Edmund G. Brown Jr.
Governor

LIGHTING CALIFORNIA'S FUTURE: SMART LIGHT-EMITTING DIODE LIGHTING IN RESIDENTIAL FANS

PIER FINAL PROJECT REPORT

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Preface

The California Energy Commission 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 conducts public interest research, development, and demonstration (RD&D) projects to benefit California.
The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Lighting California's Future: Wireless Smart Light-emitting Diode Lighting in Residential Fans is the final report for the Lighting California's Future project (Contract number 500-06-035 conducted by Architectural Energy Corporation and California Lighting Technology Center. The information from this project contributes to PIER's Building End-Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

Lighting California's Future was a $3.7 million California Energy Commission Public Interest Energy Research Program focused on lighting technologies for buildings. For the Smart Light-emitting Diode Lighting in Residential Fans Project, the California Lighting Technology Center and Hunter Fan Company collaborated on the design of a light-emitting diode light kit for residential ceiling fans. The California Lighting Technology Center also researched and designed a light-emitting diode ceiling fan and a light-emitting diode exhaust fan. Once commercialized, light-emitting diode (LED) light kits for residential ceiling fans have the opportunity to annually provide 47 gigawatt-hours in energy savings and four megawatts in demand savings. This assumes one percent market penetration with a conservative estimate of 20 percent savings converting from incandescent to light-emitting diode light sources.

Keywords: Light-emitting diode, energy efficiency, efficacy, residential, LED

Executive Summary

Introduction

Lighting California's Future was a $3.7 million California Energy Commission Public Interest Energy Research Program focused on lighting technologies for buildings. The program, which began in May 2007, featured nine technical projects and a crosscutting market connections project. One of the nine technical projects was the Smart Light Emitting Diode Lighting in Residential Fans project.

Purpose

The light-emitting diode smart fan project sought to design, develop, and demonstrate a novel light-emitting diode lighting and controls system that optimizes emerging light-emitting diode technology and commercially available lighting controls and can be implemented in residential ceiling, exhaust, and other fans. The goal of this research is to save energy and reduce peak demand compared to existing fan lighting options. The project team included the California Lighting Technology Center and Hunter Fan Company.

Project Objectives

Specific objectives were to:

- Develop a light-emitting diode lighting system for residential ceiling fans, exploring the potential for integration of controls into light-emitting diode ceiling fans for added energy savings and user amenity.
- Develop a hybrid light-emitting diode/integrated lighting control system for residential exhaust fans (retrofit and new construction).
- Develop public specifications for a light-emitting diode optical system that has:
    - Source efficacy of at least 40 lumens per watt.
    - Fixture efficiency of at least 75 percent.
    - Light output of at least 1,000 lumens for ceiling fans.
    - Light output of at least 150 lumens for exhaust fans.
- Verify the above specifications using gonio-photometer and integrating sphere measurements. This device is a light meter designed to measure the intensity of light refracted from a surface at various angles.
- Develop a thermal management system that maintains light-emitting diode junction temperatures within manufacturer's recommended guidelines, and verify this objective with laboratory measurements using thermal probes. These probes are sensors used to detect temperature levels in a particular area.

Project Outcomes

As a result of this project, Hunter Fan Company produced three iterations of a prototype light-emitting diode light kit for residential ceiling fans and continues to work on a light-emitting diode fan product. The California Lighting Technology Center produced design concepts for a dedicated light-emitting diode ceiling fan, a light-emitting diode light kit for a residential ceiling fan, and a light-emitting diode exhaust fan. The most recent iteration of the Hunter Fan light kit tested at the California Lighting Technology Center achieved the following performance:

Table ES-1. Hunter ceiling fan LED light kit – Iteration 3 test results.

Hunter Fan Kit #3	
Lumens	877
CCT (Correlated Color Temperature)	3351 Kelvin
CRI (Color Rendering Index)	68
AC wattage	10
Efficacy	88 Lumens / Watt

Source: California Lighting Technology Center

The California Lighting Technology Center developed a set of residential fan light-emitting diode light kit specifications and prototypes that met those specifications and as designs for a decorative dedicated light-emitting diode residential ceiling fan and a light-emitting diode bathroom exhaust fan.

Hunter Fan Company and the California Lighting Technology Center developed prototypes of a light -emitting diode exhaust fan with a night light mode. The exhaust fan bezel that houses the main light-emitting diode light, the night light, and the power supply was designed to be mountable to an existing exhaust fan or easily installed in new construction.

The California Lighting Technology Center developed a specification for a light-emitting diode optical system that had a system efficacy of 40 lumens per watt. This system consists of 16 Cree XR-E light emitting diodes with a drive current of 500 – 700 milliampere. This array also met the target 1000-lumen output for the ceiling fan. This array should be properly mounted to a quality circuit board and attached to an appropriately designed heat sink. A heat sink is a component or assemble that transfers heat generated within a solid material to air or a liquid. The fixture efficiency for the light-emitting diode fan light kit is dependent on the transitivity of the decorative glass placed in front of it.

The California Lighting Technology Center also developed a specification for a light-emitting diode exhaust fan. This system consisted of 10 Osram Opto Golden Dragon Plus warm white light-emitting diodes with a drive current of 500 milliampere. The light output of the initial prototype met the target of a 150 lumens for the exhaust fan light kit.

Hunter Fan Company has not, at this time, commercialized light-emitting diode light kits for residential ceiling fans. The company also has not pursued the conceptual designs for a ceiling fan with dedicated light-emitting diode lighting or a light-emitting diode exhaust fan.

