LIGHTING RESEARCH PROGRAM

Project 2.1 Hybrid Outdoor Lighting Systems
FINAL REPORT

CONSULTANT REPORT

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California Energy Commission
Public Interest Energy Research Program

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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 (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 Light Emitting Diode (LED) Luminaires for Exterior, Porch, and Perimeter Project, PIER Lighting Research Program Contract #500-01-041, conducted by the California Lighting Technology Laboratory under contract to the Lawrence Berkeley National Laboratory and directed by Architectural Energy Corporation. The report, entitled Hybrid LED Outdoor Luminaires, also includes the following interim deliverables: Product Specs (#2.1.5), Lab Test Report (#2.1.6), and Field Test Report (#2.1.7). This project contributes to the Building End-Use Energy Efficiency 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: www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

EXECUTIVE SUMMARY

The California Lighting Technology Center (CLTC) research team generated ten luminaire concepts and developed four prototypes. The LED Hybrid prototype emerged as the most promising fixture system and the research team partnered with The Watt Stopper corporation on the controls and Shaper Lighting, a division of Cooper Lighting, on the fixture. Shaper commercialized the fixture in December 2004, selling it for about $200.

The LED Hybrid Fixture uses 5 Watts of LED lighting all night long—costing only about $0.01/night—and 60 Watts of incandescent lighting during "occupied" periods. A 13-Watt compact fluorescent lamp (CFL) could be substituted for the incandescent lamp, but the low operating hours gives it a long marginal payback—nearly 10 years for residential applications and around 5 years for commercial —compared to using an incandescent lamp. Also, the light level of the CFL at start-up may lag that of an incandescent. The LED Hybrid is expected to reduce energy consumption by 53% compared to a CFL and 87% compared to a standard incandescent fixture.

Building on the successful product development efforts in this project, the research team established a number of follow-up activities that are in progress at the project's completion:

- The National Parks will host a demonstration and testing program in one of their parks. The Regional Energy Manager, Steve Butterworth, will assist in choosing and coordinating the test site.
- Sacramento Municipal Utility District (SMUD) purchased 50 units for application and testing in the Woodburn Apartments in Sacramento.
- The Watt Stopper Company is in the tooling phase for another version of the LED Hybrid concept based on the popular residential PAR lamp security light.
- PIER-sponsored UC/CSU field demonstrations will take place on the campuses of Cal Poly Pomona, CSU San Marcos, and UC Davis in mid 2005.

ABSTRACT

The California Lighting Technology Center (CLTC) designed and prototyped a series of outdoor luminaries incorporating efficient light emitting diode (LED) technology and intelligent controls to reduce the energy consumption of typical incandescent and CFL outdoor fixtures. Shaper Lighting, a division of Cooper Lighting, manufactured the first series of production luminaries, named the LED Hybrid, and commercialized the product in December 2004. The LED Hybrid electricity cost is about $0.01/day and is expected to reduce energy consumption by 87% compared to standard incandescent fixtures and 53% compared to compact fluorescent fixtures.

A number of follow-up commercialization efforts are in progress, including field demonstrations with Sacramento Municipal Utility District (SMUD), and at University of California and California State University campuses. Furthermore, a second manufacturer is developing additional product variations.

INTRODUCTION

Background

There have been no fundamental breakthroughs in traditional lighting technologies for about 40 years. Nevertheless, there have been significant incremental improvements increasing the efficiency of building technologies by up to 50 percent. Even with these improvements, new scientific knowledge indicates there is potential for additional improvements of up to 100%. Recent advances in solid state lighting technologies have made breakthroughs that allow light emitting diodes (LEDs) to create light, including white light, at levels and efficacies approaching or exceeding that of traditional light sources. Cost effective applications such as traffic light signaling have already seen widespread adoption of LED technology, and applications for commercial and residential lighting are starting to see considerable promise and initial development.

Still, barriers remain to the widespread or rapid adoption of LED technology in illumination applications. Lumen outputs for LEDs remain low when compared to incandescent, fluorescent, or discharge type lamp sources. Currently, LEDs range in the 20 to 30 lumens per Watt (LPW) range, incandescents are around 15–20 LPW, CFLs are typically 50 to 60 LPW, full-size fluorescent lamps range from 90 to 100 LPW, and high intensity discharge lamp sources are 50-130 LPW. Costs for LEDs also remain relatively high. Thus, applications making strong headway into the lighting marketplace are those that capture and utilize the unique benefits that the technology has to offer.

Technology

LEDs are solid state light emitters. A single LED is comprised of several parts, primarily the LED “chip” or “die,” the surrounding LED “package,” and, in the case of high power LEDs, the heatsink. A high power LED is a type of LED configured to allow higher currents and higher lumen outputs than low power LEDs. To put it simply, high power LEDs typically run at 1 watt or above, and have package configurations that allow for enhanced heat dissipation away from the LED die.

The major unique properties of LED sources are typically listed as follow.

- Long lifetime
- High durability
- Very low profile
- Highly directional output

Long lifetime: The long lifetime of LEDs typically translates into low maintenance benefits for LED applications. Traffic signals and airport indicators are the usual examples given. Another benefit is the possibility to design fixtures without allowing for the replacement of the source, i.e. the life of the source is greater than or equal to the life of the fixture. This presents the opportunity to design ‘embedded’ systems where the LED source is not removable from the fixture.

High durability: The obvious application that utilizes this quality is the LED flashlight, where impact and physical shock are prevalent. Portable applications in general need to be durable. In the case of permanent fixtures, the weak link will no longer be the LED source, and the entire fixture's durability will be considered without undue special attention given to the light source.

Very low profile: The low profile nature of LED technology allows LED fixture design and placement in small, hidden, or otherwise restricted spaces too small for other light sources (cold cathode fluorescent lamps and miniature incandescent lamps are two exceptions). The benefits from this property, however, are limited by any secondary optics necessary to alter the distribution or control direct glare from the LEDs. The secondary optics are often necessary, and usually have dimensions greater than the LEDs.

Highly directional output: The light distribution of LED sources is typically contained within 180 degrees, and can be focused into a relatively narrow beam angle with the appropriate chip/lens configuration. This can be an advantage in the design of task lighting, as it reduces the optical engineering necessary to deliver light to a specific area. It can also enable the coupling of the LED light source with fiber optics or light guides, which may lead to novel perimeter lighting methods. One drawback to this approach is the relatively poor efficiency of such coupled systems, which puts a higher lumen requirement on an already lumen challenged technology.

LEDs are a very rapidly evolving technology. Even within the duration of this project, the current state-of-the-art LED has changed dramatically. Lumen outputs have increased, new package designs have emerged, and white LEDs now exist with high color rendering indexes (CRIs) and low color temperatures. This is not to say that the technology is mature – on the contrary, the barriers to adoption mentioned above still exist, but with the evolution of the technology comes the increased opportunity to develop viable, energy efficient lighting systems that can compete with the more mature lighting technologies that dominate the marketplace today.

Opportunities

The CLTC identified several near term illumination opportunities utilizing LED technology in illumination applications. These opportunities were identified in an earlier report of this project (Report 2.2.1, LED Market Opportunity Report). The list in the report was compiled during the later part of 2002, and some of these opportunities have since been developed by industry into market products or product efforts currently under development by others. A subset of these opportunities was chosen for further development and exploration under this PIER sponsored project.

Outdoor lighting was chosen as the focus for the PIER-sponsored development of LED luminaries. The outdoor environment has lower illuminance needs and less stringent color rendering requirements than many indoor environments, and is considered a good opportunity for LED lighting technologies. Dark adaptation by the eye, as well as the types of tasks performed (people usually do not read outside at night), allow lighting designers and engineers to build systems that produce less light than indoor systems. Large area, low glare fixtures, as well as those that produce very high delivered lumens, may be promising areas of development for LED exterior fixtures.

