issues may be evident. If more test luminaires were used to make the test section longer, a greater differentiation may have been seen between the lighting alternatives. Ideally, a test area will have 8 to 12 luminaires in a uniform pattern to enable an adaptation state to develop in the observer before the test targets are sighted.

Combining all of the results, this project suggests the white light sources provide equivalent or better visual performance than the existing HPS luminaires. These alternative light sources provide lower glare and equivalent performance at a lower roadway illuminance level. This suggests that the broad spectrum light sources do provide additional information in the visual scene and a higher potential performance (see Figure 24).

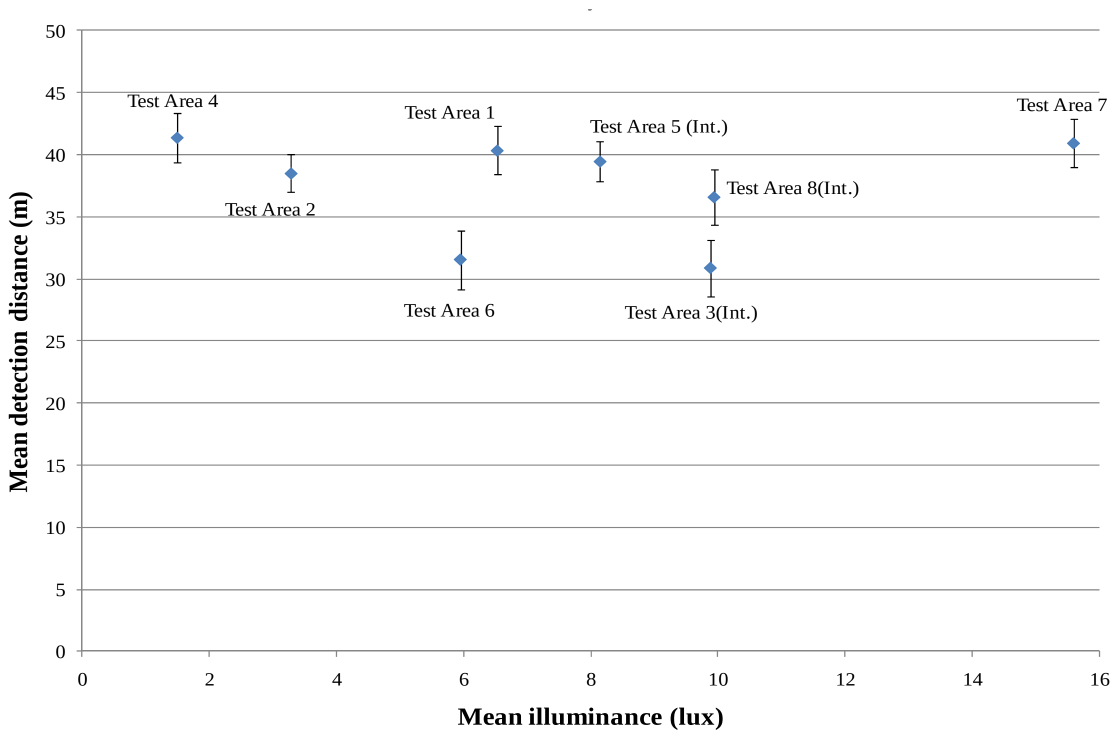


Figure 24: Overall Mean Detection Distance & Illuminance Levels by Lighting and Location.

4.7 Local Considerations – Observatory and Dark Sky Requirements

The City of SD community has a long-standing tradition of research and educational astronomy in the nearby observatories. This is an important part of the community and all sources of terrestrial lighting in the vicinity of the observatories cause degradation to the observatory's ability to do functional research at night.

The full array of the impacts of lighting is outside the scope of this report, but there are clear impacts that the scientific community would like to see addressed in any decision-making process. Several of them are listed below.

1. ***Reduce the amount of light at night where possible.*** This is based on the ecologically-sound principle that there is an appropriate amount of light for a specific task, and more light does not equate to better lighting. In fact, in many cases, more light results in reduced visibility due to glare and other factors associated with the application of high-lumen light sources.
2. ***Reduce the amount of improperly applied light.*** This addresses light sources that are ineffectively applying light to a task, resulting in a considerable amount of wasted light in many situations. Improperly aimed floodlights produce a considerable amount of skyglow, for example, especially compared to the percentage of light that they typically put on the actual task area.
3. ***Eliminate light pollution sources wherever possible.*** Many lights emit a small amount of uplight at low angles, even when adequately lighting the task in an otherwise suitable manner. This happens to be a critical condition for light pollution, and careful selection of luminaires with better performance in these critical conditions can result in a considerable improvement in the overall impact a luminaire produces.
4. ***Improve the quality of the light.*** This results in the reduction of glare, which is a key factor in how lighting is perceived, and the perception of the adequacy of the

light. It also factors heavily in the ability of a given lighting system to meet the visual task.

5. ***Control the spectral distribution of the light.*** This is important specifically for astronomy aspects, and is in some ways in conflict with general lighting needs or benefits. The astronomy community is heavily impacted by short wavelength (blue end of the spectrum) light, so it is their desire to minimize light pollution with short wavelengths. This is at least one part of the specific desire to have low pressure sodium (LPS) light sources within the 30 mile radius around the observatories.
6. ***Use controls to reduce lights wherever possible.*** This is similar to the #1 issue, but this approach addresses that approach that an unneeded light is a waste of energy. Also, at times, the activity levels (on streets, in parking lots, ball fields, etc.) are low enough that the actual light levels can be reduced (if not turned off) to meet the task requirements of the conditions. This requires a suitable design approach to implement properly. But there is considerable energy savings potential (and light pollution reduction) possible using an adaptive control approach.

The LPS light sources in direct vicinity of the observatories is a distinct light source that has several characteristics that are of particular benefit to the astronomy community. The first is the relatively long wavelength of the majority of the light (primary emission peak is at 589nm) is somewhat away from the offending wavelengths.

Also, the source is essentially monochromatic, producing very little light at wavelengths other than the peak spike at 589nm. This means the astronomy community can filter their sensors at that specific wavelength with a sharp cutoff filter, and eliminate that portion of the spectrum very effectively without impacting other very useful wavelengths.

HPS sources have a fuller spectrum, and are therefore more difficult to filter, although primary emission spikes are found at the 589nm as well. However, they are also on the warmer (longer wavelength) end of the spectrum, so the light emission for this source is generally preferable, but less so than LPS. There is a considerable improvement in color rendering and the overall appearance of the nighttime environment with HPS lights, compared to LPS.

Broad spectrum sources are a source of considerable concern for the astronomy community because they are now becoming efficient enough to compete with HPS for lumen efficiency, and there is a broad movement to begin replacing the older HPS technology with longer-life broad spectrum sources like LED and induction sources.

There are several emission frequency thresholds of particular concern for the astronomy community related to the broad spectrum sources. Emission shorter than 555nm is of particular concern. Many LED light sources are built around a primary emission in the 440-460nm range, with phosphors to convert that to longer wavelength. That strong emission peak is in a particularly damaging range for astronomy purposes.

Induction lighting has a similar emission peak at 436nm, and therefore falls into the same realm of concern.

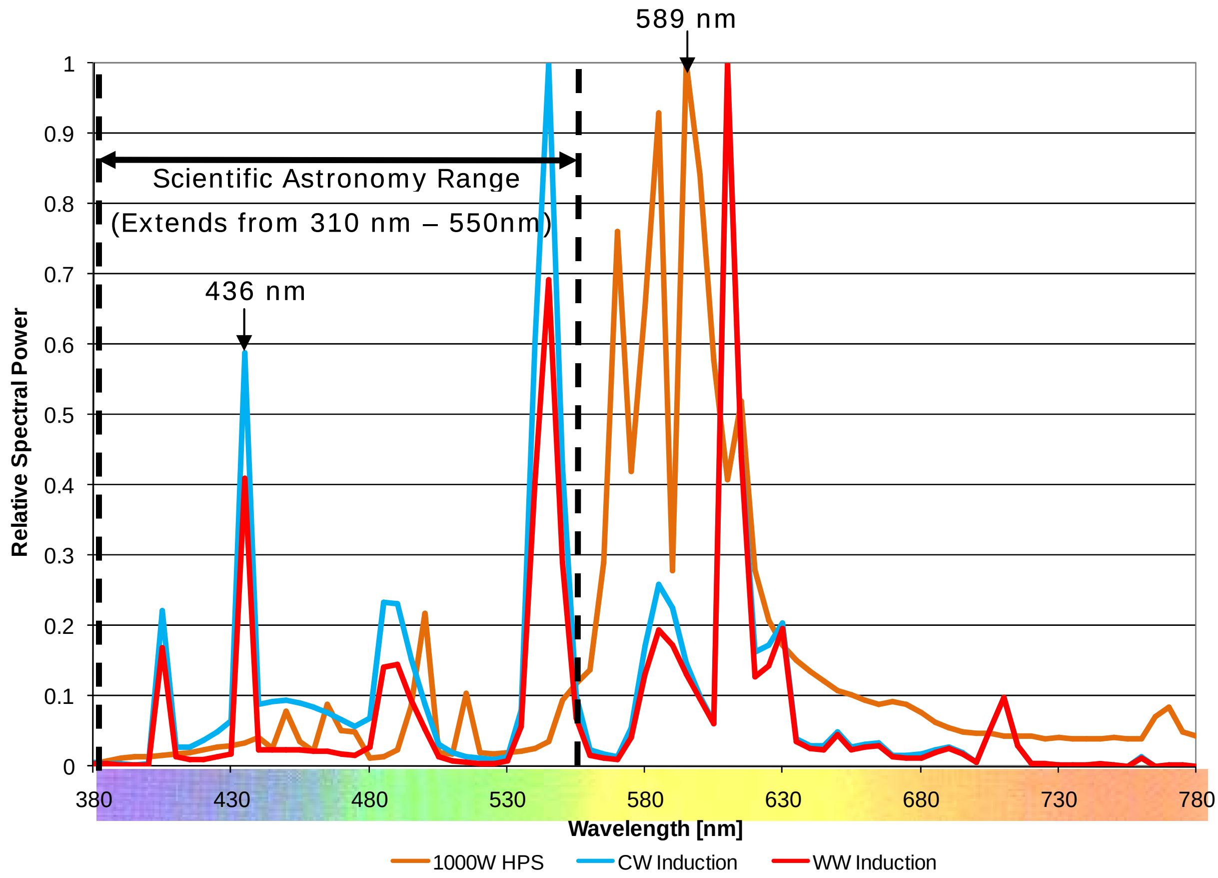


Figure 25: Spectral Power Distribution Curves Comparing HPS and Induction Sources.

Note in Figure 25 the relatively non-uniform light distribution of the HPS light source. There is a broad range of distributions through the entire visible spectrum, with several substantial peaks around the 589nm range.

The two induction lamps shown on this chart also have relatively large peaks, one at 436nm (the primary emission frequency of the mercury gas in the vessel) and two other primary peaks, which represents the wavelengths of the primary emission of the phosphors used in the vessel.

The warm white (WW) induction lamp is 3000K, and the cool white (CW) is 4000K. Note the difference in the peaks of the two light sources. While the actual peak frequency does not shift, the relative magnitude of the two shorter wavelength peaks is lower for the 3000K induction lamp. Also, the entire range from about 380nm through 600nm is lower as well. This results in a lower percentage of total output in the offending range compared to the 4000K induction lamp.