Conclusions

The California Lighting Technology Center and the manufacturing partner worked to design and commercialize light-emitting diode lighting for both a ceiling fan and an exhaust fan targeted at the residential marketplace. During this project, the residential marketplace was determined to be extremely cost-sensitive. This conclusion was observed in relation to the light-emitting diode bill of materials, the heat sink design, and the light controls. While the performance targets were technically feasible, the cost constraints made achieving them in a commercial-grade version impossible at the time this project was conducted. As the cost of light-emitting diodes and electronics continues to decrease, residential ceiling fan and exhaust fan light-emitting diode light kits will become more affordable and improve in quality.

Recommendations stemming from this project include pursuing the development of a light kit for replacing candelabra-style lights, investigating the potential for wireless controls for both the ceiling fan light kit and the exhaust fan, and conducting an in-depth market analysis of existing Triac dimmer switches and their associated performance.

Benefits to California

The benefits to California of cost-effective light-emitting diode lighting in residential fans would be increased energy and peak demand savings. Light-emitting diode lights can provide high efficacy, controllable light in an economic long-lasting package. The widespread use of dedicated light-emitting diode lighting systems in residential fan applications would increase energy savings and help meet future more stringent codes and standards.

Once commercialized, light-emitting diode light kits for residential ceiling fans have the opportunity to provide 47 gigawatt-hours annually in energy savings and 4 megawatts in demand savings. This assumes 1 percent market penetration with a conservative estimate of 20 percent savings converting from incandescent to light-emitting diode light sources.

1.0 Introduction

Lighting California's Future (LCF) was a $3.7 million California Energy Commission Public Interest Energy Research (PIER) Program focused on lighting technologies for buildings. The program, which began in May 2007, featured nine technical projects and a crosscutting market connections project. One of the nine technical projects was the Smart Light Emitting Diode (LED) Lighting in Residential Fans project. The project team comprised the California Lighting Technology Center (CLTC) and Hunter Fan Company.

1.1. Background

In California, 90% of ceiling fans sold include light kits that have incandescent sources with an average connected load of 120 watts (W). Although changes in California's Title 24 2008 Building Energy Efficiency Standards marginally increased energy savings in these applications through the use of dimmers for ceiling fan lighting and occupancy sensors for bathroom lighting, these new requirements have also complicated code compliance for builders. LEDs, which produce light by electrons moving through semiconductor material, use less energy, give off less heat, and last longer than other types of lighting. Replacing traditional incandescent fan lights with LED fan lights would save significant energy.

1.2. Project Objectives

Specific project objectives were to:

- Develop a LED lighting system for residential ceiling fans, exploring the potential for integration of controls into LED ceiling fans for added energy savings and user amenity.
- Develop a hybrid LED/integrated lighting control system for residential exhaust fans (retrofit and new construction).
- Develop public specifications for a LED optical system that has:
    - source efficacy of at least 40 lumens per watt (lm/W).
    - fixtures efficiency of at least 75 percent.
    - light output of at least 1,000 lumens (lm) for ceiling fans.
    - light output of at least 150 lm for exhaust fans.
- Verify the above specifications using an integrating sphere.
- Develop a thermal management system that maintains LED junction temperatures within manufacturer's recommended guidelines, and verify this objective with laboratory measurements using thermal probes.

1.3. Benefits to California

The benefits to California of cost-effective LED lighting in residential fans would be increased energy and peak demand savings. LED lights can provide high efficacy, controllable light in an economic long lasting package. The wide-spread use of dedicated LED lighting systems in residential fan applications would increase energy savings and help meet future more stringent codes and standards.

Once commercialized, LED light kits for residential ceiling fans have the opportunity to annually provide 47 gigawatt-hours (GWh) in energy savings and four megawatts (MW) in demand savings. This assumes 1 percent market penetration with a conservative estimate of 20 percent savings converting from incandescent to LED light sources.

1.4. Report Organization

The remainder of this report describes the project approach (Section 2.0), the project outcomes (Section 3.0), and Conclusions and Recommendations (Section 4.0).

2.0 Project Approach

The project team conducted a market analysis and developed specifications for a LED residential ceiling fan light kit. In addition, CLTC researchers explored new ceiling fan system designs with LEDs as well as designs for a LED light kit for bathroom exhaust fans. The CLTC tested prototypes all three types of designs, designed and developed a thermal management system for the LEDs, evaluated options for controls, and produced prototypes of the combined lighting and controls system. Due to delays in commercialization, field tests were not conducted for this project. A preproduction-level prototype is on display in the SMUD (Sacramento Municipal Utility District) E-House.

2.1. Market Analysis and LED Fan Light Specifications

Based on market research, the team developed specifications for a retrofit LED light kit for residential ceiling fans and a bathroom exhaust fan LED light kit. This research consisted primarily of utilizing industry partners' knowledge of the residential ceiling fan market and identifying existing residential ceiling fan kits and estimating an average lumen package based on number of sockets and socket style.

2.1.1. Market Research

Research was conducted primarily by utilizing industry partners knowledge of the residential ceiling fan market place combined with surveying big box retailers. This information combined with internet product searches resulted in the research team estimating equivalent light output values and control features for the LED lighting systems.

2.1.2. Specifications for Ceiling Fan LED Light Kit

The initial LED retrofit light kit was proposed as a direct replacement for an incandescent or compact fluorescent lamp (CFL) ceiling fan light kit that can be bolted onto pre-existing fans, with the following components:

- Array of 12-14 LEDs producing a flux of 800 lm
- Power supply
- Glass dome with hanging tree
- Mounting plate
- Dimming interface circuit
- Switch mode power supply (SMPS)

The LED fan light is intended to produce illumination comparable to that of traditional CFL or incandescent fan lights. The optical light engine system uses a combination of electronics (analog, digital, and microcontroller devices) and solid-state lighting elements that can emulate traditional CFL or incandescent illumination. Table 1 shows the initial target LED metrics for the luminaire. Figure 1 shows the target light output of the LED luminaire.

