CALIFORNIA ENERGY COMMISSION

California Outdoor Lighting Baseline Assessment

TECHNICAL REPORT

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PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- Productivity and Interior Environments
- Integrated Design of Large Commercial HVAC Systems
- Integrated Design of Small Commercial HVAC Systems
- Integrated Design of Commercial Building Ceiling Systems
- Integrated Design of Residential Ducting & Air Flow Systems
- Outdoor Lighting Baseline Assessment

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This attachment, "California Outdoor Lighting Baseline Assessment" (Attachment A-18) provides supplemental information to the program's final report within the **Outdoor Lighting Baseline Assessment** research area. The "California Outdoor Lighting Baseline Assessment" provides a snapshot of commercial and industrial outdoor lighting practices in California. This document contains data collected from visits to over 300 sites throughout California, encompassing 20 different categories of businesses as well as multifamily residential buildings.

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

This report is Attachment A-18 (Product 7.7.2) to the Final Report for the PIER *Integrated Energy Systems: Productivity and Building Science Program* (Commission publication # P500-03-083). For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

This report, "California Outdoor Lighting Baseline Assessment," was produced as part of the Outdoor Lighting Baseline Assessment project. This was one of six research projects within the *Integrated Energy Systems: Productivity and Building Science* Program, funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

Until now, there was little data about the amount of outdoor lighting energy used in California. There was even less information on outdoor lighting practices in the state. The California Outdoor Lighting Baseline Assessment is the first major study to provide real data about commercial building outdoor lighting in the state. The report identifies statewide outdoor lighting design practices; estimates energy demand and consumption; and provides a framework for outdoor lighting standards in California and future investigations of outdoor lighting.

This report contains data collected from visits to over 300 sites throughout California, encompassing 20 different categories of businesses as well as multifamily residential buildings. Data includes lighting power density (LPD) levels by functional use area (parking lots, walkways, facades, etc.); types of lamps and fixtures at each site; illuminance levels; glare and light trespass readings; and use of lighting controls.

The study also determined the state's commercial outdoor lighting energy use:

- Annual energy consumption: 3,067 GWh (1.34% of California's total energy use)
- Peak demand: 809 MW, occurring from 7 PM to 8 PM in the winter

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Key words: outdoor lighting, lighting design, building lighting, façade lighting, lighting controls, lighting power density, light trespass, exterior lighting, lighting code, glare

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The goal of this report is to understand the amount of energy currently used by outdoor lighting in California. This project fills the gaps in the knowledge about outdoor lighting by identifying design practices, and estimating the energy demand and consumption of the current practices employed statewide. Furthermore, this effort provides the framework for future, and potentially more specific investigations into outdoor lighting practices in California.

Background
Prior to this study, there has been little data on current outdoor lighting conditions and practices in California, and even less energy use information or understanding of the extent of good or bad lighting practices utilized throughout the state. Many energy codes outside of California actively regulate outdoor lighting practices. However, before California can consider similar regulation, the current nature of commercial outdoor lighting must be investigated and analyzed. This is particularly important, as current trends in outdoor lighting practices appear to be toward ever-greater numbers of fixtures, and brighter lamps, using significantly more energy for the same task with little or no additional benefit.

This Outdoor Lighting Assessment is one element of The New Buildings Institute (the Institute) contract in the California Energy Commission Public Interest Energy Research (PIER) Program. The Institute's program, called Integrated Energy Systems - Productivity and Buildings Science Program, is a three-year project. The program is funded through California's System Benefit Charges and administered by the California Energy Commission. Technical support for this report in the area of lighting design and on-site survey instrument development was provided by Clanton and Associates, and M. Neils Engineering, Inc.

This work was coordinated to support the work of the California Energy Commission's Outdoor Lighting Standards Committee. The document titled "Impact Evaluation of Proposed Standards" included in Appendix A, provides information on the relationship of this effort to the work of that committee. The document also compares these results to the proposed standards published by the committee on June 6, 2002.

Scope
This effort is the first major study of nighttime lighting in California. The report documents outdoor lighting at commercial sites throughout California and provides insight in the following areas:

- Total statewide commercial outdoor lighting energy consumption,
- Statewide energy peak demand from commercial outdoor lighting,
- Energy consumption by site functional use area (FUA),
- Lighting power density by building type and FUA, as well as by lighting zone,
- Illuminance levels for parking and other areas of outdoor lighting use,
- Type of lamps and fixtures in these FUA's,
- Glare and light trespass by building type,
- Subjective evaluations on the quality of outdoor lighting.

The tables in this report present the data collected and analyzed from 303 commercial on-site visits throughout the state of California. These findings include information on 778 lit functional use areas (parking lots, walkways, security areas, etc.) from 20 different commercial and industrial business types. The data describes the area (sqft), the lighting power density (W/SF), the fixture types, lamp type and wattage, and use schedule by functional use area. The reporting also includes a lighting zone designation for each site, and user subjective impressions for each site. This body of information provides an extensive snapshot of the commercial and industrial outdoor lighting in the state of California, incorporating data from a range of business types, outdoor lighting use types and geographic regions (including rural and urban sites).

Results

The statewide commercial and industrial outdoor lighting annual energy consumption is estimated to be 3,067 GWh. This is roughly 1.35% of the total statewide annual energy consumption of 227,087 GWh reported for 2001 on the California Independent System Operator (ISO) web page.[1] This value compares well to existing estimates of lighting energy consumption. The Lawrence Berkeley National Laboratory (LBNL) estimated the California commercial sector outdoor lighting annual energy consumption to be 5,018 GWh for the year of 1999.[2] This estimate is reduced to 4,535 GWh when adjusted for actual total electrical energy consumption numbers from the ISO for 1999.[3] These LBNL numbers result in an estimation of 1.99% of annual consumption is attributed to commercial outdoor lighting. General Electric has projected this value to be 0.7% in their breakdown of electric energy use by lighting end use.[4] Table 3 provides the General Electric estimates.

The total 2001 annual nighttime energy consumption for the state of California was 101,773 GWh, according to the ISO. Commercial outdoor lighting accounts for 3% of this nighttime energy use.[5] The maximum peak demand from commercial outdoor lighting is 809 MW, and occurs in the winter during the 7pm to 8pm evening hour. This winter peak is slightly higher than the summer's peak due to the operation of winter resorts (closed during the summer) and due to school recreation areas not in use in the summer. The commercial outdoor lighting peak demand is 2.63% of the total California system load of 30,788 MW for that hour, calculated using California ISO data (the peak demand in February, 2002, for the hour ending at 8pm).

The project team estimated the energy savings potential from a broad "what if" scenario assuming the replacement of all California high pressure sodium (HPS) lamps with metal halide (MH) lamps. This general estimate does not incorporate a cost/benefit or technical analysis of the assumptions. The scenario is included to demonstrate the type of measure-specific energy impact analysis available within this database. This lamp replacement scenario would save approximately 204 GWhs annually, a 7% reduction in the annual commercial outdoor lighting energy consumption.

One particularly important and surprising finding, involves lighting controls. More than 85% of the commercial outdoor lighting has an electronic or electromechanical control. Frequently, site surveyors found lighting that was activated by a photocell at dusk and de-activated by a timer in the late evening. Only 13.4% of the lighting encountered was controlled manually. Recreation

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[1] California Independent System Operator (ISO): http://oasis.caiso.com/.

[2] Electricity Use in California: Past Trends and Present Usage Patterns, Lawrence Berkeley National laboratory, January 2002; Source data: CEC Demand Analysis Office (Tian 2001).

[3] The LBNL estimate of total 1999 annual energy consumption is 251,600 GWh. The actual annual energy consumption (according to the ISO) for 1999 was 227,389 GWh, or 90.4% the LBNL estimate. Therefore, the adjusted LBNL estimate of commercial outdoor lighting annual energy consumption is 4,535 GWh.

[4] Joseph Oberle, General Manager Technology, GE Lighting, conversation with author November 4, 2002. Mr Oberle also estimated that Outdoor billboard advertising is responsible for 0.02% of all lighting energy consumed nationally.

[5] California Independent System Operator (ISO), calculated from ISO data for 2001 using the sunset and sunrise hours for each month at Merced, CA, a mid California location.

areas were most likely to use manual controls (66%). Electronic methods (photocells and time clocks) were the control strategy of choice for gas station canopies and storage areas (97.8% and 96.4% respectfully). Only 6.2% of parking areas relied on manual controls for the lighting. Additional results for lighting controls are presented in Table 55.

The findings are presented in the 84 tables and figures within the results section beginning on page 7. They are organized into the following sections.

- Statewide Annual Energy Consumption
- Lighting Power Density
- Outdoor Lighting Standards Impact Analysis
- Parking Illuminance
- Fixtures and Lamps
- Glare and Light Trespass
- Subjective Assessments

Lighting Satisfaction Survey
Visitors to the sites, along with site surveyors, were asked to complete "Nighttime Subjective Lighting Evaluation" questionnaires (see Appendix B). Twelve questions were presented regarding perceptions of safety, uniformity, glare and other lighting comfort issues. The results are particularly informative when compared to the glare measurements. The subjective impression of the area-lighting tends toward "worse" as the lamp wattage increases and when comparing non-cutoff to cutoff fixtures. Similarly, the glare ratio increases with increases in lamp wattage and the utilization of non-cutoff fixtures (see Table 70). This finding is important given the large number of parking lots (23.5%) that register a glare ratio of greater than 20. The glare results are presented in Table 58 within the "Glare Ratios and Lighting Trespass" section beginning on page 45.

The Illuminating Engineering Society of North America defines glare as "the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted, so as to cause annoyance, discomfort, or loss in visual performance or visibility."[6] This loss of visual performance can impact both safety (impaired visual capability of drivers), and security (inability to discern detail).

Methodology
The findings within this report relied on the complex task of choosing 303 commercial and industrial sites to represent the total commercial outdoor lighting energy consumption of California. The methodology was designed to provide statistically valid results for the entire state, requiring sampling to represent all geographical areas and a very broad array of businesses. This methodology is described in detail in the sections which begin with "Sample Design Methodology" on page 53. This is followed by explanations of the data collection methodology and wraps up with the "Statistical Methodology" section on page 69. The methods used have been thoroughly documented within the "Database Documentation" section, included in the appendices, to allow the expansion of this database with future outdoor lighting studies.

Lessons Learned
Several lessons were learned throughout the course of conducting the phone and onsite surveys. They are discussed in the section "Observations and Lessons Learned" on page 75. One key point is discussed below.

[6] RP-20-98, Illuminating Engineering Society of North America (IESNA)

A report of this significance appropriately draws considerable interest from the lighting professionals throughout the country. The many particular sub-areas of interest present a challenge when the original sample size is limited by time or budget constraints. While there is a great range of data, on a broad and diverse range of topics, the analysis that draws from this data is dependent on the number of sample points collected. This number of sample points varies from 1, for grocery store sidewalks, to 778, for the annual energy consumption for all functional use areas. For this reason, the results are presented with the sample sizes to enable the appropriate use of the information herein.

For the areas of interest which are under-represented, such as gas station canopies, or outdoor retail sales, additional data can be collected and included in this body of research. Furthermore, careful review of the results contained in this report will allow for a thoughtful evaluation of where to concentrate future resources to expand the applicability of the findings.

Note added June 2003: The energy savings from lamp replacement strategies may not be as large as expected. The PIER report proposes a theoretical scenario where all existing HPS lamps are replaced with MH lamps, and estimates a potential savings of 33% from this strategy for the referenced lamps. This estimate is based on the understanding that less power is required to achieve equal brightness lumens from MH lamps as compared to HPS lamps. However, as there is a large efficacy versus wattage effect, an estimate of 10–15% savings may be more appropriate. In addition, there are unanswered theoretical questions about whether the source for the brightness measure referenced in the "California Outdoor Lighting Baseline Assessment" is valid for use in parking lots.[i[i]] If this measure is not valid, replacing HPS lamps with MH lamps would still achieve energy savings, but at the expense of visual performance. A new PIER project is further exploring the specifics of visual, technical and energy implications of lamp selections for parking lots. Go to www.archenergy.com/lrp/lightingperf_standards/project_5_3.htm for information and outcomes.

Introduction

The Outdoor Lighting Assessment is one element of The New Buildings Institute (the Institute) contract in the California Energy Commission Public Interest Energy Research (PIER) Program. The Institute's program, titled Integrated Energy Systems - Productivity and Buildings Science Program, is a three-year project. The program is funded through California's System Benefit Charges and administered by the California Energy Commission.

PIER Overview

The Integrated Energy Systems - Productivity and Building Science Program encourages energy efficiency advances for the public benefit by supporting activities that would not be readily undertaken by private developers. As the program name suggests, it is not individual building components, equipment or material that optimize energy efficiency. Instead, optimal energy efficiency can only be achieved through the integrated design, assembly and operation of building systems. This program, therefore, focuses not on individual product development but on systems development, and to some extent on the demonstration of those systems in buildings.

The Institute's program consists of six research elements:

- Productivity and Interior Environments (Element 2)
- Integrated Design of Large Commercial HVAC Systems (Element 3)
- Integrated Design of Small Commercial HVAC Systems (Element 4)
- Integrated Design of Commercial Building Ceiling Systems (Element 5)
- Integrated Design of Residential Ducting and Air Flow Systems (Element 6)
- Exterior Lighting Baseline Assessment (Element 7) - Addressed in this report

Outdoor Lighting Baseline Assessment

The goal of this element is to understand the amount of energy currently used by outdoor lighting in California. This project fills the gaps in the knowledge on the subject and identifies design practices employed. This report estimates the energy demand and consumption statewide, and projects the energy savings potential available by improving current practices statewide. Furthermore, this effort provides the framework for future investigations into outdoor lighting practices in California.

Background

Prior to this study, there has been little data on current outdoor lighting practices in California, and even less energy use information or understanding of the extent of good or bad lighting practices utilized throughout the state. Many energy codes outside of California actively regulate outdoor lighting practices. However, before California can consider similar regulation, the current nature of commercial outdoor lighting must be investigated and analyzed. This is particularly important, as current trends in outdoor lighting practices appear to be toward ever-greater numbers of fixtures, and brighter lamps, using significantly more energy for the same task with little or no additional benefit.

This effort is the first major study of nighttime lighting in California. The report documents outdoor lighting at commercial sites throughout California and provides insight in the following areas:

- Total energy consumption,
- Total energy demand,
- Energy consumption by site functional use area (FUA),
- Lighting power density by building type and FUA, as well as by lighting zone,
- Illuminance levels for parking and other areas of outdoor lighting use,
- Type of lamps and fixtures in these FUA's,
- Glare and light trespass by building type,
- Subjective evaluations on the quality outdoor lighting.

The methodology used to identify the sites to be analyzed was developed to allow a statistically valid projection of these results to the statewide level. This statewide reporting provides understanding of the role of outdoor commercial lighting in the overall energy situation in California with regards to total consumption, demand, and demand profile. This comprehensive approach also allows for the evaluation of the impact of code and appliance standards changes on the energy consumption patterns in the state. Accordingly, this work was coordinated with the California Energy Commission's Outdoor Lighting Standards Committee to inform their development of appropriate standards. A comparison of the committee's proposed standards to the results of this work can be found in Appendix A.

This element of research has been conducted using a methodology that is easily replicated. This allows for future outdoor lighting studies to use the same methodology to measure the impacts of future outdoor lighting regulations.

The results contained herein are the result of two years of research. The road to these results began with the creation of the Sample Design Methodology and followed the steps described below. Each of these steps are discussed in greater detail in the sections following the presentation of results.

The Sample Design defined the target population and resulted in the sampling plan. This was followed by the Telephone Survey Sample Design, which lead to the On-Site Survey Sample Design. This step selected the sample of 303 commercial and industrial buildings to be included in the on-site survey portion of the work. The on-site survey conducted at each of these sites collected detailed outdoor lighting data and have become the foundation of this report. The collected on-site data was entered into an Access database, and the Statistical Methodology was implemented to provide the case weights for extrapolating the results to the statewide level. Following this methodology, queries were written and documented to create the results in the 84 figures and tables that follow.

Results

Outdoor Lighting Baseline Research Results

The following tables present the findings of 303 commercial and industrial site visits. These findings include data collected on 778 lit functional use areas (parking lots, walkways, security areas, etc.). The data describes the outdoor area (sqft), the lighting power density (W/SF), the fixture types, lamp type and wattage, and usage schedule by functional use area (FUA). The reporting also includes user subjective impressions for each site and the lighting zone designation. Each site was classified into one of four lighting zones characterizing the surrounding area by outdoor lighting intensity. Zone 1 is an area with "intrinsically dark landscape." Zone 2 is an area of "low ambient brightness." Zone 3 is an area of "medium ambient brightness." And Zone 4 is an area of high ambient brightness." [7]

This body of information provides an extensive snapshot of the current stock of commercial outdoor lighting in the state of California, incorporating data from a comprehensive range of commercial business types, outdoor lighting use types and geographic regions (including rural and urban sites).

Statewide Annual Energy Consumption

Table 1 estimates the annual outdoor lighting energy usage for California to be 3,067 GWh with an error bound of 687 GWh, resulting in a 90 percent confidence level that the actual annual energy usage falls between 2,381 GWh to 3,754 GWh. These results include commercial and light industrial sites and exclude roadway lighting as well as outdoor advertising (off premise billboards). The size of the error bound is the result of estimating the statewide results using a relatively small sample size (303 sites) and by the variation in the data. The annual outdoor lighting energy consumption of the sites ranged from 0 kWh, for unlit sites, to 986,862kWh, resulting in a standard deviation of 94,332 kWh.

Annual Outdoor Lighting Usage for California (GWh)	Error Bound (GWh)	90% Confidence Interval (GWh)
3,067	687	2,381 to 3,754

Table 1: Annual Energy Usage

[7] Model Outdoor Lighting Ordinance Classification of Outdoor Areas, Jim Benya, Illumination Engineers Society of North America .

Table 2 presents the maximum outdoor lighting peak demand to be 809 MW with an error bound of 196 MW. This maximum demand occurs in the winter months between 7pm and 8pm. The winter peak demand is slightly higher than the summer peak demand due to the seasonal operation of winter resorts and school recreation areas.

Annual Outdoor Lighting Demand for California (MW)	Error Bound (MW)	90% Confidence Interval
809	196	613 to 1005

Table 2: Peak Demand

The statewide commercial and industrial outdoor lighting annual energy consumption is estimated to be 3,067 GWh. This is roughly 1.35% of the total statewide annual energy consumption of 227,087 GWh reported for 2001 on the California Independent System Operator (ISO) web page.[8] This value compares well to existing estimates of lighting energy consumption. The Lawrence Berkeley National Laboratory (LBNL) estimated the California commercial sector outdoor lighting annual energy consumption to be 5,018 GWh for the year of 1999.[9] This estimate is reduced to 4,535 GWh when adjusted for actual total electrical energy consumption numbers from the ISO for 1999.[10] These LBNL numbers result in an estimation of 1.99% of annual consumption is attributed to commercial outdoor lighting. General Electric has projected this value to be 0.7% in their breakdown of electric energy use by lighting end use presented in Table 3 below.[11]

National Lighting Energy Use	End Use Percentages	
(20% of total energy consumed)	% of lighting	% of total energy
Commercial Lighting	51.0%	10.2%
Residential Lighting	27.0%	5.4%
Industrial Lighting	14.6%	2.9%
Outdoor Lighting	3.4%	0.7%
Street Lighting	4.0%	0.8%
	100.0%	20.0%

Table 3: General Electric Company Estimate of Lighting Energy End Use

[8] California Independent System Operator (ISO): http://oasis.caiso.com/.
[9] Electricity Use in California: Past Trends and Present Usage Patterns, Lawrence Berkeley National laboratory, January 2002; Source data: CEC Demand Analysis Office (Tian 2001).
[10] The LBNL estimate of total 1999 annual energy consumption is 251,600 GWh. The actual annual energy consumption (according to the ISO) for 1999 was 227,389 GWh, or 90.4% the LBNL estimate. Therefore, the adjusted LBNL estimate of commercial outdoor lighting annual energy consumption is 4,535 GWh.
[11] Joseph Oberle, General Manager Technology, GE Lighting, conversation with author November 4, 2002. Mr Oberle also estimated that Outdoor billboard advertising is responsible for 0.02% of all lighting energy consumed nationally.

The total 2001 annual nighttime energy consumption for the state of California was 101,773 GWh, according to the ISO. Commercial outdoor lighting accounts for 3% of this nighttime energy use.[12] The maximum peak demand from commercial outdoor lighting is 809MW, and occurs in the winter during the 7pm to 8pm evening hour. This winter peak is slightly higher than the summer's peak due to the operation of winter resorts (closed during the summer) and due to school recreation areas not in use in the summer. The commercial outdoor lighting peak demand is 2.63% of the total California system load of 30,788 MW for that hour, calculated using California ISO data (the peak demand in February, 2002, for the hour ending at 8pm).

Table 4 presents the annual energy usage for the different functional use areas. As expected, parking lots have the highest annual usage, 967 GWh. Pedestrian & walkways utilize 686 GWh of energy annually. Signage is estimated to consume 623 GWh. See "Signage Information" under data collection, page 64 for further discussion of this large estimate.

FUA	Energy Usage (GWh)	Error Bound (GWh)
Parking	967.3	270
Pedestrian & Walkway	685.6	283
Signage	622.6	213
Security	207.9	96
Storage	159.5	72
Outdoor Retail Sales	140.2	157
Internal Roadway	74.4	49
Recreation	47.6	44
Façade & Aesthetic	43.5	27
Entry	40.0	12
Landscape	39.9	17
Gas Station Canopy	29.8	30
ATM	6.8	8
Undeveloped	1.9	3
Commercial Outdoor Patio	0.5	1
Total Energy Usage	**3,067**	N/A
Error Bound for all FUAs	N/A	**687**

Table 4: Energy Usage by FUA

[12] California Independent System Operator (ISO), calculated from ISO data for 2001 using the sunset and sunrise hours for each month at Merced, CA, a mid California location.

Figure 1 presents the information in the previous table graphically, demonstrating the dominance of parking, walkways and signage in the total energy consumption calculation.

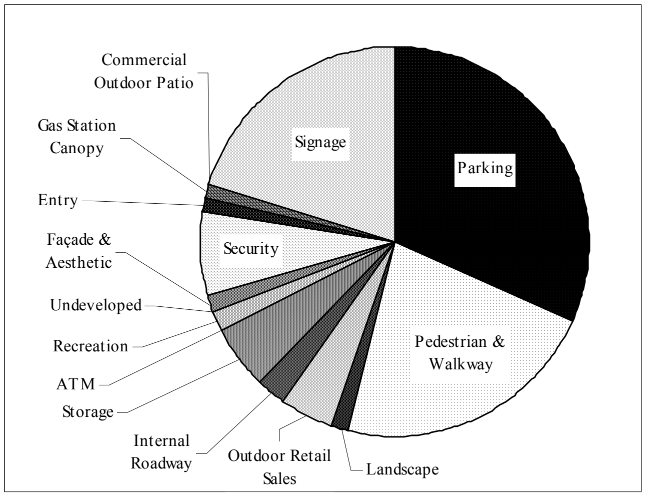

Figure 1: Functional Use Area Energy Usage by FUA

Statewide Annual Energy Consumption – Stacked Area Graphs

As part of the on-site visit the surveyor gathered information on usage patterns for each outdoor lighting fixture. Usage data was typically self-reported, recorded from a time clock controller, or estimated if the control technology was a photocell. From these data we have developed the following energy usage profiles by day-type and hour. Figure 2 through Figure 5 are stacked area graphs which displays California's outdoor lighting hourly demand profile of each functional use area for summer weekdays, winter weekdays, summer weekends, and winter weekends.

Note that in each profile displayed below the usage during the daytime hours goes to zero. We understand that some outdoor lighting is on during the day due to malfunctioning or improperly programmed equipment. However our findings intend to characterize outdoor lighting energy usage as it was reported, or expected to be operated. Moreover, the fraction of outdoor lighting found to be on during daytime hours due to failing equipment was marginal. We also included burnouts in our count of lamps if it was anticipated that they would be replaced in the near future.

Summer Hourly Demand Profiles: During the summer, months, defined for use schedules as March 22 to September 22, most outdoor lighting is on by about 7PM and continues to be lit till approximately 5AM. The peak demand for outdoor lighting in the summer months is at 9PM. Demand then slowly tapers off, with a sharp decline at 1AM due to reduced parking lighting usage, remaining constant from 2AM to approximately 4AM. Demand falls rapidly for all use types after 4AM.

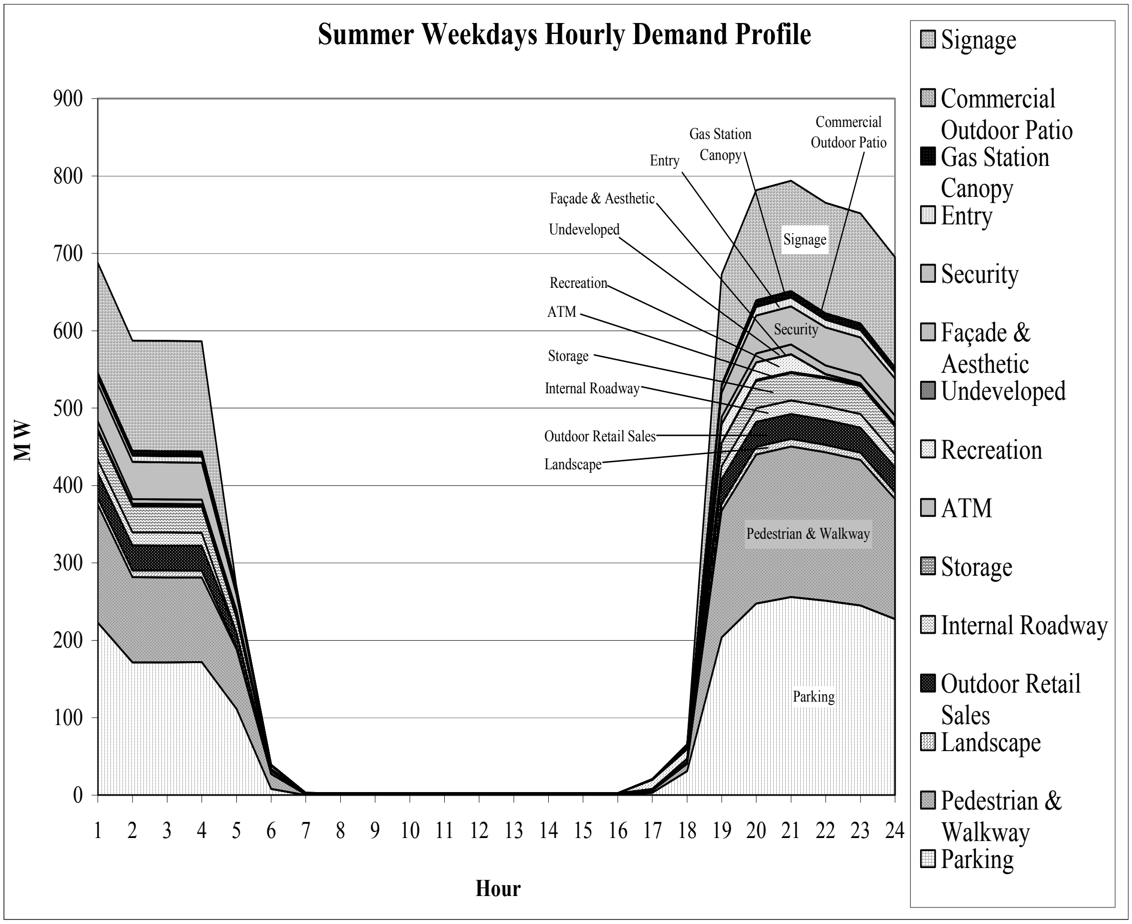

Figure 2: Summer Weekdays Hourly Demand Profile

Winter Hourly Demand Profiles: There is a noticeable shift in the demand profile for the winter months. Lighting is on for a longer period of time. As expected, most outdoor lighting is on by 5PM and continues to be lit till approximately 6AM. The peak usage for outdoor lighting is from 7PM to 9PM in the winter months. Demand then slowly tapers off until 2AM, remaining constant until 4AM. This is followed by a sharp spike in demand for about an hour, due to the parking lighting use pattern, and then a decline in demand from 5AM to 7AM. The winter peak is higher than the summer peak due to the seasonal operation of winter resorts and school recreation areas.