The term “delivered lumens” refers to the lumen output of a fixture system onto a specific task plane. For exterior lighting, this task plane is defined as the wall beneath the fixture and the ground adjacent to this wall. The exact dimensions of these surfaces are then defined to meet certain visibility or coverage requirements. In residential applications, this means providing coverage to a front porch or other area in front of the fixture with possible additional coverage to a pathway leading to a door or entryway. In commercial or institutional applications, this means installing multiple fixtures along the side of a building and providing continuous coverage along the line of the building. For commercial and institutional settings, the spacing of the fixtures becomes important in designing the system. LEDs, with their inherent directional qualities, have the potential to yield high fixture efficiencies and very good delivered lumen levels in the various applications.

The following issues were considered in the context of a viable LED illumination source for outdoor applications.

- The majority of commercial lighting fixtures and sources have lumen outputs near or above 1000 lumens. This makes building comparable LED based fixtures difficult, requiring multiple LEDs in an array, with associated cost factors. On the positive side, LEDs have specific, directional light output qualities that can be utilized to place light where it is needed.

- Colored incandescent sources rely on color filters to output specific wavelengths. As an example, a 60 Watt ‘white’ incandescent lamp emits ~ 900 lumens (lm) at about 15 LPW. The same lamp is used for colored bulbs, with a filter applied to the bulb surface. A 60 Watt yellow ‘bug’ lamp emits ~ 500 lm (8 LPW). The rest of the lumen output in other wavelengths are essentially thrown away.

- LEDs exhibit high lifetimes, low failure rates, and robust physical designs that can withstand considerable shock and vibration. These qualities have been a major driving force for LEDs in applications where lamp replacement and maintenance is difficult or expensive. Also, LEDs are low voltage and very low profile sources, which can allow for low profile fixtures or inclusion of sources in areas otherwise inaccessible.

Given these issues, researchers felt that the best near term opportunities for LEDs were outdoor applications with lower lumen output requirements, highly directional output characteristics, colored illumination, or critical performance applications where maintenance is difficult or expensive. Additionally, using LED technology for outdoor applications provides the following benefits:

- *Increased security* —the color change that occurs with motion activation increases user awareness that someone is in the control area.
- *Back-up light* —if the incandescent or CFL fails, the LED portion will remain on.
- *Increased lighting flexibility* — the LED illumination can light a door, address numbers, etc.
- *Societal benefits* — LED-based fixtures have the capability to reduce light trespass and light pollution.

PROJECT DEVELOPMENT

The LED Hybrid Approach

The product attributes and LED opportunities identified in this project were used to generate a series of LED fixture concepts for initial prototyping and testing. The incorporation of the various identified elements led to an overall fixture design approach: the ‘LED Hybrid’ fixture. These fixtures use LED arrays in conjunction with traditional incandescent or fluorescent sources. The entire fixture is controlled by a photocell that keeps all lights OFF during the day. At night, the photocell turns the fixture ON. The low wattage LED array stays on for the duration of the evening and provides low level ‘ambient’ illumination in the area around the fixture. When the motion sensor detects motion, it turns on the incandescent or fluorescent lamp for a short duration to raise the light output of the fixture to a level equal with standard outdoor fixtures (see Figure 1)

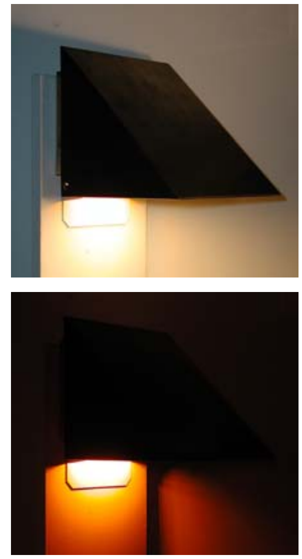


Figure 1: Top—LED and lamp on. Bottom—LED only.

This approach has the following benefits:

1) The fixtures save energy by switching on the incandescent or fluorescent lamp only when motion is detected.
2) The fixtures provide pleasant, ambient LED background light, eliminating dark spots commonly associated with motion sensor systems.
3) When the primary lamp burns out, the LED will still yield functional light from the fixture.
4) The use of incandescent or fluorescent lamps eliminates the need for higher lumen output, (more) expensive LED arrays.
5) The use of colored LEDs provides a ‘color changing’ feature as an added security benefit.

The generation and selection of prototype concepts were guided by product features such as color rendering, lumen output and delivered lumens, visibility, and control, which are detailed in an earlier report (2.1.2 Product Attribute Matrix) of this project. These features were necessary to consider in developing new concepts for energy efficient LED luminaries.

Fixture Controls

The research team determined the following fixture controls were necessary to integrate into the prototype designs:

Daylight sensing The ability of an outdoor luminaire to sense the presence of daylight and switch off a lamp in that luminaire.

Motion sensing The ability of a luminaire to sense physical movement in a specific zone and change its photometric output. It has been shown by studies at LBNL that motion sensing can produce dramatic energy savings in applications where long burn hours are seen.

Dimming - The ability of a lamp/control system to deliver a variable amount of light output.

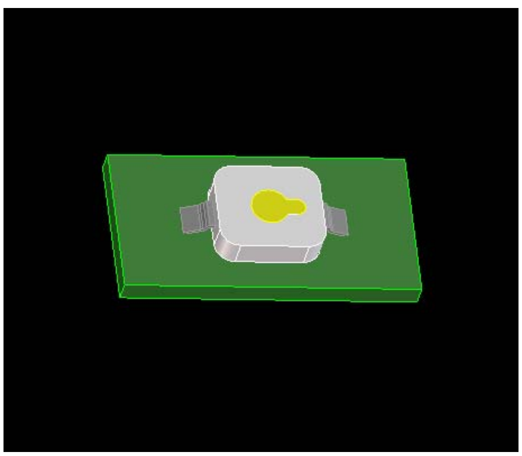
Identification of Low-Cost Efficient LEDs

The research team purchased several different LEDs from various manufacturers. Considerations included light output and its ratio against cost, availability, and assembly requirements. After initial testing and evaluation, the Lumiled LEDs and Osram LEDs were chosen for further examination. The Osram Golden Dragon was finally chosen for use in the Shaper manufactured fixtures.

Osram (Golden Dragon)

Osram's high output LED series is called the "Dragon" series (see Figure 2). These LEDs are 1-Watt devices aimed at high output, automated production applications. Product details are listed below:

- Efficacy: 20 lumens/watt, rated
- Inexpensive ($1.63/piece)
- Small package
- Automated assembly



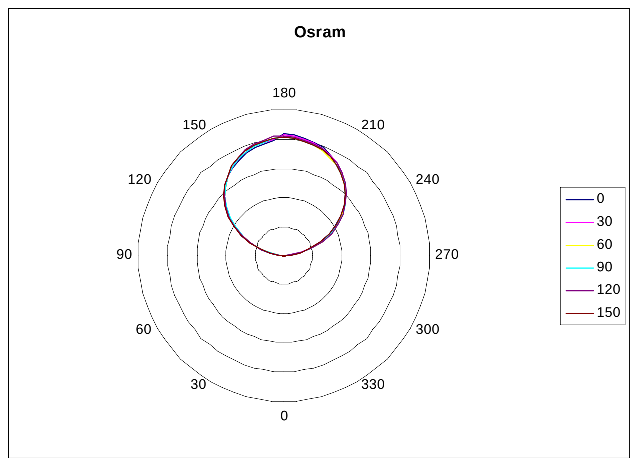


Figure 2: Osram Golden Dragon LED

Optical Configurations

Considerations

Any fixture that allows direct viewing of the LED chip source will produce objectionable disability glare to the viewer. In an outdoor nighttime environment, this glare will impair a person's dark adaptation. As LED efficiencies and outputs increase, so too will the need to mitigate the problem of direct glare.