Table 1. Target LED luminaire metrics

LED Metrics	Target Value	Units
Color Rendering Index (CRI)	75	NA
Efficacy	80	lm/W
LED Direct Current (DC) Supply	28	Volts (V)

LED Metrics	Target Value	Units
LED Forward Voltage Drop (Vfd)	3.5	V
LED Forward Current Draw (If)	700	Milliampere (mA)
LED Life	50,000	Hours
LED Power Dissipation (Pled)	1	W
Correlated Color Temperature (CCT)	4,100	Kelvin (K)

Source: California Lighting Technology Center

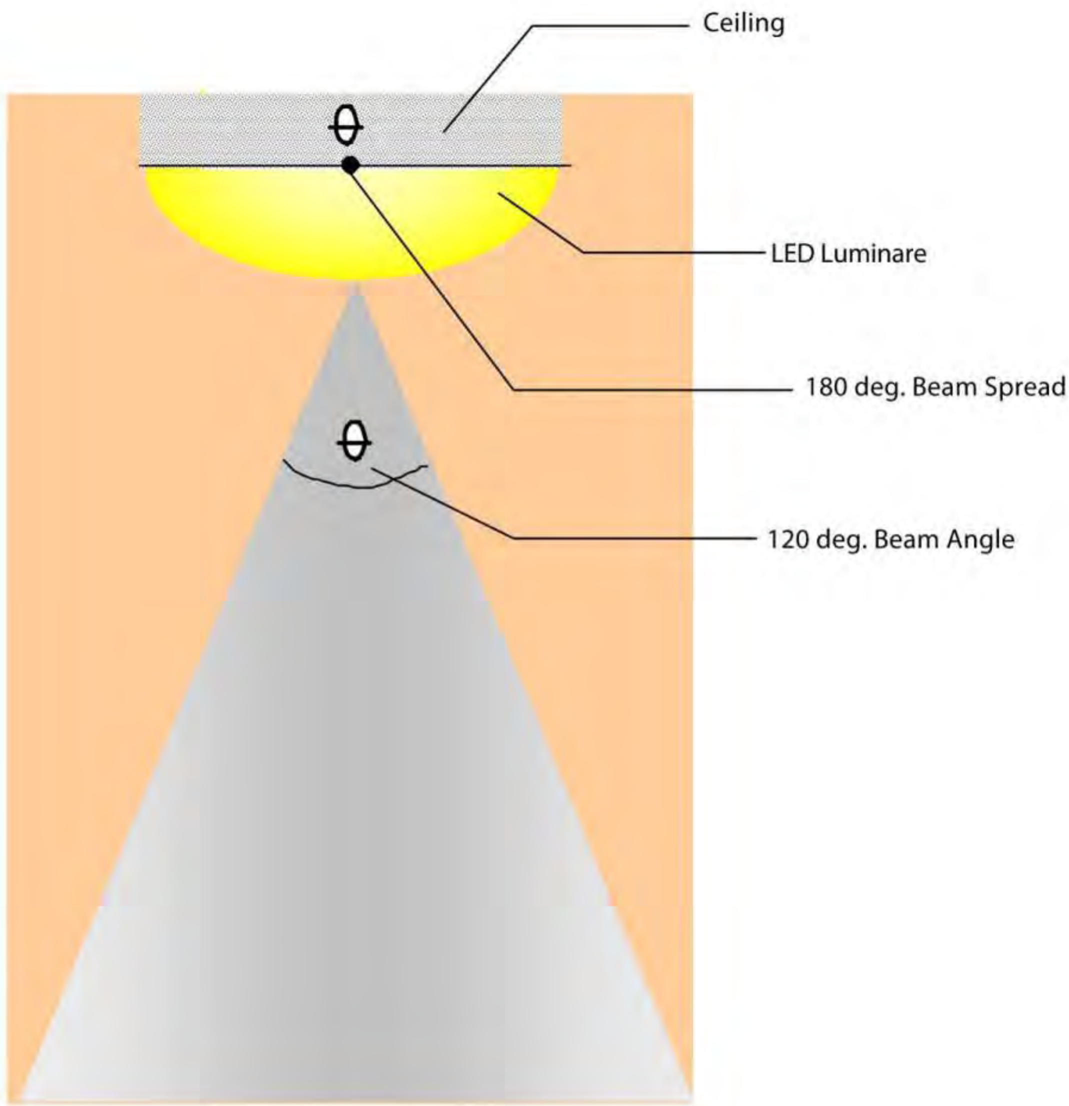

Figure 1. Target LED luminaire output

Source: California Lighting Technology Center

Figures 2 and 3 show conceptual renderings of possible LED luminaire dimming control interfaces. Figure 2 represents a remote, wall-mounted dimming control system, and Figure 3 shows a pull-chain dimming system. The dimming interface circuit was designed to use a Triac as the front end driver to the SMPS, regulating the solid-state circuit that controls the intensity level of the LED array.