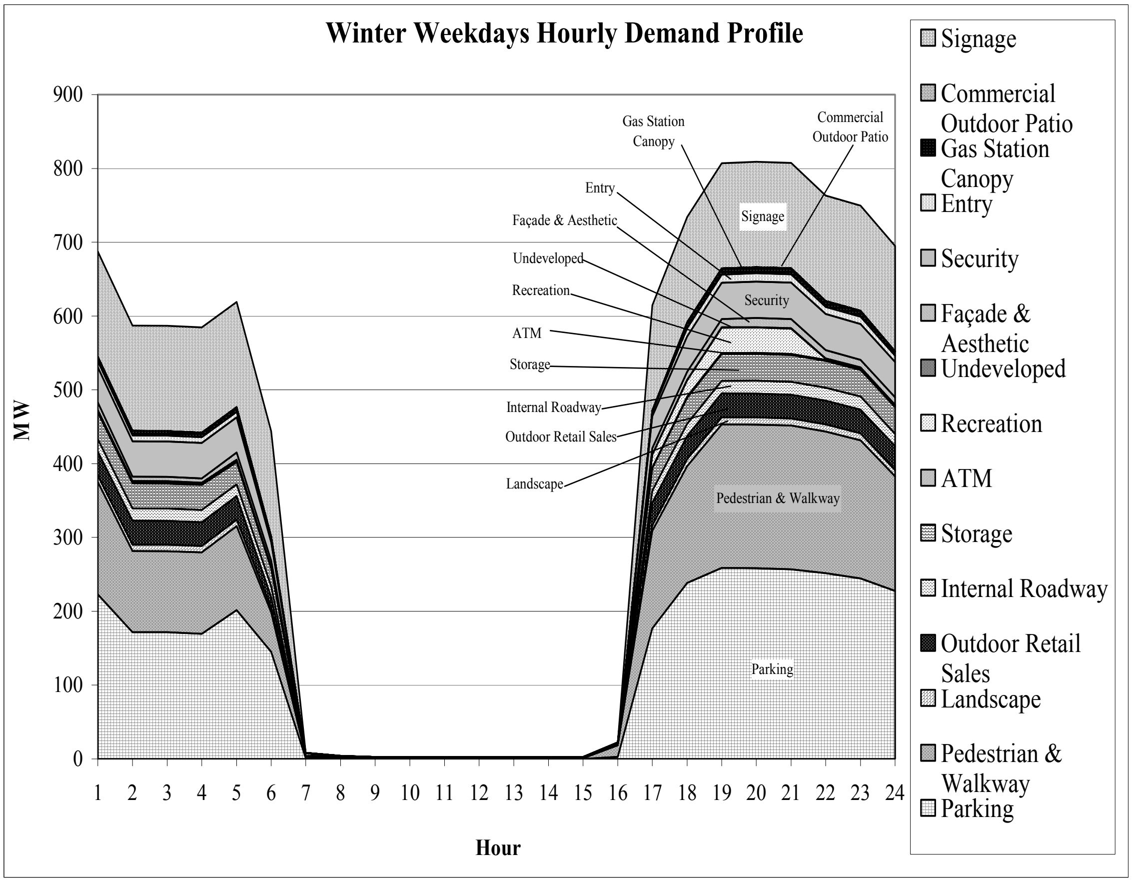

Figure 3: Winter Weekdays Hourly Demand Profile

As can be seen by comparing Figure 2 to Figure 5, outdoor lighting patterns do not change much from weekday to weekend. Though not apparent on the graph, data does show that there is a very slight decrease in energy demand on weekends.

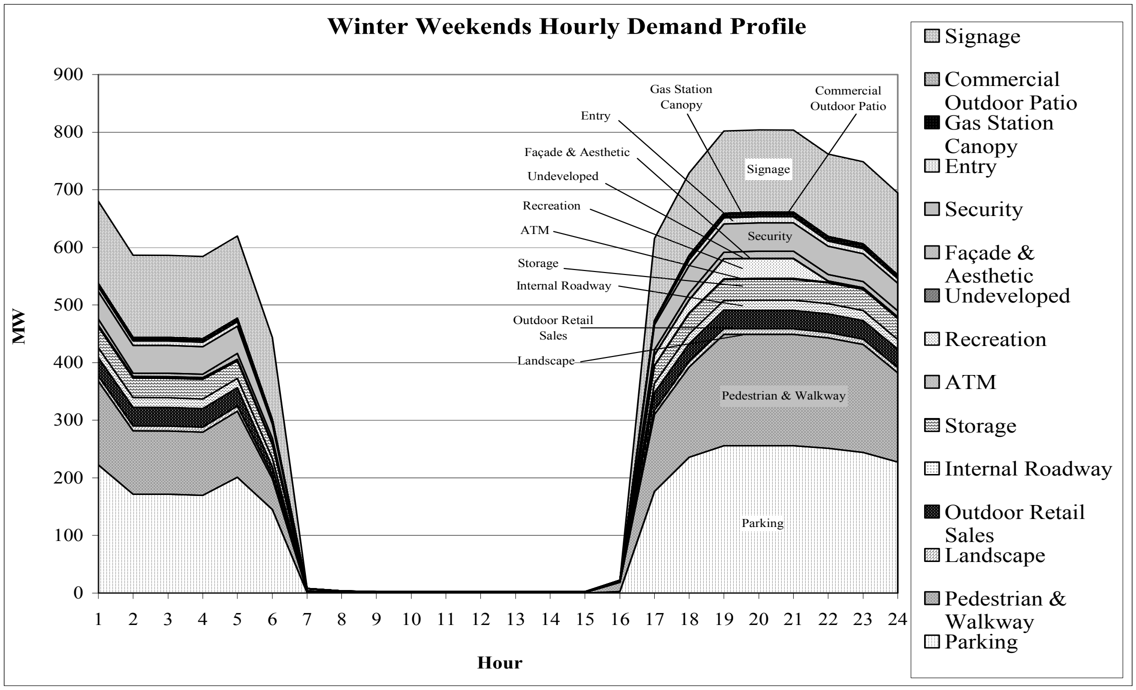

Figure 4: Winter Weekends Hourly Demand Profile

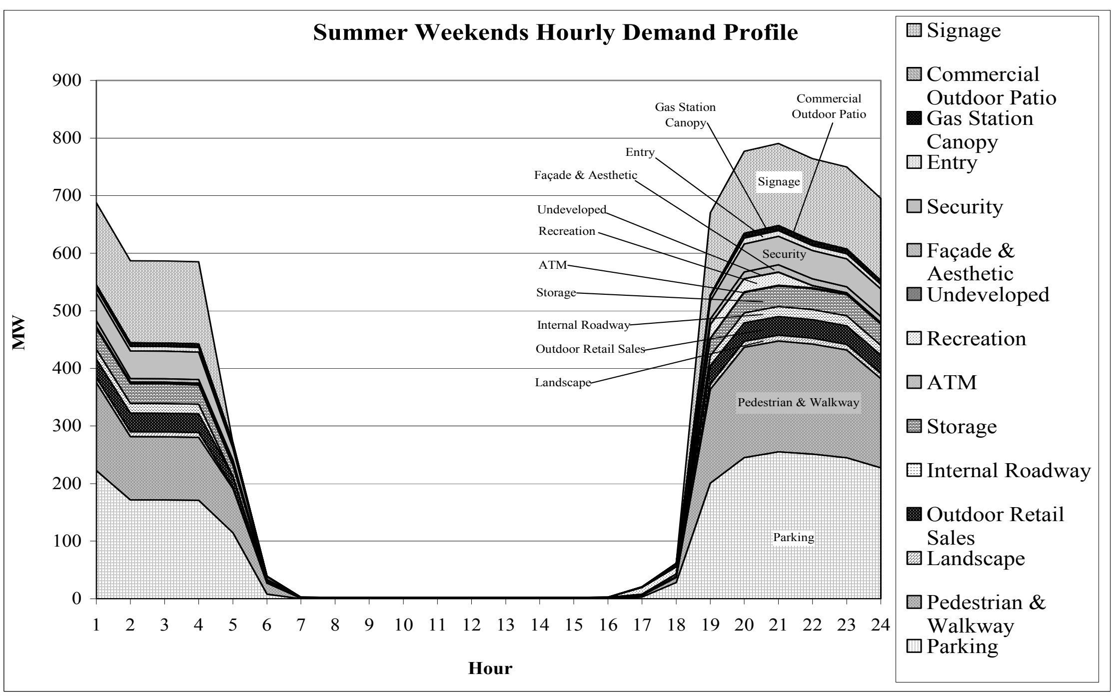

Figure 5: Summer Weekends Hourly Demand Profile

Impact Evaluations of Lamp Replacement Scenarios

Two scenarios were created to evaluate the statewide impacts on energy consumption resulting from the theoretical replacement of all existing high pressure sodium (HPS) or mercury vapor (MV) lamps with metal halide (MH) lamps. The findings are described below.

Table 5 presents the resulting annual outdoor lighting usage for California if all HPS lamps were replaced with MH lamps. Research has shown that a MH lighting design can satisfactorily replace HPS while offering lower overall lighting power density and illumination levels. This is achievable because MH light output includes more colors of the visible light spectrum than does HPS. As a result, the MH user perceives as much light as the HPS system user but at lower illumination amounts. Less illumination in this case equates to a lower power density.[13] The referenced research projects a 33% savings as a result of the replacement strategy.[14] The savings projection has been applied to all HPS lamps, regardless of wattage. This general calculation makes the assumption that the 33% savings percentage is applicable to all lamp sizes, allowing the estimation of the maximum energy savings available from this strategy.

The resulting usage for California would be 2,864 GWh. This strategy represents a savings of 204 GWh for the state of California, or roughly a 7% decrease in the energy use for these outdoor areas. Table 5 also presents the annual energy savings for each functional use area as a result of implementing this replacement of HPS lamps. The parking lot is the highest energy-consuming category for commercial outdoor lighting according to Table 4. Table 46 indicates that parking lots (and walkways) have the largest percentage of HPS lamps installed. Accordingly, the annual energy usage for parking lots is significantly reduced, by 96 GWh. The annual savings for walkways would be 40 GWh. Security and storage also would experience significant savings of 28 GWh and 23 GWh respectively.

<u>*Post Note (added June 3003):*</u> The energy savings from lamp replacement strategies may not be as large as expected. The PIER report proposes a theoretical scenario where all existing HPS lamps are replaced with MH lamps, and estimates a potential savings of 33% from this strategy for the referenced lamps. This estimate is based on the understanding that less power is required to achieve equal brightness lumens from MH lamps as compared to HPS lamps. However, as there is a large efficacy versus wattage effect, an estimate of 10–15% savings may be more appropriate. In addition, there are unanswered theoretical questions about whether the source for the brightness measure referenced in the "California Outdoor Lighting Baseline Assessment" is valid for use in parking lots.[ii] If this measure is not valid, replacing HPS lamps with MH lamps would still achieve energy savings, but at the expense of visual performance. A new PIER project is further exploring the specifics of visual, technical and energy implications of lamp selections for parking lots. Go to www.archenergy.com/lrp/lightingperf_standards/project_5_3.htm for information and outcomes.

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[13] Dr. S.M. Berman, "Energy Efficiency Consequences of Scotopic Sensitivity," Journal of the Illuminating Engineering Society, Winter 1992

[14] Based on an original horizontal illuminance level of 30 footcandles (FC) using 3000K, 75 CRI lamps, replaced by one third fewer lamps with 4100K, 85 CRI with a horizontal illuminance level of 20 FC. This substitution results in an energy savings of 33%.

FUA	Original Energy Usage (GWh)	MH instead of HPS:		
		Energy Usage (GWh)	Error Bound (GWh)	Energy Savings (GWh)
Parking	967	871	264	96
Pedestrian & Walkway	686	645	276	40
Landscape	40	39	17	1
Outdoor Retail Sales	140	140	157	0
Internal Roadway	74	66	48	8
Storage	159	137	65	23
ATM	7	6	7	1
Recreation	48	42	41	6
Undeveloped	2	2	3	0
Façade & Aesthetic	44	43	27	0
Security	208	180	91	28
Entry	40	39	12	1
Gas Station Canopy	30	30	30	0
Commercial Outdoor Patio	1	1	1	0
Signage	623	623	213	0
Total	**3,067**	**2,864**	**672**	**204**

Table 5: Statewide Impact of Replacing All High Pressure Sodium (HPS) lamps with Metal Halide (MH) lamps

Table 6 presents the resulting annual outdoor lighting usage for California if all MV lamps were replaced with MH lamps. The savings were calculated by applying an efficacy ratio of 56:90 to the mercury vapor lamp energy consumption results[15]. The resulting usage for California is 3,031 GWh. This strategy represents a savings of 37 GWh for California, or roughly 1%. These savings are significantly smaller than the scenario above due to the fewer number of mercury vapor lamps in use. As expected, the majority of savings were with parking lots at 24 GWh.

FUA	Original Energy Usage (GWh)	MH instead of MV:		
		Energy Usage (GWh)	Error Bound (GWh)	Energy Savings (GWh)
Parking	967	943	268	24
Pedestrian & Walkway	686	680	283	5
Landscape	40	37	15	3
Security	140	140	157	0
Storage	74	74	49	1
Internal Roadway	159	158	72	2
Entry	7	7	8	0
Façade & Aesthetic	48	47	44	0
Recreation	2	2	3	0
Outdoor Retail Sales	44	43	27	0
ATM	208	206	96	2
Undeveloped	40	40	12	0
Gas Station Canopy	30	30	30	0
Commercial Outdoor Patio	1	1	1	0
Signage	623	623	213	0
Total	**3,067**	**3,031**	**686**	**37**

Table 6: Statewide Impact of Replacing All Mercury Vapor lamps with Metal Halide lamps

Lighting Power Density (LPD)

These tables present information on the lighting power density[16] (LPD) levels, by building type, functional use area, and by lighting zone. All values are based on lit areas, such as lit parking, with the exception of the "site wide" results presented in Table 7 and Table 9. These tables incorporate the entire area within the property lines (excluding the building area).

Given the range of information recorded, there is a great deal of insight to be gleaned from the following material. However, due to the limited number of sites visited within some categories, appropriate utilization requires that the values reported in the "finer detail" categories (such as the LPD of hotel outdoor patios, Table 13) be balanced by the sample size associated with the result (Table 15). For another example, Table 13 indicates that grocery walkways have an installed lighting power density (LPD) of 1.39 on average. This surprisingly high result must be balanced against the sample size for this result. Due to a sample size of one, this result should be considered a case study rather than an indication of statewide design practice. However, the parking lot results for small offices have an LPD of 0.06 W/SF, and a sample size of 82. This statewide result can be utilized with great confidence.

[15] Technical Advisory Committee meeting, April 3, 2002.

[16] Lighting Power Density (LPD) is calculated by dividing the installed wattage (including ballast) by the area of interest. The area is either the entire site area minus the building footprint, or the area of the associated functional use area (FUA) such as lit parking area, or lit walkway area.

Table 7 illustrates the percentage of total area that has an installed wattage within LPD ranges. The calculations include both non-lit as well as lit areas to determine the site LPD by building type. For example: an apartment complex which has property boundaries enclosing 120,000 sqft, with a 20,000 sqft building footprint, and has a total of 1,000 watts of lamps installed (including ballasts), has a site lighting power density of 0.010 watts/sqft: 1000 / (120,000-20,000). The table below indicates that 34.5% of the overall site area, statewide, has a LPD range of 0 to 0.0049 (W/SF). This low LPD is the result of including the entire site area, lit as well as unlit. To provide some perspective, a standard parking lot lighting design with regularly spaced poles, each with two 400W metal halide luminaires, would have an LPD of 0.092 watts/sqft. Large retail, such as big box retailers, typically have very little unlit area. Accordingly, 50.3% of the large retail have a site-wide LPD of .05 to .099 W/SF, in accord with the standard design described above.

Building Type	% of Area (SQFT)						Sample Size
	Non-lit Sites	> 0 to 0.0049 (W/SF)	0.005 to 0.0099 (W/SF)	0.01 to 0.049 (W/SF)	0.05 to 0.099 (W/SF)	> = 0.1 (W/SF)	
Apartments and Condominiums	-	50.2%	15.4%	16.5%	13.5%	4.3%	15
Assembly	-	-	-	47.3%	26.3%	26.4%	11
Full Service Restaurant	-	-	-	81.3%	-	18.7%	7
Grocery	-	53.9%	-	-	31.0%	15.1%	3
Hospital	-	-	-	6.5%	58.9%	34.5%	8
Hotel	-	-	48.5%	-	39.0%	12.6%	4
Industrial	0.7%	71.4%	18.9%	4.5%	2.8%	1.7%	31
Large Office	-	-	-	26.4%	39.5%	34.1%	26
Large Retail	1.5%	-	-	9.8%	50.3%	38.4%	15
Large Schools	-	-	-	100.0%	-	-	2
Recreation	0.1%	60.1%	-	-	19.6%	20.2%	7
Small Office	-	19.0%	1.6%	44.2%	25.9%	9.4%	102
Small Retail	0.1%	-	-	6.3%	30.6%	63.0%	42
Small School	-	-	18.7%	12.1%	69.2%	-	6
University	-	-	-	99.1%	0.8%	0.2%	8
Warehouse	5.0%	-	-	78.7%	16.4%	-	16
All Building Types	**0.7%**	**34.5%**	**9.7%**	**21.2%**	**20.1%**	**13.8%**	**303**

Table 7: Site Lighting Power Density by Building Type

Table 8 presents the error bounds for the results in the table above. The error bound provides an indication of the confidence level associated with each result. The error bound is explained in more detail in the text preceding Table 12

Building Type	% of Area (SQFT)					
	Non-lit Sites	> 0 to 0.0049 (W/SF)	0.005 to 0.0099 (W/SF)	0.01 to 0.049 (W/SF)	0.05 to 0.099 (W/SF)	> = 0.1 (W/SF)
Apartments and Condominiums	-	34.7%	23.6%	16.9%	14.5%	4.6%
Assembly	-	-	-	33.3%	34.4%	31.5%
Full Service Restaurant	-	-	-	28.0%	-	28.0%
Grocery	-	51.0%	-	-	45.3%	26.1%
Hospital	-	-	-	11.1%	34.5%	32.6%
Hotel	-	-	52.0%	-	50.3%	18.1%
Industrial	0.9%	29.3%	24.7%	4.8%	3.1%	2.4%
Large Office	-	-	-	17.8%	20.6%	19.3%
Large Retail	2.5%	-	-	14.4%	30.2%	28.5%
Large Schools	-	-	-	-	-	-
Recreation	0.1%	45.1%	-	-	30.9%	27.2%
Small Office	-	25.5%	2.3%	16.7%	11.5%	5.4%
Small Retail	0.2%	-	-	6.6%	19.6%	19.6%
Small School	-	-	29.4%	17.5%	39.9%	-
University	-	-	-	1.7%	1.5%	0.4%
Warehouse	8.3%	-	-	20.1%	18.4%	-
All Building Types	**0.6%**	**23.5%**	**9.6%**	**10.0%**	**10.3%**	**7.4%**

Table 8 Error Bounds: Site Lighting Power Density by Building Type

The site level lighting power density is presented by lighting zones in Table 9 below. The results for lighting zone 1 indicate that 90% of the statewide area in this rural zone has a LPD of 0.00 to 0.0049 W/SF. The total sample size is less than 303, indicating the lack of lighting zone information for three sites.

Zone	% of Site Area (SQFT)						Sample Size
	Non-lit Sites	> 0 to 0.0049 (W/SF)	0.005 to 0.0099 (W/SF)	0.01 to 0.049 (W/SF)	0.05 to 0.099 (W/SF)	> = 0.1 (W/SF)	
Lighting Zone 1	0.2%	90.3%	2.9%	4.9%	1.3%	0.4%	31
Lighting Zone 2	0.1%	11.4%	4.4%	40.7%	36.5%	6.9%	78
Lighting Zone 3	0.2%	1.1%	20.2%	29.7%	23.6%	25.2%	141
Lighting Zone 4	4.5%	-	-	11.7%	52.3%	31.5%	50
All Lighting Zones	**0.6%**	**34.7%**	**9.7%**	**21.1%**	**20.1%**	**13.8%**	**300**

Table 9: Site Level LPD by Zone

Zone	% of Site Area (SQFT)					
	Non-lit Sites	> 0 to 0.0049 (W/SF)	0.005 to 0.0099 (W/SF)	0.01 to 0.049 (W/SF)	0.05 to 0.099 (W/SF)	> = 0.1 (W/SF)
Lighting Zone 1	0.3%	10.7%	4.6%	5.8%	1.8%	0.7%
Lighting Zone 2	0.2%	13.1%	5.9%	20.3%	18.3%	4.9%
Lighting Zone 3	0.4%	1.8%	20.5%	14.3%	15.5%	13.9%
Lighting Zone 4	5.7%	-	-	10.0%	25.5%	21.4%
All Lighting Zones	**0.5%**	**23.6%**	**9.6%**	**10.0%**	**10.3%**	**7.4%**

Table 10 Error Bounds: Site Level LPD by Zone

The site surveyors used the definitions listed in Table 11 to describe the degree of general area illumination around each site analyzed. These definitions were adopted from lighting zone definitions used by the Illumination Engineers Society of North America.[17]

[17] Model Outdoor Lighting Ordinance Classification of Outdoor Areas, Jim Benya, Illumination Engineers Society of North America.

Lighting Zone Definitions	
Zone 1	Area with intrinsically dark landscape. (Residential areas with little or no streetlighting)
Zone 2	Area of low ambient brightness. (Outer urban and rural area, residential areas)
Zone 3	Area of medium ambient brightness. (Urban residential areas, lighted to higher traffic level)
Zone 4	Area of high ambient brightness. (Urban area with both residential and commercial use, high traffic volume)

Table 11: Lighting Zone Definitions

Table 12 summarizes the statewide average LPD values together with the corresponding error bounds. The error bound, which is dependent on the sample size and variation in the data, provides a measure of the estimate relative to the sample population. For functional use areas such as parking the sample size is large and the associated error bound is relatively small. For Gas Station Canopies, the sample size is relatively small and the error bound correspondingly large. For example, the error bound for parking is 0.01 for an estimate of 0.08 W/SF. Therefore, there is a 90% confidence level that all data collected for this category falls within the bounds of 0.07 to 0.09 W/SF. Sites with a wide range of results will have large error bounds, such as commercial outdoor patios and gas station canopies. The resulting information must be utilized with caution. Commercial outdoor patios, for example, has an error bound of 0.36 which means that there is a 90% confidence level that the data falls between 0.11 W/SF and 0.83 W/SF. Such a large range limits the usefulness of the result. The error bound is not calculated for a sample size of 1 because there is no variation in the data collected. Accordingly, results based on a single entry should be evaluated as a case study. Table 12 is a good illustration of the importance of the error bounds and the sample sizes associated with each result in the appropriate interpretation of the findings within this report.

FUA	Average LPD (W/SF)		Sample Size
	Estimate	Error Bounds	
Gas Station Canopy	1.48	0.30	7
Entry	0.79	0.21	71
ATM	0.57	0.01	5
Commercial Outdoor Patio	0.47	0.36	3
Pedestrian & Walkway	0.38	0.16	201
Security	0.24	0.10	91
Façade & Aesthetic	0.18	0.13	35
Landscape	0.17	0.06	46
Outdoor Retail Sales	0.13	0.09	4
Internal Roadway	0.08	0.04	37
Parking	0.08	0.01	221
Recreation	0.08	0.06	25
Storage	0.07	0.04	31
Undeveloped	0.02	NA	1

Table 12: Summary of Average Lighting Power Density by FUA

Table 13 and Table 15, presented in landscape format on the following pages, provide the average LPD by building type and functional use area. The parking average LPD ranges from 0.05 to 0.18 W/SF. According to Table 4, this FUA is the heaviest statewide energy user. Large retail parking has an LPD of 0.08 W/SF that roughly equates to a parking lot of evenly spaced light poles with two 400 watt metal halide luminaires per pole. The hotel results are particularly interesting. The average LPD for this type is consistently higher than the other types. However, Table 14 and Table 15 indicate the error bound is 0.14 W/SF and the sample size is 4 indicating caution should be employed when generalizing these results.

