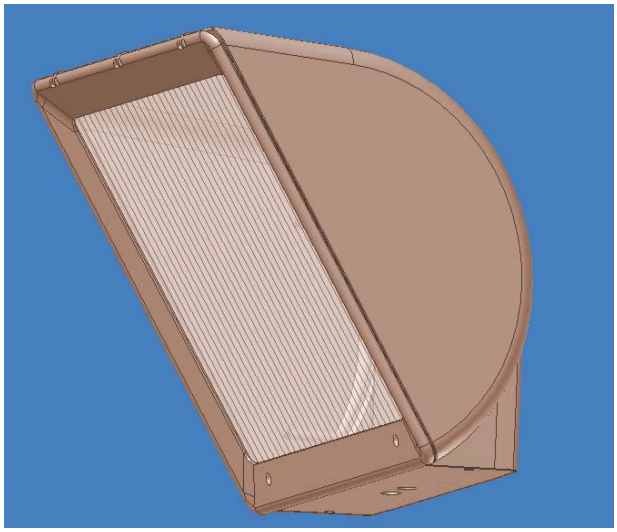
LIGHTING RESEARCH PROGRAM

Project 5.3 Low Glare Outdoor Luminaire

FINAL 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.

The PIER Program, managed by the California Energy Commission, annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

What follows is the final report for the PIER Lighting Research Program, Contract #500-01-141, conducted by Lawrence Berkeley National Laboratory. The report is entitled Low Glare Outdoor Luminaire. This project contributes to the PIER Lighting Research Program.

The key deliverables for each project, in the form of guidelines and technical reports, are attachments to this report and are listed and described at the start of the attachment section. Due to market dynamics and the normal passage of time between the completion of research and the publication of research results, products anticipated for market delivery in this report may not necessarily reflect the actual array of products as delivered, or planned for delivery, by manufacturers. Therefore, the reader is advised to contact the lighting product manufacturers directly to ascertain the current status of products.

For more information on the PIER Program, please visit the Commission's web site at http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at (916) 654-5200.

Executive Summary

Introduction

The issue of glare and light pollution is becoming more important as the number of outdoor installations has increased. Lighting fixtures for area and building lighting are classified as non-cutoff, semi-cutoff, and full-cutoff, depending upon how much light they emit at horizontal, and above horizontal. The cutoff primarily affects light pollution. The light distribution at near-to-slightly-below horizontal is the primary factor in glare. Traditionally, low-glare fixtures have been less efficient, in terms of lumens delivered to the ground, than high-glare fixtures. This is a counter-intuitive result in the sense that light lost to the horizontal or upward direction shouldn't impact efficiency. However, methods used to control this light have negatively impacted the light distributed to the ground. These light control techniques often result in less even illumination. One recent study found that full-cutoff fixtures produced more light pollution than non-cut-off fixtures, because their light distribution was so poor. It appears that manufacturers have traditionally thought only in terms of the cutoff requirements, and have not examined the larger issue of efficient distribution.

Project 5.3 focused on researching and developing an efficient low-glare, low-light pollution fixture for lighting building exteriors and surrounding areas. This type of fixture will have immediate benefits to the environment, and because glare hinders visibility, it would have the potential to allow lower light levels, and thus lower energy use as well. The new product will enhance visual performance, reduce light pollution and is more energy efficient than typical wall pack fixtures.

This project is part of a larger effort to improve outdoor lighting practice in California through the review of outdoor lighting reports and the development of an improved outdoor luminaire for building exteriors.

Project Objectives

The goals of this project are to:

- Analyze new performance standards developed in Europe for a low glare retrofit system for outdoor luminaires and determine the applicability of this work to United States manufacturers of similar luminaires now in use in California.
- Develop design concepts in coordination with a manufacturer for an energy efficient low glare retrofit system for outdoor luminaires founded on results of recent visual performance studies and research data from Europe and North America.
- Develop and demonstrate a prototype retrofit system for outdoor luminaires with manufacturer's participation with improved performance characteristics.

The objective of this project is to develop an energy efficient low glare retrofit luminaire for parking areas and roadway illumination that would improve the efficiencies of

existing luminaires by up to 30 percent. Improvements in visual performance are achieved by reducing glare and by using high color rendering sources. Further improvements in the system performance are achieved by the use of high performance electronic ballasted systems being investigated under the LRP Project 5.2.

This project is related to the PIER objectives of reducing the electric load due to lighting, while maintaining or improving the quality of light delivered. Results from the *Outdoor Lighting Baseline Assessment* study being generated by a current Commission PIER projects, under contract with New Buildings Institute, will quantify the potential impact that this technology would have on reducing the electric load in California.

Photometric and electric measurements of the prototype luminaire will demonstrate the efficiency gains that can be achieved with the complimentary technologies of improved optics optimized for visual performance and ballasting technology. Standard measurement procedures will be followed.

Project Outcomes

This project had the following key outcomes:

- Review of European reports concluded that European Performance Standards could not be easily or practically modified for use in the United States.
- The analysis of the *PIER Outdoor Lighting Baseline Assessment* report identified that over one-third of existing parking lot fixtures can be classified under the category of “wall-mount”. As wall mount fixtures often do not have any glare control, this category has the greatest potential for glare reduction. These fixtures are also the least efficient of outdoor fixtures. As a result, this LRP project was modified to focus on the design criteria for an improved wall sconce that was developed and tested in collaboration with the industrial partner Gardco.
- Gardco has developed and prototyped a new outdoor luminaire, which can provide 30% savings in energy and reduce night light pollution with improved optics.

Discussion and Conclusions

The analysis of the European Performance Standards concluded that due to the differences between the United States and European practices, the European Performance Standards could not be easily or practically modified for use in the United States.

LBNL’s analysis also helped elucidate the need to further develop design criteria for parking lot lighting, as visual performance requirements in parking lots differ greatly from those in roadway situations. Researchers raised several important points that should be considered further as standards and retrofits for parking lot lighting are developed. These include:

- Relationship between vertical illumination and veiling glare.
- Control of illumination uniformity to meet energy efficiency standards.

- Effects of lamp spectra on brightness and peripheral visibility.

As a result of this review, it is concluded that the overall intent of the European specification in limiting glare, light trespass, and light pollution should be preserved, but the specific form of the requirements should be adjusted to a system approach for use in California. LBNL concluded that possible retrofit strategies would most likely require fixture head replacement, so the primary issue is to develop a set of target candlepower distributions for manufacturers. This conclusion lead to the analysis of previous PIER-funded work as the foundation to develop the design criteria for this system approach and energy savings potential of such a strategy.

The design criteria and energy savings potential for the retrofit fixture were initially determined through an examination of two recent documents relating to outdoor lighting standards: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). The analysis of these two reports lead to the following conclusions:

- The energy savings from improved light source efficacy may not be as large as projected.
- The energy savings from lamp replacement strategies may also not be as large as expected.
- It may be difficult to meet both the power density requirements and the illuminance criteria if installations differ from the standard layout.
- Curfew switching may not be feasible due to the limitations of current technology and also to safety concerns.

Based on this analysis, LBNL recommended the following additional or alternative strategies for energy savings:

- Establish a set of optimal candlepower distributions for a range of layouts.
- Develop retrofit post-top fixtures based on optimal candlepower specifications.
- Consider wall mount fixtures as a potential target for retrofit efforts.
- Use motion detectors instead of curfews.
- Continue (at present) to allow use of both HPS and MH lamps.

The original hypothesis of the proposal was that the European Performance Standards would provide guidance on a proposed method to modify existing outdoor luminaires to improve performance. This would result in the development of a retrofit kit for centered on pole- or post-top luminaires for parking lot lighting. The conclusion of the analysis of the European Standards as stated above, proved that this was not a practical solution.

However, the subsequent analysis of the *PIER Outdoor Lighting Baseline Assessment Report* identified that over one-third of existing parking lot fixtures can be classified under the category of “wall-mount.” As wall mount fixtures often do not have any glare control, this category has the greatest potential for glare reduction. These fixtures are also

the least efficient of outdoor fixtures. Wall-mounted fixtures light the parking lot from only one side, which makes it more difficult to obtain good uniformity and good energy efficiency. Both of these problems may be addressable by changes in optical design that lead to a more optimal candlepower distribution for typical parking lot geometries. Additionally, reducing glare leads to reduced light trespass and light pollution, and enhances visibility within the space. As a result, this LRP project was modified to focus on the design criteria for an improved wall sconce that was developed and tested in collaboration with the industrial partner, Gardco. The result of the work is the development of a very efficient wall sconce that has the product performance to make the original design goals.