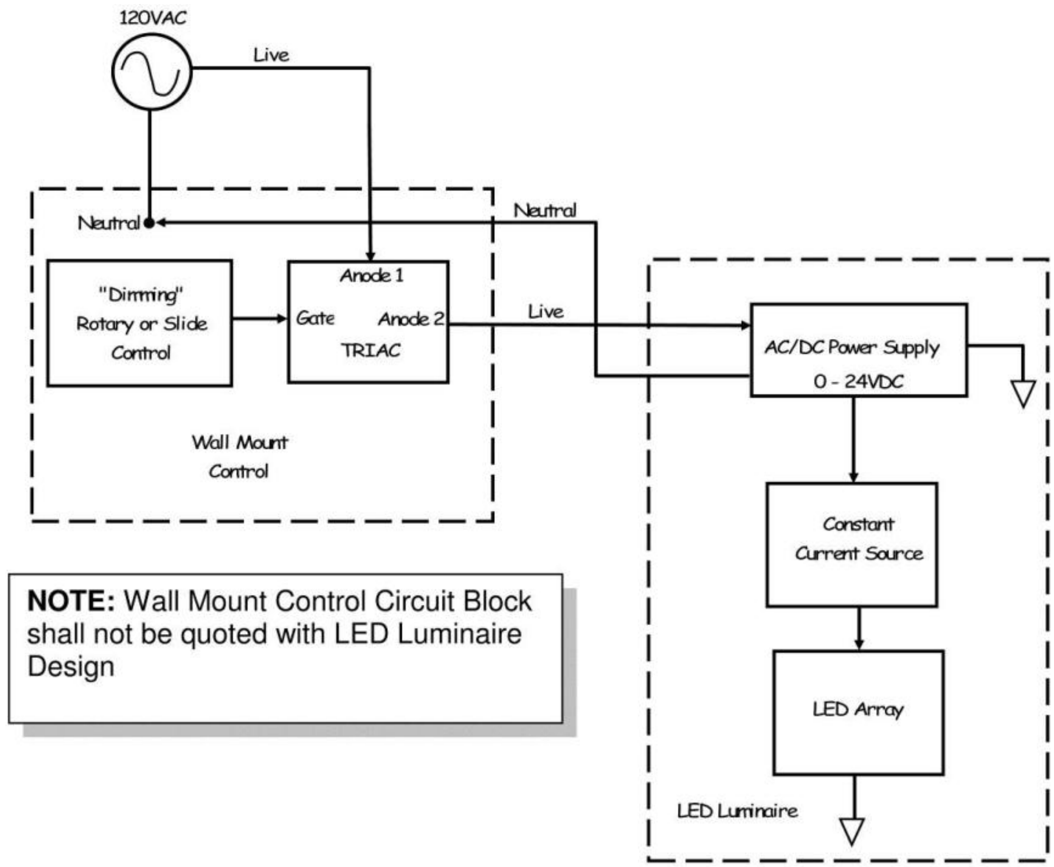

Figure 2. Remote wall-mount dimming control system

Source: California Lighting Technology Center

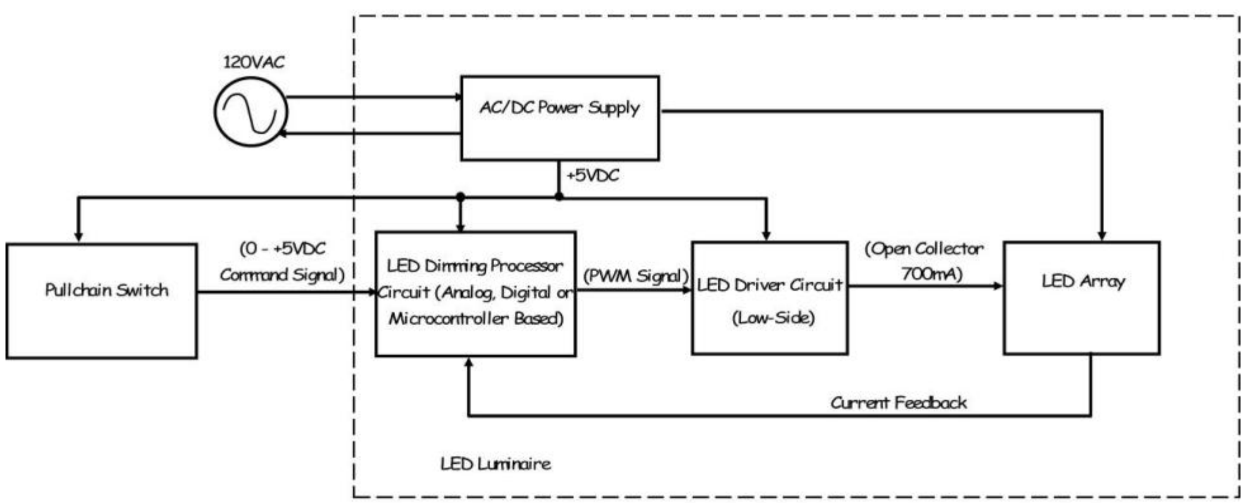

Figure 3. Pull-chain dimming control system

Source: California Lighting Technology Center

Each subcircuit block operates as described below for both the pull-chain dimming and wall-mount control concepts:

Pull-Chain Switch – A three-position switch providing input control for the LED luminaire's dimming and ON and OFF functions. The electrical modes of operation for this input control switch consist of:

a) Position 1 – OFF
b) Position 2 – ON (LED luminaire)
c) Position 3 – Dimming levels (see the "Illumination Levels" subsection below for more information about dimming levels)