Cutoff angles are also important when considering the reflector/diffuser design. Deep reflector designs can eliminate the possibility of glare, but will also be physically much larger than the

LED dimensions themselves. Also, sharp cutoff angles will create heavy shading at the edge of the distribution.

Options

The options considered for decreasing direct LED glare, and distributing the light along the wall and ground were as follows:

1) **Diffusers.** Diffusers have transmittances in the range of 45 to 70 percent. Inter-reflections within the light cavity can increase the external transmission. Researchers experimented with the traditional diffusers of acrylic and frosted glass. Neither were able to produce fixture efficiencies over 75 percent in the experiments that were performed. The light distribution was, however, aesthetically acceptable. Holographic diffusers from Wavefront Technologies were also used in experiments. Holographic diffusers have microscopic patterns pressed into thin plastic sheets. The light output distributions obtainable with these diffusers were good, but the experiments were unable to produce efficiencies greater than 80 percent.

2) **Prismatic lens arrays.** Acrylic prismatic lenses were able to mitigate the glare problem and give reasonable efficiencies. Most acrylic lenses allow transmissions higher than 90 percent. Some lens imaging occurred that would need to be addressed, but this should be possible with proper design. The experiments at the lab produced efficiencies closer to 85 percent. While the use of these lenses can produce acceptable results, other novel approaches evolved that appear more suitable.

3) **Specular reflectors.** Specular reflectors are easy to form and offer reflectivities in the 92 to 98 percent range. They do not address the issue of multiple shadows, and most designs using LEDs will need deep fixture geometries to avoid direct glare. No favorable specular reflector designs were generated.

4) **Diffuse reflectors.** Diffuse reflectors can be found with reflectivities in the 80 to 96 percent range. The type found to offer the most appealing output is a gloss white high reflection powder coat paint. Experiments were performed to determine the best configuration, and a preferred embodiment was identified.

The reflector shown in Figure 3 aims the LEDs back at the wall at an angle of 45 degrees to the horizontal. The reflector has one 90-degree angle and one 135-degree angle, and holes corresponding to the LED locations to allow light into the cavity. No front cover is used, and a portion of direct LED flux is allowed to reach the wall and floor beneath the fixture. Another portion of the flux is diffusely reflected down and away from the wall. Glare is mitigated, and multiple shadows are smoothed out from the diffuse light. The output has a wall component and a ground component, and the cutoff angle is very soft. Depending on the entire fixture geometry, there is small or no portion of the flux above the horizontal. The nature of the design makes this approach scalable to accommodate any number of LEDs in a linear row, and the diffuse reflection allows variations in reflector dimensions without greatly affecting the efficiency. The reflector is 1 to 1.5 inches in depth, and most designs have efficiencies in the 90 to 94 percent range. Overall impressions of the output have been very positive. Issues concerning the direct exposure of the LED lens are being investigated.

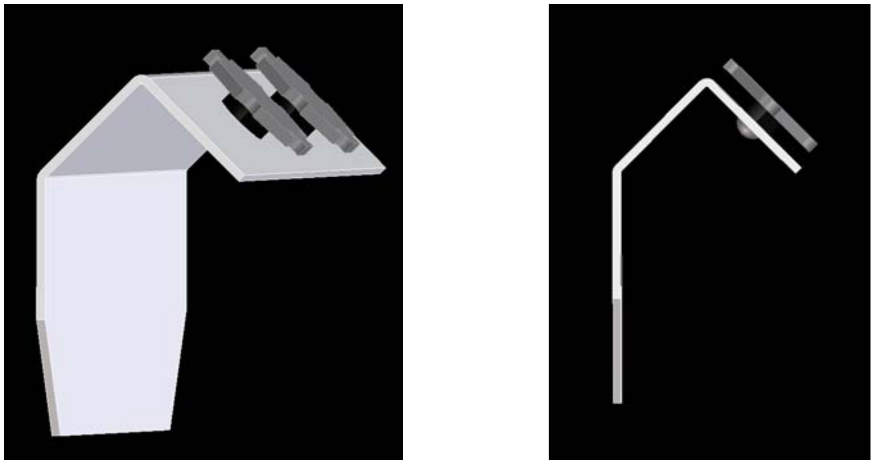


Figure 3: LED Reflector Design

The diffuse reflector approach has shown the best results for efficiency and desired output. The design is both simple and inexpensive, and allows integration into any number of fixture geometries.

LED Array Design

Osram Golden Dragon LEDs are designed to be mounted to a heat sink to conduct the heat away from the LED chip. The semiconductor chip (or 'die') is mounted to a copper slug which is exposed on the bottom of the LED package. This exposed surface then must be connected (with solder or thermal epoxy) to an external heat sink (see Figure 4).

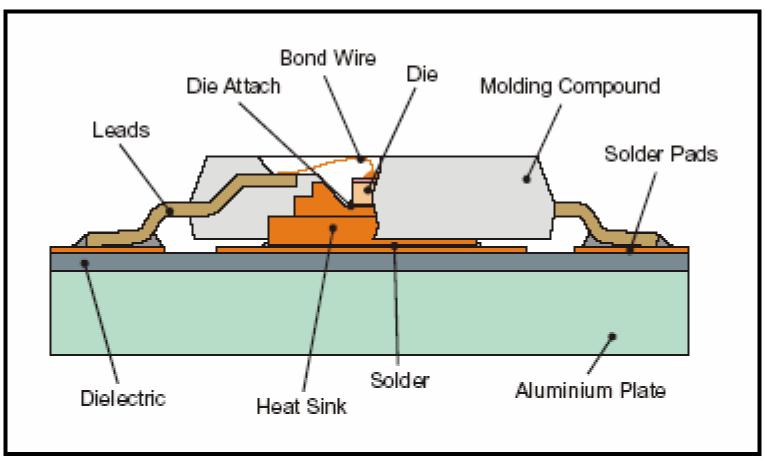


Figure 4: Side View of Osram Golden Dragon LED

Osram has tested and published acceptable methods to accomplish this thermal dissipation. One method employs metal core printed circuit board (mcpcb) technology, where a printed circuit board (pcb) layer is laminated to an aluminum base plate. This configuration is typical for high power LEDs. Another method, common to electronic assemblies in general, is to use plated through-holes on a double sided circuit board as thermal vias.

Typical circuit boards (see Figure 5) have two layers of copper laminated to both sides of a fiberglass (FR4) epoxy sheet. The copper layers are etched to produce wire ‘traces’ which carry electrical signals. Electronic components are soldered to copper ‘pads’ etched onto the pattern. Plated through-hole vias are holes that have been drilled into the sheet and metallically plated to conduct electric signals from one side of the board to the other. These vias will also conduct heat, and in this application are used to conduct heat from the copper slug of the LED package to the back side of the circuit board, where it then is conducted to another external heat sink (in this case the aluminum reflector of the assembly)

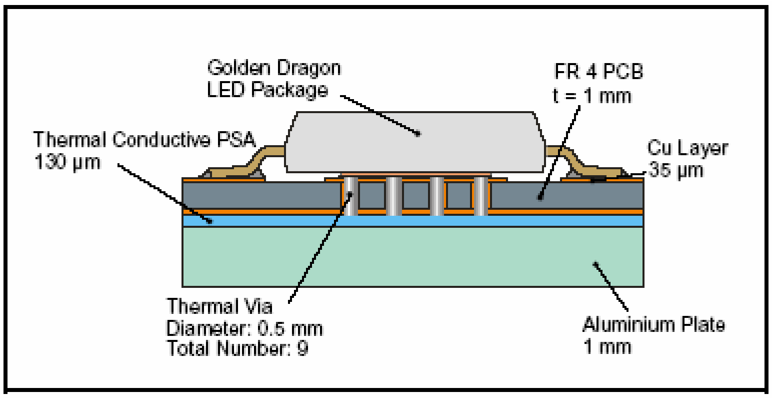


Figure 5: Dragon LED Mounted to an FR4 pcb With Thermal Vias

The pcb array design was setup using Orcad design software. The basic process for designing a pcb begins with a schematic which shows the electrical components and connections in symbolic form. This schematic is then translated to a graphical representation of the physical circuit board showing trace lines, copper pads, through hole vias, board outlines, solder mask outlines, etc. A series of files (called Gerber files) is generated which a circuit board manufacturer uses to fabricate the part.