Building Type by FUA	Average LPD (W/SF)													
	ATM	Commercial Outdoor Patio	Entry	Façade & Aesthetic	Gas Station Canopy	Internal Roadway	Landscape	Outdoor Retail Sales	Parking	Pedestrian & Walkway	Recreation	Security	Storage	Not Developed
Apartments and Condominiums	-	-	0.97	0.25	-	0.03	0.11	-	0.10	0.33	0.02	0.64	0.30	-
Assembly	-	-	0.91	0.25	-	-	5.26	-	0.06	0.39	0.18	0.12	-	-
Full Service Restaurant	-	0.13	1.79	4.48	0.27	-	-	-	0.08	0.56	-	0.25	1.19	-
Grocery	-	-	0.62	-	-	-	-	-	0.11	1.39	-	0.12	0.45	-
Hospital	-	-	0.59	0.69	-	0.15	0.14	-	0.10	0.51	0.21	0.10	0.18	-
Hotel	-	0.83	0.26	-	-	0.06	0.43	-	0.18	0.45	0.08	0.17	-	-
Industrial	-	-	1.32	0.81	2.79	0.06	0.26	-	0.09	0.22	0.02	1.20	0.07	-
Large Office	0.54	-	0.65	0.39	-	0.11	0.08	-	0.06	0.19	-	0.30	0.38	-
Large Retail	-	-	0.62	0.10	1.72	0.26	0.19	0.13	0.08	0.46	-	0.12	0.05	-
Large Schools	-	-	-	0.17	-	-	0.42	-	0.06	0.13	0.92	-	-	-
Recreation	-	-	1.27	1.17	-	0.20	-	-	0.11	0.79	0.22	0.54	-	-
Small Office	0.66	-	1.18	0.28	-	0.07	0.22	-	0.06	0.45	0.06	0.17	0.11	-
Small Retail	0.57	-	0.73	1.30	1.09	0.04	0.35	-	0.08	0.93	0.44	0.35	0.12	-
Small School	-	-	-	-	-	0.05	0.04	-	0.05	0.09	0.08	0.10	-	-
University	-	-	0.46	0.13	-	0.08	0.57	-	0.16	0.70	-	0.92	0.13	-
Warehouse	-	-	1.85	0.51	-	-	1.16	-	0.10	0.46	-	0.06	0.16	0.02
All Building Types	**0.57**	**0.47**	**0.79**	**0.18**	**1.48**	**0.08**	**0.17**	**0.13**	**0.08**	**0.38**	**0.08**	**0.24**	**0.07**	**0.02**

Table 13: Average Lighting Power Density by Building Type and FUA

Building Type by FUA	Average LPD (W/SF)													
	ATM	Commercial Outdoor Patio	Entry	Façade & Aesthetic	Gas Station Canopy	Internal Roadway	Landscape	Parking	Pedestrian & Walkway	Recreation	Security	Storage	Not Developed	Outdoor Retail Sales
Apartments and Condominiums	-	-	0.74	0.00	-	0.03	0.14	0.02	0.14	0.01	0.00	0.00	-	-
Assembly	-	-	1.57	-	-	-	0.00	0.03	0.07	0.15	0.12	-	-	-
Full Service Restaurant	-	0.06	0.09	0.89	0.00	-	-	0.01	0.28	-	0.24	0.00	-	-
Grocery	-	-	0.00	-	-	-	-	0.05	0.00	-	0.00	0.00	-	-
Hospital	-	-	0.11	0.00	-	0.11	0.03	0.04	0.16	0.00	0.10	0.00	-	-
Hotel	-	0.00	0.00	-	-	0.00	0.00	0.14	0.13	0.03	0.07	-	-	-
Industrial	-	-	0.13	0.27	0.00	0.04	0.05	0.03	0.17	0.00	1.27	0.03	-	-
Large Office	0.02	-	0.41	0.29	-	0.07	0.01	0.02	0.11	-	0.12	0.13	-	-
Large Retail	-	-	0.00	0.04	0.11	0.00	0.00	0.01	0.44	-	0.11	0.03	-	0.09
Large Schools	-	-	-	0.00	-	-	0.02	0.00	0.24	0.00	-	-	-	-
Recreation	-	-	0.24	-	-	0.00	-	0.07	0.16	0.00	0.03	-	-	-
Small Office	0.00	-	0.39	0.13	-	0.04	0.13	0.01	0.12	0.02	0.05	0.05	-	-
Small Retail	0.00	-	0.64	0.29	0.03	0.00	0.02	0.02	0.34	0.65	0.38	0.08	-	-
Small School	-	-	-	-	-	0.00	0.00	0.01	0.04	0.00	0.02	-	-	-
University	-	-	0.45	0.00	-	0.00	0.01	0.02	0.23	-	0.00	0.00	-	-
Warehouse	-	-	0.34	0.69	-	-	0.42	0.03	0.15	-	0.02	0.09	0.00	-
All Building Types	**0.01**	**0.36**	**0.21**	**0.13**	**0.30**	**0.04**	**0.06**	**0.01**	**0.16**	**0.06**	**0.10**	**0.04**	**0.00**	**0.09**

Table 14 Error Bounds: Average LPD by Building Type and FUA

Building Type by FUA	Sample Size													
	ATM	Commercial Outdoor Patio	Entry	Façade & Aesthetic	Gas Station Canopy	Internal Roadway	Landscape	Outdoor Retail Sales	Parking	Pedestrian & Walkway	Recreation	Security	Storage	Not Developed
Apartments and Condominiums	-	-	5	1	-	4	5	-	9	15	5	1	1	-
Assembly	-	-	3	1	-	-	1	-	8	8	5	5	-	-
Full Service Restaurant	-	2	2	2	1	-	-	-	4	5	-	4	1	-
Grocery	-	-	1	-	-	-	-	-	3	1	-	1	1	-
Hospital	-	-	5	1	-	3	2	-	7	6	2	3	1	-
Hotel	-	1	1	-	-	1	1	-	4	3	2	2	-	-
Industrial	-	-	5	2	1	8	3	-	24	15	1	9	8	-
Large Office	2	-	9	3	-	5	5	-	21	21	-	7	3	-
Large Retail	-	-	1	2	2	1	2	4	11	11	-	4	5	-
Large Schools	-	-	-	1	-	-	2	-	1	2	1	-	-	-
Recreation	-	-	2	1	-	1	-	-	4	3	1	3	-	-
Small Office	2	-	29	13	-	9	16	-	82	68	4	28	2	-
Small Retail	1	-	3	5	3	2	3	-	26	28	2	12	3	-
Small School	-	-	-	-	-	2	1	-	5	5	2	2	-	-
University	-	-	2	1	-	1	3	-	5	8	-	1	1	-
Warehouse	-	-	3	2	-	-	2	-	7	2	-	9	5	1
All Building Types	**5**	**3**	**71**	**35**	**7**	**37**	**46**	**4**	**221**	**201**	**25**	**91**	**31**	**1**

Table 15 Sample Size: Average Lighting Power Density by Building Type and FUA

Table 16 presents the percentage of parking lot area within LPD ranges. This table indicates that 27% of lit parking lots are in the LPD range of 0.075 to 0.099 (W/SF) which conforms to the standard parking lot design described above (2 luminaires per 20ft. pole in square pattern LPD=0.092 W/SF). The results of Table 16 are complimented by the data in Table 34, which provides the parking illumination levels by lighting zone.

LPD (W/SF)	% of Area (SQFT)	
	Parking (n = 221)	Error Bound
0 to 0.0249	7.65%	4.09%
0.025 to 0.049	25.02%	13.41%
0.05 to 0.0749	19.55%	7.93%
0.075 to 0.099	27.35%	17.27%
0.1 to 0.149	13.18%	8.17%
> 0.15	7.25%	3.78%

Table 16: Parking - Lighting Power Density Ranges

Table 17 presents the percentage of FUA area within average LPD ranges. Statewide, 33.04% of all lit FUA area has an LPD of 0.025 to 0.0749 (W/SF). Almost half (45%) of all lit parking area also falls into this range. The Gas Station Canopy results are particularly interesting. The vast majority (96.5%) of Gas Station Canopy area is lit at levels well above the lighting levels of 93% of the remaining lit commercial outdoor area in the state.

FUA	% of FUA Area (SQFT)									Sample Size
	< 0.025 (W/SF)	0.025 to 0.049 (W/SF)	0.05 to 0.0749 (W/SF)	0.075 to 0.099 (W/SF)	0.1 to 0.249 (W/SF)	0.25 to 0.99 (W/SF)	1 to 2.99 (W/SF)	3 to 7.99 (W/SF)	8 to 18 (W/SF)	
ATM	-	-	-	-	-	100.0%	-	-	-	5
Commercial Outdoor Patio	-	-	-	33.5%	17.4%	49.0%	-	-	-	3
Entry	-	4.9%	-	-	10.2%	66.8%	14.4%	3.6%	0.1%	71
Façade & Aesthetic	-	-	1.9%	71.1%	11.9%	11.5%	3.6%	0.0%	-	35
Gas Station Canopy	-	-	-	-	-	3.5%	96.5%	-	-	7
Internal Roadway	17.8%	36.0%	8.4%	11.6%	14.2%	12.0%	-	-	-	37
Landscape	11.4%	8.6%	1.6%	33.8%	26.7%	17.4%	0.3%	0.3%	0.0%	46
Outdoor Retail Sales	-	-	9.4%	70.7%	-	19.9%	-	-	-	4
Parking	7.6%	25.0%	19.6%	27.3%	18.9%	1.5%	0.0%	0.0%	-	221
Pedestrian & Walkway	5.3%	3.3%	3.3%	16.3%	43.5%	21.4%	5.7%	1.3%	-	201
Recreation	55.9%	0.7%	0.9%	28.7%	1.0%	12.7%	0.0%	-	-	25
Security	1.7%	8.8%	28.6%	5.7%	43.9%	9.3%	0.9%	0.9%	0.1%	91
Storage	45.0%	17.9%	15.4%	3.8%	14.8%	3.0%	0.1%	-	-	31
Undeveloped	100%	-	-	-	-	-	-	-	-	1
All FUAs	**15.63%**	**18.22%**	**14.82%**	**25.21%**	**18.78%**	**6.44%**	**0.74%**	**0.16%**	**0.01%**	**778**

Table 17: FUA Area Lighting Power Density Range

FUA	% of FUA Area (SQFT)								
	< 0.025 (W/SF)	0.025 to 0.049 (W/SF)	0.05 to 0.0749 (W/SF)	0.075 to 0.099 (W/SF)	0.1 to 0.249 (W/SF)	0.25 to 0.99 (W/SF)	1 to 2.99 (W/SF)	3 to 7.99 (W/SF)	8 to 18 (W/SF)
ATM	-	-	-	-	-	-	-	-	-
Commercial Outdoor Patio	-	-	-	46.6%	29.1%	51.2%	-	-	-
Entry	-	8.0%	-	-	8.6%	15.9%	8.1%	2.7%	0.2%
Façade & Aesthetic	-	-	3.3%	35.3%	17.2%	15.2%	5.2%	0.1%	-
Gas Station Canopy	-	-	-	-	-	6.4%	6.4%	-	-
Internal Roadway	24.6%	27.6%	9.3%	11.6%	12.0%	16.8%	-	-	-
Landscape	16.1%	10.2%	2.1%	36.8%	20.7%	13.0%	0.4%	0.4%	0.0%
Outdoor Retail Sales	-	-	18.0%	42.5%	-	35.0%	-	-	-
Parking	4.1%	13.4%	7.9%	17.3%	9.0%	1.1%	0.0%	0.0%	-
Pedestrian & Walkway	8.0%	5.1%	4.8%	14.7%	28.6%	12.1%	3.9%	1.9%	-
Recreation	42.9%	1.0%	1.6%	39.7%	1.3%	18.6%	0.1%	-	-
Security	2.0%	9.8%	19.0%	4.4%	19.2%	6.5%	0.8%	1.3%	0.2%
Storage	42.9%	21.4%	20.2%	4.8%	14.6%	3.7%	0.1%	-	-
Undeveloped	-	-	-	-	-	-	-	-	-
All FUAs	**9.1%**	**8.5%**	**5.0%**	**11.8%**	**6.8%**	**2.7%**	**0.3%**	**0.2%**	**0.0%**

Table 18 Error Bounds: FUA Area Lighting Power Density Range

The important categories of Gas Station Canopies and Outdoor Retail Sales have small sample sizes that require caution when used to extrapolate to the statewide level. For this reason, and due to the general interest in the professional community, the data for these sites are presented below, in Table 19, as case studies. The modern gas stations, common throughout California, have LPD values between 1.075 and 1.921 watt per sqft (W/SF), with average horizontal illuminance readings of 12.47 to 14.97 footcandles (FC)[18]. The LPD values are 4 times the maximum lighting power density of 98% of the lit parking lot area in California. Several of the sites did not permit collection of the detailed illumination data (accessibility or traffic conflicts). These are noted as "no data".

Case Studies: Gas Station Canopies					
Business Description	**Lighting Style**	**FUA sqft**	**LPD (W/SF)**	**Ave Horiz. Illumance (FC)**	**Max/Min Horiz. Illumance (FC)**
Gas Station	Modern	3,990	1.075	no data	no data
Gas Station	Modern	1,880	1.569	12.47	17.88 / 5.57
Gas Station	Older	960	1.921	14.97	17.06 / 10.8
Large Retail Gas Island	Modern	4,190	2.747	no data	no data
Large Retail Gas Island	Modern	6,960	1.59	18.7	21.51 / 14.27
Industrial Gas Island	Older	1,320	2.794	51.08	64.7 / 38.7
Rural Restaurant Gas Island	Older	630	0.27	3.61	7.86 / 1.59
Case Studies: Outdoor Retail Sales					
Business Description	**Luminaire Style**	**FUA sqft**	**LPD (W/SF)**	**Ave Horiz. Illumance (FC)**	**Max/Min Horiz. Illumance (FC)**
Modern Car Dealership	"Shoe Box" 175w MH	191,796	0.055	8.76	17.22 / 2.24
Modern Car Dealership	"Shoe Box" 400w MH	278,300	0.335	14.89	30.7 / 5.58
RV sales	"Floodlamp" 400w MH	1,219,766	0.083	no data	no data
Auto Auction	"Flrcnt Strip" 32w T8 Flr.	2,400	0.375	no data	no data

Table 19 Case Studies: Gas Station Canopies and Outdoor Retail Sales

[18] Footcandles (FC) is a unit of illuminance measured using a light meter per the methodology described in "Illuminance Measurements" within the "Data Collection" section of this report.

Outdoor Lighting Standards Impact Analysis

The California Outdoor Lighting Standards Committee published proposed standards for public comment on June 6th, 2002. The following tables allow the determination of the impact of these lighting standards on each functional use area, if that standard were applied to the existing outdoor lighting in the state. Furthermore, the structure of the table allows calculation of the change of impact if the standard is adjusted up or down. Comparisons of these baseline results to values listed in the June 6th document are contained in Appendix A. A current list of proposed outdoor lighting standards can be obtained from the California Energy Commission (http://www.energy.ca.gov/title24/). While significant effort was expended to make the field measurements consistent with the developments of the Standards Committee, the concurrent timelines resulted in some inconsistencies. The lighting zone definitions, for example, evolved through the work of the Standards Committee to be slightly different than the definitions used in the data collection (see Table 11). The collection of this data was completed prior to the Committee's development of the definitions required to meet their objectives.

Table 20 presents information for evaluating proposed parking standards. For example: a proposed lighting standard of 0.06 W/SF would include all lit parking area in the ranges less than, or including this value, which would equate to 45% of the lit parking area in the state (calculated by adding up all percentages in the ranges to the left of, and including "0.0551 to 0.06"). If this standard were reduced to 0.050 W/SF, an additional 12.5% (7.08 + 5.41) would be above the standard. This would reduce the percentage of existing parking area in compliance to 33%.

Parking	% of Area (SQFT)									Sample Size
	< 0.03	0.03 to 0.04	0.041 to 0.045	0.0451 to 0.05	0.051 to 0.055	0.0551 to 0.06	0.061 to 0.065	0.0651 to 0.07	0.071 to 0.075	
Estimates	14.67%	5.23%	1.64%	11.12%	5.41%	7.08%	2.59%	1.84%	2.63%	221
Error Bounds	6.31%	2.90%	1.12%	13.49%	3.56%	4.44%	2.38%	1.40%	3.27%	
Results Continued	0.0751 to 0.08	0.081 to 0.085	0.0851 to 0.09	0.091 to 0.095	0.0951 to 0.10	0.11 to 0.15	0.151 to 0.20	0.21 to 0.25	> 0.25	
Estimates	3.98%	0.93%	20.91%	0.88%	0.65%	13.18%	3.63%	2.12%	1.50%	
Error Bounds	3.13%	0.93%	18.13%	1.05%	0.55%	8.15%	2.92%	1.58%	1.12%	

Table 20: Parking Results Organized for Lighting Standards Impact Evaluation

Figure 6 provides this information graphically. The lighter bar represents the percentage of sites within the specific LDP range, and the darker bar represents the total percentage of sites above the LPD range. For example, if the standard were established at 0.03 W/SF, 85% of the parking area would be non-compliant (the sum of all the small bars to the right of the 0.03 W/SF bin). Using the example for Table 20, if a standard of 0.06 W/SF were applied to existing parking, it would result in non-compliance of roughly 55% of the statewide parking area. If this standard were changed to 0.050 W/SF, roughly 67% would be non-compliant.

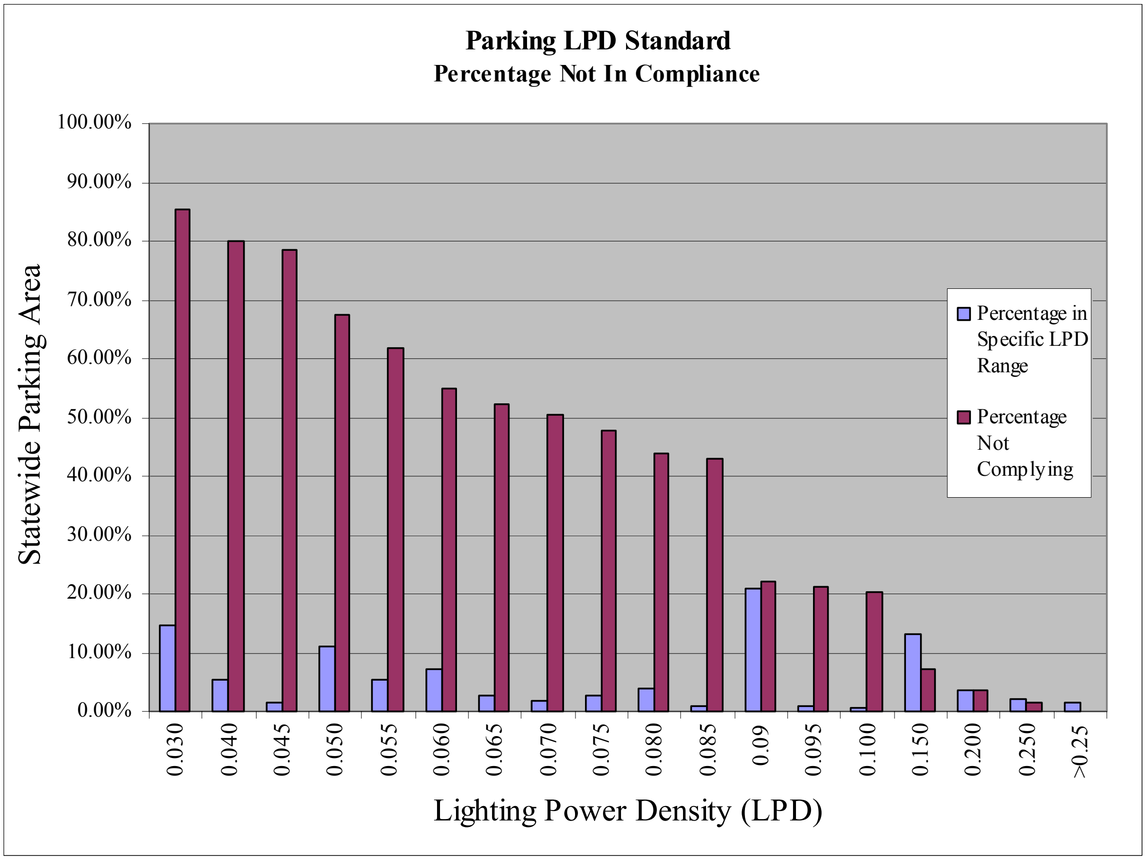


Figure 6: Percentage of Parking Area Affected by Standard

Table 21 applies this evaluation tool to building entrances. In this example: if a proposed lighting standard of 0.500 W/SF were applied to existing entrances, 50% of lit building entry area in the state would be within code (calculated by adding up all percentages in the ranges above 0.5). If this standard were increased to 0.90 W/SF, an additional 31% (3.5+1.5+25.7) would be within the proposed standard, for a total percentage of 81%, indicating a minimal impact on current standard lighting design practice for entrances. Figure 7 presents this information graphically.

Entry	% of Area (SQFT)								Sample Size
	< 0.4	0.40 to 0.45	0.451 to 0.50	0.51 to 0.55	0.551 to 0.60	0.61 to 0.75	0.751 to 0.90	0.91 to 0.95	
Estimates	39.76%	1.70%	8.09%	3.47%	1.51%	19.65%	6.02%	0.52%	71
Error Bounds	20.86%	2.83%	9.79%	5.69%	2.45%	22.32%	6.09%	0.61%	
Results Continued	0.951 to 1.0	1.01 to 1.05	1.051 to 1.10	1.11 to 1.40	1.41 to 1.45	1.451to 1.50	1.51 to 1.55	> 1.55	
Estimates	1.17%	0.00%	0.72%	6.05%	0.00%	0.89%	0.45%	10.02%	
Error Bounds	1.96%	0.00%	1.21%	4.60%	0.00%	1.49%	0.76%	6.19%	

Table 21: Building Entry Results Organized for Lighting Standards Impact Evaluation

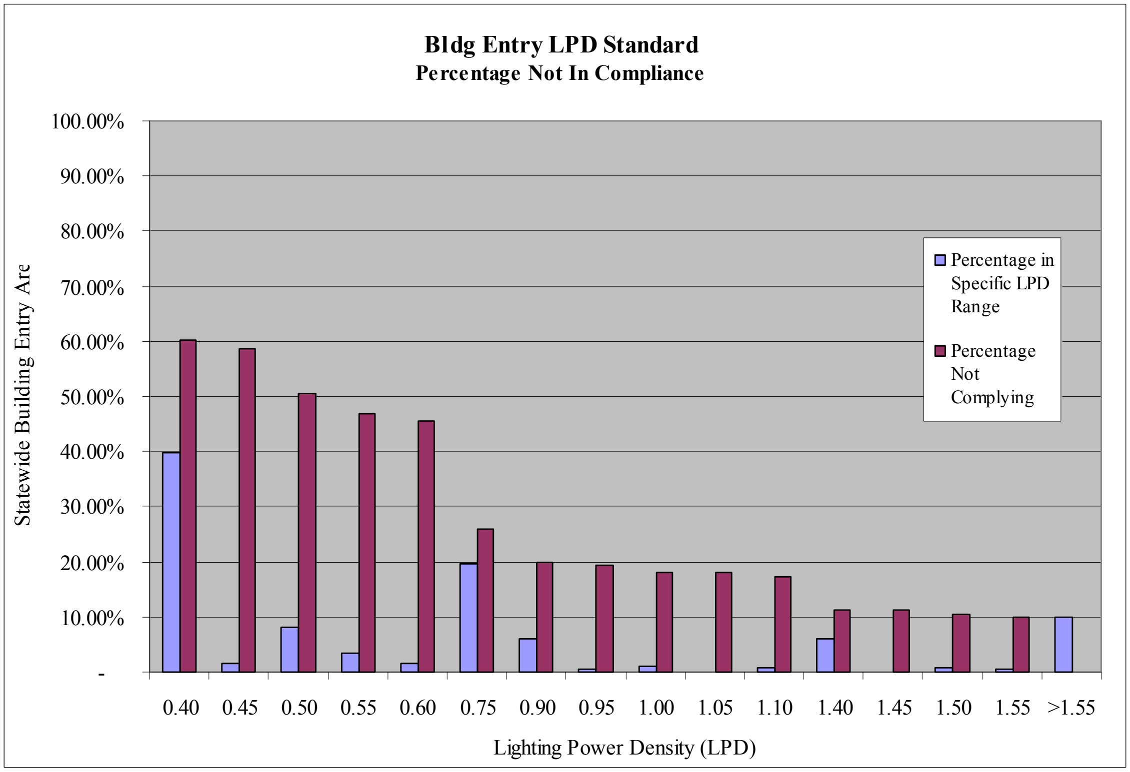


Figure 7: Percentage of Entry Area Affected by Standard

Table 22 extends this method to Gas Station Canopies. For this example: if a proposed lighting standard of 1.250 W/SF is applied to existing Gas Station Canopies, 65% would not meet the LPD standard. However, due to the small sample size (7), and the clumping of the results, the available data does not support the evaluation of incremental changes.

Gas Station Canopy	% of Area (SQFT)								Sample Size
	<= 0.3	0.3 to 0.33	0.331 to 0.6	0.61 to 0.67	0.671 to 0.75	0.751 to 1.2	1.21 to 1.25	1.251 to 1.3	
Estimates	3.48%	-	-	-	-	31.91%	-	-	7
Error Bounds	6.37%	-	-	-	-	42.92%	-	-	
Results Continued	1.31 to 2.4	2.41 to 2.45	2.451 to 2.5	> 2.5					
Estimates	62.41%	-	-	2.21%	-	-	-	-	
Error Bounds	43.23%	-	-	4.07%	-	-	-	-	

Table 22: Gas Station Canopy Results Organized for Lighting Standards Impact Evaluation

Table 23 presents a similar analysis for Outdoor Retail Sales. For this example: a proposed lighting standard of 0.250 W/SF would exclude 25% of such areas. Again, due to the small sample size (4), and the clumping of the results, the data offer little opportunity to evaluate the impact of adjustments in the standards on Outdoor Retail Sales. This table does provide a template for future research in this important area.

Outdoor Retail Sales	**% of Area (SQFT)**								**Sample Size**
	<= 0.2	**0.21 to 0.25**	**0.251 to 0.3**	**0.31 to 0.45**	**0.451 to 0.5**	**0.51 to 0.55**	**0.551 to 0.6**	**0.61 to 0.9**	
Estimates	80.13%	-	-	19.87%	-	-	-	-	**4**
Error Bounds	34.97%	-	-	34.97%	-	-	-	-	
Results Continued	**0.91 to 0.95**	**0.951 to 1**	**1.01 to 1.05**	**> 1.05**					
Estimates	-	-	-	-					
Error Bounds	-	-	-	-					

Table 23: Outdoor Retail Sales Results Organized for Lighting Standards Impact Evaluation

Functional Use Area Illumance

The area illumination is explored in Table 30 which displays the percentage of sites with lit area illuminance grid readings whose averages fall within specified footcandle ranges. These values were calculated using data collected from the site illumination grid per the methodology described in "Data Collection" section (page 64). The following case study provides some perspective to these numbers: A big box retailer visited, which had a regular grid of light poles (30 ft. high spaced 30 ft. apart) with 2 and 3 fixtures per pole, has an LPD of 0.11 W/SF and an average horizontal illuminance of 1.81 FC. The table below indicates that 30.4% of parking lot measurements fall within roughly ±50% of this value (1.0 to 2.49 FC). However, 100% of outdoor retail sales, and 48% of gas station canopies are more than 4 times this value, with averages in excess of 8 FC.

FUA	**% of Sites**										**Sample Size**
	< 0.5 (FC)	**0.5 to 0.99 (FC)**	**1 to 1.49 (FC)**	**1.5 to 2.49 (FC)**	**2.5 to 4.99 (FC)**	**5 to 7.99 (FC)**	**8 to 9.99 (FC)**	**10 to 14.99 (FC)**	**15 to 24.99 (FC)**	**25 to 51 (FC)**	
ATM	-	-	-	-	-	-	100%	-	-	-	1
Entry	8.5%	-	3.8%	33.2%	47.6%	-	5.1%	-	-	1.8%	13
Gas Station Canopy	-	-	-	-	50.2%	-	-	5.6%	29.0%	15.2%	5
Internal Roadway	-	-	-	50.2%	-	49.8%	-	-	-	-	3
Outdoor Retail Sales	-	-	-	-	-	-	40.8%	59.2%	-	-	2
Parking	21.5%	14.7%	17.5%	12.9%	21.7%	7.7%	1.5%	2.5%	-	-	183
Pedestrian & Walkway	14.5%	17.6%	14.8%	12.6%	13.7%	15.7%	2.8%	3.4%	4.4%	0.2%	155
Security	9.2%	36.3%	13.8%	10.3%	17.4%	13.1%	-	-	-	-	22
Storage	-	-	-	23.9%	20%	56.1%	-	-	-	-	3
All FUAs	**17%**	**16.2%**	**15.3%**	**13.6%**	**19%**	**11.5%**	**2.5%**	**2.7%**	**1.9%**	**0.2%**	**387**

Table 24: Average Horizontal Illuminance by FUA

FUA	**% of Sites**									
	< 0.5 (FC)	**0.5 to 0.99 (FC)**	**1 to 1.49 (FC)**	**1.5 to 2.49 (FC)**	**2.5 to 4.99 (FC)**	**5 to 7.99 (FC)**	**8 to 9.99 (FC)**	**10 to 14.99 (FC)**	**15 to 24.99 (FC)**	**25 to 51 (FC)**
ATM	-	-	-	-	-	-	-	-	-	-
Entry	10.3%	-	6.4%	24.6%	28.4%	-	8.4%	-	-	3.0%
Gas Station Canopy	-	-	-	-	49.3%	-	-	8.4%	42.2%	25.6%
Internal Roadway	-	-	-	51.2%	-	51.2%	-	-	-	-
Outdoor Retail Sales	-	-	-	-	-	-	56.2%	56.2%	-	-
Parking	6.6%	5.4%	5.7%	5.0%	6.6%	4.0%	1.5%	2.9%	-	-
Pedestrian & Walkway	6.4%	6.7%	6.3%	5.2%	5.8%	6.6%	2.3%	2.9%	3.1%	0.4%
Security	11.7%	21.3%	12.3%	10.4%	18.3%	19.4%	-	-	-	-
Storage	-	-	-	38.0%	33.1%	49.7%	-	-	-	-
All FUAs	**4.2%**	**4.0%**	**3.8%**	**3.4%**	**4.3%**	**3.6%**	**1.4%**	**1.8%**	**1.3%**	**0.2%**

Table 25 Error Bounds: Average Horizontal Illuminance by FUA

Table 26 displays the percentage of FUAs with illuminance grid minimum horizontal measurements within specified footcandle ranges. Gas Station Canopies and Outdoor Retail Sales have the largest percentages within the higher footcandle ranges (5 FC and above). Nearly 70% of all FUAs have a minimum horizontal illuminance measurement of less than 1.0 footcandle.