1. LED Dimming Processor – An electronic circuit capable of reading the pull-chain switch contact and generating ON, OFF, and dimming pulse width modulation control signals for the LED array. A microcontroller, digital, analog or mixed signal solution for input-output processing is used with the circuit's input interface.
2. LED Driver Circuit – Low side – Open collector driver circuit capable of sinking up to 700 milliamperes (mA).
3. LED Array – A 2x5 solid-state lighting topology using 1-watt (W), 700 mA, high-intensity LEDs. The LED array is mounted on a self-thermal management circuit board along with a series-limiting resistor.
4. Alternating current (AC)/DC Power Supply – An electronic circuit capable of converting 120VAC into constant regulated voltages of a +5VDC. A maximum of 1 ampere of constant current is required. An SMPS with a power efficiency rating of 85% or higher is used in the LED luminaire electronics.
5. Dimming Rotary or Slide Control – A simple variable resistor used to change the pulse width modulation signal for operation of a Triac for AC solid-state light dimming control. This is part of the wall control unit.
6. Triac – An AC solid-state switch used to provide a variable control signal for LED light dimming. A DPak, 8-ampere maximum rating device shall be used in the wall-mount control circuit design. This is part of the wall control unit.
7. Constant Current Source – An electronic circuit capable of maintaining a 700-mA output under an operation voltage range of +5 VDC thru +28VDC. A current (I) feedback mechanism is used for monitoring and regulating a constant I for the LED array.

Illumination Levels

The LED luminaire has two illumination control modes: Full ON, OFF, and dimming. The illumination control modes specifications are:

1. Full ON = Light Illumination at 100% brightness
2. Dimming Level Modes – Five levels of Light Dimming Illumination:
    a. 75% Brightness
    b. 50% Brightness
    c. 25% Brightness

d. 10% Brightness

e. 0% - Off

Table 2 shows the output voltage based on the pull-chain position.

Table 2. Pull-chain switch position, component identification, resistor value and V out data

Switch Position	Mode	R-Designator	R-Value	Vout
1	OFF	NA	NA	≈+5V
2	ON	R3	10KΩ, 1%	+4.55V
3	DIMMING	R2	1KΩ, 1%	+2.50V

Source: California Lighting Technology Center

Electrical Specifications

The electrical specifications are as follows:

- Supply voltage: 120 VAC/ 60 Hertz (Hz)
- Current control switching will use Triacs for continuous ON and Dimming mode functions.
- Use 100 nano-farads (nF) Decoupling capacitors for power pins of digital, analog, microcontroller, and erasable programmable read only memory integrated circuit components and 10nF capacitors for pull-chain switch multiplexed network circuit.

Figure 4 shows an example of a decoupling circuit scheme.

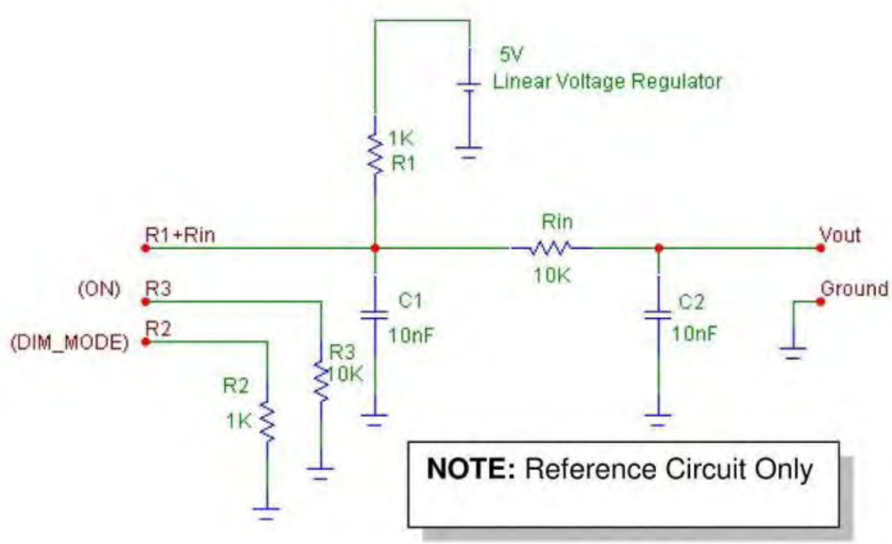

Figure 4. Pull-chain switch resistive multiplexed network input interface circuit

Source: California Lighting Technology Center\

Mechanical Specifications

For mechanical specifications, the target dimension of the LED luminaire's printed circuit board (PCB) is 8 inches in diameter, maximum (reference Figure 5).