The pcb array for this design uses 2 ounce copper layers on a .032” thick FR4 board. The via drill diameters are .015”. The overall board dimension is .625” X 3.25”

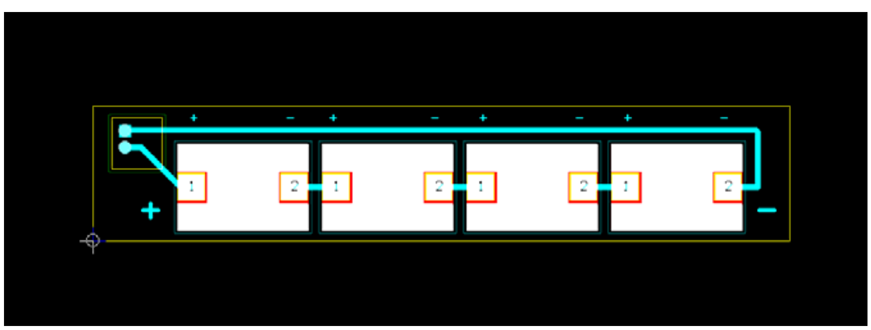


Figure 6: Orcad Screen Shot Showing the LED Array

The array in Figure 6 has four Osram LEDs connected in series with mounting pads for an external electrical connector (header) used to connect the array to the driver.

Once the pcb has been fabricated, the LEDs are then ‘assembled’ onto the board. Basically, this means soldering the LEDs onto the appropriate pads. The design of the Osram Dragon LED requires the use of solder paste in a reflow process. Solder paste is applied to the pads, the LEDs are placed onto the solder paste, and the board is heated to a temperature high enough to melt the solder and ‘reflow’ the electrical connections.

The assembled LED array gets mounted to an external heatsink. In this design, the aluminum reflector also serves as the heatsink. Several different methods for attaching the array to the heatsink exist. Typically these methods fall into three major categories: thermal transfer tapes, thermal epoxies, and mechanical thermal greases/pads.

Thermal transfer tapes are essentially double-sided tapes with thermally enhanced fillers to allow heat conduction through the tape. The advantages of these tapes are ease of assembly, the ability to remove the part if necessary, and low cost.

Thermal epoxies are epoxies that are specifically formulated to allow heat conduction through the epoxy. They typically offer higher performance than the thermal tapes but are more difficult to use in the assembly process. They are also higher cost. Thermal epoxies require the assembly process to include time for the epoxy to cure, during which the part must not be disturbed. Epoxies typically are permanent.

Mechanical attachment of the assembly onto the heatsink is also standard practice. This usually means set screws hold the pcb onto the heatsink. A thermal pad or thermal grease is applied to the back contact surface to fill gaps and encourage heat transfer. Mechanical attachment requires the heatsink to include screw posts or screw holes. During assembly, mechanical attachment is frequently more labor intensive that thermal tapes and on par with thermal epoxies.

PROJECT OUTCOMES

Energy Savings

Energy savings for these fixtures are based on estimated occupancy rates for the coverage area of the fixtures and the base energy usage of comparable fixture systems. When compared to existing motion-controlled fixtures with the same primary lamp source, no energy savings can be achieved because of the added 5-Watt LED component. When compared to non-motion controlled systems with the same primary lamp source, energy savings are inversely proportional to the occupancy of the coverage area (less motion = higher savings) Finally, when compared to existing systems with different primary lamp sources (specifically, incandescent + LED versus CFL), there is an energy use crossover point dependent on the duration of activation of the incandescent lamp.

The sample analysis in Table 1 assumes 12 hours per night average usage and fixtures using a 60-Watt incandescent lamp or 13-Watt CFL lamp (requiring 16 Watts including the ballast). We assumed occupancy-sensor controlled usage for the incandescent in the hybrid fixture to be 0.5 hour/night. Under this scenario, the hybrid LED fixture with incandescent cuts energy use by 87% compared to the continuously operating incandescent lamp, and 53% compared to a continuously operating CFL. The hybrid fixture with an incandescent lamp always uses less energy than a continuously operating CFL until the hybrid fixture's occupancy sensor requires more than 8.25 hours of operation.

Substituting a 13-Watt CFL for the 60-Watt incandescent shows modest energy savings—about $1.00/year—but this is not enough to justify an estimated $10 additional equipment cost. Also, the light level of the CFL at start-up may lag that of an incandescent lamp.

Scenario	*Lamp #1*					*Lamp #2*					*Total*		
	type	*W*	*hr/night*	*kWh/yr*	*$/yr*	*type*	*W*	*hr/night*	*kWh/yr*	*$/yr*	*$/yr*	*%*	*%*
1. Base Case	Inc	60	12	263	34.16	n/a	0	0	0	0.00	$34.16	100%	
2. Base w/occ	Inc	60	0.5	11	1.42	n/a	0	0	0	0.00	$1.42	4%	
3. CFL	CFL	16	12	70	9.11	n/a	0	0	0	0.00	$9.11	27%	213%
4. CFL w/occ	CFL	16	0.5	3	0.38	n/a	0	0	0	0.00	$0.38	1%	
5. LED w/inc	LED	5	12	22	2.85	Inc	60	0.5	11	1.42	$4.27	13%	100%
6. LED w/CFL	LED	5	12	22	2.85	CFL	16	0.5	3	0.38	$3.23	9%	76%
7. x-over #5 vs #3	LED	5	12	22	2.85	CFL	16	8.25	48	6.26	$9.11	27%	

Table 1: Energy Use Comparison (see Appendix B for additional notes)

As can be seen in the above calculations, the energy use and savings of the LED Hybrid fixture is a function of the application environment. This fixture is intended for areas where traditional motion controlled fixtures and CFL-based fixtures have not been able to penetrate the incandescent market.

A 2000 survey conducted by RLW Analytics of 1000 California homes found the following conclusions on the use of exterior residential lights:

- Roughly 80% of all porch lights use incandescent lamps, with just over 6% of homes using a CFL.
- Only 15% of all porch lights are equipped with some form of control device such as a motion detector, photocell, timer, etc.

A 1% product penetration would reduce California energy use by about 3.3 million kWh/year.[1]

Prototypes

The following prototypes are representative of the designs that have received subsequent development. Many other prototypes were developed but are not shown in this report. The hybrid fixture prototypes utilize LED technology with incandescent; however, the fixtures may also use CFL lamps.

These prototypes used optical and thermal design elements identified earlier in this report (see Optical Configurations and LED Array Design sections). All designs started with some form of existing exterior fixture modified to incorporate an LED optical array. This was a conscious decision made to increase the ease of manufacturability and the chances of the prototypes achieving market development.

Included in each prototype description are photometric test results of the LED light output of each fixture. Output tests were performed with an integrating sphere and a goniophotometer.