FUA	% of FUAs										Sample Size
	< 0.1 (FC)	0.1 to 0.249 (FC)	0.25 to 0.49 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 7.99 (FC)	8 to 11.99 (FC)	12 to 19.99 (FC)	20 to 40 (FC)	
ATM	-	-	-	-	100.0%	-	-	-	-	-	1
Entry	-	4.9%	15.8%	35.7%	17.8%	24.1%	-	-	-	1.8%	13
Gas Station Canopy	-	-	-	-	50.2%	-	3.3%	2.3%	29.0%	15.2%	5
Internal Roadway	33.3%	-	-	-	66.7%	-	-	-	-	-	3
Outdoor Retail Sales	-	-	-	-	40.8%	-	59.2%	-	-	-	2
Parking	18.6%	32.8%	18.6%	14.3%	11.7%	2.0%	0.8%	1.2%	-	-	183
Pedestrian & Walkway	3.0%	14.2%	17.7%	21.0%	18.9%	9.6%	8.9%	4.4%	2.2%	0.2%	155
Security	7.4%	22.7%	37.1%	4.9%	14.9%	13.1%	-	-	-	-	22
Storage	-	23.9%	-	-	20.0%	56.1%	-	-	-	-	3
All FUAs	**10.8%**	**23.1%**	**18.7%**	**16.8%**	**16.1%**	**6.8%**	**4.1%**	**2.3%**	**1.0%**	**0.2%**	**387**

Table 26: Minimum Horizontal Illuminance Range

FUA	% of FUAs									
	< 0.1 (FC)	0.1 to 0.249 (FC)	0.25 to 0.49 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 7.99 (FC)	8 to 11.99 (FC)	12 to 19.99 (FC)	20 to 40 (FC)
ATM	-	-	-	-	-	-	-	-	-	-
Entry	-	8.1%	19.4%	26.7%	19.7%	26.9%	-	-	-	3.0%
Gas Station Canopy	-	-	-	-	49.3%	-	6.2%	4.3%	42.2%	25.6%
Internal Roadway	46.5%	-	-	-	46.5%	-	-	-	-	-
Outdoor Retail Sales	-	-	-	-	56.2%	-	56.2%	-	-	-
Parking	5.8%	7.6%	5.7%	5.7%	4.7%	1.6%	1.3%	1.9%	-	-
Pedestrian & Walkway	3.9%	6.0%	6.5%	7.2%	6.1%	4.7%	5.6%	3.1%	2.5%	0.4%
Security	11.7%	16.4%	21.4%	6.3%	16.8%	19.4%	-	-	-	-
Storage	-	38.0%	-	-	33.1%	49.7%	-	-	-	-
All FUAs	**3.3%**	**4.7%**	**4.0%**	**4.2%**	**3.7%**	**2.7%**	**2.4%**	**1.5%**	**1.0%**	**0.2%**

Table 27 Error Bounds: Minimum Horizontal Illuminance Range

Table 28 displays the percentage of FUAs within minimum vertical illuminance ranges. Seventy four percent of all FUAs have a minimum vertical illuminance measurement less than 0.25 footcandles.

FUA	% of FUAs									Sample Size
	< 0.025 (FC)	0.025 to 0.049 (FC)	0.05 to 0.09 (FC)	0.1 to 0.149 (FC)	0.15 to 0.249 (FC)	0.25 to 0.49 (FC)	0.5 to 0.99 (FC)	1 to 1.99 (FC)	2 to 5 (FC)	
ATM	-	-	-	-	100%	-	-	-	-	1
Entry	-	-	15.8%	12.9%	45.4%	13.3%	10.9%	-	1.8%	13
Gas Station Canopy	-	-	-	50.2%	-	-	5.6%	-	44.2%	5
Internal Roadway	-	50.2%	-	-	-	49.8%	-	-	-	3
Outdoor Retail Sales	-	-	-	-	-	-	-	100%	-	2
Parking	24.5%	8.8%	31.3%	10.6%	12.0%	9.6%	2.4%	-	0.8%	183
Pedestrian & Walkway	7.0%	3.4%	18.9%	17.4%	13.4%	12.7%	18.1%	6.7%	2.3%	155
Security	17.9%	22.6%	13.5%	11.6%	7.2%	14.2%	13.1%	-	-	22
Storage	-	-	-	23.9%	-	76.1%	-	-	-	3
All FUAs	**15.6%**	**7.3%**	**24%**	**13.6%**	**13.5%**	**11.9%**	**9.6%**	**2.9%**	**1.6%**	**387**

Table 28: Minimum Vertical Illuminance Range

FUA	% of FUAs								
	< 0.025 (FC)	0.025 to 0.049 (FC)	0.05 to 0.09 (FC)	0.1 to 0.149 (FC)	0.15 to 0.249 (FC)	0.25 to 0.49 (FC)	0.5 to 0.99 (FC)	1 to 1.99 (FC)	2 to 5 (FC)
ATM	-	-	-	-	-	-	-	-	-
Entry	-	-	19.4%	14.8%	28.5%	16.1%	16.9%	-	3.0%
Gas Station Canopy	-	-	-	49.3%	-	-	8.4%	-	47.3%
Internal Roadway	-	51.2%	-	-	-	51.2%	-	-	-
Outdoor Retail Sales	-	-	-	-	-	-	-	-	-
Parking	6.8%	3.8%	7.6%	4.2%	5.1%	4.1%	2.5%	-	1.3%
Pedestrian & Walkway	4.7%	2.3%	6.9%	6.9%	5.4%	4.9%	7.3%	3.4%	2.2%
Security	15.5%	19.7%	11.7%	12.9%	9.7%	16.4%	19.4%	-	-
Storage	-	-	-	38.0%	-	38.0%	-	-	-
All FUAs	**4.0%**	**2.4%**	**4.8%**	**3.6%**	**3.6%**	**3.1%**	**3.6%**	**1.4%**	**1.1%**

Table 29 Error Bounds: Minimum Vertical Illuminance Range

Parking Illuminance

The parking lot illumination is explored in Table 30. This table presents information on the maximum illumination value recorded at each site. The percentage of sites with a maximum reading within horizontal illuminance ranges is listed by business type. Small office and small retail have the greatest sample sizes and therefore allow the greatest generalization about the results. Both of these business types have a significant percentage of sites with relatively high maximum illuminance readings (above 10 FC). However, according to Table 32, the average parking illuminance for 85% of these business types is less than 5 FC. The comparison of Table 30 to Table 32 indicates that there is room for improvement in the parking lot lighting uniformity for these business types.

Building Type	% of Sites								Sample Size
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 9.99 (FC)	10 to 14.99 (FC)	15 to 19.99 (FC)	20 to 50 (FC)	
Apartments and Condominiums	80.5%	-	1.2%	9.1%	9.2%	-	-	-	7
Assembly	6.7%	14.4%	25.0%	8.1%	-	36.1%	9.7%	-	7
Full Service Restaurant	-	-	90.4%	9.6%	-	-	-	-	2
Grocery	-	-	-	-	-	100.0%	-	-	1
Hospital	54.0%	-	-	34.8%	1.4%	-	9.8%	-	7
Hotel	6.1%	-	51.1%	42.8%	-	-	-	-	4
Industrial	3.8%	17.7%	-	12.3%	27.3%	30.8%	-	8.1%	19
Large Office	3.0%	18.7%	14.7%	30.3%	14.8%	-	-	18.7%	16
Large Retail	-	-	15.8%	32.3%	22.2%	29.7%	-	-	11
Large Schools	-	-	100.0%	-	-	-	-	-	1
Recreation	-	-	24.9%	-	-	-	52.7%	22.3%	3
Small Office	2.7%	5.0%	20.5%	24.9%	19.8%	8.3%	8.0%	10.9%	70
Small Retail	24.0%	-	19.6%	10.7%	30.7%	8.3%	-	6.7%	20
Small School	-	0.6%	69.1%	-	30.3%	-	-	-	5
University	-	10.8%	-	78.3%	10.9%	-	-	-	4
Warehouse	-	17.9%	7.0%	30.5%	28.5%	16.1%	-	-	6
All Building Types	**9.3%**	**5.9%**	**21.7%**	**20.2%**	**18.9%**	**11.1%**	**5.2%**	**7.6%**	**183**

Table 30: Parking - Maximum Horizontal Illuminance Range

Building Type	% of Sites							
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 9.99 (FC)	10 to 14.99 (FC)	15 to 19.99 (FC)	20 to 50 (FC)
Apartments and Condominiums	22.6%	-	2.1%	15.1%	15.5%	-	-	-
Assembly	10.4%	23.0%	35.2%	13.9%	-	42.4%	16.3%	-
Full Service Restaurant	-	-	20.3%	20.3%	-	-	-	-
Grocery	-	-	-	-	-	-	-	-
Hospital	45.1%	-	-	38.0%	2.6%	-	17.3%	-
Hotel	11.0%	-	47.0%	48.2%	-	-	-	-
Industrial	6.1%	21.8%	-	12.6%	22.0%	19.5%	-	12.7%
Large Office	5.0%	26.3%	13.0%	23.2%	14.3%	-	-	26.3%
Large Retail	-	-	17.9%	26.6%	21.6%	30.2%	-	-
Large Schools	-	-	-	-	-	-	-	-
Recreation	-	-	38.7%	-	-	-	50.2%	35.7%
Small Office	3.2%	6.2%	8.9%	10.0%	8.3%	6.6%	6.7%	8.8%
Small Retail	21.3%	-	17.2%	12.1%	22.8%	9.1%	-	7.8%
Small School	-	1.2%	43.3%	-	43.3%	-	-	-
University	-	21.1%	-	32.8%	18.2%	-	-	-
Warehouse	-	27.0%	11.9%	38.5%	30.9%	24.8%	-	-
All Building Types	**4.8%**	**3.9%**	**6.6%**	**5.9%**	**6.0%**	**4.7%**	**3.6%**	**4.3%**

Table 31 Error Bounds: Parking - Maximum Horizontal Illuminance Range

Table 32 displays the percentage of sites with parking lot illuminance grid readings that average within specified footcandle ranges. These values were calculated using data collected from the site illumination grid per the methodology described in "Data Collection" section (page 64) under "Illuminance Measurement". The average illumination value for 52% of all parking lots is between 1 and 5 FC. The values in this table are interesting when compared to the Gas Station Canopy numbers presented in Table 19.

Building Type	% of Sites						Sample Size
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 7.99 (FC)	8 to 11 (FC)	
Apartments and Condominiums	81.7%	0.3%	18.1%	-	-	-	7
Assembly	21.1%	25.0%	44.2%	-	9.7%	-	7
Full Service Restaurant	-	-	100.0%	-	-	-	2
Grocery	-	-	-	100.0%	-	-	1
Hospital	54.0%	-	34.8%	11.2%	-	-	7
Hotel	57.2%	-	42.8%	-	-	-	4
Large Office	21.5%	2.6%	17.7%	48.0%	10.1%	-	19
Large Retail	25.7%	14.7%	40.8%	0.1%	18.7%	-	16
Large Schools	-	11.6%	60.6%	27.8%	-	-	11
Manufacturing	100.0%	-	-	-	-	-	1
Recreation	-	24.9%	-	22.3%	52.7%	-	3
Small Office	16.6%	16.1%	27.1%	27.3%	6.0%	6.9%	70
Small Retail	24.0%	9.6%	21.4%	29.9%	8.3%	6.7%	20
Small School	0.6%	69.1%	30.3%	-	-	-	5
University	10.8%	-	84.4%	4.8%	-	-	4
Warehouse	17.9%	30.5%	35.5%	-	-	16.1%	6
All Building Types	**21.5%**	**14.7%**	**30.5%**	**21.7%**	**7.7%**	**4.0%**	**183**

Table 32: Parking - Average Horizontal Illuminance Range

Building Type	% of Sites					
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 7.99 (FC)	8 to 11 (FC)
Apartments and Condominiums	22.2%	0.5%	22.1%	-	-	-
Assembly	25.6%	35.2%	40.7%	-	16.3%	-
Full Service Restaurant	-	-	-	-	-	-
Grocery	-	-	-	-	-	-
Hospital	45.1%	-	38.0%	17.9%	-	-
Hotel	48.2%	-	48.2%	-	-	-
Industrial	22.0%	4.4%	16.6%	23.3%	11.6%	-
Large Office	26.2%	13.1%	25.3%	0.1%	26.3%	-
Large Retail	-	13.8%	29.6%	30.1%	-	-
Large Schools	-	-	-	-	-	-
Recreation	-	38.7%	-	35.7%	50.2%	-
Small Office	9.0%	8.5%	9.5%	10.6%	4.9%	7.6%
Small Retail	21.3%	11.2%	17.5%	23.0%	8.3%	8.6%
Small School	1.2%	43.3%	43.3%	-	-	-
University	21.1%	-	25.9%	9.7%	-	-
Warehouse	27.0%	38.5%	32.7%	-	-	24.8%
All Building Types	**6.6%**	**5.4%**	**7.0%**	**6.6%**	**4.0%**	**3.2%**

Table 33 Error Bounds: Parking - Average Horizontal Illuminance Range

The data within Table 34 reconfigures the data in Table 32 to present the results by Lighting Zone. As one would expect, the illumination levels are lower in Lighting Zone 1 (rural) and higher in Lighting Zone 4 (urban). The results within Lighting Zone 2 (outer urban) and Lighting Zone 3 (urban residential) are very similar. The table below indicates the results in LZ 2, 3, and 4 are also very similar in the percentage of parking lots with average illuminances between 2.5 and 4.99 FC. Note that these zones are different than those defined in the California Outdoor Lighting Standards report dated June 6th, 2002, where Lighting Zone 1 includes national parks and wilderness, Lighting Zone 2 includes rural areas not qualifying as Zone 1, Lighting Zone 3 is defined as urban, and Lighting Zone 4 is a special high intensity area defined by the jurisdiction.

Zone	% of Sites						Sample Size
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 7.99 (FC)	8 to 11 (FC)	
Lighting Zone 1	11.4%	64.0%	6.4%	18.2%	-	-	18
Lighting Zone 2	24.4%	8.5%	38.8%	20.1%	8.2%	-	56
Lighting Zone 3	23.8%	10.0%	28.4%	23.3%	8.6%	5.9%	86
Lighting Zone 4	9.9%	7.0%	40.4%	21.7%	9.0%	12.0%	23
All Lighting Zones	**21.5%**	**14.7%**	**30.5%**	**21.7%**	**7.7%**	**4.0%**	**183**

Table 34: Parking - Average Horizontal Illumination

Zone	% of Sites					
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 7.99 (FC)	8 to 11 (FC)
Lighting Zone 1	10.9%	21.4%	7.8%	17.1%	-	-
Lighting Zone 2	12.6%	7.7%	14.0%	11.2%	6.4%	-
Lighting Zone 3	9.9%	5.5%	9.7%	10.1%	6.7%	5.8%
Lighting Zone 4	15.1%	8.0%	19.3%	15.7%	10.6%	14.4%
All Lighting Zones	**6.6%**	**5.4%**	**7.0%**	**6.6%**	**4.0%**	**3.2%**

Table 35 Error Bounds: Parking - Average Horizontal Illumination

Table 36 presents the parking illumination grid maximum values by footcandle range. There are significant percentages (7% and 10%) of extremely bright parking areas (20 to 50 FC) within the more rural lighting zones, LZ1 and LZ2.

Zone	% of Sites								Sample Size
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 9.99 (FC)	10 to 14.99 (FC)	15 to 19.99 (FC)	20 to 50 (FC)	
Lighting Zone 1	6.8%	4.7%	55.6%	12.3%	2.5%	11.6%	-	6.6%	18
Lighting Zone 2	11.6%	11.2%	4.8%	32.6%	17.7%	8.8%	3.0%	10.3%	56
Lighting Zone 3	9.9%	3.9%	26.5%	13.6%	21.9%	11.1%	7.1%	6.1%	86
Lighting Zone 4	-	-	16.0%	23.5%	25.3%	19.3%	7.6%	8.3%	23
All Lighting Zones	**9.3%**	**5.9%**	**21.7%**	**20.2%**	**18.9%**	**11.1%**	**5.2%**	**7.6%**	**183**

Table 36: Parking Maximum Horizontal Illumination

Zone	% of Sites							
	< 0.5 (FC)	0.5 to 0.99 (FC)	1 to 2.49 (FC)	2.5 to 4.99 (FC)	5 to 9.99 (FC)	10 to 14.99 (FC)	15 to 19.99 (FC)	20 to 50 (FC)
Lighting Zone 1	7.6%	7.7%	23.7%	14.6%	4.1%	13.9%	-	10.7%
Lighting Zone 2	9.1%	10.0%	4.2%	13.3%	10.2%	9.1%	4.8%	8.6%
Lighting Zone 3	7.5%	4.3%	10.0%	6.5%	9.6%	6.4%	6.3%	5.9%
Lighting Zone 4	-	-	16.0%	17.2%	15.2%	16.5%	8.9%	12.9%
All Lighting Zones	**4.8%**	**3.9%**	**6.6%**	**5.9%**	**6.0%**	**4.7%**	**3.6%**	**4.3%**

Table 37 Error Bounds: Parking Maximum Horizontal Illumination

Table 38 shows the percentage of sites with parking lots within uniformity ranges. The uniformity is the ratio of the maximum value to the minimum value recording for the parking illumination grid measurements. A higher value indicates a lower uniformity. For example, a large parking lot with one lamp providing light would have a high reading under the light and a low reading away from the lamp resulting in a high uniformity ratio. The table below indicates industrial sites, with 51.3% of sites in the greater than 30 range, have the poorest uniformity. Apartments and condominium parking areas have the best uniformity with 80.5% falling in the "less than 5" range. Statewide, 23.9% of parking lots have a poor uniformity value of over 30.

Building Type	% of Sites						Sample Size
	< 5	5 to 9.99	10 to 14.99	15 to 19.99	20 to 29.99	> = 30	
Apartments and Condominiums	80.5%	10.0%	-	9.2%	-	0.3%	7
Assembly	30.7%	0.9%	14.4%	8.1%	9.7%	36.1%	7
Full Service Restaurant	-	90.4%	-	9.6%	-	-	2
Grocery	-	-	100.0%	-	-	-	1
Hospital	66.9%	13.9%	-	19.2%	-	-	7
Hotel	6.1%	31.4%	-	42.8%	-	19.7%	4
Industrial	23.4%	0.1%	4.3%	12.6%	8.3%	51.3%	19
Large Office	38.5%	19.5%	3.2%	6.1%	28.6%	4.1%	16
Large Retail	26.4%	-	5.0%	51.5%	-	17.1%	11
Large Schools	-	-	-	100.0%	-	-	1
Recreation	-	-	-	77.7%	-	22.3%	3
Small Office	14.8%	20.8%	12.0%	7.1%	11.5%	33.7%	70
Small Retail	54.5%	21.5%	9.6%	6.0%	0.2%	8.2%	20
Small School	0.6%	-	48.1%	19.3%	-	32.0%	5
University	78.3%	10.8%	4.8%	-	6.2%	-	4
Warehouse	41.0%	-	18.5%	40.5%	-	-	6
All Building Types	**26.9%**	**16.1%**	**10.2%**	**15.6%**	**7.4%**	**23.9%**	**183**

Table 38: Parking - Uniformity Ranges

Building Type	% of Sites					
	< 5	5 to 9.99	10 to 14.99	15 to 19.99	20 to 29.99	> = 30
Apartments and Condominiums	22.6%	15.4%	-	15.5%	-	0.5%
Assembly	35.8%	1.7%	23.0%	13.9%	16.3%	42.4%
Full Service Restaurant	-	20.3%	-	20.3%	-	-
Grocery	-	-	-	-	-	-
Hospital	36.2%	22.1%	-	25.3%	-	-
Hotel	11.0%	43.1%	-	48.2%	-	31.3%
Industrial	21.9%	0.2%	7.1%	14.0%	8.8%	23.3%
Large Office	27.8%	15.6%	5.4%	9.9%	26.5%	6.8%
Large Retail	21.7%	-	8.3%	29.0%	-	24.9%
Large Schools	-	-	-	-	-	-
Recreation	-	-	-	35.7%	-	35.7%
Small Office	7.8%	9.1%	7.7%	5.8%	7.7%	11.3%
Small Retail	23.1%	22.9%	11.2%	9.6%	0.4%	8.4%
Small School	1.2%	-	49.9%	31.4%	-	43.5%
University	32.8%	21.1%	9.7%	-	12.4%	-
Warehouse	34.9%	-	27.7%	37.6%	-	-
All Building Types	**6.8%**	**6.2%**	**4.7%**	**5.7%**	**3.7%**	**6.5%**

Table 39 Error Bounds: Parking - Uniformity Ranges

Table 40 presents the uniformity data by lighting zone. Lighting zone 1 appears to have the least amount of uniformity problems, however there are also far fewer sample sites.

Zone	% of Sites						Sample Size
	< 5	5 to 9.99	10 to 14.99	15 to 19.99	20 to 29.99	> = 30	
Lighting Zone 1	17.5%	18.1%	36.1%	15.8%	-	12.6%	18
Lighting Zone 2	27.5%	11.5%	10.7%	10.6%	4.4%	35.2%	56
Lighting Zone 3	29.7%	18.7%	4.9%	16.9%	10.2%	19.6%	86
Lighting Zone 4	19.8%	15.2%	8.8%	25.0%	9.6%	21.5%	23
All Lighting Zones	**26.9%**	**16.1%**	**10.2%**	**15.6%**	**7.4%**	**23.9%**	**183**

Table 40: Parking – Uniformity by Lighting Zone

Zone	% of Sites					
	< 5	5 to 9.99	10 to 14.99	15 to 19.99	20 to 29.99	> = 30
Lighting Zone 1	18.8%	15.2%	26.4%	15.6%	-	12.9%
Lighting Zone 2	12.2%	8.3%	8.4%	10.6%	4.3%	13.9%
Lighting Zone 3	10.3%	10.4%	3.4%	8.1%	6.7%	8.2%
Lighting Zone 4	15.7%	11.3%	10.4%	18.0%	9.7%	18.7%
All Lighting Zones	**6.8%**	**6.2%**	**4.7%**	**5.7%**	**3.7%**	**6.5%**

Table 41 Error Bounds: Parking - Uniformity by Lighting Zone

Fixtures and Lamps

Table 42 displays the percentage of the total lamps installed for each building type, presented by lamp type. For example: 57.7% of all lamps installed in apartments and condominiums are compact fluorescent lamps. Similarly, 28.1% of all lamps installed in small retail are high pressure sodium lamps. Small offices have significant room for improvement. Incandescent lamps represent over 30% of outdoor lighting installed in this building type. The lamp types are abbreviated as follows: Compact Fluorescent (CFL), Fluorescent (FL), Halogen (HAL), High Pressure Sodium (HPS), Incandescent (INC), Low Pressure Sodium (LPS), Metal Halide (MH), Mercury Vapor (MV).

Building Type	% of Lamps									Sample Size
	No Lamps	CFL	FL	HAL	HPS	INC	LPS	MH	MV	
Apartments and Condominiums	-	57.7%	22.3%	1.3%	4.0%	14.4%	-	0.1%	0.1%	15
Assembly	-	13.9%	-	2.8%	25.6%	37.1%	-	13.8%	6.8%	11
Full Service Restaurant	-	58.2%	5.7%	3.6%	9.8%	14.8%	-	6.9%	1.0%	7
Grocery	-	-	55.2%	2.7%	36.8%	-	-	5.3%	-	3
Hospital	-	6.3%	18.8%	5.6%	37.1%	4.5%	-	15.3%	12.4%	8
Hotel	-	41.6%	0.7%	-	5.5%	39.4%	-	10.9%	1.8%	4
Industrial	0.6%	3.1%	1.0%	0.1%	37.9%	43.2%	1.0%	8.8%	4.4%	31
Large Office	0.1%	34.5%	8.1%	0.9%	8.3%	21.9%	0.3%	21.3%	4.5%	26
Large Retail	0.0%	2.3%	5.6%	0.4%	2.8%	48.7%	-	40.0%	0.3%	15
Large Schools	-	57.9%	-	2.5%	-	27.4%	-	12.2%	-	2
Recreation	0.0%	10.3%	16.2%	-	27.1%	19.7%	-	24.5%	2.2%	7
Small Office	0.1%	34.0%	7.5%	1.8%	12.2%	30.7%	3.2%	7.2%	3.3%	102
Small Retail	0.2%	15.6%	20.7%	2.5%	28.1%	15.1%	0.9%	13.4%	3.4%	42
Small School	-	10.9%	1.2%	-	68.5%	13.6%	-	4.1%	1.6%	6
University	-	8.4%	2.2%	3.6%	6.3%	21.1%	-	50.7%	7.7%	8
Warehouse	1.0%	5.0%	1.6%	2.2%	46.0%	19.1%	-	19.0%	6.1%	16
All Building Types	**0.1%**	**22.1%**	**9.3%**	**1.3%**	**14.3%**	**30.7%**	**0.8%**	**18.8%**	**2.6%**	**303**

Table 42: Installed Lamp Percentages for Each Building Type

Building Type	% of Lamps								
	No Lamps	CFL	FL	HAL	HPS	INC	LPS	MH	MV
Apartments and Condominiums	-	19.0%	22.0%	1.0%	3.2%	10.3%	-	0.1%	0.2%
Assembly	-	8.4%	-	4.5%	10.5%	12.6%	-	11.8%	3.5%
Full Service Restaurant	-	30.9%	10.5%	6.3%	15.5%	7.8%	-	3.0%	1.5%
Grocery	-	-	24.0%	5.5%	24.0%	-	-	1.6%	-
Hospital	-	7.5%	14.4%	5.0%	22.5%	4.0%	-	13.0%	16.7%
Hotel	-	25.7%	0.9%	-	5.6%	16.5%	-	13.4%	2.2%
Industrial	0.6%	3.4%	1.2%	0.1%	22.4%	25.2%	1.2%	3.5%	4.9%
Large Office	0.2%	9.5%	6.6%	0.7%	5.5%	5.9%	0.4%	7.8%	5.9%
Large Retail	0.1%	1.9%	5.0%	0.6%	2.7%	20.6%	-	15.0%	0.5%
Large Schools	-	8.5%	-	3.4%	-	17.4%	-	12.2%	-
Recreation	0.0%	14.2%	22.3%	-	18.2%	13.0%	-	27.5%	3.8%
Small Office	0.1%	11.8%	5.4%	1.3%	4.7%	8.9%	2.4%	3.5%	1.8%
Small Retail	0.3%	8.1%	13.4%	3.8%	19.7%	8.7%	1.3%	6.9%	2.4%
Small School	-	10.0%	2.4%	-	22.8%	2.3%	-	7.1%	3.3%
University	-	14.0%	3.7%	1.2%	3.0%	6.1%	-	13.2%	2.0%
Warehouse	1.7%	7.5%	2.4%	3.6%	18.7%	10.9%	-	18.3%	7.1%
All Building Types	**0.1%**	**5.8%**	**3.6%**	**0.6%**	**4.6%**	**8.6%**	**0.5%**	**5.0%**	**1.1%**

Table 43 Error Bounds: Installed Lamp Percentages for Each Building Type

Table 44 displays the distribution of lamps across FUAs. Incandescent lamps represent 30.8% of all lamps installed, and high pressure sodium lamps are the most frequently used lamps for security areas (41.2%). Although the results indicate that 84.9% of commercial outdoor patio lighting is incandescent, this result must be used with caution as the sample size is too small to draw statewide conclusions. This caution also applies to the ATM results. (See Table 48 for the sample sizes for each functional use area).