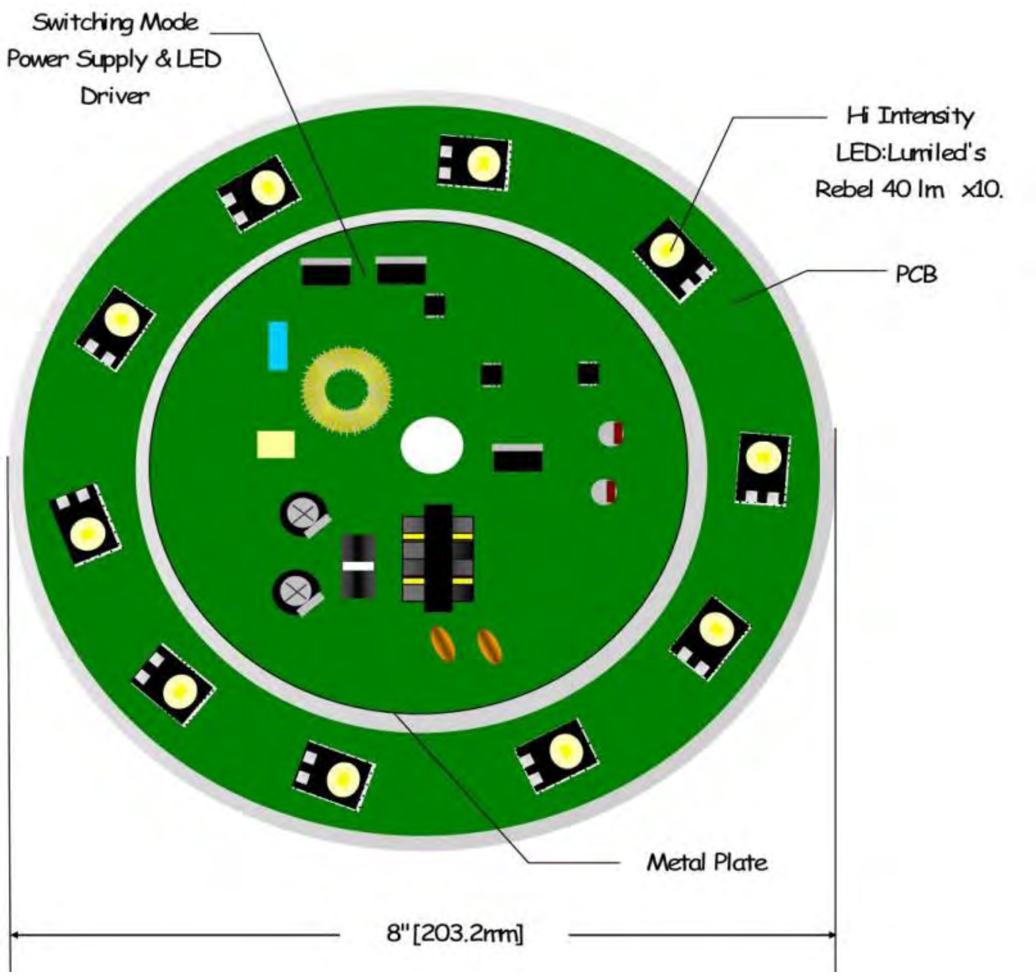

Figure 5. Metal plate/ PCB diameter dimension

Source: California Lighting Technology Center

To maintain proper thermal management for the LEDs, the solid-state lighting components are attached to a small copper pad with ventilating holes on the PCB. Thermal conductive paste or material improves the heat dissipation path, allowing the PCB to cool the LED (reference Figure 6).

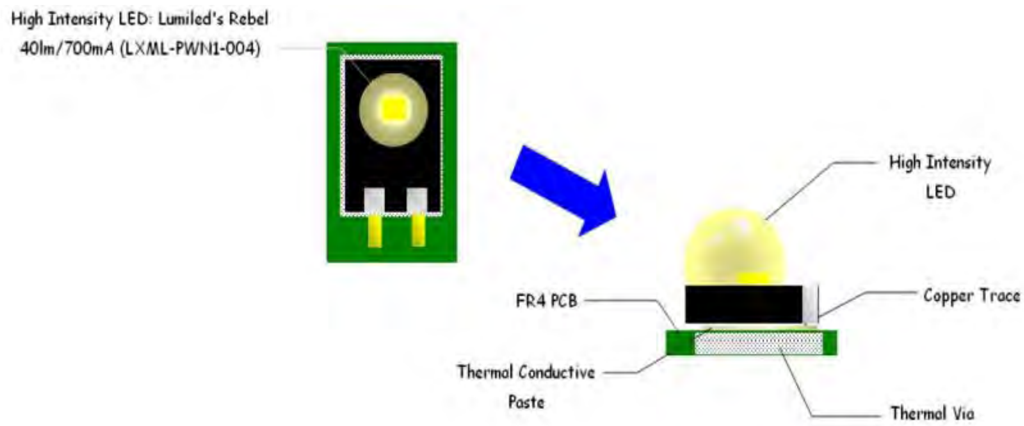

Figure 6. Mounting the high-intensity LED onto a National Electrical Manufacturers Association-grade PCB for thermal management

Source: California Lighting Technology Center

The SMPS and LED driver electronics are mounted either in the switch housing assembly or the LED array plate. (Reference Figure 7.) The SMPS allows easy removal and installation of defective parts using a simple screwdriver. Service mount devices, packaging, and housing assist in meeting the target PCB size.

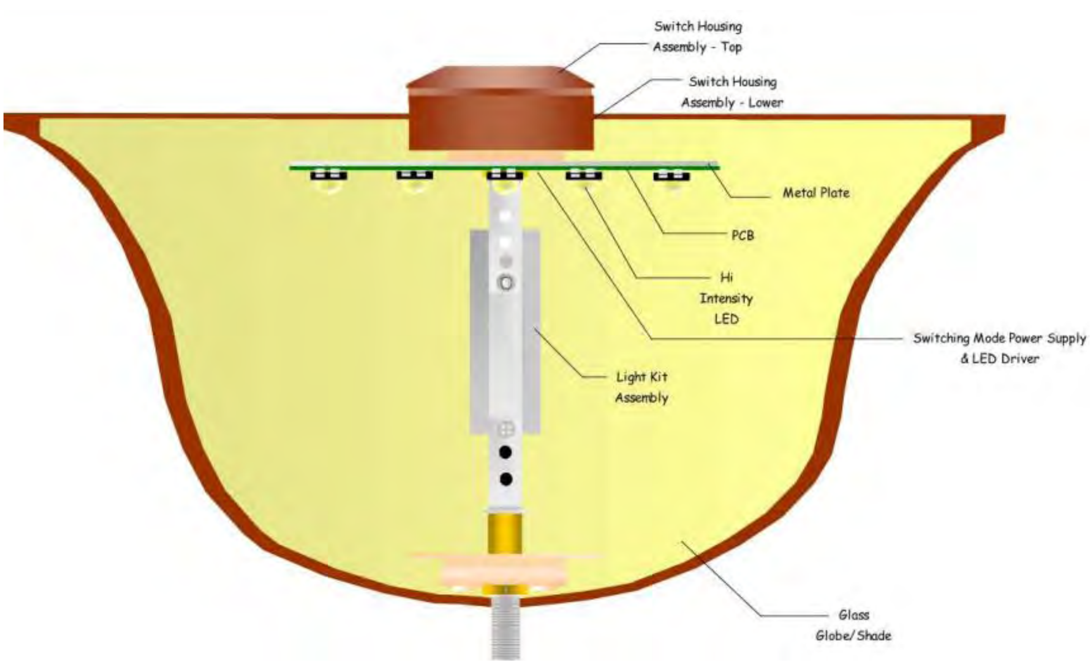

Figure 7. SMPS and driver electronics packaging, LED array metal plate, and switch housing assembly