Prototype 1: Hybrid fixture – LED with incandescent

Wall pack fixture. 2 x 3 watt Luxeon III white. (Figure 7, Figure 8)
LED power usage: 7W (one LED = 4 watt)
LED output: 122 lm
Fixture efficiency: 92%

Figure 7: Photo of Prototype Fixture

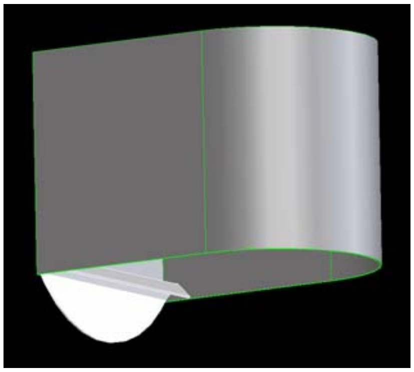


Figure 8: Solid Model CAD Drawing of Fixture

[1] 28,443,000 sockets in California residential porch lights (Energy Commission report P400-98-004-VI, pg 56) with 230 kWh/year savings (as noted in APPENDIX B: Energy Analysis) for 5% of the fixtures.

As shown in Figure 9, the plot of the LED light has a flux directed back at the wall and down to the ground.

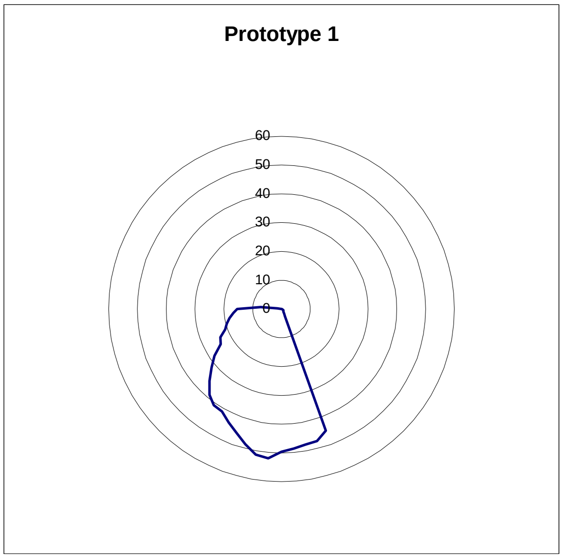


Figure 9: Goniometer Plot

Prototype 2: Hybrid fixture – LED with incandescent

Wall pack fixture. 8 x 1 watt Osram Golden Dragon (Figure 1010, Figure 1111, Figure 12).
LED power usage: 8.6 W (could be 4.4 watt)
LED output: 101 lm
Fixture efficiency: 90%

Figure 1010: Photo of Prototype Fixture

Figure 1111: Solid Model CAD Drawing of Fixture

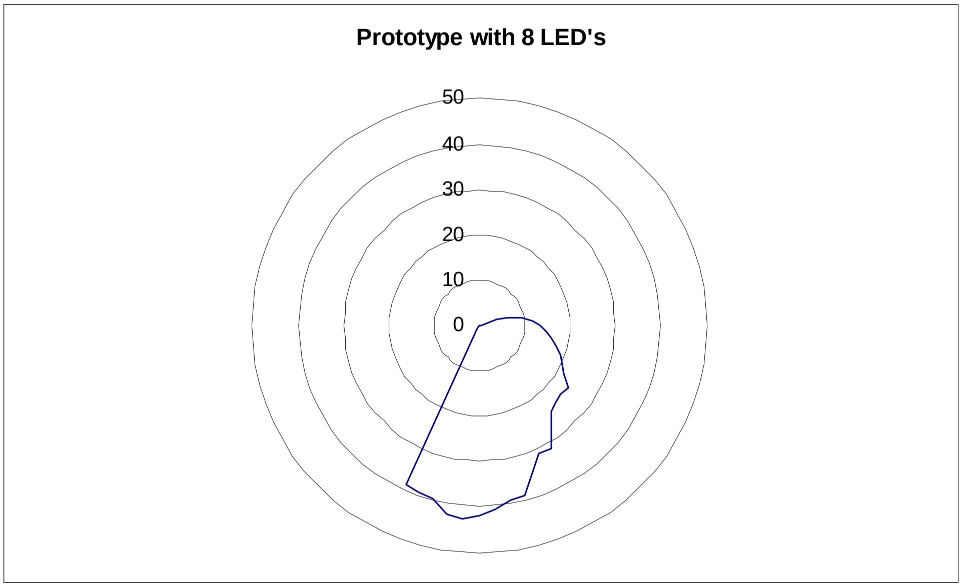


Figure 12: LED Array Output (wall on left side)

Prototype 3: Hybrid fixture – LED with incandescent

PAR lamp security fixture. 4 x 1 watt Osram Golden Dragon (Figure 13, Figure 14, Figure 15).
LED power usage: 4.4 W
LED output: 61 lm
Fixture efficiency: 91%

Figure 13: PAR Security Lamp w/LED Off

Figure 14: PAR Security Lamp w/LED On

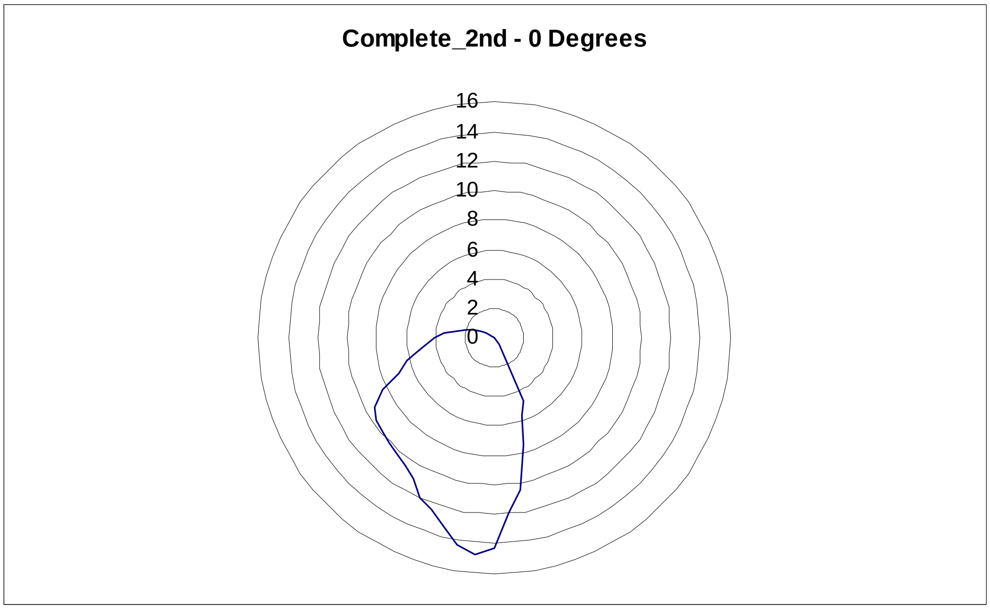


Figure 15: LED array output (wall on right side)

Laboratory Tests

The research team performed thermal tests with the different methods of array/heatsink attachment to evaluate which method was appropriate for use. The tests used similar heatsinks, and, where possible, the same heatsink, to determine the steady state LED chip junction temperature under typical operating conditions.

The tests used the following thermal materials:

- 3M Thermal Transfer Tape # 8810
- Aavid Ultrastick thermal grease
- Wakefield Delta Bond epoxy

The tests were performed under different ambient temperatures. Each heatsink was 3”x 4” .040 aluminum. Test results show pin temperature ranges for each array, as given in Table 2. The cathode pin of each LED package is electrically and thermally connected to the heatsink slug of the LED. The temperature of this pin corresponds to the chip junction temperature and can therefore be used to calculate the approximate temperature of the LED chip.