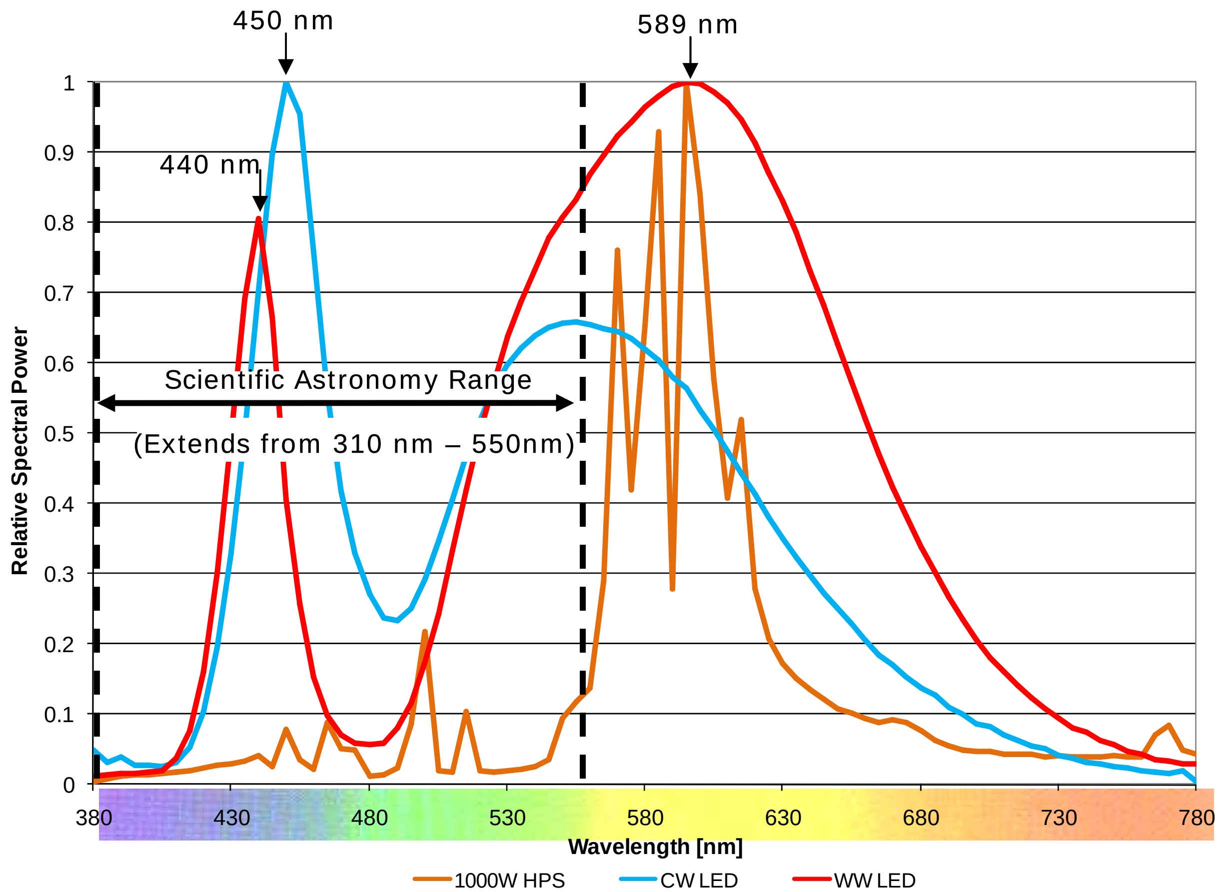


Figure 26: Spectral Power Distribution Curves Comparing HPS and LED Sources.

Figure 26 shows the same HPS spectral plot, this time compared with two LED lamps. The WW LED has a CCT of 3100K, and the CW has a CCT of 5500K. In this case, it is apparent that the initial LED chip selected to produce the light changes from 450nm for the WW to 440nm for the CW. The phosphors employed for the output is considerably different as well, and appears to have a much more continuous curve compared to the induction lamps.

The relative peaks of the two LED's are considerably different, and it is clear that selecting a warmer white LED will reduce the light emission in the range that is of primary concern to astronomers.

The project team is discussing some methods to define light emission limits in the range that is of primary concern to astronomers. This approach is still being developed, but the basic premise behind the approach is to set percentage light output limits for the light source within certain ranges. There may be two different limits, one for a range of shorter wavelengths (possibly from 310nm to 450nm), and one for the longer range (from 450nm to 550nm). There could then be percentage output limits set based on proximity ranges to the observatory, so the regions closer have stricter percentage limits for the two emission ranges.

4.8 Street Lighting Standards Criteria

The difference between 'roadway' lighting and 'street' lighting is becoming more important to consider, as the current belief is that they require different visual tasks to perform adequately. The current IESNA recommendations were established when the de facto standard for street lighting and roadway lighting was HPS technology, so the performance conditions of emerging broad spectrum street lighting is not considered currently.

The City of SD Street lighting Guidelines are currently under review and this variable should be considered in that document to establish appropriate calculation procedures for broad spectrum sources.

5.0 Future Project Recommendations

Future recommendations include repeating this project in different locations to compare for similar results. Additionally, controlling the light sources at two different light output levels and repeating this process would test the concept of Adaptive Lighting Control. This concept recognizes that the current lighting criterion provides for the worst case scenario, but the worst case is only occasionally present. Much of the time, criteria and lighting levels could be lowered in response to time of day, time of year, and weather.

5.1 Mesopic and Scotopic Lighting Calculation Statement

Recently the IESNA published a Position Statement (IESNA PS-02-09) regarding the "Use of Spectral Weighting Functions for Compliance with IES Recommendations." Research has shown that other spectral weighing functions can be useful in evaluating radiation that produces human visual sensation. This realization has led to the development of other possible spectral weighing functions which in turn have misrepresented the true definition of photopic lumens. The IESNA has determined that at this time, there is not sufficient research available to support the application of any alternative to photopic luminous efficiency function.

This position statement by the IESNA clarifies that any calculations that modify photopic lumens are not supported as an appropriate calculation method.

As a result, lighting calculations and energy savings predictions that use 'modified' lumens (S/P ratio lumens, for example) cannot be used as a basis for comparing the performance of various lighting systems.

5.0 Conclusions

This assessment project illustrates that advanced street light technologies using broad spectrum lighting utilized with LED and induction light sources can provide energy savings of up to 40% without compromising the light characteristics required of street lights.

Only two of test areas assessed (Areas 4 and 6 – both LED) as part of this project did not meet IESNA criteria in accordance with RP-8. All of the other test areas (Areas 1, 2, 3, 5, 7, 8) met IESNA criteria in accordance with RP-8, in addition to providing energy savings. Therefore, this assessment indicates that there is not a significant decrease in visual performance with the reduction in light level with the advanced street lighting technologies utilizing broad spectrum 'white light' sources, particularly with induction sources.

The subjective portion of the assessment indicates that there is not a strong preference for or against broad spectrum 'white light' sources for the street lights in the City of SD. This implies that the community will accept a change from the mild yellow HPS to a white light source.

The subjective survey and performance test results provide a reasonable starting point to consider a reinterpretation of traditional street lighting approaches based on new lighting technologies and better understanding of the visual performance of these various systems.

While the IESNA is slow to adopt new design philosophies based on changing technology, there is movement to address some of the performance and design discrepancies that have become apparent in the current street lighting standards.

When deciding to change to street lighting utilizing broad spectrum light sources, there are many factors that may be unique and require careful consideration. Each city should consider their economics, in regards to maintenance and installation, as well as their current local standards. The results of this assessment project indicate the potential energy savings of broad spectrum light sources, LED and induction street lights. However, in this project the life cycle cost analysis illustrated the importance of considering all aspects of street lighting regarding the economic viability in each city.

The Roadway Lighting committee members, (the authors of RP-8), are developing an approach to separate *Road* and *Street* Lighting into two separate sets of recommendations, because there are subtly different visual tasks associated with these two activities, as well as differing speeds, risks for conflict, and navigational issues.

There is a technical and research committee within IESNA that is charged with new research for the questions associated with the broad spectrum influence visibility calculations: the Mesopic Light Committee. There is new research currently being defined and funded as part of that committee's focus that will help identify appropriate procedures for the IESNA design committees to adopt to create lighting design standards that appropriately address the full impact of spectrum and color rendering.

6.0 References

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7.0 Appendix A: Subjective Lighting Survey Form

Cover Sheet for Survey Packet

America's Finest City
THE CITY OF SAN DIEGO

SDGE
A Sempra Energy utility
Serving you today.
Planning for tomorrow.

San Diego Nighttime Street Lighting Subjective Evaluation

First Name		Surveyor #
Last Name		

Thank you for participating in this important research on behalf of the City of San Diego and San Diego Gas and Electric! We are trying to understand the effect of different lighting systems for potential application throughout the City. The main goal is to understand public acceptance of various street lighting systems. Please respond to each of the questions with that goal in mind.

General Questions

G1. Do you live in San Diego?

Yes ________ No__________

G2. Do you live within three blocks of the 6th Avenue test area?

Yes ________ No__________

G3. Please provide the ZIP Code of your primary residence.

ZIP Code __________________

Demographic Questions

D1	*Gender*	M	F	*(circle one)*
D2	*Age*			*(in years)*

Page 1 of 9

Typical Through-Street Test Sheet (Test Area #1 Shown)

S.D. Nighttime Street Lighting Subjective Evaluation

TEST AREA #1

6th, Hawthorn to Ivy

Surveyor #

S1. Weather conditions --- Clear _____ Cloudy_____ Rain_____ Fog_____

S2. Ground conditions --- Streets Dry _____ Streets Wet_____

All of the statements in the table below (**except #1**) refer to the lighting of the immediate area around you, ***during darkness***. Please rate your level of agreement with each of the following statements about the lighting, on a 1 to 5 scale, with 1 being 'strongly disagree' and 5 being 'strongly agree'.

	Statements	Strongly Disagree .....Neutral.........Strongly Agree					Don't Know
1	It would be safe to walk here, alone, **during daylight**	1	2	3	4	5	DK
2	It would be safe to walk here, alone, during darkness hours.	1	2	3	4	5	DK
3	The lighting is comfortable.	1	2	3	4	5	DK
4	There is too much light on the street.	1	2	3	4	5	DK
5	There is not enough light on the street.	1	2	3	4	5	DK
6	The light is uneven (patchy).	1	2	3	4	5	DK
7	The light sources are glaring.	1	2	3	4	5	DK
8	**It would be safe to walk on the sidewalk here at night.**	1	2	3	4	5	DK
9	I **cannot** tell the colors of things due to the lighting.	1	2	3	4	5	DK
10	The lighting enables safe vehicular navigation.	1	2	3	4	5	DK
11	I like the color of the light.	1	2	3	4	5	DK
12	I would like this style lighting on my city streets.	1	2	3	4	5	DK

13. How does the lighting in this area compare with the lighting of similar city streets at night?

Much worse Worse About the same Better Much Better

14. Write additional comments below.

Page 2 of 9

Typical Intersection Test Sheet (Test Area #3 Shown)

S.D. Nighttime Street Lighting Subjective Evaluation

TEST AREA #3
Laurel Intersection

Surveyor #

S1. Weather conditions --- Clear _____ Cloudy_____ Rain_____ Fog_____

S2. Ground conditions --- Streets Dry _____ Streets Wet_____

All of the statements in the table below (**except #1**) refer to the lighting of the immediate area around you, ***during darkness***. Please rate your level of agreement with each of the following statements about the lighting, on a 1 to 5 scale, with 1 being ‘strongly disagree’ and 5 being ‘strongly agree’.

	Statements	Strongly Disagree .....Neutral.........Strongly Agree					Don’t Know
1	It would be safe to walk here, alone, **during daylight**	1	2	3	4	5	DK
2	It would be safe to walk here, alone, during darkness hours.	1	2	3	4	5	DK
3	The lighting is comfortable.	1	2	3	4	5	DK
4	There is too much light on the street.	1	2	3	4	5	DK
5	There is not enough light on the street.	1	2	3	4	5	DK
6	The light is uneven (patchy).	1	2	3	4	5	DK
7	The light sources are glaring.	1	2	3	4	5	DK
8	**It would be safe to cross the street here as a pedestrian.**	1	2	3	4	5	DK
9	I **cannot** tell the colors of things due to the lighting.	1	2	3	4	5	DK
10	The lighting enables safe vehicular navigation.	1	2	3	4	5	DK
11	I like the color of the light.	1	2	3	4	5	DK
12	I would like this style lighting on my city streets.	1	2	3	4	5	DK

13. How does the lighting in this area compare with the lighting of similar city streets at night?

Much worse   Worse   About the same   Better   Much Better

14. Write additional comments below.

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8.0 Appendix B: Site Measurements

Test Area #1 Site Measurements

Figure 27: Nighttime and Daytime Photos of Test Area 1

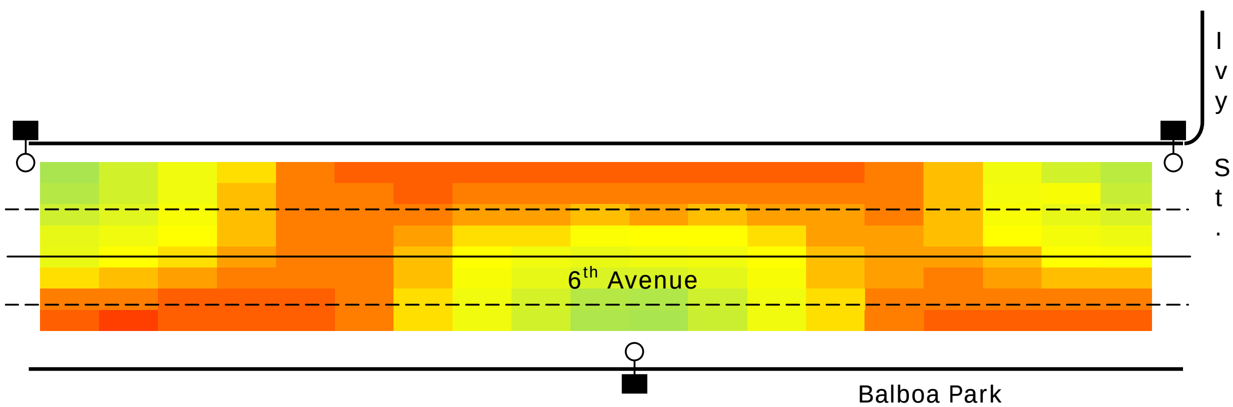

Figure 28: Test Area 1; Measured Photopic False Color Rendering.