FUA	% of Lamps							
	CFL	FL	HAL	HPS	INC	LPS	MH	MV
ATM	32.1%	52.2%	-	9.4%	6.2%	-	-	-
Commercial Outdoor Patio	12.9%	-	-	-	84.9%	-	2.2%	-
Entry	36.8%	25.4%	1.6%	2.2%	30.4%	-	2.6%	0.8%
Façade & Aesthetic	17.7%	11.6%	14.3%	0.9%	27.7%	4.7%	18.5%	4.6%
Gas Station Canopy	-	2.4%	-	-	-	-	97.6%	-
Internal Roadway	16.5%	4.6%	0.3%	16.0%	38.9%	2.3%	20.4%	1.0%
Landscape	27.9%	-	2.7%	2.3%	51.6%	0.1%	6.6%	8.8%
Outdoor Retail Sales	-	3.7%	-	1.0%	-	-	95.4%	-
Parking	8.9%	6.7%	3.1%	26.8%	6.6%	2.9%	37.8%	7.2%
Pedestrian & Walkway	28.5%	10.0%	0.4%	9.2%	39.6%	0.0%	11.2%	1.1%
Recreation	10.8%	-	0.4%	15.1%	44.8%	-	28.6%	0.3%
Security	15.8%	0.3%	0.9%	41.2%	25.6%	1.0%	13.0%	2.4%
Storage	0.0%	26.4%	0.9%	37.6%	4.5%	-	27.6%	3.1%
Undeveloped	-	-	-	-	-	-	100.0%	-
All FUAs	**22.1%**	**9.3%**	**1.3%**	**14.3%**	**30.8%**	**0.8%**	**18.8%**	**2.6%**

Table 44: Lamp Types by Functional Use Area

FUA	% of Lamps							
	CFL	FL	HAL	HPS	INC	LPS	MH	MV
ATM	43.7%	47.8%	-	10.6%	6.0%	-	-	-
Commercial Outdoor Patio	2.0%	-	-	-	3.7%	-	4.8%	-
Entry	18.7%	15.9%	1.6%	1.6%	12.2%	-	2.2%	1.4%
Façade & Aesthetic	13.7%	16.7%	11.9%	1.3%	17.4%	7.5%	15.3%	7.5%
Gas Station Canopy	-	4.5%	-	-	-	-	4.5%	-
Internal Roadway	19.1%	7.0%	0.6%	10.7%	24.8%	2.1%	25.1%	1.4%
Landscape	18.1%	-	3.0%	1.8%	18.6%	0.2%	7.6%	9.6%
Outdoor Retail Sales	-	6.9%	-	1.2%	-	-	6.9%	-
Parking	6.5%	4.7%	1.7%	6.9%	2.8%	1.6%	10.3%	3.6%
Pedestrian & Walkway	10.0%	5.9%	0.3%	5.4%	14.1%	0.0%	6.6%	0.8%
Recreation	10.5%	-	0.7%	16.6%	26.8%	-	19.0%	0.5%
Security	11.7%	0.5%	1.0%	15.5%	18.6%	1.1%	7.3%	2.5%
Storage	0.1%	21.3%	1.5%	17.3%	3.1%	-	13.5%	3.1%
Undeveloped	-	-	-	-	-	-	-	-
All FUAs	**5.3%**	**3.5%**	**0.5%**	**3.8%**	**9.1%**	**0.4%**	**4.5%**	**1.0%**

Table 45 Error Bounds: Lamp Types by Functional Use Area

Table 46 explains where the various lamp types can be found. Mercury vapor, for example, are most frequently located in parking lots. 70.1% of incandescent lamps are used to illuminate pedestrian & walkways, and 68.1% of low pressure sodium lamps are used to light parking lots.

FUA	% of Lamps							
	CFL	FL	HAL	HPS	INC	LPS	MH	MV
Parking	7.4%	13.4%	42.8%	34.7%	3.9%	68.1%	37.2%	50.7%
Pedestrian & Walkway	70.1%	58.7%	14.8%	34.8%	70.1%	2.2%	32.4%	23.3%
Landscape	4.3%	-	7.0%	0.5%	5.7%	0.6%	1.2%	11.3%
Outdoor Retail Sales	-	0.6%	-	0.1%	-	-	8.3%	-
Internal Roadway	2.7%	1.8%	0.9%	4.0%	4.5%	10.4%	3.9%	1.4%
Storage	0.0%	7.4%	1.8%	6.8%	0.4%	-	3.8%	3.1%
ATM	0.4%	1.5%	-	0.2%	0.1%	-	-	-
Recreation	1.2%	-	0.7%	2.7%	3.7%	-	3.8%	0.3%
Undeveloped	-	-	-	-	-	-	0.1%	-
Façade & Aesthetic	1.7%	2.6%	22.4%	0.1%	1.9%	12.3%	2.0%	3.6%
Security	3.8%	0.2%	3.5%	15.3%	4.4%	6.5%	3.7%	4.8%
Entry	8.4%	13.7%	6.3%	0.8%	5.0%	-	0.7%	1.6%
Gas Station Canopy	-	0.1%	-	-	-	-	2.8%	-
Commercial Outdoor Patio	0.1%	-	-	-	0.4%	-	0.0%	-
Lamp Type Sample Size	**113**	**57**	**37**	**178**	**156**	**15**	**133**	**56**

Table 46: Distribution of Lamp Types by Functional Use Area

FUA	% of Lamps							
	CFL	FL	HAL	HPS	INC	LPS	MH	MV
Parking	5.4%	9.5%	12.6%	8.9%	2.3%	13.0%	9.2%	12.7%
Pedestrian & Walkway	8.7%	16.6%	9.7%	11.1%	14.6%	3.2%	15.8%	11.4%
Landscape	3.2%	-	7.7%	0.4%	3.9%	1.0%	1.4%	11.0%
Outdoor Retail Sales	-	1.1%	-	0.2%	-	-	8.6%	-
Internal Roadway	3.4%	2.7%	1.6%	2.1%	3.9%	3.9%	5.1%	1.8%
Storage	0.0%	9.1%	2.9%	3.9%	0.3%	-	2.2%	2.8%
ATM	0.6%	2.4%	-	0.2%	0.1%	-	-	-
Recreation	1.0%	-	1.2%	2.7%	4.0%	-	3.4%	0.4%
Undeveloped	-	-	-	-	-	-	0.2%	-
Façade & Aesthetic	1.4%	4.1%	12.9%	0.2%	1.6%	15.7%	1.7%	6.0%
Security	3.0%	0.3%	3.9%	4.9%	4.4%	6.2%	2.3%	5.0%
Entry	6.0%	9.8%	6.0%	0.5%	2.8%	-	0.7%	2.6%
Gas Station Canopy	-	0.2%	-	-	-	-	2.7%	-
Commercial Outdoor Patio	0.2%	-	-	-	0.7%	-	0.0%	-

Table 47 Error Bound: Distribution of Lamps by Functional Use Areas

Table 48 displays the percentage of FUAs having a certain lamp type. Mercury vapor lamps can be found in 14% of parking lots and 19.1% of storage areas statewide. 48.3% of parking lots have high pressure sodium lamps. Incandescent lamps are utilized in almost 70% of building entrances.

FUA	% of FUAs								Sample Size
	CFL	FL	HAL	HPS	INC	LPS	MH	MV	
ATM	26.8%	56.0%	-	44.0%	46.8%	-	-	-	5
Commercial Outdoor Patio	31.3%	-	-	-	68.8%	-	31.3%	-	3
Entry	21.0%	12.7%	2.9%	10.5%	63.2%	-	5.9%	0.6%	71
Façade & Aesthetic	19.9%	7.0%	18.1%	1.1%	37.5%	2.1%	24.2%	6.5%	35
Gas Station Canopy	-	19.5%	-	-	-	-	80.5%	-	7
Internal Roadway	5.9%	3.7%	1.4%	40.2%	27.3%	13.3%	12.5%	5.0%	37
Landscape	30.1%	-	9.1%	11.7%	48.8%	0.6%	9.2%	5.1%	46
Outdoor Retail Sales	-	17.3%	-	26.9%	-	-	82.7%	-	4
Parking	8.2%	3.9%	8.5%	48.3%	15.4%	5.3%	31.1%	14.0%	221
Pedestrian & Walkway	44.1%	13.3%	3.4%	27.0%	50.8%	0.5%	20.1%	7.1%	201
Recreation	16.7%	-	4.6%	27.7%	45.4%	-	25.8%	1.7%	25
Security	20.0%	2.3%	1.7%	59.9%	27.7%	2.7%	21.7%	3.7%	91
Storage	0.3%	9.0%	4.3%	59.1%	18.5%	-	30.7%	19.1%	31
Undeveloped	-	-	-	-	-	-	100.0%	-	1
All FUAs	**21.6%**	**7.3%**	**5.6%**	**35.3%**	**35.2%**	**2.6%**	**22.4%**	**8.0%**	**778**

Table 48: Percentage of Functional Use Area Utilizing Lamp Type

FUA	% of FUAs							
	CFL	FL	HAL	HPS	INC	LPS	MH	MV
ATM	38.9%	43.9%	-	43.9%	47.3%	-	-	-
Commercial Outdoor Patio	43.3%	-	-	-	43.3%	-	43.3%	-
Entry	10.3%	8.1%	3.3%	6.7%	11.9%	-	5.2%	0.9%
Façade & Aesthetic	13.3%	10.8%	13.7%	1.6%	17.6%	3.4%	14.1%	10.2%
Gas Station Canopy	-	29.6%	-	-	-	-	29.6%	-
Internal Roadway	5.6%	4.5%	2.2%	15.7%	15.6%	9.6%	11.0%	5.0%
Landscape	16.2%	-	7.8%	7.4%	15.8%	1.1%	7.4%	5.2%
Outdoor Retail Sales	-	27.2%	-	37.7%	-	-	27.2%	-
Parking	4.3%	2.4%	3.9%	7.0%	5.5%	2.9%	6.4%	4.9%
Pedestrian & Walkway	7.4%	4.4%	2.0%	6.5%	7.4%	0.6%	5.4%	3.5%
Recreation	15.0%	-	7.5%	18.6%	20.8%	-	18.9%	2.8%
Security	9.7%	3.7%	1.8%	11.0%	10.7%	2.6%	8.5%	3.2%
Storage	0.5%	10.2%	7.0%	17.2%	14.8%	-	14.7%	14.2%
Undeveloped	-	-	-	-	-	-	-	-
All FUAs	**3.2%**	**1.8%**	**1.6%**	**3.6%**	**3.7%**	**1.0%**	**3.0%**	**2.0%**

Table 49 Error Bounds: Percentage of Functional Use Area Utilizing Lamp Type

Table 50 provides the list of fixture types for use with the following tables. The fixture catalogue, complete with pictures, is included in Error! Reference source not found.. Table 51 illustrates the percentage of FUAs having certain fixture types. 38.7% of parking lots are equipped with Fixture Type A ("shoebox" style). Wall packs (type P) are the next most common fixture for parking lots at 19.3%. The most common fixture type for façade and aesthetic is the PAR lamp holder (type U) at 33%. The most commonly found fixture type for all FUAs is the "wall pack" at 18%, followed by the "shoe box" at 14.5%. The "barnyard" fixtures (type E) are represented in most of the functional use areas. These fixtures frequently have the inefficient mercury vapor lamps.

Table 53 is similar to Table 51 except that it presents the percentage of FUAs illuminated by each fixture type. For example, 64.2% of Gas Station Canopy Areas are illuminated using "drop lens canopy" lights (type N). The remaining 35.8% of the areas are illuminated using "small dropped lens canopy" lights (type O), "fluorescent wrap" (type AA), and "dropped lens downlight" for smaller lamps (DD). Internal roadways are significant users of "pole mounted globe area lights" (type CC) which are a concern to "night sky" proponents.

Fixture Types (See "Fixture Catalogue" for wattages and pictures)		
Type	**Description**	**Common Lamp Types**
A	Shoebox' style with horizontal lamp	HPS, MH
B	Hockey Puck' style with horizontal lamp	HPS, MH
C	Parking lot fixture with vertical lamp	HPS, MH
D	Cube' fixture with vertical lamp	HPS, MH
E	Barnyard' style fixture with vertical lamp	HPS, MH, MV
F	Flat Lens 'Cobra Head' style with horizontal lamp	HPS, MH
G	Drop Lens 'Cobra Head' style with horizontal lamp	HPS, MH, MV
H	Decorative lantern with optical tray	HPS, MH
I	Decorative lantern with refractor optics	HPS, MH
J	Cutoff decorative fixture	HPS, MH, INC
K	Sports floodlight fixture	MH
L	Floodlight	HPS, MH, Q
M	Floodlight with optics	HPS, MH
N	Dropped lens canopy or wall light	HPS, MH
O	Small, dropped lens canopy or wall light	HPS, MH, CFL, INC
P	Wall Pack' Fixture	HPS, MH
Q	Cutoff 'Wall Pack' fixture	HPS, MH, CFL
R	Cylinder' fixture	HPS, MH, CFL, INC
S	Bollard	HPS, MH, CFL
T	Jelly Jar' or 'Globe' surface mount	CFL, INC
U	PAR lamp Holder	MV, INC
V	RLM Shade (Decorative)	INC
W	Open Downlight	HPS, MH, INC, CFL
X	Lensed Downlight	HPS, MH, INC, CFL
Y	Fluorescent one lamp 'Strip'	FL
Z	Fluorescent two lamp 'Strip'	FL
AA	Fluorescent 'Wrap'	FL
BB	Fluorescent 'Waterproof Wrap'	FL
CC	Pole mounted 'Globe' area light	HPS, MH, INC, CFL
DD	Dropped lens downlight	HPS, MH, INC, CFL
EE	Decorative incandescent string lights	INC
FF	Steplight'	HPS, MH, INC, CFL
GG	Pole mounted light with angled head	MV, FL
HH	2x2 Fluorescent 'Troffer'	FL
JJ	2x4 Fluorescent 'Troffer'	FL
KK	Decorative landscape Path Light	INC
LL	Low voltage landscape/accent light	INC
MM	Wall mounted 'Bullseye' or 'Bulkhead'	MH, INC, CFL
NN	In-grade mounted 'Well light'	HPS, MH, INC
OO	Decorative 'steplight' or bollard	VARIOUS
PP	Custom or decorative sconce	VARIOUS
QQ	Fluorescent floodlight for landscape or signage	FL, CFL

Table 50: Fixture Types

Fixture Type	% of FUAs														
	ATM	**Commercial Outdoor Patio**	**Entry**	**Façade & Aesthetic**	**Gas Station Canopy**	**Internal Roadway**	**Landscape**	**Outdoor Retail Sales**	**Parking**	**Pedestrian & Walkway**	**Recreation**	**Security**	**Storage**	**Un-developed**	**All FUAs**
Type A	-	-	0.6%	-	-	14.5%	-	55.8%	38.7%	2.0%	19.5%	7.7%	10.5%	100.0%	**14.5%**
Type B	-	-	-	-	-	7.5%	0.7%	-	2.1%	0.2%	1.2%	-	1.3%	-	**1.1%**
Type C	-	-	0.8%	-	-	-	-	-	1.3%	0.5%	1.7%	-	-	-	**0.6%**
Type D	-	-	-	-	-	-	1.2%	-	0.6%	0.8%	-	-	-	-	**0.4%**
Type E	-	31.3%	-	-	-	3.9%	-	-	12.0%	6.2%	1.7%	13.0%	22.5%	-	**7.9%**
Type F	-	-	-	-	-	-	2.2%	-	1.8%	-	-	-	-	-	**0.7%**
Type G	-	-	-	-	-	1.7%	-	-	5.3%	-	7.4%	0.5%	-	-	**1.9%**
Type H	-	-	-	-	-	0.4%	0.2%	-	0.3%	0.6%	-	-	-	-	**0.3%**
Type I	-	-	5.5%	6.1%	-	8.6%	5.7%	-	1.9%	11.6%	20.4%	0.5%	-	-	**5.7%**
Type J	-	-	2.8%	-	-	-	-	-	0.3%	0.2%	-	-	-	-	**0.4%**
Type K	-	-	-	-	-	-	-	-	1.3%	0.0%	9.2%	-	-	-	**0.7%**
Type L	-	-	0.6%	22.8%	-	6.2%	20.9%	-	16.2%	11.9%	7.9%	12.8%	9.5%	-	**12.5%**
Type M	-	-	0.6%	23.5%	-	3.6%	5.9%	60.0%	14.0%	4.8%	15.5%	9.5%	31.6%	-	**10.2%**
Type N	-	-	1.8%	-	80.5%	1.3%	-	-	1.9%	5.9%	-	4.9%	14.7%	-	**4.0%**
Type O	-	-	2.4%	-	33.0%	-	-	-	2.2%	11.6%	8.7%	2.9%	-	-	**4.6%**
Type P	44.0%	-	2.7%	-	-	27.3%	5.9%	22.8%	19.3%	14.0%	0.2%	47.6%	34.6%	-	**18.4%**
Type Q	-	-	1.8%	0.9%	-	-	-	-	0.2%	1.9%	0.2%	-	-	-	**0.8%**
Type R	-	-	5.7%	4.4%	-	-	2.7%	-	2.0%	6.8%	-	0.5%	-	-	**3.2%**
Type S	-	-	2.0%	-	-	7.8%	1.7%	-	0.5%	7.1%	8.6%	2.0%	-	-	**3.1%**
Type T	-	31.3%	9.7%	-	-	6.0%	1.6%	-	1.1%	14.5%	7.2%	6.6%	7.0%	-	**6.6%**
Type U	46.8%	68.8%	5.6%	33.8%	-	2.4%	23.3%	-	10.4%	9.6%	19.5%	16.6%	10.2%	-	**12.6%**
Type V	-	-	7.4%	0.9%	-	-	-	-	-	1.5%	16.2%	-	-	-	**1.7%**
Type W	26.8%	-	32.5%	5.7%	-	-	8.2%	-	1.2%	28.1%	-	3.6%	-	-	**11.8%**
Type X	-	-	23.3%	5.9%	-	1.3%	15.0%	-	-	18.1%	3.6%	12.9%	-	-	**9.7%**
Type Y	-	-	1.6%	0.2%	-	2.4%	-	-	1.9%	3.1%	-	-	-	-	**1.6%**
Type Z	-	-	3.3%	6.9%	-	1.3%	-	17.3%	0.6%	6.2%	-	2.3%	-	-	**2.7%**
Type AA	-	-	-	-	19.5%	-	-	-	0.4%	0.9%	-	-	5.5%	-	**0.7%**
Type BB	-	-	4.4%	-	-	1.3%	-	-	-	2.2%	-	-	-	-	**1.0%**
Type CC	-	-	0.6%	7.2%	-	7.6%	7.5%	-	2.4%	6.7%	1.6%	0.3%	-	-	**3.6%**
Type DD	-	-	2.9%	-	28.2%	-	2.0%	-	-	9.4%	-	0.9%	-	-	**3.0%**
Type EE	-	-	-	-	-	-	-	-	-	0.2%	-	-	-	-	**0.1%**
Type FF	-	-	0.4%	-	-	6.2%	-	-	0.6%	6.9%	-	-	-	-	**2.2%**
Type GG	-	-	-	-	-	-	-	-	1.0%	0.4%	-	-	-	-	**0.4%**
Type HH	-	-	2.1%	-	-	-	-	-	0.3%	0.0%	-	-	-	-	**0.3%**
Type JJ	56.0%	-	4.5%	-	-	-	-	-	1.0%	1.0%	-	-	3.5%	-	**1.5%**
Type KK	-	-	-	-	-	1.5%	16.3%	-	-	1.3%	0.2%	-	-	-	**1.4%**
Type LL	-	-	-	2.4%	-	6.6%	2.7%	-	-	-	-	-	-	-	**0.6%**
Type MM	-	-	-	-	-	-	-	-	-	1.6%	-	-	-	-	**0.4%**
Type NN	-	-	1.8%	2.9%	-	-	4.3%	-	-	2.4%	-	-	-	-	**1.2%**
Type OO	-	-	0.9%	-	-	-	2.7%	-	-	2.8%	-	-	-	-	**1.0%**
Type PP	-	31.3%	3.2%	3.3%	-	1.4%	-	-	2.0%	7.0%	10.6%	-	-	-	**3.3%**
Type QQ	-	-	-	-	-	-	5.5%	-	-	0.3%	-	-	-	-	**0.4%**

Table 51: Functional Use Areas with Fixture Types

Fixture Type	% of FUAs														
	ATM	**Commercial Outdoor Patio**	**Entry**	**Façade & Aesthetic**	**Gas Station Canopy**	**Internal Roadwa y**	**Landscape**	**Outdoor Retail Sales**	**Parking**	**Pedestrian & Walkway**	**Recreation**	**Security**	**Storage**	**Un-developed**	**All FUAs**
Type A	-	-	1.0%	-	-	10.9%	-	41.4%	6.6%	1.5%	16.3%	4.7%	7.9%	-	**2.4%**
Type B	-	-	-	-	-	10.2%	1.1%	-	1.7%	0.3%	2.0%	-	2.2%	-	**0.7%**
Type C	-	-	1.4%	-	-	-	-	-	1.3%	0.9%	2.9%	-	-	-	**0.5%**
Type D	-	-	-	-	-	-	2.1%	-	1.0%	1.3%	-	-	-	-	**0.4%**
Type E	-	43.3%	-	-	-	4.7%	-	-	5.0%	3.9%	2.8%	7.7%	15.2%	-	**2.2%**
Type F	-	-	-	-	-	-	3.7%	-	1.4%	-	-	-	-	-	**0.5%**
Type G	-	-	-	-	-	2.6%	-	-	2.9%	-	11.7%	0.8%	-	-	**0.9%**
Type H	-	-	-	-	-	0.6%	0.4%	-	0.4%	0.7%	-	-	-	-	**0.2%**
Type I	-	-	5.8%	7.2%	-	10.5%	5.4%	-	1.5%	5.2%	17.0%	0.8%	-	-	**1.8%**
Type J	-	-	4.6%	-	-	-	-	-	0.5%	0.4%	-	-	-	-	**0.5%**
Type K	-	-	-	-	-	-	-	-	1.6%	0.0%	11.8%	-	-	-	**0.6%**
Type L	-	-	1.1%	15.8%	-	6.3%	15.2%	-	5.2%	4.9%	8.6%	7.4%	9.5%	-	**2.6%**
Type M	-	-	1.0%	14.9%	-	4.3%	5.9%	39.8%	4.8%	2.2%	16.7%	5.7%	15.5%	-	**2.1%**
Type N	-	-	2.2%	-	29.6%	2.2%	-	-	2.0%	3.2%	-	4.3%	12.9%	-	**1.4%**
Type O	-	-	2.5%	-	41.4%	-	-	-	2.0%	4.4%	13.5%	3.2%	-	-	**1.5%**
Type P	43.9%	-	4.3%	-	-	13.3%	5.8%	33.6%	5.3%	5.0%	0.3%	11.2%	15.8%	-	**2.8%**
Type Q	-	-	3.0%	1.5%	-	-	-	-	0.3%	1.8%	0.4%	-	-	-	**0.5%**
Type R	-	-	5.7%	7.1%	-	-	4.4%	-	2.1%	3.3%	-	0.9%	-	-	**1.2%**
Type S	-	-	3.3%	-	-	10.3%	2.8%	-	0.7%	3.1%	11.6%	3.2%	-	-	**1.1%**
Type T	-	43.3%	9.1%	-	-	7.7%	2.6%	-	1.1%	5.7%	11.4%	6.3%	9.0%	-	**2.0%**
Type U	47.3%	43.3%	5.2%	18.3%	-	4.0%	12.7%	-	4.9%	3.9%	16.5%	9.4%	12.8%	-	**2.7%**
Type V	-	-	8.3%	1.6%	-	-	-	-	-	1.5%	14.8%	-	-	-	**1.1%**
Type W	38.9%	-	11.7%	6.9%	-	-	6.7%	-	1.2%	6.5%	-	5.3%	-	-	**2.3%**
Type X	-	-	10.7%	5.5%	-	2.2%	11.5%	-	-	5.8%	4.6%	7.9%	-	-	**2.3%**
Type Y	-	-	2.0%	0.3%	-	3.9%	-	-	2.0%	2.2%	-	-	-	-	**0.8%**
Type Z	-	-	5.3%	10.8%	-	2.2%	-	27.2%	0.7%	3.4%	-	3.7%	-	-	**1.2%**
Type AA	-	-	-	-	29.6%	-	-	-	0.7%	0.9%	-	-	8.7%	-	**0.6%**
Type BB	-	-	4.9%	-	-	2.2%	-	-	-	1.7%	-	-	-	-	**0.6%**
Type CC	-	-	1.1%	7.0%	-	10.1%	8.7%	-	1.9%	3.5%	2.7%	0.6%	-	-	**1.3%**
Type DD	-	-	3.4%	-	38.2%	-	3.0%	-	-	5.3%	-	1.5%	-	-	**1.5%**
Type EE	-	-	-	-	-	-	-	-	-	0.4%	-	-	-	-	**0.1%**
Type FF	-	-	0.7%	-	-	7.5%	-	-	0.7%	4.3%	-	-	-	-	**1.2%**
Type GG	-	-	-	-	-	-	-	-	1.6%	0.6%	-	-	-	-	**0.5%**
Type HH	-	-	3.3%	-	-	-	-	-	0.5%	0.0%	-	-	-	-	**0.4%**
Type JJ	43.9%	-	5.7%	-	-	-	-	-	1.0%	1.3%	-	-	5.7%	-	**0.9%**
Type KK	-	-	-	-	-	2.5%	13.0%	-	-	1.4%	0.4%	-	-	-	**1.0%**
Type LL	-	-	-	3.9%	-	10.4%	4.4%	-	-	-	-	-	-	-	**0.6%**
Type MM	-	-	-	-	-	-	-	-	-	1.9%	-	-	-	-	**0.5%**
Type NN	-	-	3.0%	2.8%	-	-	5.3%	-	-	2.2%	-	-	-	-	**0.7%**
Type OO	-	-	1.5%	-	-	-	4.4%	-	-	2.5%	-	-	-	-	**0.7%**
Type PP	-	43.3%	4.5%	4.2%	-	2.2%	-	-	2.4%	4.0%	13.7%	-	-	-	**1.4%**
Type QQ	-	-	-	-	-	-	7.0%	-	-	0.5%	-	-	-	-	**0.5%**