		Aavid UltraStick Thermal Paste	*Wakefield Delta Bond 155*	*3M Thermally Conductive Tape*
sample 1	Tambient=25°C	Pin Temp = 46 - 49 ° C	Pin Temp = 45 - 48 ° C	Pin Temp = 48 - 51 ° C
sample 2	Tambient=22°C	Pin Temp = 43 - 44 ° C	Pin Temp = 43 - 45 ° C	Pin Temp = 44 - 46 ° C
sample 3	Tambient=24°C	Pin Temp = 42 - 44 ° C	Pin Temp = 43 - 45 ° C	Pin Temp = 47 - 50 ° C
sample 4	Tambient=25°C	Pin Temp = 46 - 49 ° C	Pin Temp = 46 - 49 ° C	Pin Temp = 47 - 52 ° C

Table 2: Heat Sink Temperatures

Using the thermal resistance of the chip to heatsink of the individual LED package, the researchers calculate the maximum chip junction temperature with any of the methods used to be 78° C. The maximum allowable chip junction temperature for this device is 125° C so the researchers concluded that any of the above methods would be suitable for use in heatsinking these arrays.

Field Tests

As of the writing of this report, the field tests that were performed were done using the available laboratory prototypes manufactured during the development of the final fixture designs. Basic functionality tests were done with all of the prototypes and configurations, and modifications made to improve performance.

Several final prototypes were displayed and functioned for a period of several months on display at the CLTC. These units saw heavy foot traffic in excess of what would be anticipated for this design. Two units were tested at the homes of CLTC researchers and performed as expected. Another two units were installed at the Southern California Edison Lighting Center. During all of these tests, problems were identified and addressed as necessary. In addition to tests performed with completed fixtures, the individual components used in these fixtures have also been tested in this and other products. The LED arrays have seen continuous operation for up to 6 months with no identified problems. The drivers and controls have been used in other commercial products and received testing from their own manufacturers.

Product Specification Overview

LED Hybrid Fixture

The final specifications given in this report are for the LED Hybrid fixtures manufactured by Shaper Lighting. Current Specifications for The Watt Stopper Security Light are also provided.

There are two basic fixture models in production at the time of this report. The wedge fixture and the hooded lantern fixture are intended for wall mounting or can also be used as a post mount with available additional cedar (direct burial) post.

The fixtures have the following basic specifications:

Lamp/Socket
One (1) 60 watt A-19 lamp. INC socket fired ceramic rated for 660W – 250V. Lamps furnished by others.

Installation
Supplied with a mounting bracket for a standard 4” J-box or stucco ring.

Motion Sensor
WattStopper FS-155 lighting control. Timeout set range approximately 1 minute.

LED driver
Xitanium LED Driver #120A0350C33F 350mA output @ 4Watts.

More detailed specifications can be found in Appendix A of this report.

PAR Lamp Security Light

The Watt Stopper security light design is not as progressed as the Shaper unit. The design thus far includes 3 dimensional drawings and solid model prototypes.

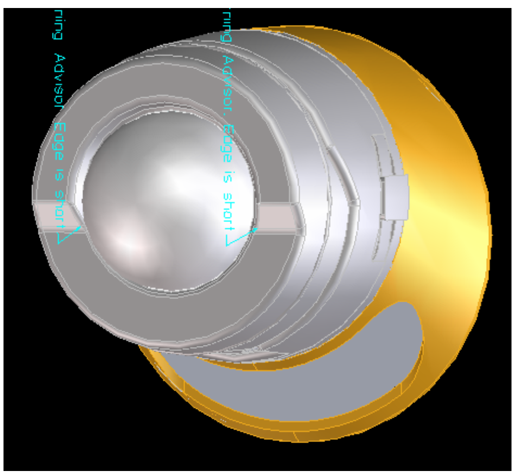


Figure 16: PAR Security Lamp

Figure 16 shows a drawing of The Watt Stopper unit without incandescent lampholders. The base portion of the drawing will house the lampholders and LED array. Figure 17 and Figure 18 show the PAR security fixture with LED lights on and off, respectively.

Figure 17: Solid model prototype with LEDs on and PAR lamps off

Figure 18: Solid model prototype with LEDs off and PAR lamps on

Market Connections

CLTC and Southern California Edison's Southern California Lighting Technology Center have the Hybrid fixture on display and have demonstrated it to hundreds of visitors. CLTC also plans to send a fixture to the Pacific Gas and Electric's Pacific Energy Center and to Sacramento Utility District's energy center for display as well. Shaper Lighting is expected to issue a formal product announcement in the spring of 2005 after getting more field experience.

PIER-sponsored UC/CSU field studies are in the planning stages and will take place on the campuses of Cal Poly Pomona, CSU San Marcos, and UC Davis. Approximately 50 fixtures will be purchased and installed in mid 2005. Studies on energy use patterns and user preference will be made. The details of these studies are still under development.

SMUD will purchase 50 units, the 685 Hooded Lantern style, for installation in the Woodburn Apartments in Sacramento. The energy use of these units will be monitored for approximately 2 months to establish energy use patterns. Follow up surveys will be conducted of the apartment tenants to determine user acceptance.

CLTC will purchase 30 more units, both the 685 Hooded Lantern and the 682 Wedge fixture types, for demonstration in the National Parks and other applications. The National Parks Regional Energy Manager, Steve Butterworth, will assist in choosing and coordinating the test site.

OTHER CONSIDERATIONS

There are a number of ways in which LEDs are difficult to quantify using the metrics typically used for incandescent, fluorescent, and metal halide lamps, such considerations are summarized below.

LED Efficacy

With the hybrid fixtures and the concrete mount LED pathlight, it is questionable whether the performance of these LED fixtures is good enough 'on paper' to fulfill the "high efficacy" requirements of Title 24 2005, since Title 24 requires a lamp efficacy of 40 lm/W, and LEDs a present provide only around 25lm/W. The requirement for a minimum bare-lamp efficacy favors omni directional lamps such as CFLs that have high bare lamp efficacies but lower application efficacies (because a reflector is required that typically reduces efficacy by 20-60%).

Alternative methods of quantifying luminaire efficiency, such as the Luminaire Efficiency Rating (LER) might be more equitable because they *do* account for reflector losses, but they do not capture the ability of LEDs to project lumens toward a particular target. The ability of point sources such as tungsten halogen lamps and LEDs to project lumens efficiently toward a target is generally not recognized by luminaire efficiency metrics, and this is a major barrier to the use of potentially efficient fixtures. One solution would be to define "application efficacy", i.e. the number of lumens that arrive at a target, divided by the power consumed by the fixture. There is at present no standard measure of application efficacy, except for the "cone diagrams" for spotlights that give the diameter of the pool of light at various distances from the fixture and the average illuminance within this pool of light. Application efficacy would have to be calculated differently for each application.

LED Color Rendering

Color rendering is an important issue; the poor color rendering of CFL lamps (despite CRI values in excess of 80) is widely regarded as a contributory factor to their low acceptance in the residential market (differences in chromaticity are also believed to be a factor). LED luminaires intended for the residential market should therefore pay very close attention to the color quality of the light sources used, and not rely on CRI as a guide.

LEDs are sometimes not optimized to score well on the color rendering index (CRI), so their CRI values vary widely. Many LED manufacturers do not give figures for CRI, but Lumileds, for instance, produces 'warm white" LEDs with CRI values between 70 and 90, and a paper by Shakir and Narendran quotes measured CRI values as low as 48 and as high as 80. Triphosphor fluorescent lamps typically score between 80 and 85, incandescents score 100 by definition since they are one of the standards by which other lamps are judged.