The luminaire uses the highest performance metal halide lamp and electronic ballast offering the greatest energy savings. The ceramic metal halide lamp is a white light source with very high color rendition, providing a better quality of light and esthetic appearance. The lamp life of the ceramic metal halide has improved to be comparable to the high pressure sodium lamp that it replaces. The small arc tube of the light source provides for better optical control, which has resulted in a design that is very efficient. The new design provides a more even distribution over a greater surface area than competitive product. The result is that fewer luminaires and consequently less energy is used to illuminate a parking area. On average, there is a 30% savings in energy. The better optical control significantly reduces light pollution to the night sky and light trespass to neighboring buildings and properties. A further advantage is that it also reduces glare, except when in the direct beam of the light. The result is a luminaire that addresses one of the least efficient outdoor lighting systems with superior performance and energy efficiency.

Product Features and Benefits

The features and benefits of the Gardco wall sconce can be summarized as:

Better lighting quality. The Gardco wall pack will produce white light with high color rendition as compared to wall packs using high pressure sodium sources producing orange light with very low color rendition. Esthetically enhancing the environment and allowing users of the space to identify their cars more easily.

The high efficiency of the optical design provides for the following:

- Better light control. The Gardco wall pack will provide illumination up to 45 feet from the building compared to 30 feet for a conventional luminaire.
- A reduction in lamp wattage. A 100-watt Gardco luminaire may replace a 150-watt conventional luminaire if using the same luminaire spacing.
- Less glare, improved light dispersion and cutoff.
- Less wasted light. The Gardco luminaire will eliminate light pollution to the night sky and light trespass to neighboring buildings and properties.

- Comparable lamp life. The lamps in the Gardco and conventional luminaires will each last approximately 20,000 hours.
- Fewer Luminaires. The wider distribution of light means 50% more coverage of parking surface area, reducing the number of luminaires.
- Increased Security. The combination of the better light distribution, lower glare, and higher color definition will enhance the security of the lit environment.

Recommendations

The PIER program has previously funded to two lighting programs that produced recommendations for standards for outdoor lighting: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). These documents have a wealth of information that was used in this analysis. From the analysis, LBNL suggests the following additional or alternative strategies for energy savings:

The following is not recommended:

- The adoption of the practice for the standard layout proposed in the *Outdoor Lighting Research* report.

As an alternative, the following is recommended:

- Establishing a set of optimal candlepower distributions for a range of layouts for outdoor parking and common use areas.

In order to meet both the power density requirements and the recommended illuminance criteria, a reasonably good control of the illuminance uniformity is required.

The following is not recommended:

- The mandated adoption of curfew switching.

As an alternative, the following is recommended:

- The use of motion detectors as an acceptable alternative to curfew switching, and
- Continue (at present) to allow use of both HPS and MH lamps.

LBNL recommends continued support of efforts to develop retrofit post-top fixtures based on optimal candlepower specifications derived from above. This could be supported by an incentive through the utilities.

LBNL recommends support of utility and state outdoor lighting programs that support the development, demonstration, and application of energy and optically efficient wall mount luminaires, such as the product developed within this program.

More demonstrations of this technology are recommended.

Benefits to California

Research performed in the first years work identified a significant need and opportunity for the development of an energy efficient, cost competitive, low glare luminaire to replace the existing “wall pack”. From the analysis of the Outdoor Lighting Baseline Database (OLBD), the wall pack has the least control of glare of any of the luminaire types and represents a major fraction of the outdoor luminaires in California. Hence, the development of an energy efficient, low glare product could have significant benefit to California outdoor lighting applications.

The luminaires designed have energy savings of approximately 30% over current products. The energy savings are realized through the high optical performance of the design and the improved performance of the ceramic metal halide lamp used in conjunction with an electronic ballast. The improved optical performance of the Gardco wall sconce will provide illumination up to 45 feet from the building compared to 30 feet for a conventional luminaire, resulting in 50% more coverage of parking surface area, a reduced number of luminaires, and 30% energy savings. This is most applicable for new installations. For existing installations, the current 150-watt wall packs can be replaced with the more efficient Gardco 100-watt wall sconce for a comparable 30% energy savings.

Another important benefit to California is to the improvement of the social and physical environment. The optical performance and energy efficiency of outdoor lighting will be improved. Building owners can expect better lighting of their parking space and reduced energy costs. Security will be increased from illuminating more area around building with better quality light. The surrounds of the building should also experience less light trespass and light pollution.

Abstract

This LRP project focused on the design criteria for an improved wall sconce that was developed and tested in collaboration with the industrial partner Gardco. The result of the work is the development of a very efficient wall sconce that has the product performance to make the original design goals.

The luminaire uses the highest performance metal halide lamp and electronic ballast offering the greatest energy savings. The ceramic metal halide lamp is a white light source with very high color rendition, providing a better quality of light and esthetic appearance. The lamp life of the ceramic metal halide has improved to be comparable to the high pressure sodium lamp that it replaces. The small arc tube of the light source provides for better optical control, which has resulted in a design that is very efficient.

The new design provides a more even distribution over a greater surface area than competitive product. The result is that fewer luminaires and consequently less energy is used to illuminate a parking area. On average, there is a 30% savings in energy. The better optical control significantly reduces light pollution to the night sky and light trespass to neighboring buildings and properties. A further advantage is that it also reduces glare, except when in the direct beam of the light. The result is a luminaire that addresses one of the least efficient outdoor lighting systems with superior performance and energy efficiency.

Introduction

Background and Overview

The issue of glare and light pollution is becoming more important as the number of outdoor installations has increased. Lighting fixtures for road and area lighting are classified as non-cutoff, semi-cutoff, and full-cutoff, depending upon how much light they emit at horizontal, and above horizontal. The cutoff primarily affects light pollution. In California there are between 6 and 7 million outdoor luminaires of which one third are full-cutoff fixtures; therefore, there are about 4 million luminaires, which could be improved by a retrofit reflector.

The light distribution at near-to-slightly-below horizontal is the primary factor in glare. Traditionally, low-glare fixtures have been less efficient, in terms of lumens delivered to the ground, than high-glare fixtures. This is a counter-intuitive result in the sense that light lost to the horizontal or upward direction shouldn't impact efficiency. However, methods used to control this light have negatively impacted the light distributed to the ground. These light control techniques often result in less even illumination.

One recent study found that full-cutoff fixtures produced more light pollution than non-cut-off fixtures, because their light distribution was so poor. It appears that manufacturers have traditionally thought only in terms of the cutoff requirements, and have not examined the larger issue of efficient distribution. There does not seem to be any theoretical reason why an efficient low-glare, low light pollution fixture cannot be built. This type of fixture will have immediate benefits to the environment, and because glare hinders visibility, it would have the potential to allow lower light levels, and thus lower energy use as well. Hence, there appears to be an opportunity to develop an energy efficient retrofit system that enhances visual performance, reduces light pollution and is more energy efficient.

In the first phase of this project, information will be gathered to provide a basis for the design of the retrofit luminaire to be developed later in the project. The information gathered will include data on a retrofit system being specified in Europe and on human performance measurements that have been made under the relatively low light level conditions typical of outdoor lighting. LBNL also will review two recent documents relating to outdoor lighting standards: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002).

Finally, LBNL will work with Gardco to design, prototype, and test an improved outdoor fixture.

Project Objectives

The goals of this project are to:

- Analyze new performance standards developed in Europe for a low glare retrofit system for outdoor luminaires and determine the applicability of this work to United States manufacturers of similar luminaires now in use in California.
- Develop design concepts in coordination with a manufacturer for an energy efficient low glare retrofit system for outdoor luminaires founded on results of recent visual performance studies and research data from Europe and North America.
- Develop and demonstrate a prototype retrofit system for outdoor luminaires with manufacturer's participation with improved performance characteristics.

The objective of this project is to develop an energy efficient low glare retrofit luminaire for parking areas and roadway illumination that would improve the efficiencies of existing luminaires by up to 30 percent. Improvements in visual performance are achieved by reducing glare and by using high color rendering sources. Further improvements in the system performance are achieved by the use of high performance electronic ballasted systems being investigated in Project 5.2.

This project is related to the PIER objectives of reducing the electric load due to lighting, while maintaining or improving the quality of light delivered. Results from the *Outdoor Lighting Baseline Assessment* study being generated by a current Commission PIER projects, in contract with New Buildings Institute, will quantify the potential impact that this technology would have on reducing the electric load in California. Photometric and electric measurements of the prototype luminaire will demonstrate the efficiency gains that can be achieved with the complimentary technologies of improved optics optimized for visual performance and ballasting technology. Standard measurement procedures will be followed.