Test Area 1 - Photopic and Scotopic Data

POLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	POLE
P	3.2	2.1	1.2	0.7	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6	1.2	2.1	2.7	Ivy Street
S	3.8	2.6	1.4	0.7	0.4	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.4	0.6	1.3	2.4	3.4	
P	2.9	2.1	1.2	0.6	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	1.1	1	2.4	
S	3.5	2.5	1.3	0.7	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.4	0.6	1.2	2.1	2.9	
P	2.2	1.7	1	0.6	0.4	0.4	0.4	0.5	0.5	0.6	0.5	0.6	0.5	0.5	0.4	0.6	1	1.5	1.9	
S	2.6	2	1.1	0.6	0.4	0.4	0.4	0.5	0.5	0.6	0.5	0.6	0.5	0.4	0.4	0.6	1.1	1.7	2.3	
P	1.5	1.2	0.8	0.6	0.4	0.4	0.5	0.7	0.7	0.9	0.8	0.8	0.7	0.5	0.5	0.6	0.8	1.1	1.3	
S	1.7	2.4	0.9	0.6	0.4	0.4	0.5	0.7	0.8	1	0.9	0.9	0.7	0.5	0.4	0.6	0.9	1.2	1.6	
P	1.4	0.8	0.7	0.5	0.4	0.4	0.6	0.8	1.2	1.4	1.3	1.2	0.8	0.6	0.5	0.5	0.6	0.8	0.9	
S	1.1	0.9	0.7	0.5	0.4	0.4	0.6	0.9	1.3	1.6	1.6	1.4	0.9	0.6	0.4	0.5	0.6	0.9	0.25	
P	0.7	0.6	0.5	0.4	0.4	0.4	0.6	1	1.5	1.9	1.9	1.6	1	0.6	0.5	0.4	0.5	0.6	0.6	
S	0.7	0.7	0.5	0.4	0.3	0.4	0.6	1.1	1.8	2.3	2.2	1.8	1.1	0.7	0.4	0.4	0.5	0.7	0.7	
P	0.4	0.4	0.3	0.3	0.3	0.4	0.7	1.2	2	2.9	3	2.2	1.2	0.7	0.4	0.4	0.4	0.4	0.4	
S	0.4	0.3	0.3	0.3	0.3	0.4	0.7	1.4	2.4	3.6	3.6	2.6	14	0.7	0.4	0.3	0.3	0.4	0.4	
P	0.3	0.2	0.3	0.3	0.3	0.4	0.7	1.2	2.1	3.1	3.2	2.3	1.2	0.7	0.4	0.3	0.3	0.3	0.3	
S	0.2	0.2	0.2	0.2	0.2	0.4	0.7	1.4	2.6	3.8	3.9	2.8	1.5	0.7	0.4	0.3	0.2	0.2	0.3	
										POLE										

Balboa Park

Test Area 1 - Luminance Data

POLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	POLE
Lum	0.86	0.52	0.39	0.19	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.07	0.1	0.1	0.14	0.15	0.28	0.46	0.65	Ivy Street
Lum	0.76	0.48	0.31	0.19	0.14	0.1	0.13	0.12	0.13	0.11	0.12	0.12	0.12	0.1	0.11	0.17	0.31	0.41	0.72	
Lum	0.53	0.39	0.25	0.17	0.12	0.1	0.11	0.12	0.14	0.16	0.15	0.16	0.11	0.12	0.12	0.15	0.25	0.3	0.46	
Lum	0.38	0.32	0.21	0.14	0.12	0.12	0.12	0.16	0.19	0.23	0.21	0.2	0.22	0.13	0.16	0.16	0.22	0.27	0.44	
Lum	0.24	0.22	0.18	0.13	0.11	0.11	0.14	0.21	0.28	0.31	0.3	0.28	0.2	0.16	0.15	0.13	0.16	0.22	0.22	
Lum	0.15	0.17	0.14	0.11	0.13	0.11	0.17	0.25	0.37	0.46	0.43	0.36	0.24	0.16	0.11	0.11	0.14	0.17	0.2	
Lum	0.1	0.09	0.09	0.08	0.09	0.11	0.17	0.28	0.49	0.68	0.65	0.46	0.3	0.16	0.11	0.1	0.11	0.12	0.11	
Lum	0.08	0.07	0.08	0.07	0.09	0.1	0.15	0.27	0.54	0.74	0.85	0.51	0.29	0.18	0.08	0.09	0.09	0.08	0.1	
										POLE										

Balboa Park

Test Area #2 Site Measurements

Figure 29: Nighttime and Daytime Photos of Test Area 2

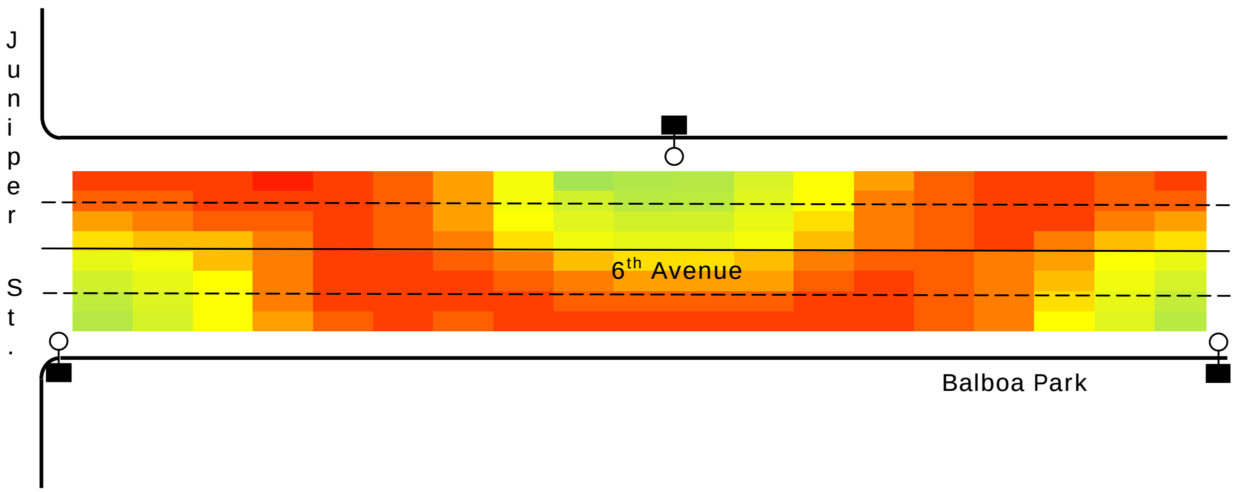

Figure 30: Test Area 2; Measured Photopic False Color Rendering.

Test Area 2 - Photopic and Scotopic Data

POLE (above column 9)

Juniper Street (left side)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
P	0.2	0.2	0.2	0.1	0.2	0.3	0.5	1.1	3.3	3	2.9	1.9	0.9	0.5	0.3	0.2	0.2	0.3	0.2
S	0.2	0.2	0.2	0.1	0.3	0.3	0.7	1.5	3.1	4.1	4	2.6	1.2	0.6	0.3	0.2	0.2	0.2	0.3
P	0.3	0.3	0.2	0.2	0.2	0.3	0.5	1.1	2.1	2.8	2.7	1.7	0.8	0.4	0.3	0.2	0.2	0.3	0.3
S	0.3	0.3	0.3	0.2	0.3	0.4	0.7	1.5	2.9	3.7	3.7	2.4	1.1	0.6	0.4	0.3	0.3	0.4	0.4
P	0.5	0.4	0.3	0.3	0.2	0.3	0.5	0.9	1.7	2.1	2.1	1.4	0.7	0.4	0.3	0.2	0.2	0.4	0.5
S	0.5	0.4	0.4	0.2	0.3	0.4	0.6	1.2	2.3	2.8	2.8	2	1	0.6	0.4	0.3	0.3	0.6	0.6
P	0.7	0.6	0.6	0.4	0.2	0.3	0.4	0.7	1.2	1.5	1.5	1.1	0.6	0.4	0.3	0.2	0.4	0.6	0.7
S	0.8	0.6	0.8	0.5	0.2	0.3	0.5	0.9	1.7	2	2	1.5	0.8	0.5	0.4	0.3	0.5	0.8	1
P	1.5	1.1	0.6	0.4	0.2	0.2	0.3	0.4	0.6	0.7	0.7	0.6	0.4	0.3	0.3	0.4	0.5	0.9	1.4
S	2	1.4	0.8	0.5	0.2	0.2	0.4	0.5	0.8	0.9	1	0.8	0.6	0.4	0.4	0.5	0.7	1.3	1.9
P	2.1	1.5	0.8	0.4	0.2	0.2	0.2	0.3	0.4	0.5	0.5	0.5	0.3	0.2	0.3	0.4	0.6	1.2	2
S	2.7	1.9	1.1	0.5	0.3	0.2	0.3	0.4	0.5	0.6	0.7	0.4	0.4	0.3	0.4	0.5	0.8	1.7	2.7
P	2.6	1.8	0.9	0.4	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.4	0.7	1.5	2.5
S	3.4	2.4	1.2	0.6	0.3	0.1	0.2	0.3	0.4	0.4	0.5	0.4	0.3	0.2	0.4	0.6	1	2.1	3.4
P	2.9	2	0.9	0.5	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.8	1.7	2.8

POLE (bottom left) POLE (bottom right)

Balboa Park

Test Area 2 - Luminance Data

POLE (above column 9)

Juniper Street (left side)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Lum	0.08	0.08	0.07	0.06	0.07	0.11	0.15	0.32	0.51	0.63	0.63	0.46	0.21	0.09	0.09	0.08	0.06	0.06	0.07
Lum	0.1	0.1	0.08	0.07	0.07	0.11	0.15	0.3	0.49	0.7	0.66	0.38	0.21	0.12	-9	0.07	0.08	0.1	0.1
Lum	0.12	0.11	0.09	0.07	0.07	0.09	0.12	0.21	0.41	0.51	0.42	0.32	0.18	0.11	0.09	0.08	0.12	0.12	0.18
Lum	0.18	0.15	0.1	0.07	0.07	0.08	0.1	0.2	0.33	0.37	0.34	0.26	0.14	0.13	0.1	0.08	0.1	0.14	0.24
Lum	0.3	0.35	0.2	0.12	0.09	0.09	0.1	0.14	0.2	0.22	0.23	0.21	0.13	0.11	0.11	0.11	0.16	0.24	0.47
Lum	0.52	0.38	0.23	0.14	0.1	0.08	0.08	0.11	0.14	0.17	0.17	0.18	0.1	0.09	0.1	0.14	0.21	0.34	0.58
Lum	0.72	0.46	0.3	0.14	0.1	0.09	0.09	0.1	0.1	0.16	0.15	0.13	0.1	0.11	0.13	0.16	0.16	0.53	0.86

POLE (bottom left) POLE (bottom right)

Balboa Park

Test Area #4 Site Measurements

Figure 31: Nighttime and Daytime Photos of Test Area 4

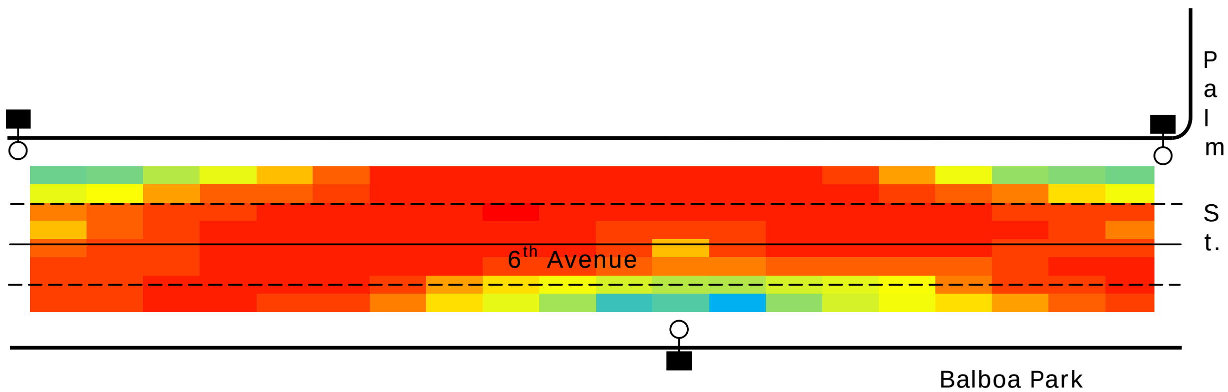

Figure 32: Test Area 4; Measured Photopic False Color Rendering.