Table 52 Error Bounds: Functional Use Areas with Fixture Types

Fixture Type	% of Fixture Types														
	ATM	**Commercial Outdoor Patio**	**Entry**	**Façade & Aesthetic**	**Gas Station Canopy**	**Internal Roadway**	**Landscape**	**Outdoor Retail Sales**	**Parking**	**Pedestrian & Walkway**	**Recreation**	**Security**	**Storage**	**Undeveloped**	**All FUAs**
Type A	-	-	0.6%	-	-	5.5%	-	51.5%	35.1%	0.4%	11.1%	1.3%	11.8%	100.0%	8.6%
Type B	-	-	-	-	-	3.2%	0.2%	-	3.9%	0.1%	0.2%	-	0.9%	-	0.9%
Type C	-	-	0.7%	-	-	-	-	-	1.7%	0.0%	1.0%	-	-	-	0.4%
Type D	-	-	-	-	-	-	0.3%	-	0.3%	0.0%	-	-	-	-	0.1%
Type E	-	2.2%	-	-	-	1.0%	-	-	3.5%	0.4%	0.3%	3.1%	3.3%	-	1.2%
Type F	-	-	-	-	-	-	0.5%	-	0.7%	-	-	-	-	-	0.2%
Type G	-	-	-	-	-	0.7%	-	-	5.6%	-	1.2%	0.3%	-	-	1.1%
Type H	-	-	-	-	-	0.1%	0.0%	-	0.1%	13.5%	-	-	-	-	7.4%
Type I	-	-	2.0%	1.1%	-	19.7%	1.2%	-	1.9%	2.3%	5.3%	0.1%	-	-	2.6%
Type J	-	-	1.3%	-	-	-	-	-	0.1%	0.8%	-	-	-	-	0.5%
Type K	-	-	-	-	-	-	-	-	0.3%	0.0%	19.1%	-	-	-	0.6%
Type L	-	-	0.5%	13.5%	-	3.6%	10.1%	-	7.5%	2.2%	1.3%	4.3%	2.4%	-	3.7%
Type M	-	-	0.1%	22.5%	-	2.3%	5.3%	44.1%	7.5%	0.5%	10.5%	8.9%	23.4%	-	4.5%
Type N	-	-	0.6%	-	64.2%	0.6%	-	-	1.0%	2.5%	-	1.9%	9.6%	-	2.3%
Type O	-	-	0.5%	-	12.3%	-	-	-	3.3%	3.9%	0.7%	0.6%	-	-	2.9%
Type P	15.4%	-	0.3%	-	-	5.8%	1.5%	0.8%	8.5%	2.4%	0.0%	36.5%	29.1%	-	5.9%
Type Q	-	-	0.2%	0.8%	-	-	-	-	0.1%	0.5%	0.0%	-	-	-	0.3%
Type R	-	-	1.8%	4.5%	-	-	2.4%	-	0.7%	2.3%	-	14.7%	-	-	2.4%
Type S	-	-	0.5%	-	-	10.7%	0.2%	-	0.1%	3.4%	3.5%	0.3%	-	-	2.4%
Type T	-	66.8%	21.9%	-	-	7.3%	0.9%	-	2.4%	7.0%	0.6%	1.9%	1.5%	-	5.9%
Type U	10.1%	9.5%	1.4%	23.6%	-	0.4%	13.1%	-	3.6%	2.6%	12.7%	7.3%	2.9%	-	4.0%
Type V	-	-	1.2%	0.1%	-	-	-	-	-	0.6%	22.7%	-	-	-	1.0%
Type W	52.3%	-	27.5%	4.2%	-	-	7.7%	-	1.0%	17.9%	-	1.5%	-	-	11.8%
Type X	-	-	16.0%	6.3%	-	0.2%	13.4%	-	-	6.9%	3.0%	15.4%	-	-	6.0%
Type Y	-	-	1.9%	0.2%	-	0.3%	-	-	3.8%	2.0%	-	-	-	-	1.9%
Type Z	-	-	0.4%	6.2%	-	1.6%	-	3.7%	0.3%	2.3%	-	0.3%	-	-	1.6%
Type AA	-	-	-	-	2.4%	-	-	-	0.1%	0.2%	-	-	11.0%	-	0.4%
Type BB	-	-	14.5%	-	-	0.8%	-	-	-	0.3%	-	-	-	-	0.9%
Type CC	-	-	1.2%	6.3%	-	10.3%	1.7%	-	1.6%	4.7%	1.6%	0.8%	-	-	3.6%
Type DD	-	-	0.5%	-	21.1%	-	2.5%	-	-	6.8%	-	0.9%	-	-	4.0%
Type EE	-	-	-	-	-	-	-	-	-	5.6%	-	-	-	-	3.0%
Type FF	-	-	0.3%	-	-	9.6%	-	-	2.0%	2.4%	-	-	-	-	2.0%
Type GG	-	-	-	-	-	-	-	-	0.9%	0.0%	-	-	-	-	0.2%
Type HH	-	-	0.5%	-	-	-	-	-	0.3%	0.0%	-	-	-	-	0.1%
Type JJ	22.3%	-	1.4%	-	-	-	-	-	1.1%	1.5%	-	-	4.2%	-	1.2%
Type KK	-	-	-	-	-	1.9%	9.5%	-	-	0.2%	0.1%	-	-	-	0.5%
Type LL	-	-	-	3.7%	-	13.9%	6.3%	-	-	-	-	-	-	-	0.8%
Type MM	-	-	-	-	-	-	-	-	-	0.2%	-	-	-	-	0.1%
Type NN	-	-	0.2%	3.8%	-	-	19.8%	-	-	0.8%	-	-	-	-	1.2%
Type OO	-	-	0.6%	-	-	-	1.2%	-	-	0.5%	-	-	-	-	0.3%
Type PP	-	21.6%	1.1%	3.3%	-	0.4%	-	-	0.9%	2.2%	5.2%	-	-	-	1.7%
Type QQ	-	-	-	-	-	-	2.3%	-	-	0.1%	-	-	-	-	0.1%

Table 53: Fixture Types within Functional Use Areas

Fixture Type	% of Fixture Types														
	ATM	**Commercial Outdoor Patio**	**Entry**	**Façade & Aesthetic**	**Gas Station Canopy**	**Internal Roadway**	**Landscape**	**Outdoor Retail Sales**	**Parking**	**Pedestrian & Walkway**	**Recreation**	**Security**	**Storage**	**Undevelope d**	**All FUAs**
Type A	-	-	1.0%	-	-	5.5%	-	49.5%	9.2%	0.4%	6.6%	1.0%	11.4%	-	3.0%
Type B	-	-	-	-	-	4.0%	0.3%	-	3.0%	0.1%	0.3%	-	1.5%	-	0.6%
Type C	-	-	1.1%	-	-	-	-	-	2.0%	0.1%	1.6%	-	-	-	0.4%
Type D	-	-	-	-	-	-	0.5%	-	0.5%	0.1%	-	-	-	-	0.1%
Type E	-	4.8%	-	-	-	1.5%	-	-	2.3%	0.3%	0.5%	2.0%	2.8%	-	0.5%
Type F	-	-	-	-	-	-	0.8%	-	0.7%	-	-	-	-	-	0.1%
Type G	-	-	-	-	-	1.2%	-	-	6.8%	-	2.0%	0.5%	-	-	1.3%
Type H	-	-	-	-	-	0.1%	0.0%	-	0.2%	19.5%	-	-	-	-	11.2%
Type I	-	-	2.0%	1.3%	-	20.2%	1.3%	-	1.7%	1.5%	4.0%	0.1%	-	-	1.2%
Type J	-	-	2.2%	-	-	-	-	-	0.2%	1.4%	-	-	-	-	0.8%
Type K	-	-	-	-	-	-	-	-	0.3%	0.0%	20.8%	-	-	-	0.6%
Type L	-	-	0.8%	12.2%	-	4.7%	9.7%	-	3.2%	1.7%	1.4%	2.9%	2.6%	-	1.3%
Type M	-	-	0.1%	17.4%	-	2.7%	6.7%	49.7%	3.5%	0.3%	12.4%	6.5%	14.9%	-	1.7%
Type N	-	-	0.9%	-	20.1%	1.0%	-	-	1.0%	2.0%	-	1.6%	8.1%	-	1.2%
Type O	-	-	0.5%	-	13.3%	-	-	-	4.9%	2.7%	1.2%	0.6%	-	-	1.7%
Type P	9.0%	-	0.5%	-	-	4.2%	1.6%	1.5%	3.5%	2.4%	0.0%	14.4%	12.7%	-	2.0%
Type Q	-	-	0.3%	1.3%	-	-	-	-	0.2%	0.5%	0.1%	-	-	-	0.3%
Type R	-	-	1.6%	7.3%	-	-	3.8%	-	0.8%	1.1%	-	20.9%	-	-	1.4%
Type S	-	-	0.8%	-	-	14.8%	0.3%	-	0.1%	2.5%	3.2%	0.4%	-	-	1.4%
Type T	-	10.1%	22.9%	-	-	8.7%	1.4%	-	3.7%	4.0%	1.0%	1.9%	1.6%	-	2.6%
Type U	15.8%	10.7%	1.4%	17.0%	-	0.6%	8.8%	-	1.9%	1.7%	9.6%	5.0%	3.5%	-	1.2%
Type V	-	-	1.4%	0.2%	-	-	-	-	-	0.9%	21.2%	-	-	-	1.0%
Type W	40.7%	-	13.1%	4.9%	-	-	6.9%	-	1.3%	8.3%	-	2.1%	-	-	4.2%
Type X	-	-	10.8%	7.1%	-	0.3%	11.9%	-	-	2.8%	4.6%	9.2%	-	-	1.7%
Type Y	-	-	2.6%	0.3%	-	0.6%	-	-	3.9%	2.1%	-	-	-	-	1.3%
Type Z	-	-	0.6%	9.5%	-	2.7%	-	6.9%	0.4%	1.8%	-	0.5%	-	-	1.0%
Type AA	-	-	-	-	4.5%	-	-	-	0.2%	0.2%	-	-	14.2%	-	0.5%
Type BB	-	-	12.6%	-	-	1.3%	-	-	-	0.3%	-	-	-	-	0.7%
Type CC	-	-	1.9%	8.2%	-	15.7%	2.0%	-	1.8%	5.1%	2.7%	1.3%	-	-	3.0%
Type DD	-	-	0.6%	-	29.0%	-	3.8%	-	-	5.4%	-	1.4%	-	-	2.9%
Type EE	-	-	-	-	-	-	-	-	-	8.0%	-	-	-	-	4.6%
Type FF	-	-	0.5%	-	-	11.4%	-	-	2.8%	1.8%	-	-	-	-	1.2%
Type GG	-	-	-	-	-	-	-	-	1.5%	0.1%	-	-	-	-	0.3%
Type HH	-	-	0.8%	-	-	-	-	-	0.6%	0.0%	-	-	-	-	0.1%
Type JJ	32.4%	-	2.0%	-	-	-	-	-	1.4%	2.3%	-	-	6.8%	-	1.3%
Type KK	-	-	-	-	-	3.1%	7.9%	-	-	0.2%	0.2%	-	-	-	0.3%
Type LL	-	-	-	5.8%	-	20.6%	9.4%	-	-	-	-	-	-	-	0.9%
Type MM	-	-	-	-	-	-	-	-	-	0.2%	-	-	-	-	0.1%
Type NN	-	-	0.3%	4.5%	-	-	19.7%	-	-	1.0%	-	-	-	-	1.0%
Type OO	-	-	1.1%	-	-	-	1.9%	-	-	0.5%	-	-	-	-	0.3%
Type PP	-	3.3%	1.6%	4.9%	-	0.6%	-	-	1.1%	1.5%	6.8%	-	-	-	0.9%
Type QQ	-	-	-	-	-	-	3.1%	-	-	0.1%	-	-	-	-	0.1%

Table 54 Error Bounds: Fixture Types within Functional Use Areas

Lighting Controls

Table 55 below provides the type of lighting controls utilized by each functional use area. The totals at the bottom summarize the estimated use of each type for all commercial sites throughout the state. Of the total lit outdoor area, only 13.4% percent is controlled manually. The totals also document the frequent use of time clocks and photocells. There is some overlap in these numbers which results in a sum of the percentages exceeding 100%. This overlap results from the use of multiple methods, such as the combined system of a photocell and a time clock, a commonly reported method of control. The photocell activates the lights in the evening and the time clock turns the lights off after business hours late in the night. This strategy contributes to the sharp reduction in the load shape after midnight reported in Figure 2.

FUA	% of FUAs						Sample Size
	Manual		Time Clock		Photocell		
	Estimate	Error Bound	Estimate	Error Bound	Estimate	Error Bound	
ATM	26.8%	38.9%	56.0%	43.9%	90.8%	16.1%	5
Commercial Outdoor Patio	100.0%	-	-	-	-	-	3
Entry	29.0%	12.5%	56.4%	12.7%	27.6%	10.6%	71
Façade & Aesthetic	12.0%	13.7%	59.4%	17.3%	43.8%	17.5%	35
Gas Station Canopy	2.2%	3.1%	72.4%	31.7%	25.4%	31.2%	7
Internal Roadway	8.8%	10.6%	47.3%	16.1%	47.6%	16.1%	37
Landscape	7.1%	6.7%	65.3%	14.2%	45.2%	15.4%	46
Outdoor Retail Sales	17.3%	27.2%	55.8%	41.4%	26.9%	37.7%	4
Parking	6.2%	4.1%	52.4%	7.0%	51.9%	7.1%	221
Pedestrian & Walkway	14.3%	5.9%	51.9%	7.5%	37.3%	7.0%	201
Recreation	66.1%	17.9%	21.8%	15.2%	19.6%	14.9%	25
Security	8.3%	6.8%	49.3%	11.3%	48.0%	11.2%	91
Storage	3.6%	5.9%	38.8%	17.2%	57.5%	17.3%	31
Undeveloped	-	-	100.0%	-	-	-	1
All FUAs	**13.4%**	**2.9%**	**51.5%**	**3.8%**	**43.5%**	**3.7%**	**778**

Table 55: Control Types by Functional Use Areas

Glare Ratios and Lighting Trespass

The Illuminating Engineering Society of North America defines glare as "the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted, so as to cause annoyance, discomfort, or loss in visual performance or visibility."[19] This loss of visual performance can impact both safety (impaired visual capability of drivers), and security (inability to discern detail).

Table 56 displays the percentage of sites within glare ratio ranges. Surveyors were asked to gather data on the most offending fixture (in terms of glare) noticeable to them. This measurement is a ratio of the direct light meter reading divided by the reflected meter reading per the methodology presented in the Data Collection section. Therefore, the glare intensifies with increases in the glare reading. Overall, 22.3% of sites had glare ratios of above 20.

[19] RP-20-98, Illuminating Engineering Society of North America (IESNA)

Building Type	% of Sites						Sample Size
	> 0 to 3.99	4 to 7.99	8 to 11.99	12 to 15.99	16 to 19.99	> = 20	
Apartments and Condominiums	16.6%	33.6%	16.9%	19.2%	9.9%	3.9%	13
Assembly	12.3%	32.2%	-	-	0.4%	55.1%	9
Full Service Restaurant	41.4%	-	8.4%	-	4.8%	45.3%	7
Grocery	-	-	-	37.8%	62.2%	-	2
Hospital	14.2%	71.2%	-	-	0.9%	13.7%	8
Hotel	61.4%	38.6%	-	-	-	-	2
Industrial	25.9%	5.1%	23.6%	19.4%	0.1%	25.9%	20
Large Office	26.0%	31.7%	20.2%	17.9%	-	4.2%	21
Large Retail	51.3%	19.1%	5.1%	8.5%	-	16.0%	13
Large Schools	60.0%	40.0%	-	-	-	-	2
Recreation	57.4%	-	-	18.3%	24.3%	-	3
Small Office	32.3%	20.5%	7.4%	8.4%	5.7%	25.8%	83
Small Retail	30.3%	1.8%	32.3%	17.7%	2.7%	15.2%	32
Small School	19.3%	0.6%	-	-	48.1%	32.0%	5
University	0.3%	8.8%	-	0.5%	-	90.4%	8
Warehouse	5.9%	28.6%	26.5%	-	-	39.0%	13
All Building Types	**29.5%**	**18.2%**	**13.7%**	**10.8%**	**5.6%**	**22.3%**	**241**

Table 56: Glare Ratio

Building Type	% of Sites					
	> 0 to 3.99	4 to 7.99	8 to 11.99	12 to 15.99	16 to 19.99	> = 20
Apartments and Condominiums	23.9%	22.3%	20.2%	-	19.9%	22.9%
Assembly	15.5%	29.1%	-	-	0.7%	31.5%
Full Service Restaurant	37.7%	-	14.4%	-	8.6%	44.4%
Grocery	-	-	-	54.7%	-	54.7%
Hospital	10.8%	-	0.6%	29.1%	-	24.8%
Hotel	55.1%	55.1%	-	-	-	-
Industrial	16.3%	6.0%	18.7%	-	0.1%	22.0%
Large Office	14.2%	22.1%	19.5%	20.4%	6.9%	5.0%
Large Retail	27.8%	4.9%	24.2%	15.5%	-	18.9%
Large Schools	55.8%	-	-	-	-	55.8%
Recreation	49.4%	-	-	-	38.7%	30.9%
Small Office	10.1%	7.6%	5.0%	6.4%	4.3%	10.4%
Small Retail	12.3%	14.8%	17.7%	12.4%	9.8%	15.0%
Small School	-	-	-	-	-	-
University	-	0.7%	16.2%	0.9%	-	16.7%
Warehouse	9.4%	25.0%	14.6%	-	0.3%	26.8%
All Building Types	**5.6%**	**4.8%**	**4.6%**	**4.0%**	**2.7%**	**6.5%**

Table 57 Error Bounds: Glare Ratio

Table 58 displays the percentage of sites within glare ratio ranges displayed by the measurement location. A large number of measurements taken from parking lots (23.5%) register a glare ratio of greater than 20.

FUA	% of Sites						Sample Size
	1 to 3.99	4 to 7.99	8 to 11.99	12 to 15.99	16 to 19.99	> = 20	
Building Entry	26.1%	40.9%	2.9%	-	0.2%	29.8%	18
Parking	23.9%	18.0%	17.8%	10.0%	6.8%	23.5%	160
Pedastrian / Walkway	25.9%	22.2%	6.2%	24.4%	5.6%	15.7%	31
Property Edge	61.9%	2.2%	4.3%	15.3%	2.9%	13.3%	26
Site Entry / Exit	74.0%	1.4%	-	-	-	24.6%	6
All FUAs	**29.5%**	**18.2%**	**13.7%**	**10.8%**	**5.6%**	**22.3%**	**241**

Table 58: Glare Ratio by Measurement Location

FUA	% of Sites					
	1 to 3.99	4 to 7.99	8 to 11.99	12 to 15.99	16 to 19.99	> = 20
Building Entry	22.9%	20.0%	12.7%	16.4%	4.9%	21.1%
Parking	6.5%	4.7%	6.1%	4.9%	2.5%	8.1%
Pedastrian / Walkway	15.9%	17.4%	7.7%	16.5%	-	17.6%
Property Edge	19.7%	20.5%	8.8%	2.9%	16.8%	14.6%
Site Entry / Exit	37.2%	36.1%	-	-	-	35.4%
All FUAs	**5.6%**	**4.8%**	**4.6%**	**4.0%**	**2.7%**	**6.5%**

Table 59 Error Bounds: Glare Ratio by Measurement Location

Table 60 displays the percentage of sites within glare ratio ranges presented by lighting zone. Approximately 21% of sites having glare ratios of above 20 are located in lighting zone 1.

Zone	% of Sites						Sample Size
	> 0 to 3.99	4 to 7.99	8 to 11.99	12 to 15.99	16 to 19.99	> = 20	
Lighting Zone 1	13.2%	12.9%	6.5%	23.6%	22.7%	21.1%	25
Lighting Zone 2	21.4%	18.5%	20.4%	9.5%	4.6%	25.7%	69
Lighting Zone 3	37.3%	17.6%	11.0%	10.5%	2.8%	21.0%	113
Lighting Zone 4	28.5%	25.1%	15.2%	4.4%	6.0%	20.8%	34
All Lighting Zones	29.5%	18.2%	13.7%	10.8%	5.6%	22.3%	241

Table 60: Glare Ratio by Lighting Zone

Zone	% of Sites					
	> 0 to 3.99	4 to 7.99	8 to 11.99	12 to 15.99	16 to 19.99	> = 20
Lighting Zone 1	9.2%	11.6%	8.9%	15.0%	16.5%	22.4%
Lighting Zone 2	9.6%	8.6%	8.8%	8.1%	5.5%	12.2%
Lighting Zone 3	8.9%	7.2%	6.7%	5.4%	2.7%	9.4%
Lighting Zone 4	12.4%	13.0%	13.1%	10.2%	4.1%	14.4%
All Lighting Zones	**5.6%**	**4.8%**	**4.6%**	**4.0%**	**2.7%**	**6.5%**

Table 61 Error Bounds: Glare Ratio by Lighting Zone

Table 62 presents the percentage of sites within trespass ranges. Surveyors selected the area they felt had the greatest amount of light crossing the property line. From this point on the property line surveyors recorded the light levels. Overall, 21.2% of all building types have a trespass reading of greater than 1.0 FC, with 42.8% of hotels and 57.3% of restaurants falling in this range.

Building Type	% of Sites						**Sample Size**
	No Data	**> 0 to 0.49**	**0.5 to 0.99**	**1 to 1.49**	**1.5 to 1.99**	**>= 2**	
Apartments and Condominiums	22.4%	31.4%	24.9%	17.9%	3.4%	-	15
Assembly	24.5%	43.1%	10.7%	-	-	21.7%	11
Full Service Restaurant	-	42.7%	-	57.3%	-	-	7
Grocery	36.3%	39.6%	-	-	-	24.1%	3
Hospital	0.3%	85.7%	6.1%	-	-	7.8%	8
Hotel	6.1%	19.7%	31.4%	-	42.8%	-	4
Industrial	44.2%	30.9%	4.0%	9.2%	8.6%	3.1%	31
Large Office	37.7%	29.8%	9.9%	1.5%	13.7%	7.4%	26
Large Retail	10.7%	43.6%	8.0%	13.4%	-	24.3%	15
Large Schools	-	100.0%	-	-	-	-	2
Recreation	4.9%	20.3%	13.7%	-	-	61.1%	7
Small Office	29.0%	43.0%	15.0%	7.7%	1.2%	4.2%	102
Small Retail	27.9%	26.4%	20.6%	5.6%	-	19.6%	42
Small School	23.0%	52.3%	-	1.3%	-	23.3%	11
University	32.2%	67.8%	-	-	-	-	3
Warehouse	40.3%	37.3%	3.4%	9.3%	9.7%	-	16
All Building Types	**27.8%**	**37.8%**	**13.1%**	**7.7%**	**3.9%**	**9.6%**	303

Table 62: Trespass Measurements (FC)

Building Type	% of Sites					
	No Data	**> 0 to 0.49**	**0.5 to 0.99**	**1 to 1.49**	**1.5 to 1.99**	**>= 2**
Apartments and Condominiums	19.6%	22.1%	23.7%	18.9%	5.6%	-
Assembly	25.6%	29.9%	12.9%	-	-	30.0%
Full Service Restaurant	-	38.0%	-	38.0%	-	-
Grocery	47.0%	48.5%	-	-	-	36.9%
Hospital	0.6%	18.5%	10.8%	-	-	13.6%
Hotel	11.0%	31.3%	43.1%	-	48.2%	-
Industrial	18.2%	16.5%	5.2%	12.1%	8.8%	5.1%
Large Office	19.9%	19.2%	11.7%	2.5%	13.5%	7.3%
Large Retail	16.6%	26.0%	9.4%	16.0%	-	18.0%
Large Schools	-	-	-	-	-	-
Recreation	7.5%	31.2%	22.6%	-	-	38.9%
Small Office	9.8%	9.7%	6.8%	4.6%	1.4%	3.7%
Small Retail	13.5%	12.8%	14.0%	7.0%	-	14.2%
Small School	34.0%	42.1%	-	2.4%	-	34.3%
University	38.3%	38.3%	-	-	-	-
Warehouse	28.0%	24.1%	5.7%	11.5%	12.5%	-
All Building Types	**5.5%**	**5.7%**	**4.1%**	**3.1%**	**2.3%**	**3.8%**

Table 63 Error Bounds: Trespass Reading

Table 64 indicates that 95.4% of sites in Lighting Zone 1 have a trespass reading less than 1.5.

Zone	% of Sites						Sample Size
	No Data	> 0 to 0.49	0.5 to 0.99	1 to 1.49	1.5 to 1.99	>= 2	
Lighting Zone 1	14.8%	48.3%	11.7%	20.5%	-	4.6%	31
Lighting Zone 2	16.9%	38.0%	14.9%	8.2%	4.7%	17.3%	78
Lighting Zone 3	23.8%	41.1%	16.9%	6.8%	3.1%	8.3%	141
Lighting Zone 4	52.8%	28.1%	1.0%	4.4%	8.2%	5.5%	50
All Lighting Zones	**25.8%**	**38.9%**	**13.5%**	**7.9%**	**4.0%**	**9.9%**	**300**

Table 64: Trespass Reading by Zone

Zone	% of Sites					
	No Data	> 0 to 0.49	0.5 to 0.99	1 to 1.49	1.5 to 1.99	>= 2
Lighting Zone 1	13.7%	20.6%	11.6%	16.6%	-	7.5%
Lighting Zone 2	9.6%	11.1%	8.8%	6.2%	6.8%	9.3%
Lighting Zone 3	7.4%	8.5%	6.5%	4.3%	2.3%	5.6%
Lighting Zone 4	13.1%	11.3%	1.7%	5.0%	7.0%	5.6%
All Lighting Zones	**5.3%**	**5.7%**	**4.2%**	**3.2%**	**2.4%**	**3.9%**

Table 65 Error Bounds: Trespass Reading by Zone

Subjective Assessments

Table 66 displays the results of the site users (including the surveyors) who answered the Nighttime Subjective Lighting Evaluation (Appendix B). The lighting was considered comfortable by 70.6% of respondents. Over 50% of respondents find security lighting to be adequate. When asked to compare site lighting to lighting at similar areas, over 55% concluded that lighting at other similar sites are about the same, and 43% of respondents considered university lighting worse than lighting at similar areas.

Building Types	% of Respondents						Sample Size
	Lighting is Comfortable	A good example of security lighting	Able to tell the color of things	Site lighting compared to lighting at similar areas			
				Worse	Same	Better	
Apartments and Condominiums	75.0%	50.0%	95.8%	33.3%	54.2%	12.5%	24
Assembly	66.7%	53.3%	86.7%	40.0%	60.0%	-	15
Full Service Restaurant	55.6%	55.6%	88.9%	22.2%	66.7%	11.1%	9
Grocery	60.0%	40.0%	40.0%	20.0%	80.0%	-	5
Hospital	75.0%	87.5%	62.5%	25.0%	50.0%	25.0%	8
Hotel	100.0%	100.0%	80.0%	-	100.0%	-	5
Industrial	66.0%	46.8%	83.0%	31.9%	46.8%	19.1%	47
Large Office	87.5%	62.5%	81.3%	6.3%	59.4%	25.0%	32
Large Retail	90.5%	85.7%	85.7%	9.5%	33.3%	57.1%	21
Large Schools	50.0%	50.0%	100.0%	-	100.0%	-	2
Recreation	77.8%	77.8%	88.9%	11.1%	88.9%	-	9
Small Office	73.5%	54.8%	81.9%	19.4%	64.5%	13.5%	155
Small Retail	63.1%	58.5%	81.5%	24.6%	58.5%	15.4%	65
Small School	84.6%	53.8%	76.9%	23.1%	38.5%	15.4%	13
University	50.0%	37.5%	87.5%	43.8%	56.3%	-	16
Warehouse	43.5%	43.5%	69.6%	26.1%	56.5%	4.3%	23

Table 66: Subjective Response to Lighting at Site

Table 67 summarizes the surveyor's assessment of lighting adequacy and glare. This table presents a subjective evaluation of the lighting and glare levels at each site visited. Surveyor evaluations indicate that 68.7% of the sites had adequate amount of lighting and all grocery stores, large schools, and universities all had adequate lighting. Over 40% of sites were found to be "glary."

Building Type	% of Sites						Sample Size
	Lighting Adequacy			Glare Level			
	Inadequate	Adequate	More than needed	Not Glary	Somewhat Glary	Very Glary	
Apartments and Condominiums	40.0%	53.3%	6.7%	73.3%	20.0%	6.7%	15
Assembly	40.0%	60.0%	-	50.0%	50.0%	-	10
Full Service Restaurant	14.3%	85.7%	-	57.1%	42.9%	-	7
Grocery	-	100.0%	-	66.7%	33.3%	-	3
Hospital	12.5%	87.5%	-	62.5%	37.5%	-	8
Hotel	25.0%	50.0%	25.0%	100.0%	-	-	4
Industrial	41.9%	51.6%	6.5%	56.7%	40.0%	3.3%	31
Large Office	20.0%	76.0%	4.0%	60.0%	40.0%	-	25
Large Retail	6.7%	73.3%	20.0%	66.7%	33.3%	-	15
Large Schools	-	100.0%	-	50.0%	50.0%	-	2
Recreation	28.6%	71.4%	-	14.3%	85.7%	-	7
Small Office	25.5%	72.4%	2.0%	66.3%	29.6%	4.1%	98
Small Retail	26.2%	61.9%	11.9%	56.1%	41.5%	2.4%	42
Small School	20.0%	80.0%	-	40.0%	60.0%	-	5
University	-	100.0%	-	50.0%	37.5%	12.5%	8
Warehouse	42.9%	57.1%	-	28.6%	71.4%	-	14
All Building Types	**26.2%**	**68.7%**	**5.1%**	**59.2%**	**38.0%**	**2.7%**	**294**

Table 67: Surveyor Assessment of Lighting Adequacy and Glare Levels

Table 68 presents the findings of Table 67 by lighting zone.