Project Approach

Project Tasks

The project's work scope involves the following technical tasks:

5.3 Task 1. Analysis and Performance Specifications
5.3 Task 2. Prototype Development and Evaluation
5.3 Task 3. Field Test and Evaluation
5.3 Task 4. Technology Transfer Activities
5.3 Task 5. Production Readiness Plan
5.3 Task 6. Monthly Progress Report
5.3 Task 7. Annual Report
5.3 Task 8. Final Report

Changes and Modifications

The original hypothesis of the proposal was that the European Performance Standards would provide guidance on a proposed method to modify existing outdoor luminaires to improve performance. This would result in the development of a retrofit kit for centered on pole- or post-top luminaires for parking lot lighting. The conclusion of the analysis of the European Standards proved that this was not a practical solution. The subsequent analysis of the PIER *Outdoor Lighting Baseline Assessment* report identified that over one-third of existing parking lot fixtures can be classified under the category of "wall-mount." As wall mount fixtures often do not have any glare control, this category has the greatest potential for glare reduction. These fixtures are also the least efficient of outdoor fixtures. As a result, this LRP project was modified to focus on the design criteria for an improved wall sconce that was developed and tested in collaboration with the industrial partner, Gardco.

Project Outcomes

Summary of Project Outcomes

The following summarizes the project outcomes.

Analysis of European Performance Standards

The European specification establishes specific performance criteria for street and park lighting, including luminance and illuminance values, light pollution restrictions, and minimum lamp efficacies. LBNL compared these criteria to currently available technology used in parking lots in the United States, and to the IESNA RP-20-98 and California Energy Commission draft code for parking lot lighting.

Although the net effect of the European performance standards is to minimize glare, reduce light trespass, and light pollution, and limit energy use (all desirable goals), there are a number of aspects of the European specification that greatly limit its applicability to outdoor lighting standards and retrofit luminaires for California. These findings can be summarized as follows:

- **Luminance and illuminance values are inconsistent with current fixture design practice for streets and parking lots in the United States.** When the European performance standard is applied to available fixtures that are sized to fit HID sources, a discrepancy arises in which the minimum required candlepower to meet specified illuminance levels is actually larger than maximum allowed candlepower based on luminance restrictions. To make the design functional, the fixture would need to be at least 0.5 m^2 in size, which is inappropriate for most parking lot applications.

- **Single-fixture approach leads to a system where there is essentially no interaction between fixtures.** The European specification directs its requirements to the individual fixture, as opposed to the IES recommended practice for parking facilities (RP-20-98), which controls the performance of the lighting system as a whole. The European approach may be unacceptable in a parking lot installation, as such systems will provide almost no light near the pole when there is a lamp or fixture failure.

- **Differences in physical layout of lighting installations between Europe and the United States will affect system performance.** The European specification is tied to a specific geometry, which differs from typical luminaire mounting heights, pole spacing, and road widths used in the United States for street and parking lighting. As these variables have a significant effect on candlepower distribution, it may be more appropriate to use the IESNA approach, which allows for greater flexibility in lighting system design.

LBNL's analysis also helped elucidate the need to further develop design criteria for parking lot lighting, as visual performance requirements in parking lots differ greatly from those in roadway situations. LBNL raises several important points that should be considered further as standards and retrofits for parking lot lighting are developed. These include:

- **Relationship between vertical illumination and veiling glare.** Vertical illumination is an important part of IESNA recommended practice for parking lots, as it aids in detection of pedestrians. However, vertical illumination is most efficiently produced by the type of light distribution that also produces veiling glare. Before any specific glare reduction measures are implemented for parking lots, it must be determined whether it is possible to reduce glare and still meet the IESNA recommendations on the minimum vertical illuminance.

- **Control of illumination uniformity to meet energy efficiency standards.** The Commission's draft standard for outdoor lighting limits energy use (as watts/ft2) in parking lots as a function of the environmental lighting zone, and thus restricts the average light levels for each zone. In contrast, the IESNA recommended practice for parking lots specifies minimum illuminance levels to meet visibility and security requirements for two categories, "basic" and "enhanced security." To meet these recommended levels in lighting zones 1 and 3 (of the Commission draft standard), a reasonably good control of the uniformity (a ratio of around 5:1) is required.

- **Effects of lamp spectra on brightness and peripheral visibility.** There is currently a great deal of interest in the impact of changes in light spectrum on energy use and visual performance in parking lots, but these issues are not covered in current standards. Further investigation of the relationship of lamp spectra to brightness and peripheral visibility is needed before any light spectrum requirements are included as part of a lighting standard for parking lots.

As a result of this review, LNBL has concluded that the overall intent of the European specification in limiting glare, light trespass, and light pollution should be preserved, but the specific form of the requirements should be adjusted to a system approach for use in California. Possible retrofit strategies for pole-mounted luminaires in parking lots include replacing the fixture or head, changing the optics, or shielding the fixtures. Other types of fixtures, including wall packs and canopy lights, will most likely require fixture head replacement, so the primary issue is to develop a set of target candlepower distributions for manufacturers.

Design Criteria and Energy Savings Potential

The design criteria and energy savings potential for the retrofit fixture were initially determined through an examination of two recent documents relating to outdoor lighting standards: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). The PIER report provides

baseline information that is used to estimate the potential energy savings from retrofit strategies and changes to the energy code. The Eley report proposes draft standards for outdoor lighting. In this analysis, LBNL evaluated the three main energy saving strategies proposed in these documents for parking lot lighting: 1) light source efficacy improvements and lamp replacements; 2) reduced power densities; and 3) application of lighting controls (curfews). The following are the most important findings with regard to these proposed strategies:

- **The energy savings from improved light source efficacy may not be as large as expected.** Because there are large differences in efficacy between the various light sources that are currently used in parking lots, this represents a potential avenue for future energy savings. However, the information available in the PIER report suggests that existing parking lot lighting that uses inefficient sources has lower power densities and illumination levels than lots with more efficient sources. Incandescent and halogen lamps (the most inefficient sources) constitute almost 10% of installed sources, but represent only about 6% of the total energy used in parking lots. This suggests that replacement of these sources may only save a small fraction of this energy use.

- **The energy savings from lamp replacement strategies may also not be as large as expected.** The PIER report proposes a theoretical scenario where all existing high pressure sodium lamps (HPS) are replaced with metal halide (MH) lamps, and estimates a potential savings of 33% from this strategy. This estimate is based on the hypothesis 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 theoretical questions that remain to be answered with regard to whether Berman's brightness measure is valid for use in parking lots. If this measure is not valid, replacing HPS lamps with MH lamps would still achieve energy savings, but at the expense of visual performance.

- **It may be difficult to meet both the power density requirements and the illuminance criteria if installations differ from the standard layout.** The power density requirements proposed in the draft standard are based on illuminance criteria established by the IESNA in its recommendations for parking lot lighting (RP-20-98). The Eley report establishes a standard grid for calculating both the power densities and the illuminance requirements. Actual parking lot installations are likely to vary from this standard layout, and may not be able to meet the illuminance criteria under the specified power densities. In addition, there may have been an error in calculating the minimum illuminance in the Eley report. If adequate illumination (especially for safety reasons) is a significant concern, these possible discrepancies should be considered more carefully as changes are made to the lighting code.

- **Curfew switching may not be feasible due to the limitations of current technology and also to safety concerns.** The Eley report proposes a 50% reduction in power after curfew for Lighting Zones 2 through 4, and a 90% reduction for Lighting Zone 1 (LZ1). It may be difficult to meet these reduced power requirements without compromising the illumination levels required for safety purposes. The especially low light levels required in LZ1 may not be sufficient to prevent transient blindness in pedestrians in the face of automobile headlights.

Based on this analysis, LBNL recommends the following additional or alternative strategies for energy savings:

- **Establish a set of optimal candlepower distributions for a range of layouts.** In order to meet both the power density requirements and the recommended illuminance criteria, a reasonably good control of the illuminance uniformity is required. As actual parking lots will vary in their size and shape, the candlepower distribution from a particular luminaire may not be ideal for all situations. The best approach is to define the most common layouts for parking lots and then specify a set of candlepower distributions that works best over a range of conditions for these layouts.

- **Develop retrofit post-top fixtures based on optimal candlepower specifications.** This represents the most promising opportunity to develop energy-efficient new and retrofit fixtures for existing parking lots.