Test Area 4 - Photopic and Scotopic Data

POLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	POLE
P	5	4.7	2.9	1.4	0.6	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.5	1.2	3.8	4.3	4.8	
S	6.9	6.4	3.9	1.8	0.7	0.3	0.1	0	0	0	0	0	0	0	0.2	0.6	1.7	2.6	6.4	6.7	
P	1.4	0.9	0.5	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.7	1.1	
S	1.7	0.9	0.6	0.3	0.4	0.2	0	0	0	0	0	0	0	0	0.1	0.2	0.4	0.5	1	1.4	
P	0.4	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	
S	0.4	0.3	0.2	0.1	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0.1	0.2	0.3	
P	0.6	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.4	Palm Street
S	0.8	0.3	0.1	0.1	0	0	0	0	0	0.1	0.1	0.2	0.1	0.1	0	0	0.1	0.1	0.2	0.4	
P	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.6	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	
S	0.3	0.2	0.1	0.1	0	0	0	0	0	0.1	0.2	0.7	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	
P	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.1	0.1	
S	0.2	0.1	0.1	0	0	0	0	0.1	0.1	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.1	0.1	0.1	
P	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.5	0.7	1.1	2	2.9	3	2	1.6	1	0.4	0.2	0.2	0.1	
S	0.2	0.1	0.1	0	0	0	0.2	0.6	0.8	1.4	2.4	4.2	3.7	2.8	2.2	1.3	0.5	0.2	0.1	0.1	
P	0.2	0.2	0.1	0.1	0.2	0.2	0.4	0.7	1.5	3.4	6.4	5.7	8	3.9	2	1.1	0.7	0.5	0.3	0.2	
S	0.2	0.1	0.1	0.1	0.2	0.2	0.5	0.9	2	4.7	8.9	8.1	5.7	5.4	2.8	1.5	1	0.6	0.3	0.2	
												POLE									

Balboa Park

Test Area 4 - Luminance Data

POLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	POLE
Lum	1.5	1.27	1.04	0.45	0.21	0.12	0.05	0.05	0.03	0.04	0.04	0.04	0.03	0.04	0.05	0.1	0.14	0.83	1.32	2	
Lum	0.53	0.22	0.15	0.12	0.09	0.07	0.04	0.03	0.03	0.03	0.04	0.05	0.03	0.03	0.04	0.14	0.1	0.16	0.19	0.35	
Lum	0.14	0.1	0.06	0.06	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.05	0.05	0.04	0.03	0.16	0.04	0.06	0.06	0.08	
Lum	0.27	0.11	0.07	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.06	0.06	0.06	0.04	0.03	0.08	0.03	0.05	0.07	0.11	Palm Street
Lum	0.09	0.09	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.07	0.17	0.07	0.04	0.04	0.04	0.04	0.05	0.08	0.07	
Lum	0.07	0.06	0.05	0.04	0.03	0.03	0.04	0.03	0.06	0.05	0.09	0.12	0.11	0.09	0.08	0.07	0.08	0.07	0.05	0.04	
Lum	0.08	0.06	0.05	0.04	0.03	0.04	0.06	0.13	0.24	0.33	0.52	0.83	0.93	0.62	0.44	0.28	0.13	0.08	0.06	0.5	
Lum	0.07	0.07	0.06	0.06	0.05	0.08	0.12	0.21	0.52	1.22	1.67	1.66	1.69	1.11	0.57	0.32	0.23	0.15	0.1	0.05	
												POLE									

Balboa Park

Test Area #6 Site Measurements

Figure 33: Nighttime and Daytime Photos of Test Area 6

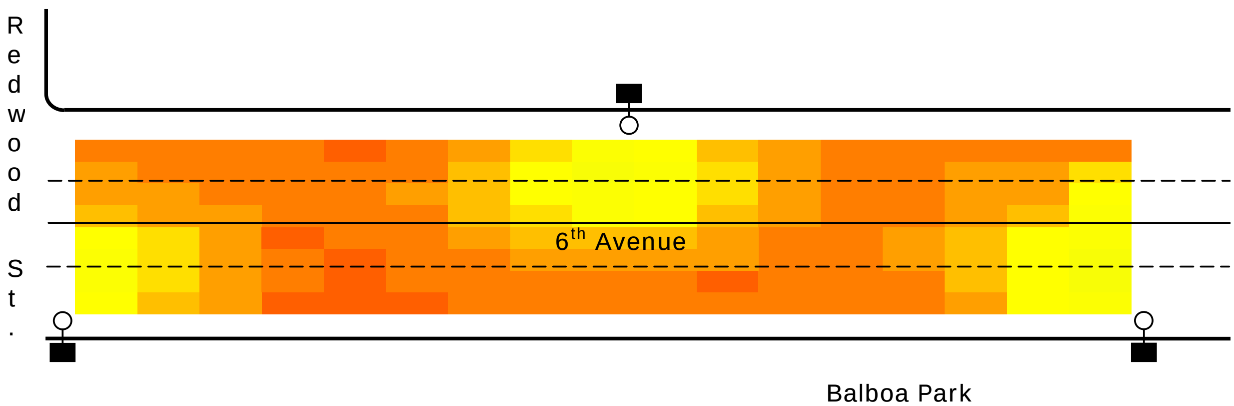

Figure 34: Test Area 6; Measured Photopic False Color Rendering.

Test Area 6 - Photopic and Scotopic Data

POLE (above column 9)

Redwood Street	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
P	0.4	0.4	0.4	0.4	0.3	0.4	0.5	0.7	0.9	0.8	0.6	0.5	0.4	0.4	0.4	0.4	0.4
S	0.5	0.5	0.6	0.5	0.4	0.6	0.8	1.1	1.3	1.3	0.9	0.7	0.6	0.5	0.5	0.5	0.6
P	0.5	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	0.9	0.7	0.5	0.4	0.4	0.5	0.5	0.7
S	0.7	0.6	0.5	0.5	0.5	0.6	0.9	1.2	1.4	1.3	1	0.7	0.6	0.5	0.7	0.7	0.5
P	0.5	0.5	0.4	0.4	0.4	0.5	0.6	0.8	0.9	0.8	0.7	0.5	0.4	0.4	0.5	0.5	0.8
S	0.8	0.7	0.6	0.6	0.5	0.7	0.9	1.2	1.4	1.3	1	0.8	0.6	0.6	0.7	0.7	0.5
P	0.6	0.5	0.5	0.4	0.4	0.4	0.6	0.7	0.9	0.8	0.6	0.5	0.4	0.4	0.5	0.6	0.9
S	1	0.8	0.7	0.6	0.5	0.7	0.9	1.1	1.3	1.3	1	0.8	0.6	0.6	0.8	0.9	0.6
P	0.8	0.7	0.5	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.5	0.4	0.4	0.5	0.6	0.8	0.9
S	1.2	1	0.8	0.5	0.5	0.6	0.8	0.9	1	0.9	0.8	0.6	0.6	0.7	1	1.2	1.4
P	0.9	0.7	0.5	0.4	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.4	0.4	0.5	0.6	0.8	1
S	1.3	1	0.8	0.5	0.5	0.6	0.6	0.8	0.8	0.8	0.7	0.6	0.6	0.7	0.9	1.2	1.4
P	0.9	0.7	0.5	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.6	0.8	1
S	1.3	1	0.7	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.4	0.5	0.5	0.6	0.8	1.2	1.4
P	0.8	0.6	0.5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.8	0.9
S	1.2	1	0.7	0.4	0.4	0.4	0.5	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.7	1.2	1.4

POLE (below left) — POLE (below right)

Balboa Park

Test Area 6 - Luminance Data

POLE (above column 9)

Redwood Street	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Lum	0.12	0.19	0.11	0.11	0.1	0.12	0.11	0.15	0.26	0.31	0.24	0.17	0.15	0.14	0.11	0.12	0.16
Lum	0.23	0.17	0.13	0.11	0.11	0.11	0.14	0.16	0.27	0.32	0.32	0.23	0.18	0.12	0.15	0.14	0.2
Lum	0.18	0.16	0.13	0.1	0.12	0.12	0.14	0.16	0.26	0.31	0.25	0.2	0.16	0.14	0.14	0.14	0.21
Lum	0.21	0.17	0.13	0.1	0.12	0.11	0.13	0.19	0.2	0.28	0.26	0.21	0.16	0.15	0.15	0.17	0.24
Lum	0.15	0.14	0.14	0.1	0.12	0.14	0.2	0.25	0.32	0.19	0.17	0.13	0.15	0.12	0.14	0.28	0.26
Lum	0.13	0.15	0.12	0.11	0.12	0.17	0.18	0.24	0.25	0.15	0.16	0.12	0.12	0.12	0.15	0.23	0.24

POLE (below left) — POLE (below right)

Balboa Park

Test Area #7 Site Measurements


Figure 35: Nighttime and Daytime Photos of Test Area 7

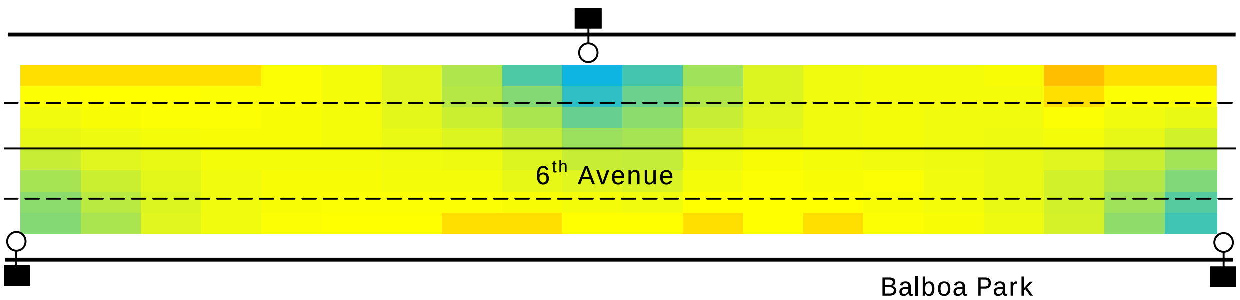

Figure 36: Test Area 7; Measured Photopic False Color Rendering.

Test Area 7 - Photopic and Scotopic Data

POLE (above column 10)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
P	0.7	0.7	0.7	0.7	0.9	1.1	1.7	3.1	5.8	7.6	6.1	3.5	1.8	1.2	1.1	1.1	1	0.6	0.7	0.7
S	0.4	0.4	0.4	0.6	0.6	0.8	1.2	2.3	4.3	5.8	4.7	2.6	1.3	0.9	0.7	0.7	0.6	0.5	0.4	0.4
P	0.9	0.8	0.8	0.9	0.9	1.1	1.7	2.9	4.3	6.7	5	3	1.8	1.2	1.1	1.1	1.1	0.7	0.9	0.9
S	0.6	0.5	0.5	0.6	0.6	0.8	1.2	2.2	3.2	5.1	3.9	2.2	1.3	0.8	0.7	0.7	0.7	0.5	0.6	0.6
P	1.2	1	0.9	0.9	1	1.1	1.6	2.3	3.2	5.1	4.1	2.4	1.7	1.2	1.1	1.2	1.2	0.9	1.2	1.4
S	0.8	0.6	0.6	0.6	0.6	0.8	1.1	1.7	2.3	3.9	3.1	1.8	1.2	0.8	0.7	0.8	0.8	0.6	0.8	0.9
P	1.5	1.3	1.1	1	1	1.1	1.4	1.8	2.5	3.6	3.3	1.9	1.5	1.2	1.1	1.2	1.3	1.1	1.5	2.1
S	1	0.8	0.7	0.7	0.7	0.7	1	1.4	1.8	2.7	2.5	1.4	1	0.8	0.8	0.8	0.9	0.8	1	1.4
P	2.4	1.7	1.4	1.1	1.1	1.1	1.2	1.3	1.8	2.4	2.5	1.3	1	1.1	1.2	1.3	1.4	1.7	2.3	3.4
S	1.6	1.1	0.9	0.8	0.7	0.7	0.9	1	1.3	1.8	1.9	1	0.7	0.8	0.8	0.9	0.9	1.3	1.6	2.4
P	3.3	2.3	1.6	1.2	1	1	1.1	1.1	1.5	1.7	1.9	1.1	0.9	1	0.9	1.2	1.4	2.1	2.9	4.4
S	2.3	1.6	1.1	0.8	0.7	0.7	0.7	0.8	1	1.2	1.4	0.7	0.6	0.6	0.5	0.8	0.9	1.4	2	3.2
P	4.1	2.8	1.8	1.2	1	0.9	0.9	0.9	1	1.1	1.2	0.8	0.8	0.8	1	1.1	1.4	2.1	3.5	5.6
S	2.9	2	1.2	0.8	0.6	0.6	0.6	0.6	0.7	0.8	0.8	0.5	0.5	0.5	0.6	0.7	0.9	1.4	2.5	4
P	4.3	3.2	1.7	1.2	0.9	0.8	0.8	0.7	0.7	0.8	0.8	0.7	0.8	0.7	0.9	1	1.3	2	4	6.2
S	3.1	2.3	1.2	0.8	0.6	0.5	0.5	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.5	0.6	0.9	1.4	2.9	4.5

POLE (lower left) POLE (lower right)