CRI is intended as a measure of how accurately a light source allows the colors of illuminated surfaces to be judged, but it is a very simple system and, although very widely used, has not been extensively tested against subjective judgments of overall color quality. CRI may also not be suitable as an indicator of other qualities such as 'colorfulness' which may be equally important as color accuracy in many applications. Shakir and Narendran found that LEDs with low CRI values were judged to be more colorful than LEDs and other light sources with higher CRI values. A similar effect can be seen with neodymium-doped incandescent lamps such as GE's 'Reveal' which has a lower CRI value than a regular incandescent lamp but is often judged to produce more vibrant color.

Although there has been no conclusive evidence of the shortcomings of CRI, there is widespread skepticism among the research community about its usefulness, and further research is ongoing. The CIE published a document in 1997 establishing a set of standards for LED photometry. These standards are under continuing review by CIE committees TC2-45 *Measurement of LEDs - Revision of CIE 127* and TC2-46 *CIE/ISO standards on LED intensity measurements*. Some of this research work is being carried out at NIST.

End-User Acceptability

The suitability of this fixture for the residential market is predicated on the assumption that homeowners will accept the fixture as long as the LED provides "illumination…sufficient to provide coverage to the wall and ground area adjacent to and under the fixture." This is a photometric rather than an aesthetic requirement, and it assumes that the purpose of the luminaire is to provide functional illumination (for security or way-finding) of the ground and the wall, rather than to contribute to the night-time appearance of the building.

The reasons why homeowners buy porch lights and other exterior fixtures are not well understood, and it seems likely that their requirements include both functional and aesthetic criteria. No research has been conducted in this area, although the area of commercial outdoor lighting is much better understood. Furthermore, since residential outdoor fixtures are rarely sold directly by the manufacturer, manufacturers have only a second-hand understanding of homeowners' reasons for buying these fixtures, or their reasons for either keeping them, returning them to the store, or disposing of them. Consequently there is little understanding of the market for residential outdoor fixtures even among key market actors.

Some basic research into the key aesthetic and performance criteria that homeowners look for would clarify whether the appearance and the photometry of the current LED units are appropriate, or whether a different design would make this fixture better suited to its target market.

Title 24 Standards

Commercial and institutional exterior, porch, and perimeter lighting employing lamps over 100 watts are covered by the current California Title 24 energy standards. These are considered permanently installed luminaires, which must either be high efficacy (i.e., lamp efficacy of at least 60 LPW), or be controlled by motion control devices along with photocontrols. Also, residential lighting requirements have a provision to use high efficacy light sources or motion sensors on porch lights.

The 2005 Title 24 standards also include similar provisions that require either high efficacy lighting or occupancy sensor based control. Thus, LED light fixtures without occupancy sensors currently will not qualify for the outdoor lighting requirements. However, integrating daylight and occupancy sensing features along with the combination of LEDs during non-occupied hours and a high efficacy source (such as CFL) when there is occupancy would help this product meet the code requirements. Further, in absence of an astronomical time clock or daylight sensing, the LEDs would remain on during daytime hours too. This would affect the potential energy savings from the product on a daily and seasonal basis.

CURRENT STATUS AND NEXT STEPS

PIER-sponsored UC/CSU field studies are in the planning stages and will take place on the campuses of Cal Poly Pomona, CSU San Marcos, and UC Davis. Approximately 50 fixtures will be purchased and installed in mid 2005. Studies on energy use patterns and user preference will be made. The details of these studies are still under development.

SMUD will purchase 50 units, the 685 Hooded Lantern style, for installation in the Woodburn Apartments in Sacramento. The energy use of these units will be monitored for approximately 2 months to establish energy use patterns. Follow up surveys will be conducted of the apartment tenants to determine user acceptance.

CLTC will purchase 30 more units, both the 685 Hooded Lantern and the 682 Wedge fixture types, for demonstration in the National Parks and other applications. The National Parks Regional Energy Manager, Steve Butterworth, will assist in choosing and coordinating the test site.

The Watt Stopper PAR Lamp LED security light is currently under development. Solid model prototypes have been fabricated for testing and development. Tooling has been designed for the plastic injection molded parts. The electronics for the system will be designed to integrate the motion sensing controls and LED driver circuitry on one circuit board, which will result in significant cost savings. Specific LEDs have not been chosen for this unit but several options, including the Osram LEDs used in the Shaper units, are possibilities.

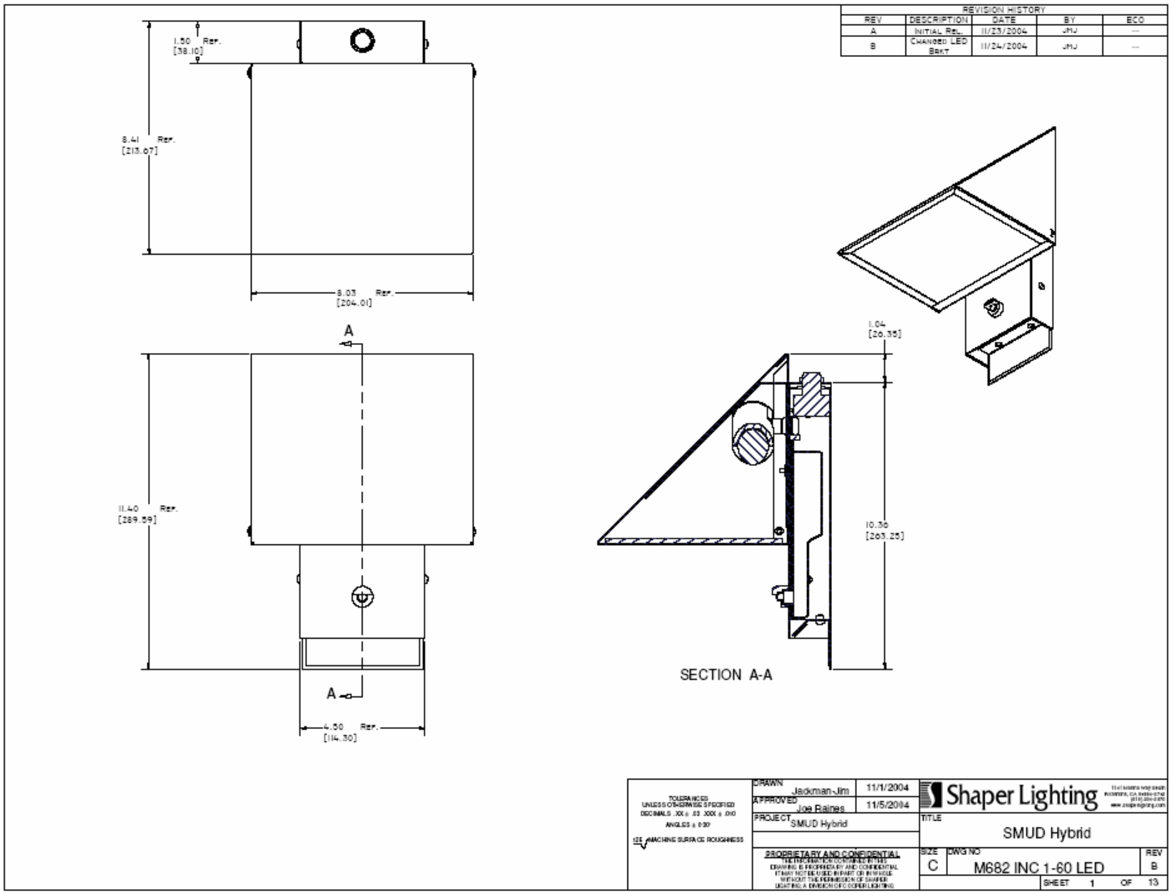
CONCLUSIONS AND RECOMMENDATIONS

The CLTC research team generated ten luminaire concepts and developed four prototypes. The team then successfully built two pre-production prototypes—a Hybrid LED fixture and a PAR security light. The hybrid fixture is commercially available from Shaper Lighting and the PAR security light is expected to be commercialized by The Watt Stopper in 2005.