- **Consider wall mount fixtures as a potential target for retrofit efforts.** Much of the ongoing discussion regarding retrofit fixtures for parking lot lighting has centered on pole- or post-top fixtures. The PIER report indicates that over one-third of existing parking lot fixtures can be classified under the category of "wall-mount." As wall mount fixtures often do not have any glare control, this category has the greatest potential for glare reduction. These are also the least efficient type of fixtures. Wall-mounted fixtures light the lot from only one side, which makes it more difficult to obtain good uniformity, and hence good energy efficiency. Both of these problems may be addressable by changes in optical design that lead to a more optimal candlepower distribution for typical parking lot geometries. Additionally, reducing glare leads to reduced light trespass and light pollution, and enhances visibility within the space.

- **Use motion detectors instead of curfews.** As it may not be feasible or desirable to reduce lighting power to the proposed curfew levels, using motion detectors is a possible strategy to consider. It might be argued that it is the *potential* for demand, and not actual demand, that is low during curfew periods. A motion detector would allow the installed lighting to provide full illumination when it is required and to turn down the lights when there is no activity.

- **Continue (at present) to allow use of both HPS and MH lamps**. Because it is not clear whether the brightness lumen hypothesis referenced in the PIER report is valid for parking lots, it is not appropriate at this time to mandate a replacement of HPS lamps with MH lamps. For most visual tasks that depend upon photopic luminance, previous research has shown that HPS lamps are superior to MH lamps at equal wattages. This suggests that MH lighting may not provide equal performance if HPS lamps are replaced with lower-wattage MH lamps.

Prototype Development and Evaluation

LBNL collaborated with Gardco to develop a prototype wall pack fixture. The design criteria and goals of this process are described below.

Design Criteria

The primary design criteria for the prototype fixture were as follows:

1. The product will be cost competitive and offer significant advantages over currently available wall packs: high efficiency, higher optical performance, and better light quality.

2. The luminaire will be designed to be better than a cut-off fixture, if possible, and have the versatility to be made into a full cut-off fixture.

3. Projection from base of the wall outward will significantly exceed a full cut-off fixture. The criteria that the new fixture will be designed to are:

   - Mounting height of 15 ft
   - Projection: Horizontal projection from the wall of 40-45 ft
   - Lateral project of 4 mounting heights
   - At the projection limits to have an illuminance of 0.5 fc

4. The prototype will have a fixture efficiency equal to or greater than 60 percent
5. Fixture will be designed for tilt versus sag lens
6. The source will be Metal Halide

Researchers realized there is significant need and opportunity for the development of an energy efficient, cost competitive, low glare luminaire to replace the existing “wall pack”. From the analysis of the Outdoor Lighting Baseline Database (OLBD), the wall pack has the least control of glare of any of the luminaire types and represents a major fraction of the outdoor luminaires in California. This is demonstrated in following table.

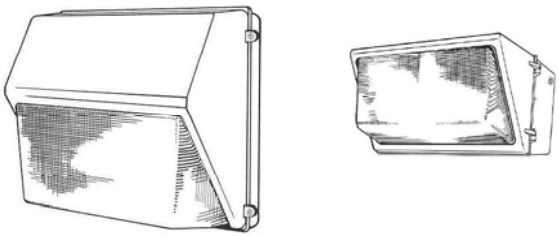
Table 1. Fraction of luminaires by type and glare control.

Fixture type	Percentage	Cut-off

Fixture type	Percentage	Cut-off
Post top mount	44.6%	91.5%
Wall or landscape	22.9%	15.7%
Wall mount	14.6%	4.4%
Pole mount	10.7%	6.5%
Canopy	6.6%	37.9%
Undefined	0.4%	25.0%
Landscape	0.1%	100.0%

A cut-off design would provide much better visual quality as compared to the existing product. The OLBD identified two types of luminaire as wall pack. In the database, these luminaires are designated as Type P wall pack, and Type Q cut-off wall pack. The OLBD diagram and description of these luminaires is given below.

Diagram of luminaires identified in survey



Type P – 'Wall Pack' fixture
HPS: 70,100,150,250,400
MH: 70,100,175,250,400
Very common on back of buildings for 'security' lighting. Large glare source. Single horizontal lamp, often HPS.

Type Q – Cutoff 'Wall Pack' fixture
HPS: 70,100,150
MH: 70,100,175
CF: 26,32,42
Often used on higher budget projects at side entrances. Lamp not visible from a distance. Uses lower wattage lamps compared to Type 'P'. Single horizontal lamp.

Low Percentage of Cut-Off Luminaires used in California

LBNL analyzed all relevant data available as designated belonging to P and Q type luminaires. The database contains data on 205 different sites using wall pack luminaires. Nine out of the 205 sites, or only 4.4 percent of the sites, used Type Q or cut-off fixtures. Four of the nine cut-off luminaires used Metal Halide (MH) sources. Of the four, three used 100W MH and one used 175W MH. All of the cut-off luminaires studied used sources of 180 watts or less.

Population Distribution of Luminaires as a Function of Wattage

793 luminaires were recorded on the 205 sites studied in the OLBD. The following bar graph gives a distribution of lamp wattages as a function of number of fixtures. A significant number of the fixtures used lamps of 200 watts or above. Also, it is assumed

that the new California outdoor lighting specification for 2005 will limit wall packs to wattages under 200 watts. The following graph also demonstrates that the 150-watt lamp is the source of preference below 200 Watts.

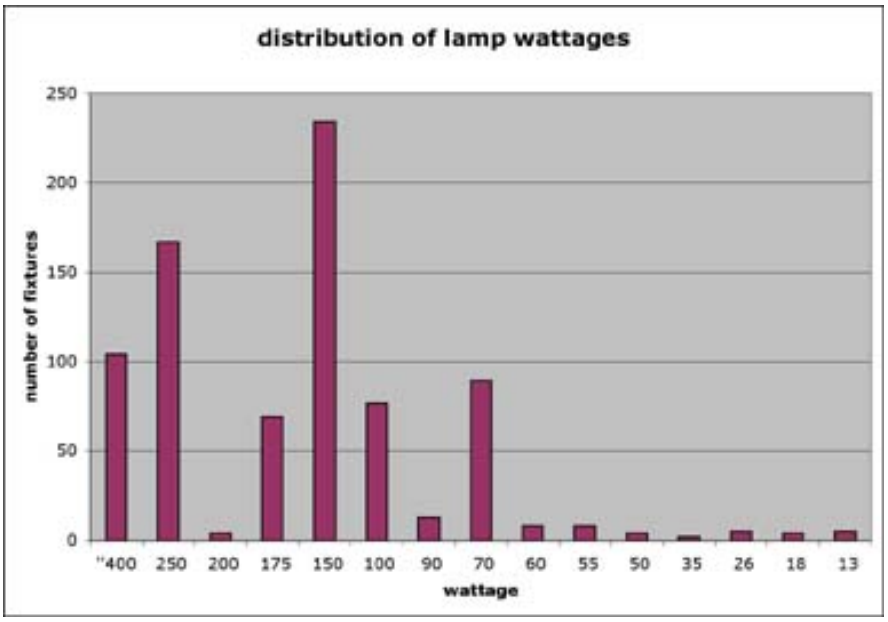


Figure 1. Distribution of fixtures by lamp wattage.

Population Distribution of Luminaires as a Function of Mounting Height for Different Wattages

LBNL also analyzed the data to determine the mounting heights most frequently used for the different wattage light sources.

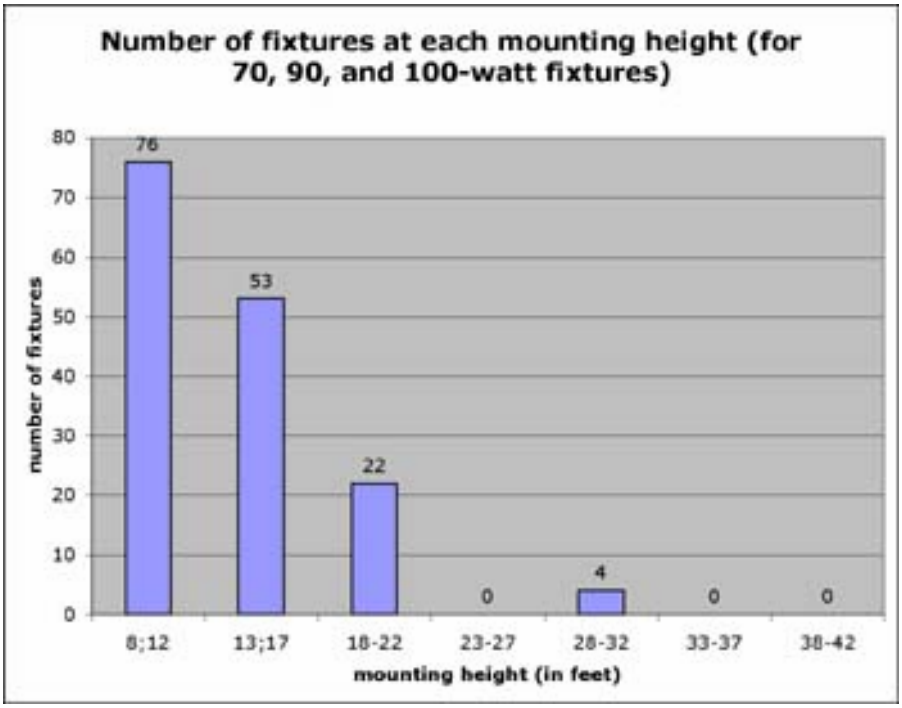


Figure 2. Distribution of fixtures by mounting height for 70, 90, and 100-watt fixtures.