Balboa Park

Test Area 7 - Luminance Data

POLE (above column 10)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Lum	0.22	0.19	0.2	0.2	0.22	0.3	0.32	0.97	1..52	2	1.6	0.85	0.46	0.36	0.31	0.29	0.32	0.26	0.21	0.23
Lum	0.27	0.26	0.24	0.23	0.24	0.26	0.51	0.77	1.12	1.81	1.35	0.73	0.43	0.35	0.31	0.33	0.3	0.29	0.26	0.27
Lum	0.36	0.3	0.26	0.26	0.26	0.27	0.4	0.54	0.78	0.94	0.98	0.65	0.4	0.31	0.32	0.32	0.36	0.33	0.31	0.42
Lum	0.48	0.35	0.29	0.29	0.29	0.32	0.4	0.48	0.62	0.96	0.93	0.48	0.35	0.33	0.31	0.31	0.38	0.36	0.37	0.53
Lum	0.62	0.41	0.39	0.3	0.26	0.25	0.31	0.34	0.49	0.62	0.64	0.31	0.31	0.28	0.3	0.34	0.38	0.43	0.53	0.9
Lum	0.81	0.65	0.39	0.29	0.25	0.24	0.27	0.25	0.38	0.42	0.47	0.29	0.25	0.25	0.31	0.32	0.37	0.54	0.67	1.1
Lum	0.98	0.7	0.44	0.32	0.26	0.21	0.22	0.22	0.26	0.31	0.34	0.27	0.22	0.22	0.26	0.28	0.39	0.54	0.85	1.35
Lum	1.19	0.95	0.44	0.31	0.23	0.24	0.2	0.19	0.21	0.24	0.22	0.18	0.22	0.18	0.24	0.25	0.34	0.47	0.9	1.5

POLE (lower left) POLE (lower right)

Balboa Park

Nighttime System Comparison
Intersections (Test Areas 3, 5, 8)

Figure 37: Test Area 3

Figure 38: Test Area 5

Figure 39: Test Area 8

Nighttime System Comparison
Roadway (Test Areas 1, 2, 4, 6, 7)

Figure 40: Test Area 1

Figure 41: Test Area 2

Nighttime System Comparison
Roadway (Test Areas 1, 2, 4, 6, 7)

Figure 42: Test Area 4

Figure 43: Test Area 6

Figure 44: Test Area 7

Typical Luminous Scene Recorded with RLMMS

9.0 Appendix C: Site Calculations

Road and Pedestrian Conflict Area		Criteria for R3 Pavement	Uniformity Ratio	Veiling Luminance Ratio
Road	Pedestrian Conflict Area	Illuminance (lux)	E_{avg}/E_{min}	L_{vmax}/L_{avg}
Expressway	High	14	3.0	0.3
	Medium	12	3.0	0.3
	Low	9	3.0	0.3
Major	High	17	3.0	0.3
	Medium	13	3.0	0.3
	Low	9	3.0	0.3
Collector	High	12	4.0	0.4
	Medium	9	4.0	0.4
	Low	6	4.0	0.4
Local	High	9	6.0	0.4
	Medium	7	6.0	0.4
	Low	4	6.0	0.4

Table 16: IESNA RP-8 Illuminance Criteria Table

Road and Pedestrian Conflict Area		Average Luminance	Uniformity Ratio	Uniformity Ratio	Veiling Luminance Ratio
Road	Pedestrian Conflict Area	L_{avg} (cd/m^2)	L_{avg}/L_{min}	L_{max}/L_{min}	L_{vmax}/L_{avg}
Expressway	High	1.0	3.0	5.0	0.3
	Medium	0.8	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Major	High	1.2	3.0	5.0	0.3
	Medium	0.9	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Collector	High	0.8	3.0	5.0	0.4
	Medium	0.6	3.5	6.0	0.4
	Low	0.4	4.0	8.0	0.4
Local	High	0.6	6.0	10.0	0.4
	Medium	0.5	6.0	10.0	0.4
	Low	0.3	6.0	10.0	0.4

Table 17: IESNA RP-8 Luminance Criteria Table

	Test Area	IESNA RP-8 Luminance Criteria Met	IESNA RP-8 Illuminance Criteria Met
1	Induction	Collector: Low	Collector: Medium
2	Induction	Collector: Low	Collector: Low
3	Induction	Collector: Low	Collector: Low
4	LED	None	None
5	LED	Collector: Medium	Collector: Low
6	LED	None	None
7	HPS (roadway)	Major: High	Major: High
8	HPS (intersection)	Major: High	Major: High

Table 18: Lighting Systems IESNA Criteria Met

In Table 18, note that while there is a general correlation between the '*Illuminance*' method and the '*Luminance*' method in what level of roadway design is met, Test Area 1 shows a disagreement based on the two different calculation methods. This is in fact not a surprise, because the two methods were never effectively calibrated. In fact, due to the differing calculations that are performed for the two roadway calculation methods, it is impossible to calibrate them so that the calculations will always agree.

10.0 Appendix D: Subjective Survey Results

Ninety five percent confidence intervals were constructed around the mean score for each statement. These intervals were also compared across the lighting types. Significant differences for responses to the systems are determined by comparing confidence intervals. When the intervals do not overlap, the difference is considered statistically significant at the 95% confidence level.

It is important to note that a statistically significant difference refers to differences in results that most likely (with 95% certainty) did not occur by chance. It does not mean that the differences are significant in the practical sense of the word. Additionally, a difference that is not considered statistically significant does not mean that it may not be important.

The confidence intervals for all of the survey statements are shown in the following figures.

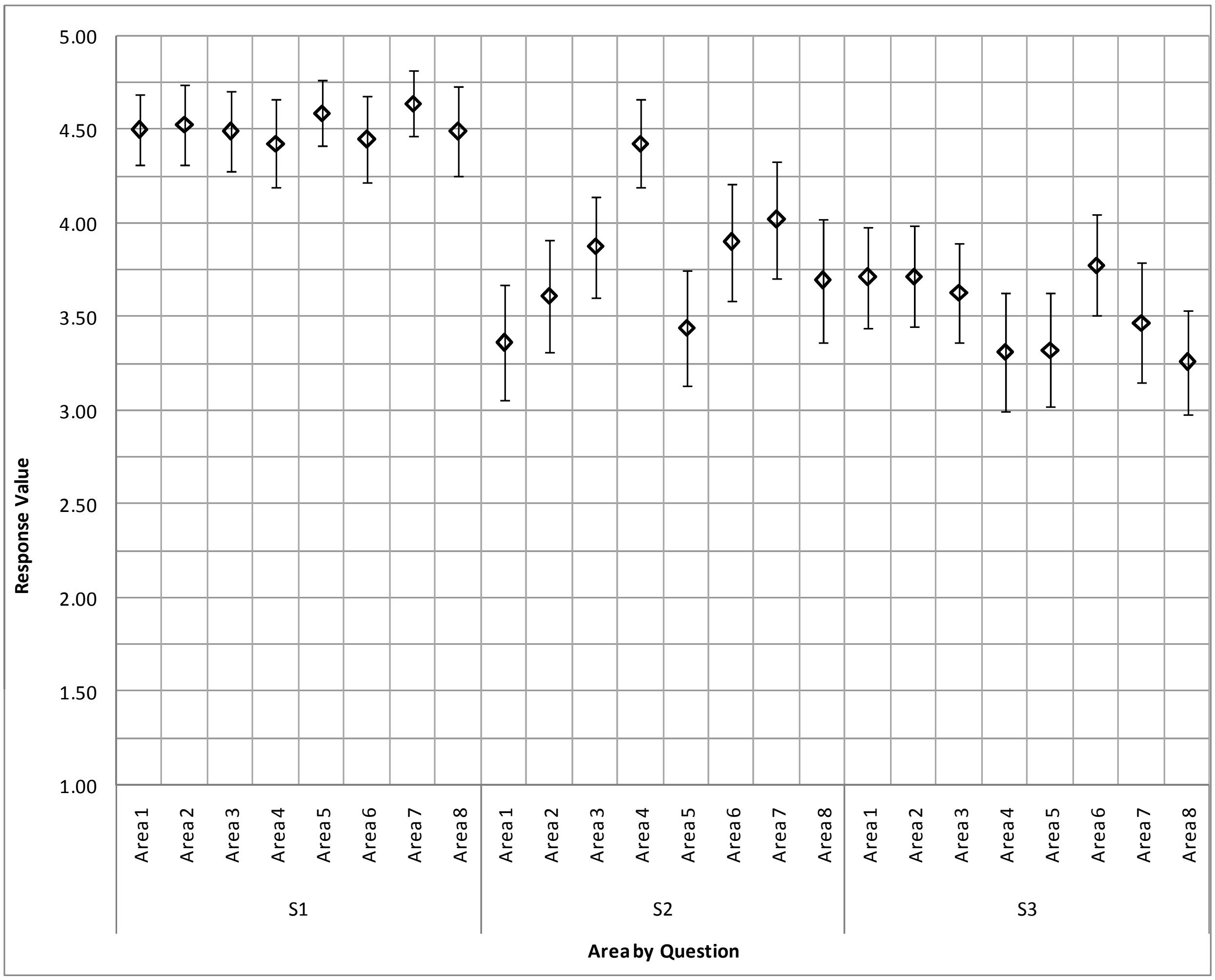

Figure 45: Confidence Intervals for Statements S1, S2, and S3.

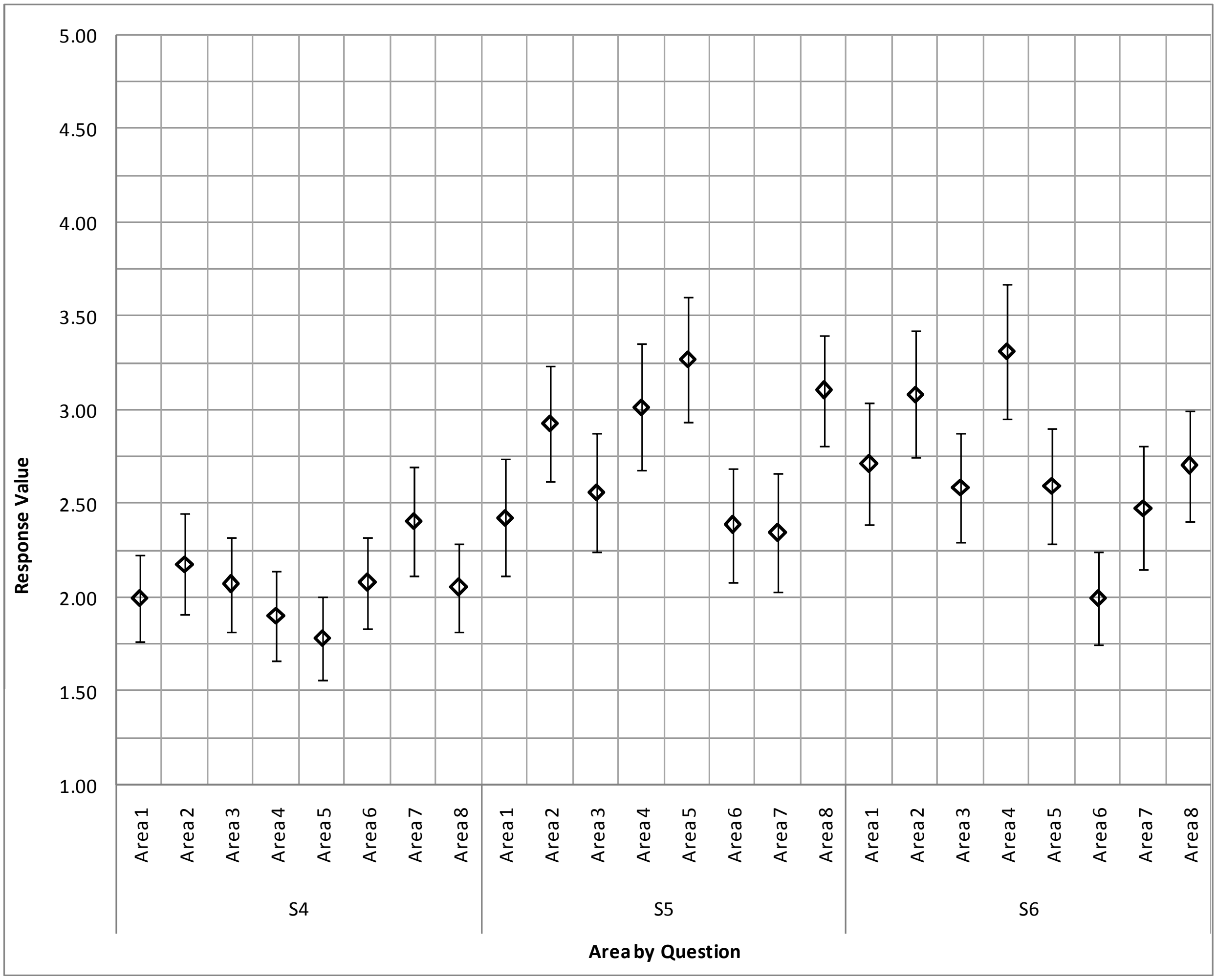

Figure 46: Confidence Intervals for Statements S4, S5, and S6.