Zone	% of Sites					
	Lighting Adequacy			Glare Level		
	Inadequate	Adequate	More than needed	Not Glary	Somewhat Glary	Very Glary
Lighting Zone 1	36.7%	60.0%	3.3%	53.3%	43.3%	3.3%
Lighting Zone 2	24.7%	70.1%	5.2%	65.8%	30.3%	3.9%
Lighting Zone 3	21.9%	74.5%	3.6%	60.6%	38.0%	1.5%
Lighting Zone 4	34.0%	56.0%	10.0%	49.0%	46.9%	4.1%
All Lighting Zones	**26.2%**	**68.7%**	**5.1%**	**59.2%**	**38.0%**	**2.7%**

Table 68: Surveyor Assessment of Lighting Adequacy and Glare Levels by Zone

Most of the site evaluations were conducted in the parking lots of the sites visited. While the parking lot lighting was not specifically addressed in the questionnaire, the quality of the parking lot lighting would clearly have a strong influence on a user's impression of the site. For this reason, Table 69 presents the results of the questionnaire by parking lot lamp type. For the sites using fluorescent lighting in the parking lot, 85.7% of respondents find the site lighting to be comfortable and also a good example of security lighting. The respondents at sites utilizing low pressure sodium lamps in the parking lot were more likely to answer no to the question regarding the ability to identify an object's color. Surprisingly, the percentage of respondents who considered the lighting quality at these sites to be about the same as similar areas, is roughly the same as for other lamp types.

Lamp Type	% of Respondents						Sample Size
	Lighting is Comfortable	A good example of security	Able to tell the color of things	Site lighting compared to lighting at similar areas			
				Worse	Same	Better	
CFL	55.6%	40.7%	92.6%	40.7%	59.3%	-	27
FL	85.7%	85.7%	85.7%	7.1%	85.7%	7.1%	14
HAL	63.3%	53.3%	83.3%	23.3%	63.3%	13.3%	30
HPS	77.1%	66.8%	83.0%	19.0%	58.1%	20.2%	253
INC	56.8%	38.6%	75.0%	43.2%	50.0%	2.3%	44
LPS	64.3%	53.6%	42.9%	28.6%	60.7%	7.1%	28
MH	75.3%	59.1%	86.4%	16.9%	61.7%	18.8%	154
MV	65.2%	56.5%	78.3%	28.3%	58.7%	13.0%	46

Table 69: Subjective Response to Parking Lamp Types

Table 70 illustrates the relationship of subjective impression and glare ratio to lamp wattages and to fixture type (cutoff or non-cutoff). The subjective impression (1 is best, 5 is worst) was determined by the site surveyor at the time of glare measurement. The subjective impression tends towards "worse" as the lamp wattage increases and when comparing non-cutoff to cutoff fixtures. Similarly, the glare ratio increases with increases in lamp wattage and the utilization of non-cutoff fixtures. Sites with incomplete glare data have been excluded. Sites with luminaire mounting heights less than 12 feet and sites utilizing non-HID lamps have also been excluded. Mercury vapor lamps are considered obsolete and were removed from the list. Therefore, this analysis evaluates only fixtures containing Metal Halide, and High Pressure Sodium lamps.

Lamp Wattage Range		**100 to < 250**
Cutoff	Total Sample	13
Subj. Impr.	Number	Percentage
SI 1	3	23%
SI 2	6	46%
SI 3	4	31%
SI 4	0	0%
SI 5	0	0%
	13	100%
Average SI =	2.08	
Average GR =	8.14	

Lamp Wattage Range		**250 to 1000**
Cutoff	Total Sample	37
Subj. Impr.	Number	Percentage
SI 1	4	11%
SI 2	13	35%
SI 3	12	32%
SI 4	6	16%
SI 5	2	5%
	37	100%
Average SI =	2.70	
Average GR =	9.75	

Lamp Wattage Range		**100 to < 250**
Non-Cutoff	Total Sample	10
Subj. Impr.	Number	Percentage
SI 1	2	20%
SI 2	3	30%
SI 3	2	20%
SI 4	3	30%
SI 5	0	0%
	10	100%
Average SI =	2.60	
Average GR =	14.95	

Lamp Wattage Range		**250 to 1000**
Non-Cutoff	Total Sample	22
Subj. Impr.	Number	Percentage
SI 1	1	5%
SI 2	4	18%
SI 3	9	41%
SI 4	3	14%
SI 5	5	23%
	22	100%
Average SI =	3.32	
Average GR =	18.32	

Table 70: Comparison of Subjective Impression to Lamp Wattage and Non-Cutoff Fixtures

Sample Design Methodology

The first step in conducting the statewide outdoor lighting baseline assessment was to define the study target population and develop an appropriate sampling plan. The target population studied was the outdoor lighting associated with existing commercial, industrial and multi-tenant apartment buildings in California. To optimize the likely relative precision of statewide estimates of energy usage and other factors, a method was devised that would allow sampling of locations with large amounts of outdoor lighting with higher inclusion probabilities than locations with small amounts of outdoor lighting and at the same time would allow maintaining manageable travel distances between sites. Specifically, a proxy was defined for the amount of outdoor lighting associated with existing construction in small geographic areas of California to devise a stratified sampling plan.

Using the idea that the amount of outdoor lighting associated with existing commercial and industrial buildings in a geographic area is likely to be directly related to the amount of commercial activity in a geographic area, a stratified sampling plan was developed based on zip codes in California using measures of commercial activity by zip code.

Approximately 1000 telephone surveys were completed with building owners and property managers in order to develop a proxy for the amount of outdoor lighting at the site. This process was driven by the requirement to have a sample frame from which a sample was selected of buildings stratified by the amount of outdoor lighting at the building within each zip code sampling class. The 1000 surveys also serve as the mechanism for extrapolating the findings from the onsite data collection back to the population of existing commercial/industrial buildings in California.

Defining the Target Population

The first step in conducting the initial market characterization was to define the study target population. The following list describes the various options that were considered in defining the target population:

- Exterior Building Lighting vs. Roadway Lighting and Billboard Lighting,
- Title 24 Building Standards vs. Title 20 Appliance Standards,
- New Buildings vs. Existing Buildings, and
- Constructed in Last Five Years vs. Last 1-2 years or last 10 years.

During the development of the project research plan, two options were considered for determining the study target population and the methodology that would be used to study each. Both options called for studying exterior building lighting and omitting roadway and billboard lighting. The first option, Option A, was an approach that would include only new construction in the study design, using F.W. Dodge new construction data as the population frame. The second option, Option B, was directed at establishing a baseline that could be used to assist in evaluating the impacts of revising Title 20 appliance standards, and to assist in reviewing possible Title 24 building codes aimed at commercial outdoor lighting. Because this study is intended to be a baseline study of existing outdoor lighting, Option B was selected for this study.
The target population studied is the outdoor lighting associated with all existing nonresidential buildings in California. The population includes both commercial and industrial buildings, as well as multi-tenant apartment buildings.

The unit of data collection and analysis was the outdoor lighting associated with a distinct street address[20]. As explained in the next section, the initial contact was a business, identified through the Pro CD database[21]. The street address in which the business was located as the unit of data collection was identified in the telephone survey. If several buildings comprised the street address, the outdoor parking and other space associated with the set of buildings was identified. If the parking and other space is common to several street addresses, a suitable proportion of the total space was allocated to the selected address.

Telephone Survey Sample Design

The 1997 Zip Code Business Patterns CD-ROM from the U.S. Census Bureau[22] was used to determine the amount of business activity in each zip code in California. The Zip Code business patterns CD provides the number of employees, first quarter payroll, annual payroll, total number of establishments, and number of establishments in nine employment size classes for every zip code. It also provides business data summarized for nine employment size classes by SIC Code and zip code.

In order to create a measure of the amount of business activity in each zip code in California, two quantities, the total number of employees and the average number of employees per business[23], were examined for each zip code. First, the average number of employees per business in each zip code was classified into one of the following categories: extra low, low, medium, high, or extra high. Next, the total number of employees in each zip code was classified into one of five categories: extra low, low, medium, high, or extra high. These classifications were designed so that the amount of employment in each cross-classification was roughly equal. In other words, the amount of employment for zip codes with extra low average number of employees and extra low total number of employees is roughly the same as the amount of employment for zip codes with extra high average number of employees per businesses and extra high number of employees.

Table 71 shows the number of zip codes in each cross-classification. The table also shows the cut-points used to classify the zip codes by the average number of employees per business. The cut-points for classifying the zip codes by total employment are not shown because they depend on the "average number of employees" classification. The greatest number of zip codes belong to the extra low average, extra low total cross-classification, while the extra high average, extra high total cross-classification has the least. Though the numbers vary greatly between the two cross-classifications, the amount of employment is roughly equal in each.

A sample of 2 zip codes was randomly selected for each cell in the matrix shown in Table 71, yielding a total of 50 sampled zip codes. Twenty buildings were surveyed in each sampled zip code, or 40 in each cross-classification.

	Total Employment				
Average # Employees per Business	Extra Low	Low	Medium	High	Extra High
Extra Low (0.33 - 11.2997)	1,234	119	71	47	31
Low (11.3 - 14.151)	183	49	35	26	18
Medium (14.152 - 17.890)	143	35	27	20	14
High (17.890 - 25.743)	160	27	18	13	8
Extra High (25.748 - 3750)	236	24	14	9	7

Table 71: Number of Zip Codes by Employment Categories

[20] For our purposes, a street number and street name within a zip code defines a distinct street address.
[21] ProCD. Select Phone 2000 1st Edition. 1999 infoUSA Inc, Omaha NE.
[22] The most recent version of the Zip Code Business Patterns CD-ROM available was the 1997 version.
[23] The average number of employees per business was calculated as the number of employees divided by the number of businesses.

After selecting a sample of approximately 50 zip codes, the Select Phone CD-ROM published by InfoUSA.com was used to identify and enumerate each business in the selected zip codes. The Select Phone CD allows the user to "query" the CD's database for all records meeting certain criteria. For example, the user can retrieve all businesses in a certain zip code or city. The Select Phone CD also provides the SIC Code for each business listed. Finally, a sample of businesses was randomly selected from each zip code.

Some zip codes, particularly those in more remote areas, contained less than 20 buildings, making it impossible to complete 20 surveys in the zip code. When this occurred, the missing surveys were supplemented with additional surveys from the other sampled zip code belonging to the same cross-classification. An additional zip code was selected from the same cross-classification when the two zip codes combined contained fewer than 40 buildings. Ultimately, 1,006 buildings in 54 zip codes were telephone surveyed. Table 73 presents the list of sampled zip codes along with the corresponding city name. The completed 1,006 surveys of buildings became the sample frame from which the 303 sites were selected for the on-site survey component of the statewide assessment.

Zip Code	City	# Phone Surveys Completed
90024	LOS ANGELES, CA	20
90035	LOS ANGELES, CA	20
90067	LOS ANGELES, CA	20
90210	BEVERLY HILLS, CA	20
90248	GARDENA, CA	20
90403	SANTA MONICA, CA	20
90703	CERRITOS, CA	20
91106	PASADENA, CA	20
91210	GLENDALE, CA	2
91304	CANOGA PARK, CA	20
91504	BURBANK, CA	20
91731	EL MONTE, CA	21
91746	LA PUENTE, CA	20
91789	WALNUT, CA	20
91910	CHULA VISTA, CA	20
92024	ENCINITAS, CA	20
92121	SAN DIEGO, CA	19
92274	THERMAL, CA	13
92337	FONTANA, CA	39
92590	TEMECULA, CA	20
92618	IRVINE, CA	21
92705	SANTA ANA, CA	21
92804	ANAHEIM, CA	21
92831	FULLERTON, CA	20
93030	OXNARD, CA	20
93612	CLOVIS, CA	20
93721	FRESNO, CA	20
93740	FRESNO, CA	8
94025	MENLO PARK, CA	21
94111	SAN FRANCISCO, CA	20
94115	SAN FRANCISCO, CA	20
94303	PALO ALTO, CA	20
94305	STANFORD, CA	20
94518	CONCORD, CA	20
94523	PLEASANT HILL, CA	20
94545	HAYWARD, CA	20
94550	LIVERMORE, CA	20
94560	NEWARK, CA	20
94576	DEER PARK, CA	10
94926	COTATI, CA	1
94947	NOVATO, CA	33
95035	MILPITAS, CA	20
95054	SANTA CLARA, CA	20
95060	SANTA CRUZ, CA	20
95374	STEVINSON, CA	7
95433	EL VERANO, CA	7
95490	WILLITS, CA	20
95670	RANCHO CORDOVA, CA	20
95814	SACRAMENTO, CA	20
95955	MAXWELL, CA	26
96051	LAKEHEAD, CA	26
96096	WHITMORE, CA	8
96115	LAKE CITY, CA	1
96146	OLYMPIC VALLEY, CA	21
Total	STATEWIDE	1,006

Table 72: Number of Completed Phone Surveys by Zip Code

On-Site Survey Sample Design

The next step in conducting the statewide assessment was to devise a method of selecting a sample of 300 buildings for an on-site survey of the outdoor lighting present at the building. The unit of data collection and analysis was the outdoor lighting associated with each distinct street address. Model Based Statistical Sampling (MBSS) methods[24] were used to design the sample. The 1,006 telephone surveys conducted for the initial market characterization provided a proxy of the amount of outdoor lighting present at each building. This proxy was used as a stratification variable in the sample design on-site survey component of the statewide assessment. The completed 1,006 surveys of buildings became the sample frame from which the 303 sites were selected for the on-site survey component.

Theoretical Foundation

MBSS™ methodology was used to develop efficient sample designs and to assess the likely statistical precision. The target variable of analysis, denoted *y*, is the outdoor lighting energy use of the project. The primary stratification variable, the proxy for the amount of outdoor lighting at the site, is denoted *x*. A ratio model is formulated to describe the relationship between *y* and *x* for all units in the sampling frame.

The MBSS™ ratio model consists of two equations called the primary and secondary equations:

$$y_k = \beta x_k + \varepsilon_k$$
$$\sigma_k = sd(y_k) = \sigma_0 x_k^{\gamma}$$

Here $x_k > 0$ is known throughout the sampling frame. k denotes the sampling unit, i.e., the project. $\{\varepsilon_1, \ldots, \varepsilon_N\}$ are independent random variables with zero expected value, and β, σ_0, and γ (gamma) are parameters of the model. The primary equation can also be written as

$$\mu_k = \beta x_k$$

Under the MBSS ratio model, it is assumed that the expected value of *y* is a simple ratio or multiple of *x*.

Here, y_k is a random variable with expected value μ_k and standard deviation σ_k. Both the expected value and standard deviation generally vary from one unit to another depending on x_k, following the primary and secondary equations of the model. In statistical jargon, the ratio model is a (usually) heteroscedastic regression model with zero intercept.

One of the key parameters of the ratio model is the error ratio, denoted *er*. The error ratio is a measure of the strength of the association between *y* and *x*. The error ratio is suitable for measuring the strength of a heteroscedastic relationship and for choosing sample sizes. It is *not* equal to the correlation coefficient. It *is* somewhat analogous to a coefficient of variation except that it describes the association between two or more variables rather than the variation in a single variable.

Using the model discussed above, the error ratio, *er*, is defined to be:

$$er = \frac{\sum_{k=1}^{N} \sigma_k}{\sum_{k=1}^{N} \mu_k} = \frac{\frac{1}{N}\sum_{k=1}^{N} \sigma_k}{\frac{1}{N}\sum_{k=1}^{N} \mu_k}$$

[24] The MBSS methodology is detailed later in this document.

Figure 8 gives some typical examples of ratio models with different error ratios. An error ratio of 0.2 represents a very strong association between *y* and *x*, whereas an error ratio of 0.8 represents a weak association.

As Figure 1 indicates, the error ratio is the principle determinant of the sample size required to satisfy the 90/10 criteria for estimating *y*. If the error ratio is small, then the required sample is correspondingly small.

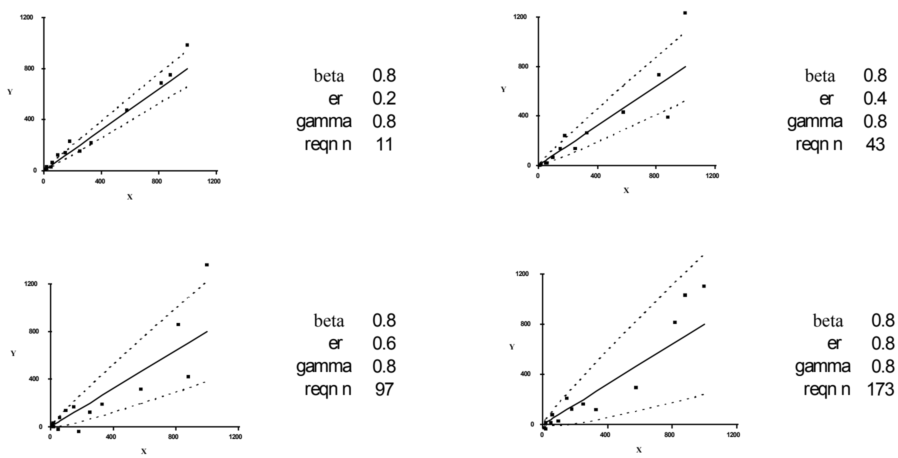


Figure 8: Examples of MBSS Ratio Models

Selecting the On-Site Survey Sample

In order to create a measure of the amount of business activity in each zip code in California, two quantities, the total number of employees and the average number of employees per business[25], were examined for each zip code, as a part of the sample design for the telephone survey[26]. First, the average number of employees per businesses in each zip code was classified into one of the following categories: extra low, low, medium, high, or extra high. Next, the total number of employees per business in each zip code was classified into one of five categories: extra low, low, medium, high, or extra high. To design the sample for the statewide assessment, we treated each cross-classification as its own sampling class.

For each address for which we had a completed telephone survey, we examined several key questions to develop a proxy for the amount of outdoor lighting present at the address. A point scheme was devised to create the proxy for the amount of outdoor lighting present at the site. One point was allocated per parking spot in an illuminated outdoor parking lot[27]. Ten points were allocated for each functional type of outdoor lighting (i.e. landscape lighting, walkway lighting, area-lighting, entrance lighting, building mounted lighting and building highlight lighting) reported to be present. Twenty points were allocated for each of the following factors: the use of outdoor lighting as an important part of the building's business, the use of outdoor lighting to attract customers or illuminate showrooms, the occurrence of serving the public or customers at night, and the existence of illuminated signs.

[25] The average number of employees per business was calculated as the number of employees divided by the number of businesses.

[26] A more detailed description of the procedure can be found in the "Telephone Survey Sample Design" section of this chapter.

[27] For parking lots that contained 251 or greater parking spaces, 400 points were allocated.

Within each sampling class, we stratified the sampling frame using MBSS methodology by the number of points that was used a proxy for the amount of outdoor lighting present at the site. We used 3 strata for each class and planned to sample 12 sites from each sampling class. The parameters we used were a $\beta = 1.0$, $er = 0.8$, and a $\gamma = 0.8$.

Table 73 presents the on-site sample size by zip code. The first and second columns show the zip code and associated city name. The third column shows the number of telephone surveys completed in each zip code, and the fourth column shows the number of completed on-site surveys in each zip code. As the table shows, the on-site survey sample consists of a total of 303 sites throughout the state of California.

Zip Code	City	# Phone Surveys Completed	# On-Site Surveys Completed
90024	LOS ANGELES, CA	20	10
90035	LOS ANGELES, CA	20	8
90067	LOS ANGELES, CA	20	5
90210	BEVERLY HILLS, CA	20	6
90248	GARDENA, CA	20	4
90403	SANTA MONICA, CA	20	5
90703	CERRITOS, CA	20	8
91106	PASADENA, CA	20	5
91210	GLENDALE, CA	2	1
91304	CANOGA PARK, CA	20	4
91504	BURBANK, CA	20	3
91731	EL MONTE, CA	21	8
91746	LA PUENTE, CA	20	2
91789	WALNUT, CA	20	5
91910	CHULA VISTA, CA	20	6
92024	ENCINITAS, CA	20	6
92121	SAN DIEGO, CA	19	9
92274	THERMAL, CA	13	2
92337	FONTANA, CA	39	11
92590	TEMECULA, CA	20	9
92618	IRVINE, CA	21	5
92705	SANTA ANA, CA	21	9
92804	ANAHEIM, CA	21	7
92831	FULLERTON, CA	20	7
93030	OXNARD, CA	20	6
93612	CLOVIS, CA	20	8
93721	FRESNO, CA	20	5
93740	FRESNO, CA	8	4
94025	MENLO PARK, CA	21	7
94111	SAN FRANCISCO, CA	20	3
94115	SAN FRANCISCO, CA	20	5
94303	PALO ALTO, CA	20	7
94305	STANFORD, CA	20	9
94518	CONCORD, CA	20	8
94523	PLEASANT HILL, CA	20	5
94545	HAYWARD, CA	20	7
94550	LIVERMORE, CA	20	6
94560	NEWARK, CA	20	4
94576	DEER PARK, CA	10	-
94926	COTATI, CA	1	1
94947	NOVATO, CA	33	12
95035	MILPITAS, CA	20	6
95054	SANTA CLARA, CA	20	7
95060	SANTA CRUZ, CA	20	7
95374	STEVINSON, CA	7	4
95433	EL VERANO, CA	7	2
95490	WILLITS, CA	20	5
95670	RANCHO CORDOVA, CA	20	4
95814	SACRAMENTO, CA	20	2
95955	MAXWELL, CA	26	10
96051	LAKEHEAD, CA	26	6
96096	WHITMORE, CA	8	1
96115	LAKE CITY, CA	1	-
96146	OLYMPIC VALLEY, CA	21	7
Total	**STATEWIDE**	**1,006**	**303**

Table 73: On-Site Sample Size by Zip Code

Data Collection

The data collection has several critical steps: telephone data collection and data entry, on-site data collection and on-site data entry. Each is quite involved. The data collected allows the scheduling of sites and the collection of required data from each site. Several instruments are required. The phone interview instruments provide preliminary site information to develop the sample frame which will allow extrapolation of results to the statewide population of commercial outdoor lighting sites. The on-site instruments ensure that the information collected is accurate, precise and will appropriately describe the site and its lighting. The methodology for these efforts is described, in detail, in the following sections allowing reliable expansion of this effort in future studies.

Telephone Survey Data Collection

RLW conducted 1,006 telephone surveys with representatives of sampled buildings. These surveys collected information about the amount of outdoor lighting present at the site as well as its uses. RLW has developed rigorous procedures for conducting successful data collection efforts, including pre-testing, varied telephone survey contact times, and comprehensive data entry and review.

The typical approach to implementing a survey is to use CATI[28] techniques. With this technique a telemarketer reads each question and records the answer. The typical telemarketer is able to read the questions but he or she is simply not equipped to talk intelligently to the respondent about the complex issues to be addressed in this study. All too often, the respondent gets frustrated and terminates the interview. The result is high non-response rates and the possibility of seriously biased data.

RLW has found a more successful way of collecting high-quality information. Our approach is to use interviewers that have the experience and training to understand the issues and to communicate intelligently with the respondents. Telephone researchers who are experienced in energy-related surveys conducted the data collection. Although data collection costs more using this method, we believe using staff familiar with energy issues does not compromise the data quality and integrity.

RLW relied on the PRO CD software for accessing building contact information. This publicly available software allows the user to look up phone numbers by address or occupant name. This is one of our best publicly available resources and is often used on projects of this nature. One pitfall when using this data is that customers who list their phone number as private do not appear in the PRO CD database, thus introducing non-response bias. However, in the case of a nonresidential study such as this, the bias is not expected to be serious.

Each outcome was recorded on the paper scripts for all calls placed to customers, with the final outcome for each participant recorded electronically in the survey database. RLW's outcome list included the following items:

- Refusal,
- Reason for Refusal,
- Completion,
- Bad or Wrong Number,
- Number of Calls Placed,
- Communication Barrier,
- Left Message,

[28] Computer Adapted Telephone Interviewing (CATI).

- Call Back Later,
- Busy,
- No Answer, and
- Termination.

RLW attempted to contact the each sample building a minimum of 7 times before a backup building was used. Calls were placed between the hours of 9AM and 5PM, Monday-Friday, excluding holidays. Calls were placed during random times to increase the possibility of reaching respondents. Of course if the first contact is not the appropriate one, we asked for the appropriate contact. In particular, if there are a large number of businesses at the address, we asked for the building manager.

Periodically throughout the project, interviews were monitored to ensure data quality is being maintained. The survey instrument was piloted or pre-tested on an initial 50 or so respondents to work out any survey inconsistencies and to refine the overall form and flow of the final survey instrument.

As the data was collected it was entered into the project telephone survey database. The RLW telephone survey manager created the data entry form, oversaw the entry of all data into the survey database, and supervised quality control.

Telephone Surveyor Training

One of the most important linkages to good high quality consistent data is a properly trained telephone survey staff. While the sample was being prepared, RLW held training sessions for its interviewers. During the project training sessions, RLW thoroughly reviewed each question in the questionnaire to insure interviewers understood the purpose of each question and how to interpret different responses. The training also included a discussion of any special procedures, instructions on how to respond to customer inquiries, and practice interviewing.

The RLW Survey Manager intensively trained each surveyor. In addition to receiving training on survey techniques, etiquette, and protocols, the surveyors were also versed on the study. Once the surveyors had been trained, they rehearsed with other RLW staff members to work out any awkward wordings in the introduction script and the survey instrument.

Telephone Survey Instrument Design

The RLW team developed a telephone survey instrument for use in this study to collect information regarding the types and functions of outdoor lighting present at the building (Appendix). This instrument was targeted at the property manager or facility manager of the building. The survey instrument was designed to collect accurate data from such a person. From our past experience, we have found that the proper phrasing of the questions, non-leading questions, and non-technical questions are all keys to the design of a successful telephone survey instrument.

Once the survey instrument had been drafted, RLW conducted pre-tests of the survey instrument to ensure that all relevant data was being collected. The RLW team, the PIER Program Director and the CEC Contract Manager worked together to finalize the survey instrument. Any modifications deemed necessary by the PEIR Program Director and or the CEC Contract Manager were incorporated into the telephone survey instrument.

Data collection conducted over the phone can in many ways be tricky. In this study, we were asking respondents about their knowledge of the extent of outdoor lighting at their building. With this in mind, a survey instrument was developed that used proper diction and content to determine the extent and function of outdoor lighting present at the building.

The following data over the telephone was collected:

- Confirmation of site street address and obtain name of respondent,
- Building type, age, and type of location (urban, suburban, or rural)
- Number of businesses at building
- Estimate number of employees at building
- Quantity of lit outdoor parking spaces
- Importance of outdoor lighting to business function
- Hours of operation
- Functional use of outdoor lighting (i.e., signage, walkway, parking, etc.)
- Name of a contact person for a future site visit.

A draft survey instrument and procedural survey document was drafted and submitted to the CEC Contract Manager for comment and ultimately approval. CEC Contract Manager comments were incorporated into the final survey instrument.

Data Entry

All telephone survey data was entered into an MS Access form designed specifically for this survey. The data entry form was designed such that variables must be within a specified parameter to be a valid entry, thus reducing the possibility for any data entry error. Furthermore, the hard copy data was randomly double-checked to insure data entry is not resulting in any systematic or non-systematic errors.

On-Site Survey Data Collection

Data collection for this project required the visit to over 300 sites throughout California. This was accomplished with teams of trained site surveyors using the "On-Site Survey Instrument" designed to allow collection of data from a vast range of unique site circumstances to be compiled effectively into a single database. Two visits were required for each site. First, during the day, to solicit information from the person responsible for the outdoor lighting such as the maintenance supervisor, and to inspect replacement lamps for type and wattage. The surveyor returned to the site after dark to take illuminance readings and to administer the "Nighttime Subjective Lighting Evaluation" to site users. These were also be completed by each site surveyor. The data collection spanned three consecutive months during the late winter and early spring of 2002. During this time, the RLW project manager provided continuous technical support via phone and email to the field teams. This single point of coordination proved to be essential in developing consistency and thoroughness in the vast amount of data collected from sites as diverse as ski resorts to RV sales complexes.

Surveyor Training

The surveyors were training by lighting professionals and energy engineers to ensure consistent and thorough collection of data. This training included a daylong classroom session in lighting fundamentals, training on the equipment to be used, and training on the data collection methodology. This training was followed by a daylong training session in the field. This training included the completion of data acquisition for several participating sites. Each surveyor was provided with the required instrumentation, including, among other aids, a camera, a light meter and attachments, a measuring wheel, and an On-Site Survey Manual.