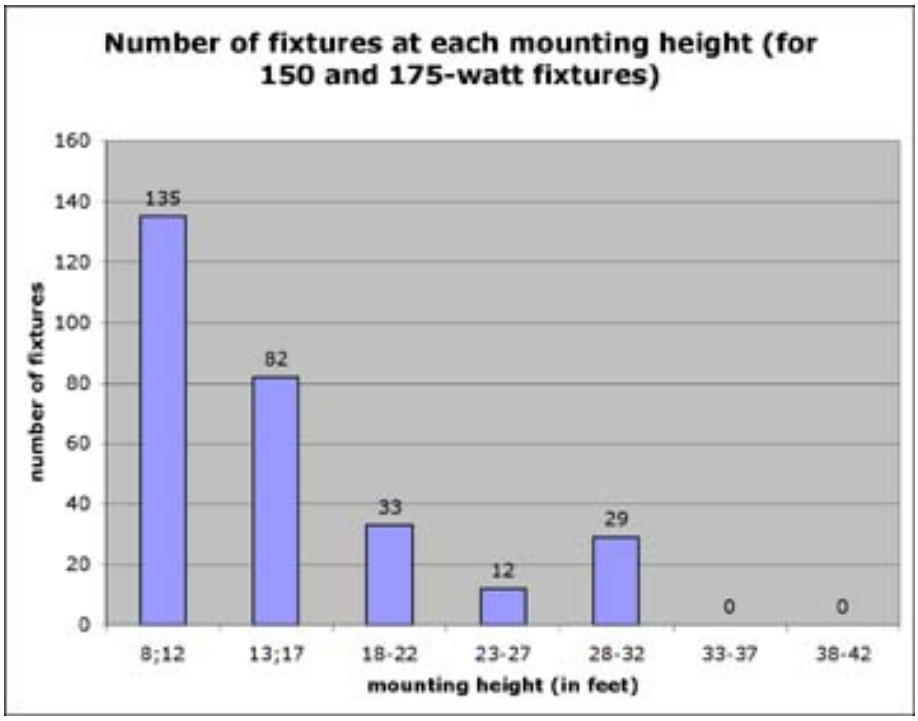


Figure 3. Distribution of fixtures by mounting height for 150 and 175-watt fixtures.

It is interesting to note that for fixtures using sources of 175 watts or lower, the most popular application is for a mounting height around 10 feet, with the majority of fixtures mounted at heights under 18 feet. This supports the concept of optimizing the fixture for a mounting height of 15 feet for greatest flexibility in application.

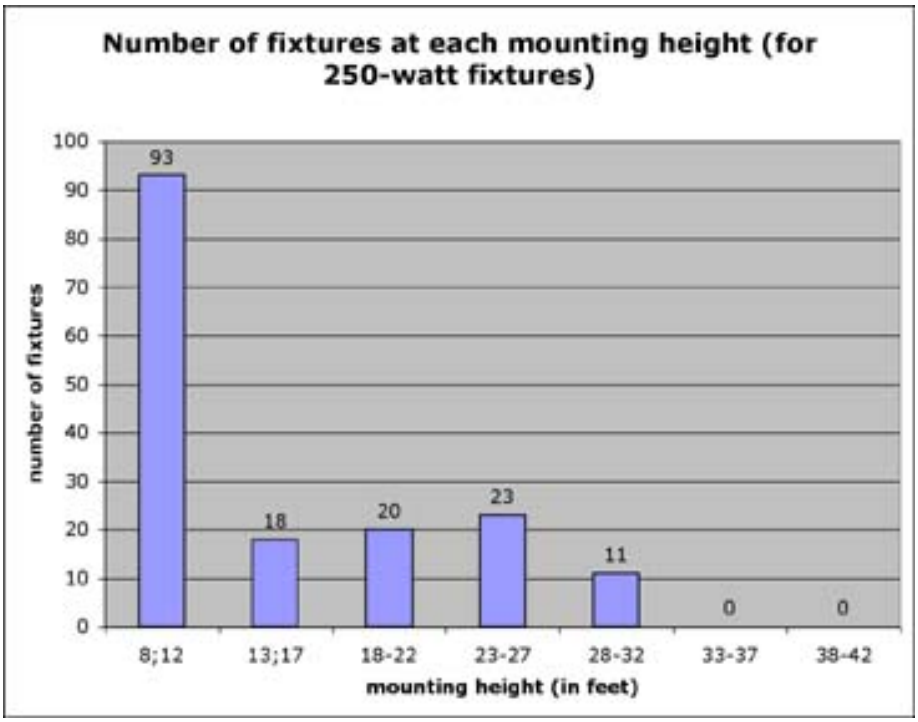


Figure 4. Distribution of fixtures by mounting height for 250-watt fixtures.

As would be expected, the higher wattage luminaires will find applications at higher mounting heights.

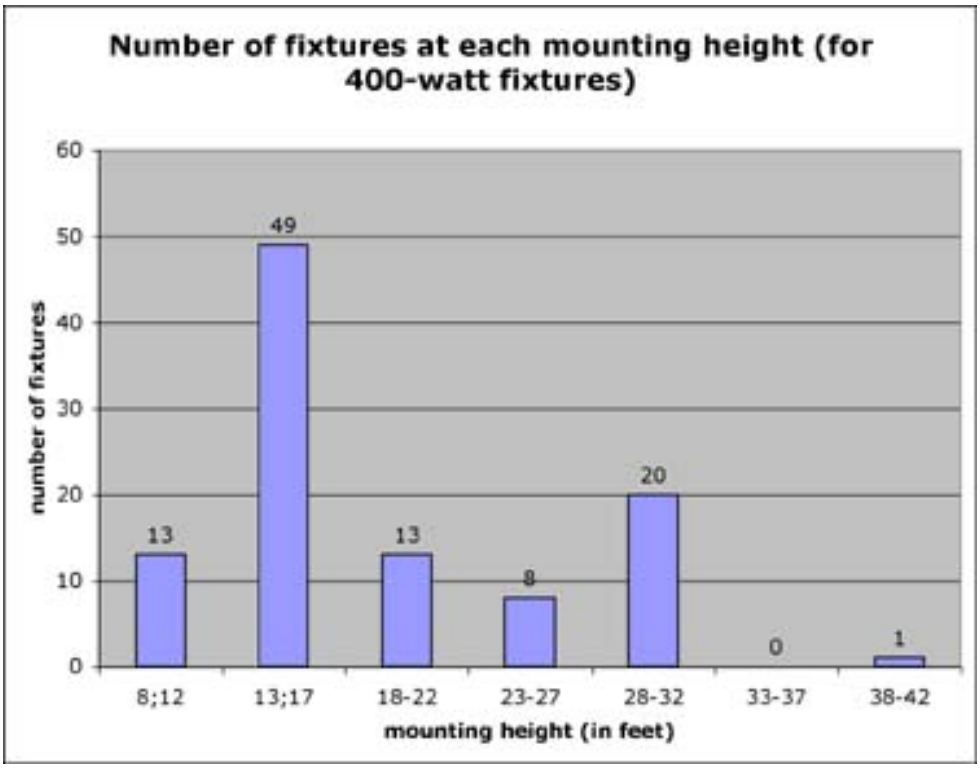


Figure 5. Distribution of fixtures by mounting height for 400-watt fixtures.

Metal Halide as a Source

Of the 793 fixtures, only 118 (or 15%) used Metal Halide sources.