Source: California Lighting Technology Center

Regulatory and Environmental Specifications

Units conform to Underwriters Laboratory Standard 507. Operating conditions are 0 to 85 degrees Celsius inside the fan housing/ control switch housing. Units must maintain 95% relative humidity. Storage conditions are -40 to 85 degrees Celsius.

The specifications above were modified during the course of the project. The initial lumen package was found to be inadequate. The initial thermal management concept was evaluated and characterized as ineffective. The initial LED array design was evaluated and found to provide inadequate light levels. This was a function of both the LEDs specified as well as the inadequate thermal management. To improve the design alternative LEDs were specified and a dedicated heat sink was incorporated into the system design.

2.2. Specifications for Ceiling Fan With Native LED Light Source

The CLTC LED ceiling fan design channels light wirelessly to transparent fan blades, pairing the aesthetic element fan blade illumination with a functional downlight component. The fan also includes an LED retrofit light kit. The thermal management of the LEDs in this design nearly eliminates the need for lamp replacement, which reduces maintenance and labor costs, a desirable feature in many commercial and some residential applications that require long burn hours.

The details of the LED transparent blade fan design are as follows:

- Circular array of LEDs oriented perpendicular to the fan blades
- Fiber optic or Polycarbonate/Acrylic blades integrated into the fan blades
- LED flux distributed to the fiber optic, transferring the light to the blade edges
- Optional integrated downlight
- Single driver unit
- Retrofit light kit

2.3. Specifications for Bathroom Exhaust Fan LED Light Kit

The CLTC staff developed the following specifications for a LED light kit for bathroom exhaust fan:

- Linear array of 10-18 LEDs
- Light output equal to or greater than 2 x 18-W CFLs
- Integrated nightlight
- Simple wiring approach to standard wall switches (3 rocker)
- Design aesthetics to showcase LED technology
- Integrated auto-cooling of LEDs at low fan speeds (using Hunter Fan’s patented technology)

The CFL exhaust fan incorporating 2 – 18 watt lamps was tested in the integrating sphere and determined to have the following fixture characteristics:

- Light output - 878 lm

- CCT - 3367 K
- CRI – 70
- Power – 36 W
- Efficacy 24 l/w

The CLTC used these values as a baseline to determine incremental improvement of the proposed LED design over the existing CFL product offering.

2.4. Fan Light Kits

The Hunter Fan Company produced three iterations of a prototype LED ceiling fan light kit, and the CLTC tested each. The first kit was based on the initial specification that incorporated no heat sink. The second kit had improved light output but still lacked adequate thermal management. The third kit achieved a high system efficacy and incorporated a separate aluminum heat sink.

The CLTC also tested a version of its own LED light kit design and designed and constructed a prototype ceiling fan with a dedicated light source and a prototype LED bathroom exhaust fan. In addition, the CLTC conducted visitor surveys to evaluate the market potential for the prototype ceiling fan with a dedicated LED light source and the prototype LED bathroom exhaust fan kit. Figure 8 shows the CAD drawing for the CLTC heat sink and circuit board design.

Figure 8. CAD drawing of the CLTC heat sink and circuit board design

Source: California Lighting Technology Center

2.4.1. Ceiling Fan LED Light Kit Test Results

Figures 9 through 11 show the Hunter Fan Company LED kit designs as the three iterations progressed. Tables 3-5 show the test results for the iterations of the residential ceiling fan LED light kit prototypes from Hunter Fan Company. Each successive prototype attempted to improve performance.

Figure 12 and Table 6 show the results for the CLTC LED fan kit design.

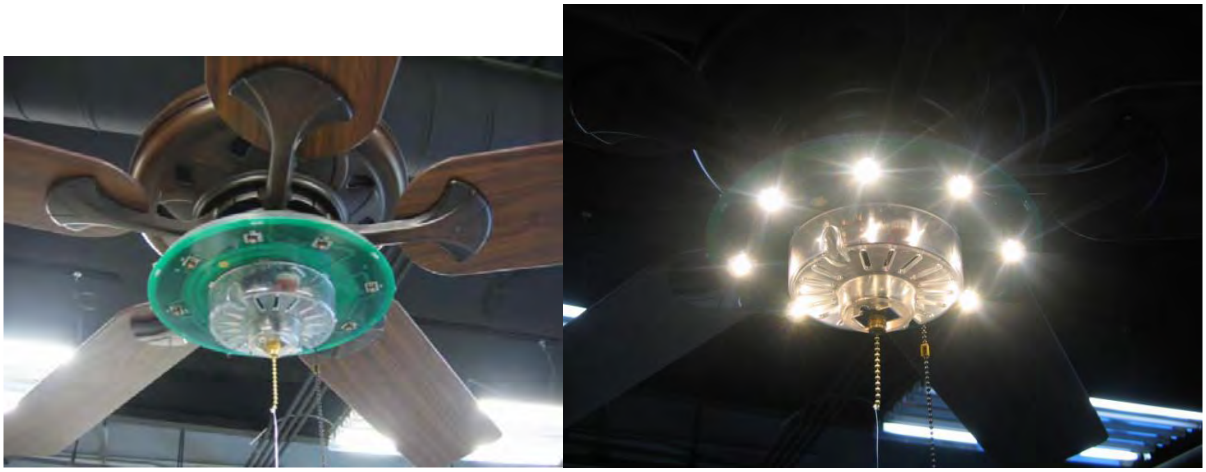

Figure 9. Hunter Fan Kit Design #1
Photo Credit: California Lighting Technology Center