On-Site Survey Manual

A reference manual was presented to each surveyor to support their field work. The manual included a copy of the training material information, fixture identification information, lamp type and wattage identification information, daytime and nighttime survey procedures, camera instructions, and the "Luminaire Catalogue for Exterior Lighting Equipment Surveys". This catalogue provided a picture and description of 41 lighting fixtures likely to be found in the field, along with a unique identification number for each. This manual ensured consistent data collection methodology across all teams and field situations. The manual can be found in Appendix .

On-Site Survey Instrument

The site visit was scripted to guide the surveyor through the many steps of the data acquisition requirements. The On-Site Survey Instrument provided the framework for the discussion with the site contact to record lighting types and lighting use schedules. The instrument then sequenced the collection of the required daytime and nighttime on-site data, and provided a clear format for recording the findings. A copy of the "On-Site Survey Instrument" is provided Appendix . The "Nighttime Subjective Lighting Evaluation" is provided in Appendix B.

The information collected within the "On-Site Survey Instrument" included:

- **Building information**: site area, building area, business type (selected from a list of 29).
- **Exterior Lighting Schedules and Controls**: time of use for each functional use area (FUA), type of lighting controls used for the FUA.
- **Functional Use Area Summary Information**: area description (selected from a list of 14), FUA area, and percentage of the FUA covered.
- **Luminaire Information** (listed by FUA): lamp type and wattage, ballast type, quantity, luminaire height, luminaire suitability and lens condition.
- **Signage Information**: quantity, fixture type, lamp type and wattage, size, suitability.
- **Lighting Zone Information**: intrinsically dark, low ambient, medium ambient, high ambient brightness.
- **Glare and Trespass Information**: light meter readings, subjective impression, offending fixture.
- **Illumination Grid Measurements**: illumination grid layout, fixture type, lamp type.
- **Nighttime Subjective Lighting Evaluation**: 12 questions pertaining to safety and quality of outdoor lighting.

Data Collection

The daytime visit began with an interview of the site contact. The interview facilitated the collection of data not easily (or always) observable by the site surveyor. Daytime data collection involved measurement of the site, identification of lighting controls and scheduling information, luminaire information, and layout of two illuminance grids (if possible) in sidewalk, security or parking areas. The performance of the lighting system was assessed at night through several measurements: illuminance grids for both parking lot and pedestrian areas, glare ratio[29] readings, light trespass[30] readings, and a subjective evaluation of the lighting system by the surveyor, and when possible other users of the surveyed space.

[29] The glare ratio is defined to ratio of the number of foot candles resulting from the light source to the number of foot candles provided by the ambient light.
[30] Light trespass is defined to be light falling where it is not wanted or needed, or obtrusive light.

The nighttime assessment was important to help determine whether the lighting system as it performs is sufficient, over-designed, or under-designed. An over-designed lighting system is one which the amount of lighting produced exceeds the amount that is required to perform visual tasks at night or produces a lot of glare, which can impede nighttime vision. An under-designed lighting system is one that the lighting is not sufficient to perform visual tasks at night. Additionally, the subjective assessment helped evaluate the overall "quality" of the nighttime visual environment, to help researchers understand what factors are important to visual tasks at night.

Site Background Information

A series of data were collected at the building level. This information was useful in providing a context for interpreting the remaining data gathered at the site. Background information on the building included the overall site area (in square feet), building footprint (in square feet), overall building floor area (in square feet), and the function of the building. The surveyors recorded daytime and nighttime weather conditions, an assessment of the amount of ambient brightness in the surrounding neighborhood at night, a subjective assessment of the overall adequacy of the lighting at the site, and a subjective assessment of whether the lighting at the site creates glare.

Functional Use Areas

The initial component of the onsite data collection required the onsite surveyor to become familiar with site geometry, layout, and property lines. At smaller sites, this is relatively simple, but at larger sites, the site contact is often critical and can provide a site map, greatly reducing the amount of time required. Once the surveyor is familiar with the site, he or she declared up to five functional use areas that adequately described the majority of the functional uses of exterior lighting at the site. These were selected from the following list: parking, pedestrian and walkway, landscape, outdoor retail sales (for example, car lot), internal roadway, storage, ATM, recreation, no use, façade and aesthetic, security, point of sale, entry (if lit differently from walkways), and gas station canopy.

It is most important that the functional use areas at the site adequately describe the majority of uses of the exterior lighting at the site. Area of the site that was unlit was not included in any functional use areas, therefore the resulting measurements produced square footages associated with up to five FUAs, total property square footage, and unlit square footage. The following components of data collection were all completed at the functional use area level.

Operating Characteristics of Lighting Controls

The operating characteristics of the lighting controls were essential to estimating the statewide energy consumption attributable to outdoor lighting. These data provided the hours of use of the exterior lighting at each site at the functional use area level. The site contact provided this information during a short interview as a part of the daytime data collection.

For each functional use area (for example, parking, walkway, ATM, etc.), we collected the control mechanism for the exterior lights. If the exterior lighting was controlled manually or by a time clock, the operating schedules were also recorded. Separate schedules were collected for summers, winters, weekdays and weekends. Some buildings used a photocell to turn on the exterior lights and a time clock to turn them off. In these cases, we recorded the use of both operating controls and the time the lights turned off.

Luminaire Information

All information specific to the luminaire equipment was recorded by functional use area for each site in the sample. These data were valuable for both estimating the statewide energy consumption and assessing the lighting system design. In addition to the specific technical information on the luminaire, we provided a data field for a subjective condition evaluation of the equipment. This is intended to help explain why one installation does not appear to perform as well as a similar installation at another site.

The following luminaire information was recorded for each functional use area at the site: luminaire type designation, general location on the site (for example, parking lot, building soffit, etc.), quantity of equipment on site, lamp technology type (for example, metal halide, high pressure sodium, etc.), ballast type (if applicable), lamp wattage, luminaire mounting height, and condition of luminaire (good/fair/poor).

The luminaire type designation came from a luminaire type catalogue (see Error! Reference source not found.) created specifically for this study. This ensured that a type "A" luminaire in every site will be from the same family of luminaires throughout the onsite data collection. The luminaire catalogue contained separate designations for the lamps and the fixture types, which allowed the surveyor to select any number of luminaire combinations.

Signage Information

Signage information was collected in a similar manner to the luminaire information, except that the signs were not assigned a FUA. However, two important assumptions were used to determine the signage energy consumption. First, the hours of use are assumed to be from dusk to dawn for all signs. Second, the energy consumption for cabinet signs, the most prominent type and least accessible for lamp inspection, was calculated by assuming 28 watts of consumption per sqft. This value has been considered high by some lighting professionals. For this reason, these resulting energy consumption numbers for signs should be considered toward the high end.

Illuminance Measurements

We recorded illuminance readings of the parking lot, sidewalk or security lighting at each site in the sample, if feasible. A reasonable assessment of the parking lot lighting can be made with readings taken at nine points in a typical parking lot, and six points on a typical lighted sidewalk. The security lighting requires six points if the lighting is similar to a sidewalk, or nine points if there is a more extensive security lighting system. The location of the grid was established based on the layout of the luminaires or luminaire poles.

These six or nine points made up a "grid" of three-by-three for the parking lot, and two-by-three for the sidewalk lighting. There were five illuminance readings taken at each point in the grid: a horizontal reading at grade, and four vertical readings, one at each compass quadrant.
The surveyor also sketched any geometry that will affect the light level readings, including buildings, walls and trees.

In addition to the five illuminance readings taken at each of the grid points (one horizontal and four vertical readings), the surveyors also recorded the locations of the lighting equipment affecting the readings relative the locations of the readings. These readings will allow researchers to assess uniformity in parking lot and sidewalk lighting design and to examine average, minimum, and maximum illuminance levels.

Glare and Light Trespass

Glare and light trespass measurements were only taken if there was at least one fixture on the site that appeared to be creating glare or light trespass. Separate attachments to the light meter were used for the glare and light trespass readings.

To measure the glare ratio at the location, two illuminance readings of the glaring fixture and the location of the readings relative the remainder of the site were recorded. Using a special snoot type attachment, a reading directly below the fixture with the snoot pointing up to measure the foot candles resulting from the light source, and a reading with the snoot pointing down to measure the foot candles of the ambient light were each documented. Up to three sets of glare readings at each site were collected.

A measurement of the light trespass of the offending fixture was taken. The location of the offending fixture relative to the remainder of the site was also recorded. A special attachment to the light meter is required; one similar to the glare snoot was used for this purpose. This attachment is pointed directly at the offending fixture from the property line, using line of site as the measurement angle. The highest reading was recorded.

Subjective Evaluation of Lighting

This portion of the onsite survey instrument asks a series of questions to help determine whether the lighting on the site is adequate. It also solicits opinions on whether the quality of the visual environment is sufficient for the safe use of the space at night, as well as the perception of safety within the space. The study borrowed the subjective outdoor lighting survey from the Rensselaer Lighting Research Center.

Consolidation of On-Site Survey Data

All data collected on-site using the on-site survey instrument was combined into a user-friendly MS Access database. There were multiple components to the consolidation of the data collected during the on-site surveys into a central database. They are:

- Definition of data tables,
- Development of an practical data entry tool,
- Data entry, and
- Quality control of entered data.

Each of these components will be discussed in detail in the following sections.

Definition of Data Tables

Many different types of data are collected throughout the course of the on-site survey. Database tables were designed to efficiently store the data collected during the on-site surveys. The end result is a collection of data tables – some with one record per site and others with multiple records for each site. One table contains the building characteristics for the site (e.g. building type, square footage, etc.), and additional tables contain the outdoor lighting data collected on site. Additional tables served as lookup tables. For a complete description of every table contained in the on-site survey database, refer to the Appendix of this report.[31]

[31] The Appendix of this report is a separate document.

Development of the Data Entry Tool

All on-site survey data was entered into a series of MS Access forms designed specifically for this survey. The forms were developed with the goal of being a user-friendly data entry tool while at the same time encompassing enough flexibility to allow for a broad range of on-site circumstances. The series of forms is organized according to the flow of the on-site survey instrument. The set of forms also serves to allow for easy viewing of on-site survey data on a site specific basis.

Data Entry

On-site data collection staff submitted their completed on-site surveys to RLW. Senior staff reviewed the surveys for completeness and reasonableness before releasing the survey for data entry. Any missing or questionable entries on the survey were investigated with the on-site surveyor.

Once the on-site surveys were released for data entry, they were entered into the project database. All information that was gathered as a part of the on-site survey was entered.

Quality Control

The data entry form was designed such that variables must be within a specified parameter to be a valid entry, thus reducing the possibility for any data entry error. Furthermore, the hard copy data was randomly double-checked to insure data entry is not resulting in any systematic or non-systematic errors. Once approximately one-third of the on-site surveys had been entered into the project on-site survey database, a random sample of surveys was double-checked by senior staff to identify and rectify any systematic data entry errors.

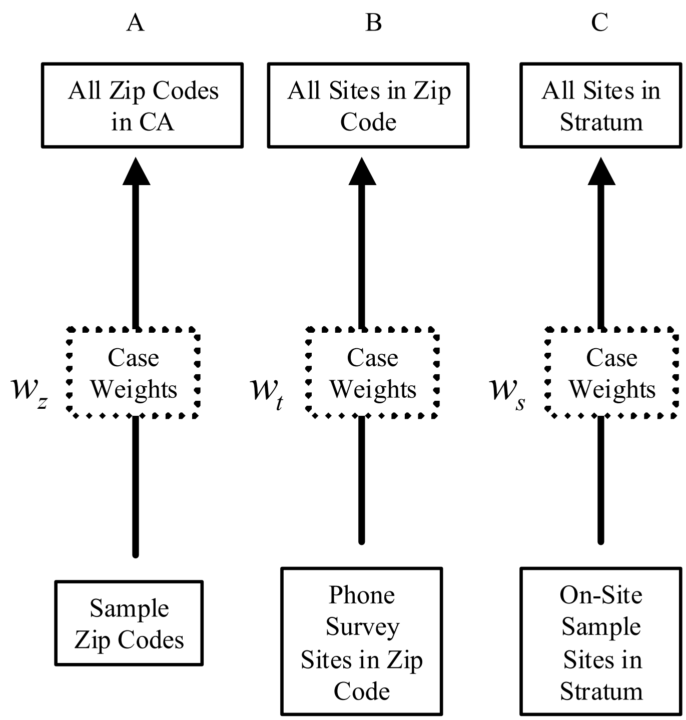
Before any analysis of the on-site data began, a series of queries were written to perform a quality control check on the entered data. These queries identified any missing or incomplete information and also identified any impossible situations, such as luminaires without a corresponding functional use area. Every attempt was made to locate any missing information that was necessary. All impossible situations were corrected before data analysis began.

Statistical Methodology

Case Weights

In analyzing sample data, case weights are used to extrapolate the sample sites to the target population. The case weight w_k is the key to unbiased extrapolation from the sample sites to the target population.

Each site in the onsite survey sample has a corresponding case weight that was used to extrapolate the findings to the state of California. For a given site, the corresponding case weight can be thought of as the number of sites in California that the site is thought to represent. The following figure illustrates the methodology that was used to calculate the case weight of a site k belonging to a certain sampling class j:



w_k = **Case Weight of Site k**

$$= w_z * w_t * w_s$$

where

$$w_z = \frac{\text{\# Zip Codes in CA in Class j}}{\text{\# Zip Codes Sampled from Class j}}$$

$$w_t = \frac{\text{\# Establishments in Zip Code}}{\text{\# Phone Surveys in Zip Code}}$$

$$w_s = \frac{\text{\# Sites in Stratum i of Class j}}{\text{\# On-Sites in Stratum i of Class j}}$$

Figure 9: Calculating the Case Weights

As Figure 9 shows, the first step in calculating the case weight of site k belonging to stratum i of sampling class j was to calculate the weight that will be used to extrapolate the on-site survey data to the sampling frame used to select the on-site survey sample, w_s. In this study, the sampling frame used to guide the on-site survey selection was the telephone survey sample. Consequently, w_s is equal to the number of sites in the telephone survey sample belonging to stratum i of sampling class j divided by the number of on-site surveys in that stratum. In essence, w_s is used to extrapolate the on-site survey data to the telephone survey data.

Balanced post-stratification techniques were used to calculate w_s. Balanced stratification is one way to calculate case weights. In this approach, the sample sites are sorted by the stratification variable, the proxy for the amount of outdoor lighting at the site from the telephone survey, and then divided equally among the strata. Then the first stratum cutpoint is determined midway between the values of the stratification variable for the last sample case in the first stratum and the first sample case in the second stratum. The remaining strata cutpoints are determined in a similar fashion. Then the population sizes are tabulated within each stratum. Finally the case weights are calculated in the usual way, $w_s = \frac{N_h}{n_h}$, where h is the stratum number.

The following example problem shown in Table 74 conveys the idea of case weights using balanced post-stratification[32]. In this example, a sample of 85 sites has been equally divided among five strata, so there are 17 sites per stratum. Then the stratum cutpoints shown in column two were calculated from the proxy for the amount of outdoor lighting present for the sample sites. Next the population sizes shown in column three were calculated from the stratum cutpoints. The final step was to calculate the case weights shown in the last column. For example, the case weight for the 17 sites in the first stratum is 136 / 17 = 8.

Stratum (h)	Max Value	Population Size (N)	Sample Size (n)	Case Weight
1	20	136	17	8.00
2	50	84	17	4.94
3	100	70	17	4.12
4	300	50	17	2.94
5	500	25	17	1.47
Total		469	85	

Table 74: Balanced Post-Stratification Example

Next, the weight that extrapolates the telephone survey data to the zip code sampling class j, w_t was calculated. As seen in the figure, w_t is equal to the total number of establishments in the zip code33 divided by the number of telephone surveys completed in that zip code.

The third step in calculating the case weights was to calculate the weight that extrapolates the sampled zip codes to all zip codes in California, w_z. The weight associated with each zip code is equal to the number of zip codes in California in sampling class j divided by the number of zip codes sampled from sampling class j. The zip code sampling classes are those previously described in the telephone survey sample design section. Lastly, the case weight of site k belonging to stratum i of sampling class j, w_k, is equal to the product of w_s, w_t, and w_z.

Finally, we applied a ratio true-up to the case weights based on the total employment in California versus the reported employment in the sample. Specifically, the case weight of each site was multiplied by the ratio $\frac{X}{\hat{X}}$, where X is the total number of employees in California, as given in the U.S. Census Bureau Zip Code Business Patterns CD, and $\hat{X}$ is the mean per unit estimator[34] of the total number of employees, calculated

[32] The complexity of the calculation of the case weights w_s makes it difficult to concisely present the calculation. For this reason, this example is provided only to demonstrate the statistical concepts used in the study. The actual numbers presented have no relevance to the current study.

[33] The number of establishments in each zip code was determined from the 1997 Zip Code Business Patterns CD-ROM from the U.S. Census Bureau. This is the same source that was used to select the sample of zip codes, as detailed in the sample design methodology chapter.

[34] The mean per unit estimator is defined to be $\hat{X} = \sum_{k=1}^{n} w_k x_k$, where x_k = number of employees at site k and $\hat{Y}$ = the statewide total number of employees.

using the case weights from the third step above. This final step was performed in order to ensure the magnitudes of the case weights were consistent with a known quantity for the state.

Creation of Computational Analysis Queries

The RLW Team created computational formulas designed to assess the hourly demand and annual energy consumption attributable to outdoor lighting at each site based on the on-site survey information about the equipment, schedules of use, and control strategies. We also created additional relationships to assess key outdoor lighting design attributes, such as lighting power densities; minimum, maximum, and average horizontal illuminances, etc. Once the computational formulas were devised, queries were designed in the project database to calculate the attributes of interest for each sampled site. These analysis queries were designed specifically for the Model Bases Statistical Sampling (MBSS) program to analyze the data. More information on the format of each query is provided in the Appendix .

Site Level Annual Energy Usage

To estimate the statewide annual energy consumption of outdoor lighting, the field data collected for each site was converted into an estimate of the annual energy use. The operating control data and the lighting schedules determined the annual operating hours of fixture i. The lamp type, number of lamps, lamp wattage and ballast type (if applicable) approximated the wattage of luminaire i. For each site, the annual operating hours of each fixture and the fixture wattage was combined to estimate the annual energy consumption attributable to outdoor lighting. The following equation illustrates the calculation:

$$Annual\ kWh = \sum_{All\ luminaires} h_i * \frac{W_i}{1000}$$

Where h_i = Annual operating hours of luminaire i

And W_i = Wattage of luminaire i

Equation 1: Site Level Annual Energy Usage Calculation

Since luminaire operating schedules were collected separately for summers and winters, and weekdays and weekends, it was necessary to determine the number of summer weekdays, etc. in a year in order to calculate the annual operating hours of luminaire i. For this purpose, we estimated that there are approximately 260 weekdays and 104 weekend days per year. These were equally allocated between summer and winter. Photocells were assumed to operate from 7PM to 5AM in the summer and from 5PM to 7AM in the winter, on average.

Extrapolation of Results

Once the on-site survey information was converted into estimates of hourly demand and annual energy usage and other attributes of interest for each site, we used Model Based Statistical Sampling (MBSS) methods to extrapolate the findings to the target population. We also used MBSS methodology to calculate the appropriate measures of statistical precision.

The case weights were used to extrapolate the sample findings to the state of California. Two types of estimates must be extrapolated to the population: estimates of population totals (e.g. annual kWh energy consumption due to outdoor lighting in California) and ratio estimates (e.g. average LPD in parking lots).

Population Totals

The mean per unit estimate of population totals is calculated as a weighted sum of the sample observations. For example, the statewide annual energy consumption of outdoor lighting will be estimated using the following calculation:

$$\hat{Y} = \sum_{k=1}^{n} w_k \, y_k \, ,$$

Where y_k = the annual energy consumption of exterior lighting at site k

And $\hat{Y}$ = the statewide annual energy consumption of exterior lighting.

Ratio Estimates

For each site *k*, the characteristic of interest is often a ratio $R_k = y_k / x_k$, e.g., average lighting power density in parking lots or kW per square foot of parking lot. In general MBSS terminology, y_k is called the dependent variable and x_k is the explanatory variable.

Then the population characteristic of interest is the ratio $R = \frac{\sum_{k \in P} y_k}{\sum_{k \in P} x_k}$. The preceding equation can also be written as $R = \frac{\sum_{k \in P} x_k \, R_k}{\sum_{k \in P} x_k}$. In this form it is evident that *R* is a weighted average of the values of R_k for all sites in the target population.

Generally we do not the values of both y_k and x_k for all sites in the population. But for each site in the sample, we do have a weight w_k that can be used to extrapolate the sample to the population. In this case we calculate an estimate of *R* that is denoted $\hat{R}$ and calculated using the equation: $\hat{R} = \frac{\sum_{k \in s} w_k \, y_k}{\sum_{k \in s} w_k \, x_k}$. The preceding equation can also be written as $\hat{R} = \frac{\sum_{k \in s} w_k \, x_k \, R_k}{\sum_{k \in s} w_k \, x_k}$.

Development of Database Summarization Tool

The final big challenge in the successful completion of this project was to make the database user-friendly. To meet this challenge, we provided a variant of the analysis software developed for a CEC Nonresidential New Construction Database project and used extensively in the San Diego Gas and Electric Statewide Residential Lighting and Appliance Saturation Study. In these prior studies we faced the challenge of providing analysis software that would implement stratified ratio estimation using an Access database of complex building characteristics. We created a Visual Basic application of MBSS that would select one or more queries in the database, carry out the statistical calculations of stratified ratio estimation, and create tables in the database with the results desired. The application tailored for this project has the ability to:

- Calculate ratio estimates, (e.g., the average lighting power density), classified by any available categorical variable such as building type or functional use area.
- Calculate the underlying sample sizes
- Calculate the appropriate model-based error bounds, and
- Calculate proportions.

This software can be used to create one-way, two-way or multi-way tables categorizing the outdoor lighting characteristics from the on-site data. The resulting tables can be easily exported to Excel and displayed graphically. This software was used to create the graphs and tables throughout this report. The software provided is fully documented in the Appendix , and a help file is available within the software if the user encounters any problems.

The following is a list of some examples of the types of weighted statistics that can be obtained from the database:

- Average Lighting Power Density (LPD) by Functional Use Area,
- Distribution of Lamp Types across Functional Use Areas, and
- Percentage of Parking Lots within a Specified Range of Maximum Horizontal Illumination.

The Visual Basic application of MBSS was used to calculate the ratio estimates throughout this report using the appropriate queries that were programmed into the database. For estimates of population totals, an additional piece of software, a Fortran application of MBSS, must be utilized. All data input files that are needed to successfully calculate the population totals using the Fortran application of MBSS can be generated using the queries that are programmed into the database. For a complete description of which queries are used for calculation, refer to Appendix .

Observations and Lessons Learned

The State and National Context

The results from this survey will provide a basis for ongoing discussions of program and code options for addressing outdoor lighting energy use. The baseline findings, survey methodology, energy metrics and the environmental assessment are already influencing nationwide discussions of exterior lighting. Some examples follow.

California Senate bill SB5X was signed into law in 2001. It provided that the California Energy Commission (CEC) could develop standards for and regulate outdoor lighting. Previously, the CEC was restricted to regulating lighting only for conditioned space. Work is currently underway to develop an outdoor lighting standard based in part on this work. If successful, this initiative would become effective in 2005.

In Washington, both Seattle and the State have had exterior lighting requirements since 1980. Both codes prohibit trading between interior and exterior lighting and categorize exterior lighting into two broad groups: facade lighting and all else. The wattage allowances are applied to the square foot of illuminated area [35]. A representative from the City of Seattle is an advisor to this PIER research and is providing valuable feedback on the application of their code approach. This project's findings, in turn, will provide expanded category definitions and characteristics beyond the current "all else" grouping in Washington, including such areas of high interest as gas station and parking lot lighting.

A consortium of lighting experts and entities, lead by the International Dark-Sky Association (IDA) is developing a Model Lighting Ordinance (MLO). The MLO Task Force was formed in early December 2001. As the CEC develops a scientific basis for outdoor lighting regulation, based in part on this survey, the MLO Task Force will incorporate results as appropriate to the outdoor lighting section of their national model ordinance.

The intent of the MLO for outdoor lighting will be to restrict unnecessary and improper uses of outdoor lighting by a combination of cutoff requirements, height limitations, power density limits, and other factors that still permit the interpretation and application of Illuminating Engineers Society of North America (IESNA) recommendations by individual lighting designers, engineers and others. The work will be based on IESNA, CIE (International Commission on Illumination) and other applicable standards to the maximum extent possible (Benya 2001)[36].

Results of this work may also feed into key lighting design guides such as the IESNA handbooks and recommended practice guidelines, the ASHRAE/IESNA 90.1 lighting standards, and the Advanced Lighting Guidelines.

The assessment methodology described in this report is highly valuable as a repeatable protocol for the establishment of outdoor lighting baselines. Combined with the interest and activity of transferring this research into programs, policies and practices this survey method will play a key role in reducing outdoor lighting energy use.

[35] Hogan, John 2002 (City of Seattle Department of Land Use). Personal communications February 2002. Seattle, WA
[36] Jim Benya, *Model Lighting Ordinance Information.* November 2001. IDA Web Site www.darksky.org

Lessons Learned

Several lessons were learned throughout the course of conducting the phone and onsite surveys. The key points are listed below.

- Continuous technical and coordination oversight by a single individual is required during data collection to monitor the data collected and to answer questions regarding unique situations. This is required to ensure consistent interpretations as the team is exposed to countless "non-conforming" situations.
- The onsite survey instrument and database that houses the onsite survey data must be designed to be flexible enough to capture a myriad of outdoor lighting applications. Even though pilot tests of 50 buildings were used to design the survey instrument, we still encountered unanticipated outdoor lighting applications that necessitated either revisions to the instrument or special handling in the database.
- The illuminance measurement grids should be defined at night right before the readings are taken. During the pilot test of the onsite survey instrument, we were defining the placement of the illuminance measurement grids as a part of the daytime component of the onsite survey. When we returned at night to take the measurements, we often found cars or other objects obstructing the grids defined during the day, requiring the grids to be redefined.

Additional Opportunities

- Gas station canopies and outdoor retail sales are of particular interest in the lighting community. Additional data would fill out the outdoor retail sales and gas station canopy code impact tables, and would allow the accurate calculation of the statewide energy consumption of these important functional use areas.
- The development of correlations between LPD and illuminance values, including associated information of lamp type, pole height, and lighting zone, would also provide valuable insight into the outdoor lighting design practices in California.
- The statewide results provide an opportunity to evaluate the energy savings available from enhancements in commercial outdoor lighting design practices. For example, the data indicate that lighting power densities (LPD) of less than 0.10 W/SF for parking are both common and adequate. The impact available from various strategies to convert over lit parking to this standard could be calculated. The opportunity exists to develop similar projections for many other lighting applications and configurations, yielding substantial information for the design and regulatory communities.

Appendix A

Impact Evaluation of Proposed Standards

Included in separate "Appendices" document (Attachment A-19 to Commission Publication #P500-03-082)

Appendix B

Nightime Subjective Lighting Evaluation

Included in separate "Appendices" document (Attachment A-19 to Commission Publication #P500-03-082)

Appendix C

Outdoor Lighting On-site Survey Instrument

Included in separate "Appendices" document (Attachment A-19 to Commission Publication #P500-03-082)

Appendix D

On-Site Surveyors Manual (Attachment A-19 to Commission Publication #P500-03-082)

Appendix E

Telephone survey instrument

Included in separate "Appendices" document (Attachment A-19 to Commission Publication #P500-03-082)

Appendix F

Database Documentation

Included in separate "Appendices" document (Attachment A-19 to Commission Publication #P500-03-082)

The database is 86 MB and only available by direct mailing. Contact the Commission at 916-654-5200.

End Note

[ii] See Dr. S.M. Berman, "Energy Efficiency Consequences of Scotopic Sensitivity," Journal of the Illuminating Engineering Society, Winter 1992.