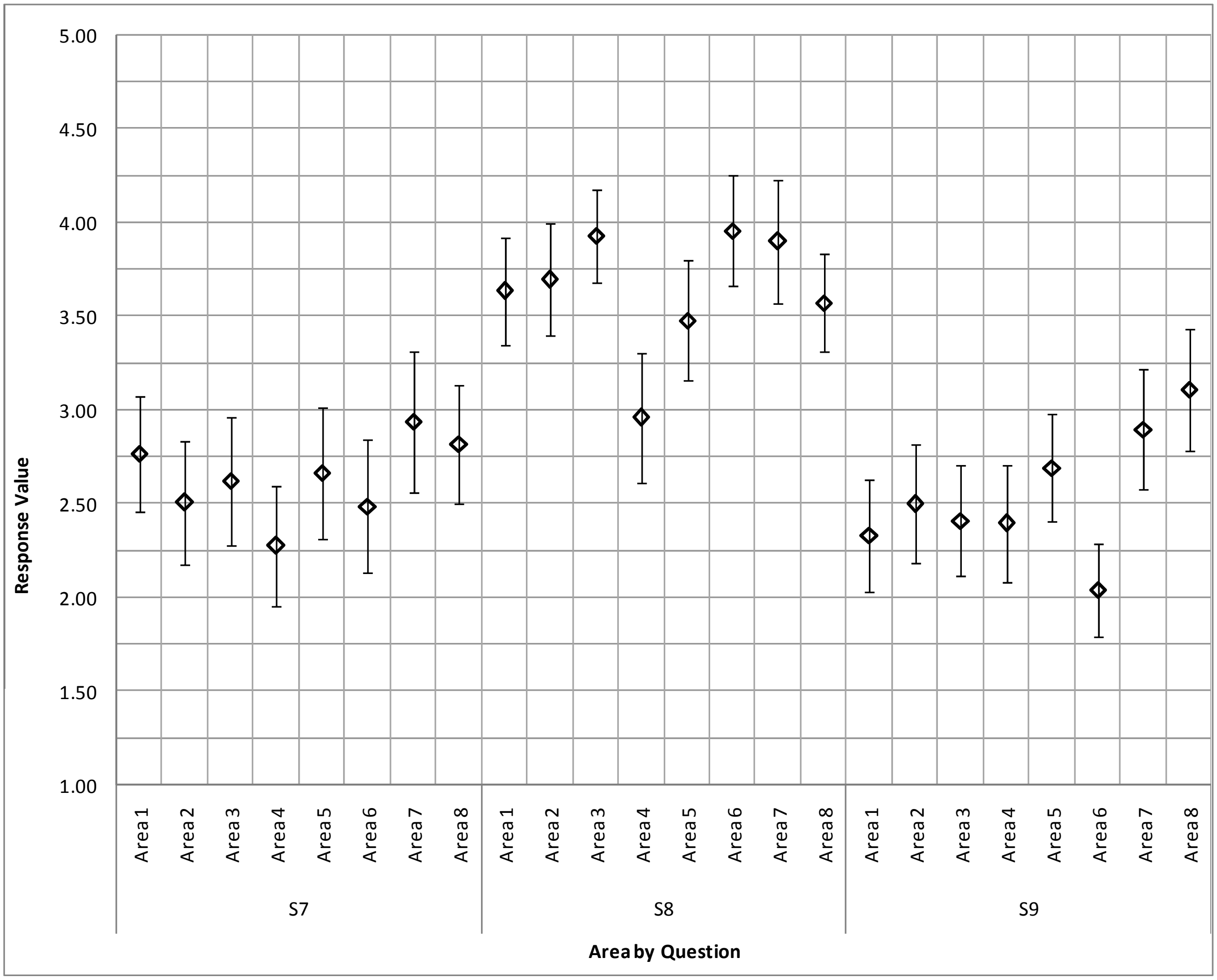

Figure 47: Confidence Intervals for Statements S7, S8, and S9.

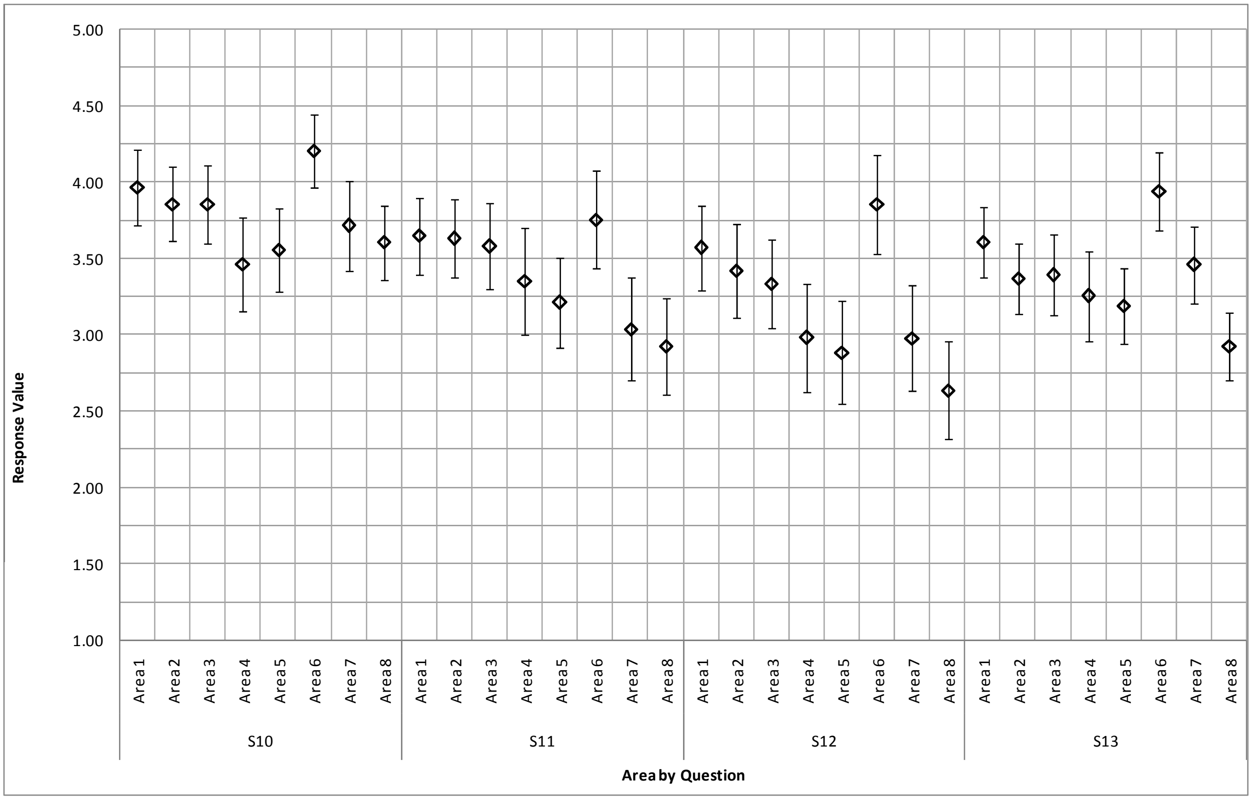

Figure 48: Confidence Intervals for Statements S10, S11, S12, and S13.

11.0 Appendix E: Objective Testing Results

Results of the ANOVA performed on this averaged illuminance data is shown in Table 19 and SNK pairwise comparisons among each lighting type are illustrated in Figure 22. As expected, significant differences were found among all lighting types. The existing HPS roadway installation had the highest illuminance levels compared to the alternative lighting technologies.

Source	F-value	P-value	Significant
Lighting type (Roof sensors only)	112.47	<0.0001	*
Lighting Type (Glare Meter Only)	36.28	<0.0001	*

Table 19: ANOVA Results for Illuminance Levels for Roof and Glare Sensors for Lighting Locations

12.0 Appendix F: SDG&E LS-2 Rate Schedule

San Diego Gas & Electric Company
San Diego, California

Revised Cal. P.U.C. Sheet No. 21065-E
Canceling Revised Cal. P.U.C. Sheet No. 20835-E

SCHEDULE LS-2

Sheet 1

LIGHTING - STREET AND HIGHWAY - CUSTOMER-OWNED INSTALLATIONS

APPLICABILITY

Applicable for service to governmental agencies and lighting districts for the lighting of streets, highways and other thoroughfares, and to other corporate agencies for the lighting of non-dedicated streets which are accessible to the public, where the customer owns the entire installation, including underground lines from a central point of connection with utility facilities.

TERRITORY

Within the entire territory served by the Utility.

RATES

Description-LS-2		Transm		Distr		PPP		ND	CTC	RS		TRAC	UDC Total	
Mercury Vapor*														
Rate A														
175	7000	0.58	R	2.80	I	(0.01)	R	0.03		0.04	I		3.44	R
250	10000	0.81	R	3.90	I	(0.01)	R	0.05		0.05	I		4.80	
400	20000	1.28	R	6.14	I	(0.02)	R	0.07		0.08	I		7.55	R
700	35000	2.17	R	10.41	I	(0.03)	R	0.12		0.14	I		12.81	R
1000	55000	3.06	R	14.70	I	(0.05)	R	0.18		0.19	I		18.08	R
Rate B														
175	7000	0.58	R	4.33	I	(0.01)	R	0.03		0.04	I		4.97	R
250	10000	0.81	R	5.43	I	(0.01)	R	0.05		0.05	I		6.33	
400	20000	1.28	R	7.67	I	(0.02)	R	0.07		0.08	I		9.08	R
Surcharge for Series Service														
175	7000			0.42									0.42	
250	10000			0.55									0.55	
400	20000			0.78									0.78	
700	35000			1.41									1.41	
HPSV														
Rate A														
50	4000	0.16		0.77	I	0.00	R	0.01		0.01	I		0.95	
70	5800	0.28		1.35	I	0.00	R	0.02		0.02	I		1.67	I
100	9500	0.39	R	1.88	I	(0.01)	R	0.02		0.02	I		2.30	R
150	16000	0.54		2.58	I	(0.01)	R	0.03		0.03	I		3.17	I
200	22000	0.68	R	3.28	I	(0.01)	R	0.04		0.04	I		4.03	R
250	30000	0.87	R	4.18	I	(0.01)	R	0.05		0.05	I		5.14	
310	37000	1.06	R	5.11	I	(0.02)	R	0.06		0.07	I		6.28	R
400	50000	1.32	R	6.35	I	(0.02)	R	0.08		0.08	I		7.81	R
1000	140000	3.06	R	14.70	I	(0.05)	R	0.18		0.19	I		18.08	R

*Closed to new installations as of June 10, 1979

(Continued)

1C11

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Lee Schavrien
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SDGE
San Diego Gas & Electric Company
San Diego, California

Revised Cal. P.U.C. Sheet No. 21066-E

Canceling Revised Cal. P.U.C. Sheet No. 20836-E

SCHEDULE LS-2

Sheet 2

LIGHTING - STREET AND HIGHWAY - CUSTOMER-OWNED INSTALLATIONS

RATES (Continued)

Description		Transm		Distr		PPP		ND	CTC	RS		TRAC	UDC Total	
HPSV Rate B														
50	4000	0.16		2.30	I	0.00	R	0.01		0.01	I		2.48	
70	5800	0.28		2.88	I	0.00	R	0.02		0.02	I		3.20	I
100	9500	0.39	R	3.41	I	(0.01)	R	0.02		0.02	I		3.83	R
150	16000	0.54		4.10	I	(0.01)	R	0.03		0.03	I		4.69	
200	22000	0.68	R	4.81	I	(0.01)	R	0.04		0.04	I		5.56	R
250	30000	0.87	R	5.71	I	(0.01)	R	0.05		0.05	I		6.67	
310	37000	1.06	R	6.64	I	(0.02)	R	0.06		0.07	I		7.81	R
400	50000	1.32	R	7.88	I	(0.02)	R	0.08		0.08	I		9.34	R
1000	140000	3.06	R	16.23	I	(0.05)	R	0.18		0.19	I		19.61	R
Reduction for 120-Volt Reactor Ballast														
50	4000			($0.09)									($0.09)	
70	5800			(0.20)									(0.20)	
100	9500			(0.26)									(0.26)	
150	16000			(0.24)									(0.24)	
Surcharge for Series Service														
50	4000			0.49									0.49	
70	5800													
100	9500													
150	16000			0.02									0.02	
200	22000			0.51									0.51	
250	30000													
LPSV Rate A														
35	4800	0.19		0.89	I	0.00	R	0.01		0.01	I		1.10	
55	8000	0.24	R	1.17	I	0.00	R	0.01		0.02	I		1.44	
90	13500	0.40	R	1.93	I	(0.01)	R	0.02		0.03	I		2.37	R
135	22500	0.57	R	2.75	I	(0.01)	R	0.03		0.04	I		3.38	
180	33000	0.65	R	3.14	I	(0.01)	R	0.04		0.04	I		3.86	
Surcharge for Series Service														
35	4800													
55	8000													
90	13500			0.49									0.49	
135	22500			0.86									0.86	
180	33000			0.56									0.56	
Incandescent Lamps Rate A (energy only)														
	1000	0.20	R	0.97	I	0.00	R	0.01		0.01	I		1.19	R
	2500	0.45	R	2.16	I	(0.01)	R	0.03		0.03	I		2.66	
	4000	0.82	R	3.94	I	(0.01)	R	0.05		0.05	I		4.85	R
	6000	1.13	R	5.40	I	(0.02)	R	0.06		0.07	I		6.64	R
	10000	1.69	R	8.11	I	(0.03)	R	0.10		0.11	I		9.98	R

(Continued)

2C11

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San Diego Gas & Electric Company
San Diego, California

Revised Cal. P.U.C. Sheet No. 21252-E

Canceling Revised Cal. P.U.C. Sheet No. 21124-E*

SCHEDULE LS-2

Sheet 3

LIGHTING - STREET AND HIGHWAY - CUSTOMER-OWNED INSTALLATIONS

RATES (Continued)