Using LEDs together with occupancy sensors is an excellent application for outdoor lighting. This combination provides low-level ambient lighting all night long, switching to full light level only when needed. The LEDs use only about 0.06 kWh per night, costing less than $0.01 per night. Because of the low usage, incandescent lamps are more cost effective than compact fluorescent for full light level, with the marginal payback for the CFLs at about 10 years. Not only do CFLs have a long marginal payback because of such low usage, but intermittent use of CFLs is not a good application because their warm-up time causes dim conditions and reduces user satisfaction for the very short illumination need.

For future efforts, the research team recommends that other manufacturers adopt LED lighting components for specialty applications such as outdoor fixtures using occupancy sensors. In particular, mass-market applications at lower cost than the semi-custom Shaper units would stimulate wide-spread use of hybrid-type fixtures. However, the research team recommends assisting manufacturers in adopting LED technology because, although relatively simple to use, it is new to many lighting manufacturers and presents technical challenges in system design and application.

APPENDIX A: Detailed Product Specifications



M682 LED Hybrid ‘Wedge’ Wall Mount Fixture Specifications

Material
Solid Bronze. 1/8” White Acrylic Diffuser

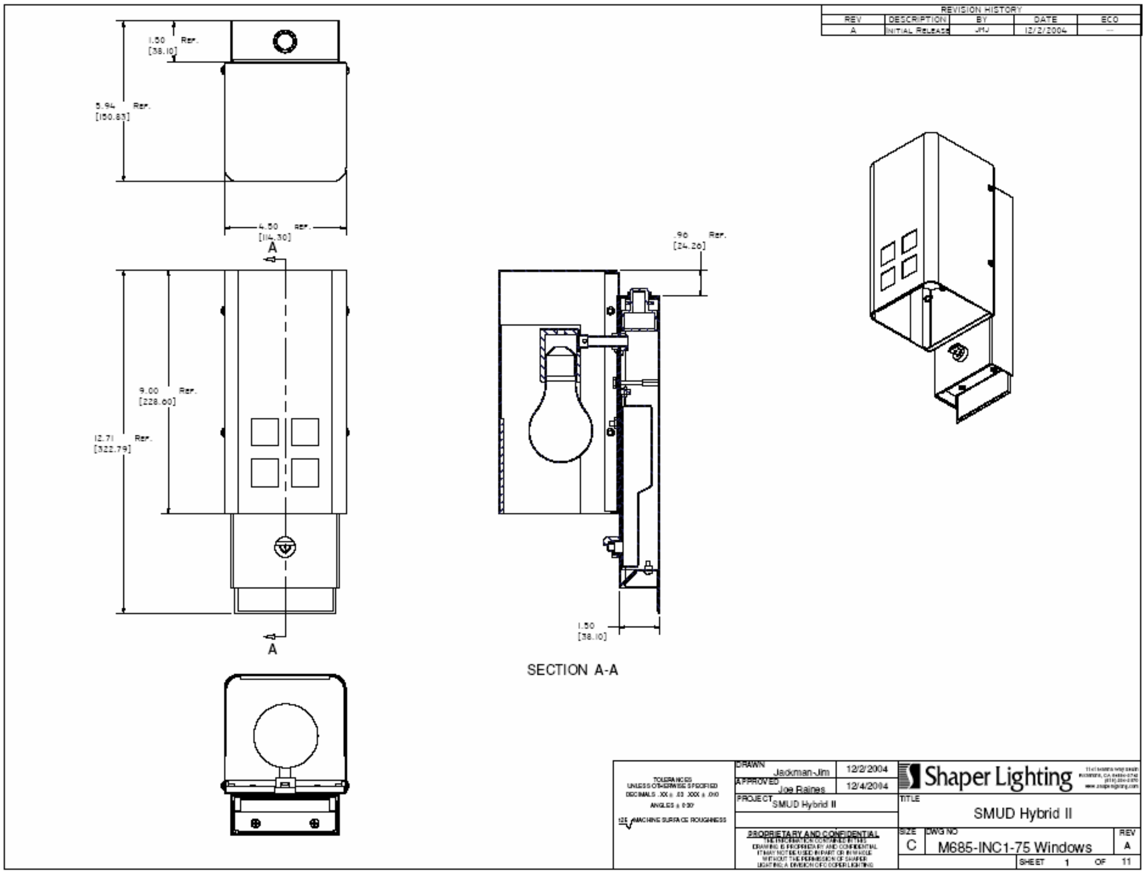
Finish
Natural Bronze. Note: Bronze will weather to a dark bronze patina

Lamp/Socket
One 60 watt A-19 lamp. Incandescent socket fired ceramic rated for 660W – 250V. Lamps furnished by others

Installation
Supplied with a mounting bracket for a standard 4” J-box or stucco ring.

Motion Sensor
WattStopper FS-155 lighting control. Timeout set range 30 sec-30 min

LED driver
Xitanium LED Driver #120A0350C33F 350mA output @ 4W



M685 LED Hybrid ‘Hooded Lantern’ Wall Mount Fixture Specifications

Material
Solid Bronze.

Finish
Natural Bronze. Note: Bronze will weather to a dark bronze patina

Lamp/Socket
One 60 watt A-19 lamp. Incandescent socket fired ceramic rated for 660W – 250V. Lamps furnished by others

Installation
Supplied with a mounting bracket for a standard 4” J-box or stucco ring

Motion Sensor
WattStopper FS-155 lighting control. Timeout set range 30 sec-30 min

LED driver
Xitanium LED Driver #120A0350C33F 350mA output @ 4W

APPENDIX B: Energy Analysis

LED HYBRID FIXTURE ENERGY ANALYSIS

Scenario	*Lamp #1*					*Lamp #2*					*Total*	
	type	*W*	*hr/night*	*kWh/yr*	*$/yr*	*type*	*W*	*hr/night*	*kWh/yr*	*$/yr*	*$/yr*	*%*
1. Base Case	Inc	60	12	263	34.16	n/a	0	0	0	0.00	$34.16	100%
2. Base w/occ	Inc	60	0.5	11	1.42	n/a	0	0	0	0.00	$1.42	4%
3. CFL	CFL	16	12	70	9.11	n/a	0	0	0	0.00	$9.11	27%
4. CFL w/occ	CFL	16	0.5	3	0.38	n/a	0	0	0	0.00	$0.38	1%
5. LED w/inc	LED	5	12	22	2.85	Inc	60	0.5	11	1.42	$4.27	13%
6. LED w/CFL	LED	5	12	22	2.85	CFL	16	0.5	3	0.38	$3.23	9%
7. x-over #5 vs #3	LED	5	12	22	2.85	CFL	16	8.25	48	6.26	$9.11	27%

Marginal Payback: LED w/incandescent vs. LED w/CFL

$1.04	/yr additional savings
$10.00	additional cost (est)
9.6	years simple payback

Cross-Over Analysis

Hybrid LED w/inc vs CFL w/cont. operation	-- LED Hybrid always has lower energy cost until the occupancy sensor requires 8.25 or more hours/night of usage

Notes:

16	W total use for 13-W CFL lamp plus ballast (Advance Smart Mate ballast)
$0.13	/kWh
occ =	occupancy sensor
0.5	hr/night use w/occupancy sensor
Concerns w/CFL w/occ	1. long (1-2 minutes) warm-up is adverse for quick, short-term use
	2. excessive starting can reduce lamp life