Gardco Prototype Characteristics

Wall pack luminaires are notorious for poor control of light output contributing to sky glow and light trespass problems. Because of the poor optical design, conventional wall packs have an effective light projection of only 30 feet at mounting heights of 15 foot. The new low glare **151 Forward Form Wall Sconce** (see Figure 7) from Gardco Lighting is a solution to the shortcomings of the conventional wall pack. Designed for the illumination of areas immediately adjacent to the outside of buildings, this luminaire effectively projects light up to 45 feet from the base of the building at a mounting height of 15 feet. This is achieved with much improved optics, for better light control that significantly reduces the light pollution problems of the standard wall pack.

The higher optical efficiency results in fewer luminaires per installation, reducing both installed and operating costs. The Gardco luminaire features a ceramic metal halide lamp and a semi-cutoff tilted lens. In addition, the optics of the wall sconce are being adapted for application as a perimeter light in the **GS04 Forward Form Perimeter Light** (See also Figure 7) from Gardco. This luminaire is being developed to effectively address light trespass from parking areas in abutting residential spaces. The optical performance and energy efficiency of outdoor lighting will be improved. Building owners can expect better lighting, less light pollution, and reduced energy costs. Security will be increased from illuminating more area around building with better quality light. Features of the new Gardco prototype fixture are summarized below.

- 150-watt ceramic metal halide luminaire
- 50% more coverage of parking surface areas
- Improved optics: semi-cutoff optical design
- Higher color rendering: whiter light
- 20,000 hour lamp life
- Easy to replace existing luminaires with the Gardco wall sconce for existing installations
- Fewer wall sconces in new installations
- Greater forward projection: up to 45 feet
- Increased exterior security

Figures 6a and 6b depict the photometric characteristics of the prototype fixture developed by Gardco. In Figure 6a, the red distribution curve is a candlepower distribution curve for the luminaire viewed from the side with the luminaire at the center of the polar diagram. One can see from the distribution that there is virtually no light above the 90 degree horizontal plane, indicating that it is a near full-cutoff fixture, and

that from the strong projection at 80 degrees results in the exceptional forward through of the luminaire. The blue curve in the lower right-hand quardrant is the uniform distribution pattern projected by the luminaire as one is looking down on top of the luminaire. Figure 6b provides the illuminance pattern at a mounting height of 15 feet.

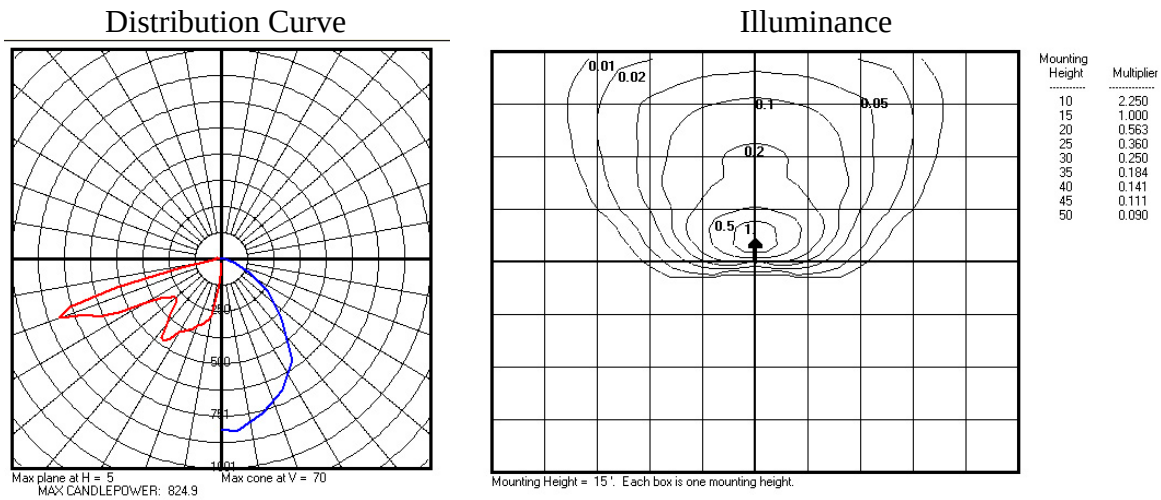


Figure 6. Distribution curve and illuminance pattern for Gardco prototype fixture.

Figure 7 shows an artists rendition of the Gardco luminaire housing that was used in the measurements of the field test and evaluation.

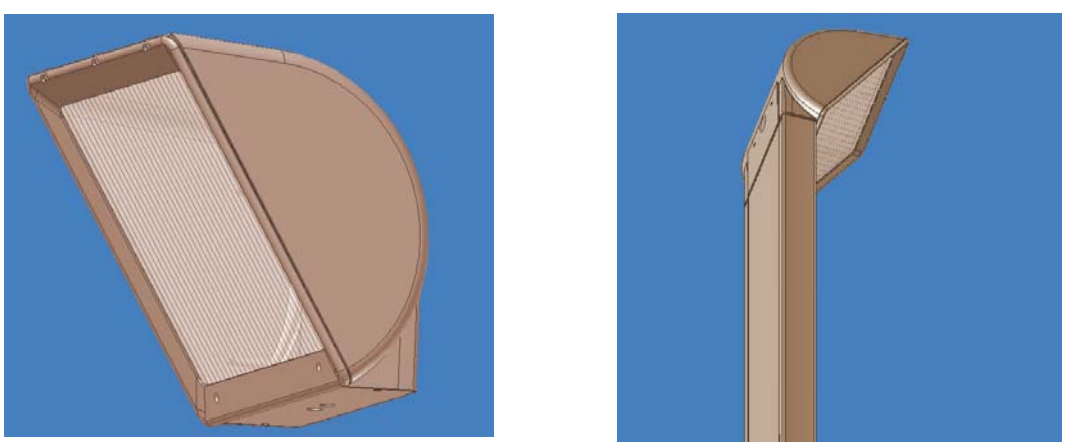
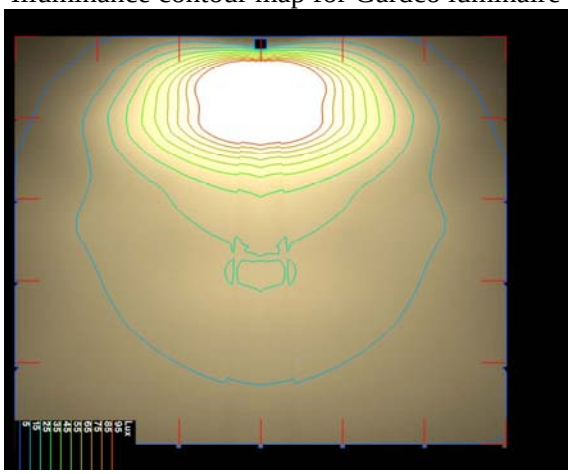


Figure 7. 151 Forward Form Wall Sconce (left) and the GS04 Forward Form Perimeter Light (right)

Field Test and Evaluation

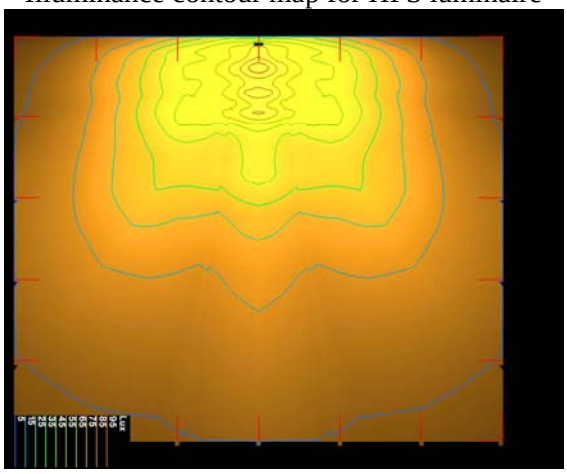
In the field test and evaluation, a standard 150-watt high pressure sodium with magnetic ballast was compared to the new Gardco wall sconce using a 150W ceramic metal halide lamp and electronic ballast. One can see the more uniform pattern from the Gardco luminaire in Figure 8. Although difficult to see, the 5fc perimeter line extends much further than that of the high pressure sodium luminaire.