Description- LS-2	Transm	Distr	PPP	ND	CTC	RS	TRAC	UDC Total
Incandescent Lamps								
Rate B								
6000	1.13	6.93	(0.02)	0.06		0.07		**8.17**
Metal Halide								
Rate A								
100 8500	0.37	1.76	(0.01)	0.02		0.02		**2.16**
175 12000	0.58	2.76	(0.01)	0.03		0.04		**3.40**
250 18000	0.80	3.84	(0.01)	0.05		0.05		**4.73**
400 32000	1.23	5.92	(0.02)	0.07		0.08		**7.28**
Rate B								
100 8500	0.37	3.29	(0.01)	0.02		0.02		**3.69**
175 12000	0.58	4.29	(0.01)	0.03		0.04		**4.93**
250 18000	0.80	5.37	(0.01)	0.05		0.05		**6.26**
400 32000	1.23	7.45	(0.02)	0.07		0.08		**8.81**
Induction								
Rate A – 5-Lamp								
55 3500	0.76	3.67	(0.01)	0.04		0.05		**4.51**
85 6000	1.21	5.80	(0.02)	0.07		0.08		**7.14**
Induction								
Rate A – 1-Lamp								
40............3440	0.11	0.53	-	0.01		0.01		**0.66**
50............3495	0.14	0.67	-	0.01		0.01		**0.83**
55............ 3500	0.15	0.73	0.00	0.01		0.01		**0.90**
80............6528	0.22	1.07	-	0.01		0.01		**1.31**
85............6000	0.24	1.13	0.00	0.01		0.01		**1.39**
100...........8800	0.28	1.33	-	0.02		0.02		**1.65**
150..........12800	0.42	2.00	(0.01)	0.02		0.03		**2.46**
165..........12000	0.46	2.20	(0.01)	0.03		0.03		**2.71**
200..........16800	0.56	2.67	(0.01)	0.03		0.03		**3.28**
250..........21040	0.70	3.34	(0.01)	0.04		0.04		**4.11**
300..........24480	0.83	4.00	(0.01)	0.05		0.05		**4.92**
400.......... 32640	1.11	5.34	(0.02)	0.06		0.07		**6.56**
Non-Standard Lamp								
Energy Charge $/kWh/Lamp/month	$0.00801	$0.03234	$(0.00012)	$0.00046		$0.00050		**$0.04119**

Notes: Transmission Energy charges include the Transmission Revenue Balancing Account Adjustment (TRBAA) of ($.00070) per KWh and the Transmission Access Charge Balancing Account Adjustment (TACBAA) of ($.00149) per kWh. PPP rate is composed of: Low Income PPP rate (LI-PPP) $.00000/kWh, Non-low Income PPP rate (Non-LI-PPP) $(.00231)/kWh (pursuant to PU Code Section 399.8, the Non-LI-PPP rate may not exceed January 1, 2000 levels), and Procurement Energy Efficiency Surcharge Rate of $.00219/kWh. The average lumen values are for informational purposes only and can vary by manufacturer and age of the facility.

Rate Components

The Utility Distribution Company Total Rates (UDC Total) shown above are comprised of the following components (if applicable): (1) Transmission (Trans) Charges, (2) Distribution (Distr) Charges, (3) Public Purpose Program (PPP) Charges, (4) Nuclear Decommissioning (ND) Charge, (5) Ongoing Competition Transition Charges (CTC), (6) Reliability Services (RS), and (7) the Total Rate Adjustment Component (TRAC).

(Continued)

3C17

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Lee Schavrien
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San Diego Gas & Electric Company
San Diego, California

	Revised	Cal. P.U.C. Sheet No.	21253-E
Canceling	Revised	Cal. P.U.C. Sheet No.	15923-E

SCHEDULE LS-2

Sheet 4

LIGHTING - STREET AND HIGHWAY - CUSTOMER-OWNED INSTALLATIONS

RATES (Continued)

Utility Distribution Company (UDC) Total Rate shown above excludes any applicable commodity charges associated with Schedule EECC and Schedule DWR-BC (Department of Water Resources Bond Charge). L

Certain Direct Access customers are exempt from the TRAC component, as defined in Rule 1 – Definitions. L

Franchise Fee Differential
A Franchise Fee Differential of 5.78% will be applied to the monthly billings calculated under this schedule for all customers within the corporate limits of the City of San Diego. Such Franchise Fee Differential shall be so indicated and added as a separate item to bills rendered to such customers.

SPECIAL CONDITIONS

1. Limited Maintenance Service. Limited Maintenance shall include the following:

   a. Renewal of lamps after original installation by customer.

   b. Replacement of glassware and luminaire equipment, which will be billed to the customer at the manufacturers' currently published suggested retail prices plus applicable taxes.

   c. Cleaning of glassware at the time of lamp replacement.

   Incandescent lamp maintenance service is limited to those incandescent lamps maintained by the utility prior to June 10, 1979.

   Maintenance service will not be furnished where, in the opinion of the utility, an undue hazard or expense would result because of location, mounting height, or other reasons.

   Customer shall furnish, install, own and maintain all equipment beyond the central point of connection except for such limited maintenance as provided above.

2. Customer Installation on Utility Pole. Service to street lights owned by governmental agencies will be allowed on utility-owned poles, served from overhead secondary service, wherein the governmental agency owns all street lights within its jurisdiction and has entered into a Pole Attachment Agreement with the utility. Installation of all new street lights will be performed by the governmental agency or its contractor.

3. Type of Service. Service to multiple lamps will be supplied at the available secondary voltage or, at the option of the utility, 480 volts. Service to series lamps will be supplied only from existing series circuits.

4. Hours of Burning. Service will be from dusk to daylight which, in accordance with the utility's switching schedule, results in approximately 4,165 burning hours per year.

5. Relocation of Facilities. Relocation of Utility's Facilities at the customer's request or because of governmental requirements will be made providing the customer pays the actual costs incurred by the utility for such relocation.

(Continued)

4C14

Advice Ltr. No. 2090-E	Issued by	Date Filed	Jun 1, 2009
	Lee Schavrien	Effective	Jul 1, 2009
Decision No.	Senior Vice President Regulatory Affairs	Resolution No.	

SDGE
San Diego Gas & Electric Company
San Diego, California

	Revised	Cal. P.U.C. Sheet No.	12634-E
	Revised		10902-E
Canceling	Revised	Cal. P.U.C. Sheet No.	10449-E

SCHEDULE LS-2

Sheet 5

LIGHTING - STREET AND HIGHWAY - CUSTOMER-OWNED INSTALLATIONS

SPECIAL CONDITIONS (Continued)

6. Change in Rate. Where systems are taken over for service under this schedule, or changed from Rate A to Rate B hereunder, they must meet the approval of the utility as to construction and condition, and the utility may decline to grant these rates if the system is not up to the standard set for other systems operating under this schedule. L

7. Contracts. A Contract for a period of not less than one year and not more than five years may be required for service under this schedule and will remain in effect from year to year thereafter until terminated. L

8. Shut-off for Non-Payment. If a customer's street lights are shut off due to non-payment of the monthly energy bill, the customer will be subject to a turn-on fee of $10.00 per light, with a minimum charge of $50.00. This fee is in addition to the Service Re-Establishment Fee and normal credit deposits.

9. Timed Auxiliary Power Device Adapter. This service is available under the terms and conditions stated below for a monthly charge of $0.81 per device plus an administrative charge of $60.00 per account per contract period plus Energy Charges billed at the rates stated in Schedule A.

   a. A Standard Installation shall consist of an individual timed auxiliary power device installed on a customer-owned ornamental street lighting pole.

   b. This rate is only available to governmental agencies who are the customer of record for ornamental street lighting service. A written Service Application and Agreement is required for service in conjunction with customer-owned street lighting poles.

   c. The customer will own and install the requested timed auxiliary power adapter and the installed timed auxiliary power adapter shall remain the sole property of the customer.

   d. The installation of the applicant's lighting decorations shall be in accordance with utility's specifications.

   e. The provisions of this service shall be in accordance with the utility's Rule 14.1, Prohibitions and Curtailment Provisions, Section B.1.a.

   f. The applicant shall specify the number of timed auxiliary power adapters required. Billing will be based on the per-unit decoration wattage and hours of operation specified by the applicant in the Service Application and Agreement. The per-unit decoration wattage shall not exceed the manufacturers' 300-watt rating for each device.

   g. At the time of installation of the timed auxiliary power adapter and monthly thereafter until such timed auxiliary power adapter has been removed, the customer will be required to pay the monthly charge.

   h. In no case shall the granting of permission to install lighted decorations for use with a timed auxiliary power adapter device on the customer-owned poles give the applicant any additional rights.

(Continued)

5C1

Advice Ltr. No.	1174-E-A	Issued by **William L. Reed**	Date Filed	Jun 29, 1999
		Vice President	Effective	Jul 1, 1999
Decision No.	99-05-051	Chief Regulatory Officer	Resolution No.	

San Diego Gas & Electric Company
San Diego, California

Revised Cal. P.U.C. Sheet No. 21125-E*

Canceling Revised Cal. P.U.C. Sheet No. 19724-E

SCHEDULE LS-2

Sheet 6

LIGHTING - STREET AND HIGHWAY - CUSTOMER-OWNED INSTALLATIONS

SPECIAL CONDITIONS (Continued)

10. Billing: A customer's bill is first calculated according to the total rates and conditions listed above. The following adjustments are made depending on the option applicable to the customer:

   a. **UDC Bundled Service Customers** receive supply and delivery services solely from the Utility. The customer's bill is based on the Total Rates set forth above. The EECC component is determined by multiplying the EECC price for this schedule during the last month by the customer's total usage.

   b. **Direct Access (DA) and Community Choice Aggregation (CCA) Customers** purchase energy from a non-utility provider and continue to receive delivery services from the Utility. The bills for a DA and CCA Customer will be calculated as if they were a UDC Bundled Service Customer, then crediting the bill by the amount of the EECC component, as determined for a UDC Bundled Customer, including the appropriate Cost Responsibility Surcharge (CRS), if applicable.

   c. **Virtual Direct Access Customers** receive supply and delivery services solely from the Utility. A customer taking Virtual Direct Access service must have a real-time meter installed at its premises to record hourly usage, since EECC change hourly. The bill for a Virtual Direct Access Customer will be calculated as if it were a UDC Bundled Service Customer, then crediting the bill by the amount of the EECC component, as determined for a UDC Bundled Customer, then adding the hourly EECC component, which is determined by multiplying the hourly energy used in the billing period by the hourly cost of energy.

   Nothing in this service schedule prohibits a marketer or broker from negotiating with customers the method by which their customer will pay the CTC charge.

11. Other Applicable Tariffs: Rules 21, 23 and Schedule E-Depart apply to customers with generators.

12, Lamp Loads: The Utility may provide service under this Schedule to street light lamps which are not listed in this Schedule (nonstandard lamps) provided that a lamp load, including lamp wattage and ballast, as application, can be reliably established by the Utility. N

13. Charges for Nonstandard Lamps: The Nonstandard lamp energy charge is used to calculate a monthly per lamp charge for nonstandard lamps. Nonstandard lamps are lamps for which a monthly charge is not listed in this Schedule. The monthly charge for nonstandard lamps under this Schedule is computed by first computing the applicable average monthly lamp load, in kWh, for the lamp. N

6C14

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Lee Schavrien
Senior Vice President
Regulatory Affairs

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13.0 Appendix G: City of San Diego Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCC)

- Identify 20 year recurring costs
- Evaluate which technology LED or Induction Emerges

Assumptions:

- No Ballast
- No Photo Electric Cell
- No other costs are considered in this analysis

Data	180 Watt LPS	250 Watt HPS	165 Watt Induction	198 Watt LED
Lamp & Fixture Costs (Material Only)	$ 550.00	$ 175.00	$ 515.00	$ 1,071.00
Lamp Cost	$ 25.00	$ 17.50	$ 100.00	$ 900.00
Lamp Life (Hours)	15,000	24,000	100,000	50,000
Monthly Energy Rate	**$ 9.89**	**$ 13.16**	**$ 6.59**	**$ 7.91**
Lamp Disposal Fee	$ 4.50	$ 3.50	$ 25.00	$ 7.50
Lamp Replacement Cost (Incl Labor)	$ 52.68	$ 44.17	$ 148.17	$ 930.67
Calculations				
Annual Energy Costs	**$ 118.68**	**$ 157.92**	**$ 79.08**	**$ 94.92**
Years to Replace Lamp	3.61	5.77	24.04	12.02
No. of Lamp Replacements in 20 years	5.5	3.5	0.83	1.66
Lamp Replacement Inflation Factor	7.38	4.76	1.36	2.43
Life Cycle Costs				
Initial Cost of Fixture (Matl & Labor)	$ 589	$ 214	$ 554	$ 1,110
20 Year Energy Costs (with Inflation)	$ 3,107	$ 4,135	$ 2,071	$ 2,485
20 Year Lamp Maintenance Costs	$ 389	$ 210	$ 202	$ 2,264
20 Year Life Cycle Costs	**$ 4,085**	**$ 4,559**	**$ 2,827**	**$ 5,860**
Annual LC Costs	**$ 204**	**$ 228**	**$ 141**	**$ 293**
	180 Watt LPS	250 Watt HPS	165 Watt Induction	198 Watt LED

Calculate Lamp Replacement Costs:

- Lamp Life Determines Frequency of Changes
- Cost of Lamps are Weighted by:

Inflation:

- End of 20 Year Period Identified by Fractional Lamp Life

Street Lighting 20 Year Economic Life Cycle Analysis

Line #	Data	150 Watt HPS	250 Watt HPS
2	Lamp & Fixture Costs (Material Only)	$ 150.00	$ 175.00
3	Lamp Cost	$ 15.00	$ 17.50
4	Lamp Life (Hours)	24,000	24,000
5	**Monthly Energy Rate**	**$ 8.09**	**$ 13.16**
6	Lamp Disposal Fee	$ 3.00	$ 3.50
7	Lamp Replacement Cost (Incl Labor)	$ 41.17	$ 44.17
	Calculations		
8	Annual Use (Hours/Year)	4160	4160
9	Annual Energy Costs 1.309	**$ 97.08**	**$ 157.92**
10	Years to Replace Lamp	5.77	5.77
11	No. of Lamp Replacements in 20 years	3.5	3.5
12	Lamp Replacement Inflation Factor	4.76	4.76
13	**Life Cycle Costs**		
14	Initial Cost of Fixture (Matl & Labor)	$ 189	$ 214
15	20 Year Energy Costs (No Inflation)	$ 1,942	$ 3,158
16	20 Year Energy Costs (with Inflation)	$ 2,542	$ 4,135
17	20 Year Lamp Maintenance Costs	$ 196	$ 210
18	**20 Year Life Cycle Costs**	**$ 2,927**	**$ 4,559**
19	**Annual LC Costs**	**$ 146**	**$ 228**
	Inflation Factor 2.5%	**150 Watt HPS**	**250 Watt HPS**

Lamp Inflation Factor:

- " 1's " Identified for Each Lamp Replacement
- For year 20, account for the partial consumption of the lamp with a decimal or fraction.
- Lamp Inflation Factor considers Lamp Life and Inflated
- Lamp Factor = Maintenance Factor

Year	Mult Factor
1	1.025
2	1.051
3	1.077
4	1.104
5	1.131
6	1.160
7	1.189
8	1.218
9	1.249
10	1.280
11	1.312
12	1.345
13	1.379
14	1.413
15	1.448
16	1.485
17	1.522
18	1.560
19	1.599
20	1.639
AVG	**1.309**

Lamp Inflation Factors

Year	Replacement Count	Factor
1		
2		
3	1	1.077
4		
5		
6		
7	1	1.189
8		
9		
10	1	1.280
11		
12		
13		
14	1	1.413
15		
16		
17	1	1.522
18		
19		
20	0.55	0.896
	5.55 # of Lamps	**7.38** Inflation Factor

Note: End of Life Fraction for Lamp Life > 20 Years

- $\frac{20 * 4160}{100,000} = 0.83\ Lamp\ Changes\ in\ 20\ Years$

Annual Inflaton Rate	2.5%
nper	1
pymt	0
PV	$ 1.00

Induction

Lamp Life	100,000	Hrs
Annual Burn	4160	Hrs
Lamp Life	24.04	Yrs

Year	Mult Factor
1	1.025
3	1.077
5	1.131
7	1.189
9	1.249
11	1.312
13	1.379
16	1.485
18	1.560
20	1.639

Lamp Inflation Factors

Year	Replacement Count	Factor
1		
3		
5		
7		
9		
11		
13		
16		
18		
20	**0.83**	**1.36**
	# of Lamps	Inflation Factor

Lamp Inflation Factor:

- Lamp inflation is the product of the annual inflation and lamp costs
- The inflation rate can be easily modified

Street Lighting 20 Year Economic Life Cycle Analysis

Line #	Data		85 Watt Induction	165 Watt Induction
2	Lamp & Fixture Costs (Material Only)		$ 450.00	$ 515.00
3	Lamp Cost		$ 75.00	$ 100.00
4	Lamp Life (Hours)		100,000	100,000
5	**Monthly Energy Rate**		**$ 3.40**	**$ 6.59**
6	Lamp Disposal Fee		$ 20.00	$ 25.00
7	Lamp Replacement Cost (Incl Labor)		$ 118.17	$ 148.17
	Calculations			
8	Annual Use (Hours/Year)		4160	4160
9	Annual Energy Costs	1.309	**$ 40.80**	**$ 79.08**
10	Years to Replace Lamp		24.04	24.04
11	No. of Lamp Replacements in 20 years		0.83	0.83
12	Lamp Replacement Inflation Factor		1.36	1.36
13	**Life Cycle Costs**			
14	Initial Cost of Fixture (Matl & Labor)		$ 489	$ 554
15	20 Year Energy Costs (No Inflation)		$ 816	$ 1,582
16	20 Year Energy Costs (with Inflation)		$ 1,068	$ 2,071
17	20 Year Lamp Maintenance Costs		$ 161	$ 202
18	**20 Year Life Cycle Costs**		**$ 1,719**	**$ 2,827**
19	**Annual LC Costs**		**$ 86**	**$ 141**
	Inflation Factor 2.5%		85 Watt Induction	165 Watt Induction

20 Year Life Cycle Costs - Identify the Component Costs

- Initial Fixture + Installation
- Energy with Inflation
- Maintenance Costs (Lamp Costs)
- No Ballast, Photo Electric Cell or other costs are considered in this analysis

Line #	Data	250 Watt HPS	165 Watt Induction
1	Lamp & Fixture Costs (Material Only)	$ 175.00	$ 515.00
2	Lamp Cost	$ 17.50	$ 100.00
3	Lamp Life (Hours)	24,000	100,000
4	**Monthly Energy Rate**	**$ 13.16**	**$ 6.59**
5	Lamp Disposal Fee	$ 3.50	$ 25.00
6	Lamp Replacement Cost (Incl Labor)	$ 44.17	$ 148.17
	Calculations		
7	Annual Use (Hours/Year)	4160	4160
8	Annual Energy Costs (Includes Inflation)	**$ 157.92**	**$ 79.08**
9	Years to Replace Lamp	5.77	24.04
10	No. of Lamp Replacements in 20 years	3.5	0.83
11	Lamp Replacement Inflation Factor	4.76	1.36
	Life Cycle Costs		
12	Initial Cost of Fixture (Matl & Labor)	$ 214	$ 554
13	20 Year Energy Costs (with Inflation)	$ 4,135	$ 2,071
14	20 Year Lamp Maintenance Costs	$ 210	$ 202
15	**20 Year Life Cycle Costs**	**$ 4,559**	**$ 2,827**
16	**Annual LC Costs**	**$ 228**	**$ 141**
	Inflation Factor 2.5%	**250 Watt HPS**	**165 Watt Induction**

Various Item Costs - Identify the Component Costs

- Material Costs
- LS -2 Rates from SDG&E
- Energy with Inflation at 20 Year Average
- Weighted Lamp Costs

Data	165 Watt Induction	
Lamp & Fixture Costs (Material Only)	$	515.00
Lamp Cost	$	100.00
Lamp Life (Hours)		100,000
Monthly Energy Rate	**$**	**6.59**
Lamp Disposal Fee	$	25.00
Lamp Replacement Cost (Incl Labor)	$	148.17
Calculations		
Annual Energy Costs W/O Inflation	$	79.08
Years to Replace Lamp		24.04
No. of Lamp Replacements in 20 years		0.83
Lamp Replacement Inflation Factor		1.36
Life Cycle Costs		
Initial Cost of Fixture (Matl & Labor)	**$**	**554**
20 Year Energy Costs (with Inflation)	**$**	**2,071**
20 Year Lamp Maintenance Costs	**$**	**202**
20 Year Life Cycle Costs	**$**	**2,827**

Calculate California Energy Commission (CEC) Payback

- $\frac{\textit{Fixture Costs}}{\textit{Annual Savings}} = \textit{Simple Payback}$
- For Retrofits do not subtract the cost of existing technology
- Must be less than 10 Years for CEC Loans

Line #	Data	150 Watt HPS	85 Watt Induction	
1	Lamp & Fixture Costs (Material Only)	$ 150.00	$ 450.00	
2	Lamp Cost	$ 15.00	$ 75.00	
3	Lamp Life (Hours)	24,000	100,000	
4	**Monthly Energy Rate**	**$ 8.09**	**$ 3.40**	
5	Lamp Disposal Fee	$ 3.00	$ 20.00	
6	Lamp Replacement Cost (Incl Labor)	$ 41.17	$ 118.17	
	Calculations			
7	Annual Use (Hours/Year)	4160	4160	
8	Annual Energy Costs	**$ 97.08**	**$ 40.80**	
9	Years to Replace Lamp	5.77	24.04	
10	No. of Lamp Replacements in 20 years	3.5	0.83	
11	Lamp Replacement Inflation Factor	4.76	1.36	
	Life Cycle Costs			
12	Initial Cost of Fixture (Matl & Labor)	$ 189	$ 489	
13	20 Year Energy Costs (with Inflation)	$ 2,542	$ 1,068	
14	20 Year Lamp Maintenance Costs	$ 196	$ 161	
15	**20 Year Life Cycle Costs**	**$ 2,927**	**$ 1,719**	$ -
16	**Annual LC Costs**	**$ 146**	**$ 86**	
	Inflation Factor 2.5%	150 Watt HPS	85 Watt Induction	

	CEC Payback 85 W Ind
150 W HPS	**8.7**

Calculate Paybacks using Life Cycle (LC) Analysis:

- $\frac{Captial\ Costs}{Annual\ LC\ Savings} = LC$
- For Retrofits may not subtract the cost of existing technology

Line #	Data	250 Watt HPS	165 Watt Induction
1	Lamp & Fixture Costs (Material Only)	$ 175.00	$ 515.00
2	Lamp Cost	$ 17.50	$ 100.00
3	Lamp Life (Hours)	24,000	100,000
4	**Monthly Energy Rate**	**$ 13.16**	**$ 6.59**
6	Lamp Replacement Cost (Incl Labor)	$ 44.17	$ 148.17
	Calculations		
8	Annual Energy Costs (Includes Inflation)	**$ 157.92**	**$ 79.08**
9	Years to Replace Lamp	5.77	24.04
10	No. of Lamp Replacements in 20 years	3.5	0.83
11	Lamp Replacement Inflation Factor	4.76	1.36
	Life Cycle Costs		
12	Initial Cost of Fixture (Matl & Labor)	$ 214	$ 554
13	20 Year Energy Costs (with Inflation)	$ 4,135	$ 2,071
14	20 Year Lamp Maintenance Costs	$ 210	$ 202
15	**20 Year Life Cycle Costs**	**$ 4,559**	**$ 2,827**
16	**Annual LC Costs**	**$ 228**	**$ 141**
	Inflation Factor 2.5%	**250 Watt HPS**	**165 Watt Induction**

	165 W Ind	
250 W HPS	**6.4**	**Payback**

Compare Paybacks Among HPS Induction LED - Surprising Results:

- Lamp Costs
- Inflation Dependent LC Costs
- LED at 3500 Kelvin Don't Payback

Email Chris Hudson CHudson@SanDiego.gov for Spread Sheet to Calculate Your Costs

Line #	Data	250 Watt HPS	165 Watt Induction	198 Watt LED
1	Lamp & Fixture Costs (Material Only)	$ 175.00	$ 515.00	$ 1,071.00
6	Lamp Replacement Cost (Incl Labor)	$ 44.17	$ 148.17	$ 930.67
	Calculations			
8	Annual Energy Costs	**$ 157.92**	**$ 79.08**	**$ 94.92**
9	Years to Replace Lamp	5.77	24.04	12.02
10	No. of Lamp Replacements in 20 years	3.5	0.83	1.66
11	Lamp Replacement Inflation Factor	4.76	1.36	2.43
	Life Cycle Costs			
12	Initial Cost of Fixture (Matl & Labor)	**$ 214**	**$ 554**	**$ 1,110**
13	20 Year Energy Costs (with Inflation)	**$ 4,135**	**$ 2,071**	**$ 2,485**
14	20 Year Lamp Maintenance Costs	**$ 210**	**$ 202**	**$ 2,264**
15	**20 Year Life Cycle Costs**	**$ 4,559**	**$ 2,827**	**$ 5,860**
16	**Annual LC Costs**	**$ 228**	**$ 141**	**$ 293**
	Inflation Factor 2.5%	**250 Watt HPS**	**165 Watt Induction**	**198 Watt LED**

Paybacks	**LC**	**CEC**	**LC**	**CEC**
	165 Watt Induction		**198 W LED**	
250 W HPS	**6.4**	**7.0**	**(17.1)**	**17.6**

Conclusion:

- The Economic Results Point to Induction
- Retrofits with 3500K LED Don't Payback
- Each Agency would have unique conditions which are not considered in our analysis
- Note: LED Costs and Wattage were increased due to Color Temperature