Illuminance contour map for Gardco luminaire



50’ X 60’ overhead view

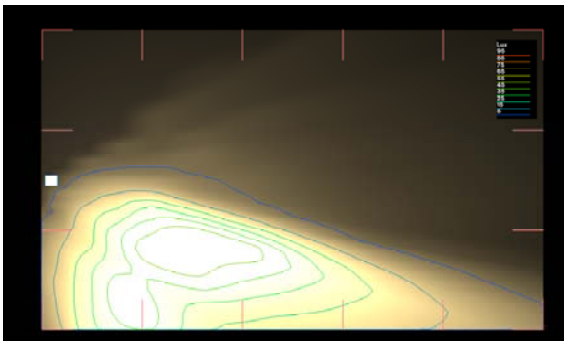
Illuminance contour map for HPS luminaire



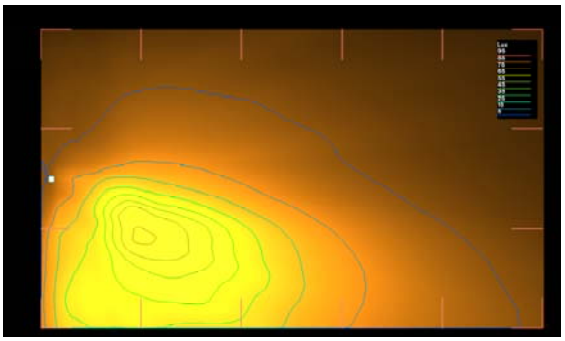
50’ X 60’ overhead view

Figure 8. Contour maps comparing illuminance patterns of standard HPS fixture to Gardco wall sconce.

The difference in distribution is more easily demonstrated by the patterns in Figure 9 that give the side view of the illuminance contour map. The Gardco fixture projects most of the light in the downward direction onto the surface it is illuminating, reducing glare, light trespass, and light pollution.



Gardco wall sconce



HPS fixture

Figure 9. Comparative side view illuminance contour map.

To demonstrate the performance of the relative fixtures, mannequins at 15 ft, 30 ft and 45 ft from the wall of the light source were arranged in the test area and the luminance on the face of the mannequin was measured. Pictures of the measurements are given in Figure 10. The measurements clearly demonstrate the cutoff performance characteristic of the Gardco fixture, where the face five feet above the parking lot surface is barely illuminated. The measurements also demonstrate the improved performance in the field of application.

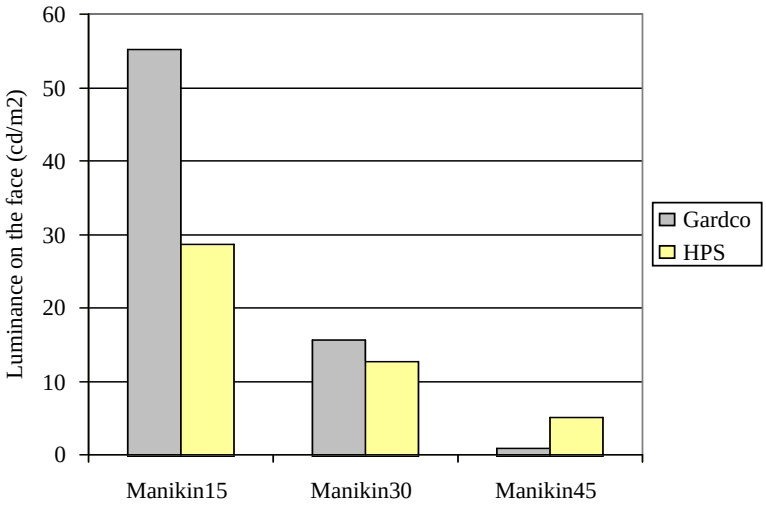


Figure 10. Comparison of luminance on the face for Gardco and HPS fixtures.

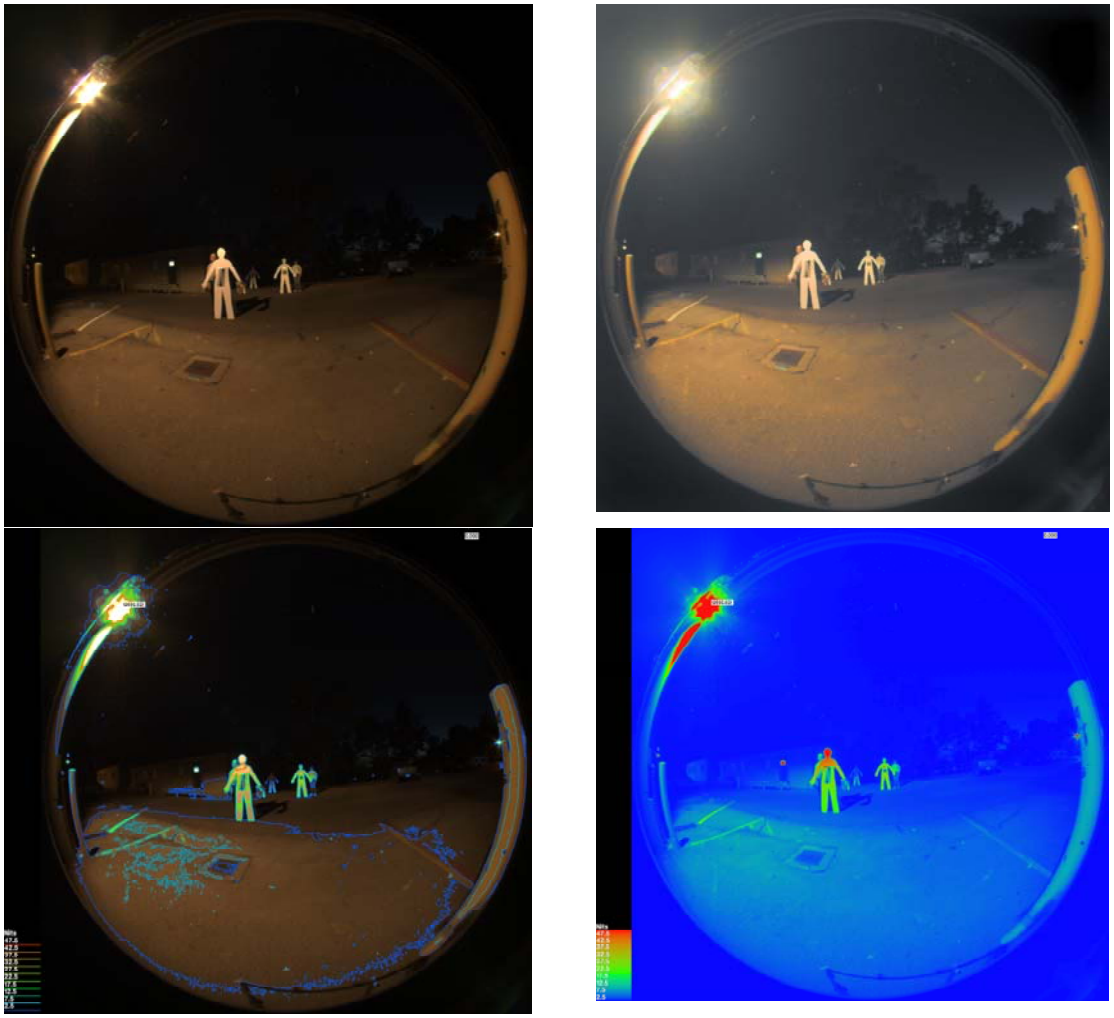


Figure 11. High Dynamic Range photographs of Gardco prototype fixture.

The false color images given above in Figure 11 demonstrates the change in luminance within the illuminated space for the two different luminaires. Finally, glare analysis using high dynamic range imagery showed much more prominent glare for the HPS versus the metal halide because of the less precise control of the light from the luminaire.

Conclusions and Recommendations

Recommendations

The PIER program has previously funded to two lighting programs that produced recommendations for standards for outdoor lighting: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). These documents have a wealth of information that was used in this analysis. From the analysis, LBNL suggests the following additional or alternative strategies for energy savings:

LBNL does not recommend the following:

- The adoption of the practice for the standard layout proposed in the *Outdoor Lighting Research* report.

It may be difficult to meet both the power density requirements and the illuminance criteria if installations differ from the standard layout. Actual parking lot installations are likely to vary from this standard layout, and may not be able to meet the illuminance criteria under the specified power densities described in the *Outdoor Lighting Research*.

LBNL does recommend the following:

- Establishing a set of optimal candlepower distributions for a range of layouts for outdoor parking and common use areas.

In order to meet both the power density requirements and the recommended illuminance criteria, a reasonably good control of the illuminance uniformity is required.

LBNL does not recommend the following:

- The mandated adoption of curfew switching.

Curfew switching may not be feasible due to the limitations of current technology and also to safety concerns. The Eley report proposes a 50% reduction in power after curfew for Lighting Zones 2 through 4, and a 90% reduction for Lighting Zone 1 (LZ1). It may be difficult to meet these reduced power requirements without compromising the illumination levels required for safety purposes

LBNL does recommend the following:

- The use of motion detectors as an acceptable alternative to curfew switching, and
- Continue (at present) to allow use of both HPS and MH lamps.

LBNL recommends continued support of efforts to develop retrofit post-top fixtures based on optimal candlepower specifications derived from above. This could be supported by an incentive through the utilities.

LBNL recommends support of utility and state outdoor lighting programs that support the development, demonstration, and application of energy and optically efficient wall mount luminaires, such as the product developed within this program.

More demonstrations of this technology are recommended.

Commercialization Potential

The new low glare Gardco **151 Forward Form Wall Sconce** has significant commercial potential to replace conventional wall packs, and the Gardco perimeter light, the **GS04 Forward Form Perimeter Light**, provides additional opportunity to effectively light the perimeter of parking spaces while reducing light trespass and light pollution, having the same optical and spectral benefits of the wall sconce. The Gardco perimeter light is being developed to effectively address light trespass from parking areas in abutting residential spaces.

The Gardco wall sconce is designed for the illumination of areas immediately adjacent to the outside of buildings, this luminaire effectively projects light up to 45 feet from the base of the building at a mounting height of 15 feet, as compared to 30 feet from the base for conventional luminaire. This is achieved with much improved optics, for better light control that significantly reduce the light pollution problems of the standard wall pack.

The higher optical efficiency results in fewer luminairs per installation, reducing both installed and operating costs. The Gardco luminaire features a ceramic metal halide lamp, electronic ballast, and a semi-cutoff tilted lens versus the high-pressure sodium lamps, magnetic ballasts, and a sag lens of the standard wall pack.

The features and benefits of the Gardco wall sconce that will make this product a commercial success are summarized as:

- Better lighting quality. The Gardco wall pack will produce white light with high color rendition as compared to wall packs using high pressure sodium sources producing orange light with very low color rendition. Esthetically enhancing the environment and allowing users of the space to identify their cars more easily.
- The high efficiency of the optical design provides for:
  - Better light control. The Gardco wall pack will provide illumination up to 45 feet from the building compared to 30 feet for a conventional luminaire.
  - A reduction in lamp wattage. A 100-watt Gardco luminaire may replace a 150-watt conventional luminaire if using the same luminaire spacing.
  - Less glare, improved light dispersion and cutoff.
  - Less wasted light. The Gardco luminaire will eliminate light pollution to the night sky and light trespass to neighboring buildings and properties.

- Comparable lamp life. The lamps in the Gardco and conventional luminaires will each last approximately 20,000 hours.
- Fewer Luminaires. The wider distribution of light means 50% more coverage of parking surface area, reducing the number of luminaires.
- Increased Security. The combination of the better light distribution, lower glare, and higher color definition will enhance the security of the lit environment.

Hence, both of the Gardco Luminaires should find commercial success in the California and United States market.

In addition, this study's findings are contributing to the demonstration work by the University of California and the California State University systems to improve the energy efficiency of equipment on their campuses. The California Public Utility Commission and the California Energy Commission fund this work. A small-scale PIER-sponsored UC/CSU field demonstration will take place in mid 2005.

Benefits to California

Research performed in the first years work identified a significant need and opportunity for the development of an energy efficient, cost competitive, low glare luminaire to replace the existing "wall pack". From the analysis of the Outdoor Lighting Baseline Database (OLBD), the wall pack has the least control of glare of any of the luminaire types and represents a major fraction outdoor luminaires in California. Hence, the development of an energy efficient, low glare product could have significant benefit to California outdoor lighting applications.

The luminaires designed have energy savings of approximately 30% over current designs. The energy savings are realized through the high optical performance of the design and the improved performance of the ceramic metal halide lamp used in conjunction with an electronic ballast. The improved optical performance of the Gardco wall sconce will provide illumination up to 45 feet from the building compared to 30 feet for a conventional luminaire, resulting in 50% more coverage of parking surface area, reducing the number of luminaires and thereby providing a 30% energy savings. This is most applicable for new installations. For existing installations, the current 150-watt wall packs can be replaced with the more efficient Gardco 100-watt wall sconce for a comparable 30% energy savings. Statewide energy projections are dependent on the lamp source that is replaced by the new product. Based upon the OLBD, wall mounted fixtures account for approximately 15% of the California outdoor lighting stock.

Another important benefit to California is to the improvement of the social and physical environment. The optical performance and energy efficiency of outdoor lighting will be improved. Building owners can expect better lighting of their parking space and reduced energy costs. Security will be increased from illuminating more area around building with better quality light. The surrounds of the building should also experience less light trespass and light pollution.

Conclusions

The analysis of the European Performance Standards lead to the following major conclusions:

- Luminance and illuminance values are inconsistent with current fixture design practice for streets and parking lots in the United States.
- Single-fixture approach leads to a system where there is essentially no interaction between fixtures.
- Differences in physical layout of lighting installations between Europe and the United States will affect system performance.

LBNL's analysis also helped elucidate the need to further develop design criteria for parking lot lighting, as visual performance requirements in parking lots differ greatly from those in roadway situations. LBNL raises several important points that should be considered further as standards and retrofits for parking lot lighting are developed. These include the following:

- Relationship between vertical illumination and veiling glare.
- Control of illumination uniformity to meet energy efficiency standards.
- Effects of lamp spectra on brightness and peripheral visibility.

As a result of this review, LBNL has concluded that the overall intent of the European specification in limiting glare, light trespass, and light pollution should be preserved, but the specific form of the requirements should be adjusted to a system approach for use in California.

Possible retrofit strategies for pole-mounted luminaires in parking lots include replacing the fixture or head, changing the optics, or shielding the fixtures. Other types of fixtures, including wall packs and canopy lights, will most likely require fixture head replacement, so the primary issue is to develop a set of target candlepower distributions for manufacturers. This leads to the following analysis to develop the design criteria for this system approach and energy savings potential of such a strategy.

The design criteria and energy savings potential for the retrofit fixture were initially determined through an examination of two recent documents relating to outdoor lighting standards: the *Outdoor Lighting Baseline Assessment* (PIER, November 11, 2002) and *Outdoor Lighting Research* (Eley Associates, June 6, 2002). LBNL's analysis of these two reports lead to the following conclusions:

- The energy savings from improved light source efficacy may not be as large as projected.

- The energy savings from lamp replacement strategies may also not be as large as expected.

- It may be difficult to meet both the power density requirements and the illuminance criteria if installations differ from the standard layout.
- Curfew switching may not be feasible due to the limitations of current technology and also to safety concerns.

Based on this analysis, LBNL recommends the following additional or alternative strategies for energy savings:

- Establish a set of optimal candlepower distributions for a range of layouts.
- Develop retrofit post-top fixtures based on optimal candlepower specifications.
- Consider wall mount fixtures as a potential target for retrofit efforts.
- Use motion detectors instead of curfews.
- Continue (at present) to allow use of both HPS and MH lamps.

The original hypothesis of the proposal was that the European Performance Standards would provide guidance on a proposed method to modify existing outdoor luminaires to improve performance. This would result in the development of a retrofit kit for centered on pole- or post-top luminaires for parking lot lighting. The conclusion of the analysis of the European Standards as stated above, proved that this was not a practical solution. The subsequent analysis of the PIER report, *Outdoor Lighting Baseline Assessment*, identified that over one-third of existing parking lot fixtures can be classified under the category of "wall-mount." As wall mount fixtures often do not have any glare control, this category has the greatest potential for glare reduction. These are also the least efficient type of fixtures. Both of these problems may be addressable by changes in optical design that lead to a more optimal candlepower distribution for typical parking lot geometries. Hence, these became the design criteria for the development of a wall sconce with the industrial partner, Gardco. The result of the work is the development of a very efficient wall sconce that has the product performance to make the original design goals.

The new Gardco luminaires use the highest performance metal halide lamp and electronic ballast offering the greatest energy savings. The ceramic metal halide lamp is a white light source with very high color rendition, providing a better quality of light and esthetic appearance. The new design provides a more even distribution over a greater surface area than competitive product. The result is that fewer luminaires and consequently less energy is used to illuminate a parking area. On average, there is a 30% savings in energy. The better optical control significantly reduces light pollution to the night sky and light trespass to neighboring buildings and properties. A further advantage is that it also reduces glare, except when in the direct beam of the light. The result is the development of luminaires that address one of the least efficient outdoor lighting systems with superior performance and energy efficiency.