Table 3. Hunter ceiling fan LED light kit – Iteration 1 test results

Hunter Fan Kit #1
Test Data N/A – Fixture would not stabilize adequately to determine values

Source: California Lighting Technology Center

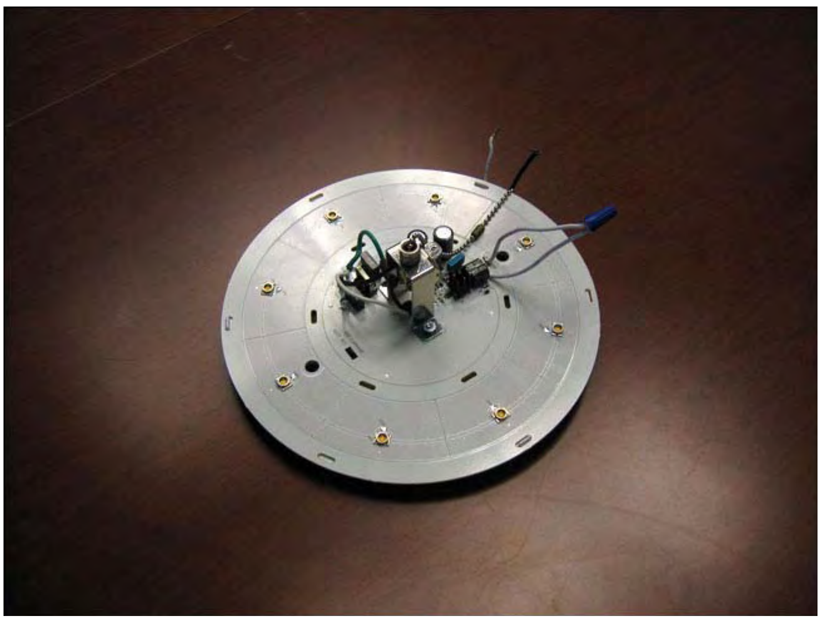

Figure 10. Hunter Fan Company Kit Design #2
Source: California Lighting Technology Center

Table 4. Hunter ceiling fan LED light kit – Iteration 2 test results

Hunter Fan Kit #2	
lm	~672
CCT	2992 K
CRI	85.8
AC wattage	19.0 W
Efficacy	35.3 lm/W

Source: California Lighting Technology Center

Power measurements were taken on Xitron power analyzer. Measurements were taken at 15-minute intervals to +/- 0.5% stabilization per Illuminating Engineering Society (IES) LM-79. Photometric measurements were made with a DAS-1100 Spectrometer in a 2-meter sphere.

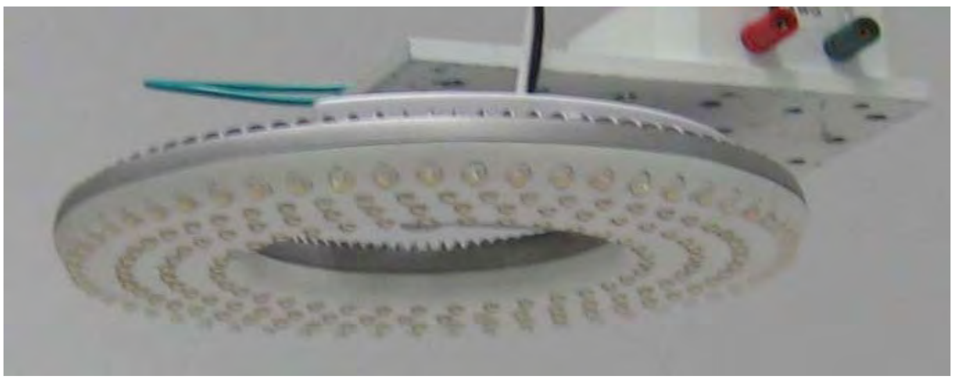

Figure 11. Hunter Fan Kit Design #3

Photo Credit: California Lighting Technology Center

Table 5. Hunter ceiling fan LED light kit – Ic teration 3 test results

Hunter Fan Kit #3	
Lumens	877
CCT	3351 K
CRI	68
AC wattage	10 W
Efficacy	88 L / W

Source: California Lighting Technology Center

Power measurements were taken on Xitron power analyzer. Measurements were taken at 15-minute intervals to +/- 0.5% stabilization per IES LM-79. Photometric measurements were made with a DAS-1100 Spectrometer in a 2-meter sphere.

Figure 12. The CLTC LED fan kit design
Photo Credit: California Lighting Technology Center

Table 6. The CLTC ceiling fan LED light kit test results

The CLTC Fan Kit	
Lumens	~1,619
CCT	2928 K
CRI	~82.7
AC wattage	39.8 W
Efficacy	40.6 lm/W

Source: California Lighting Technology Center

2.4.2. Ceiling Fan With Dedicated LED Lighting Results

Figure 13 shows the CLTC-designed prototype native LED fan in three views: with LEDs off, blade illumination on, and blade illumination and downlight on. The primary focus for evaluating this concept was to solicit industry feedback on the design. The general sentiment was that the concept was aesthetically pleasing but lacked broad appeal in the residential market place.

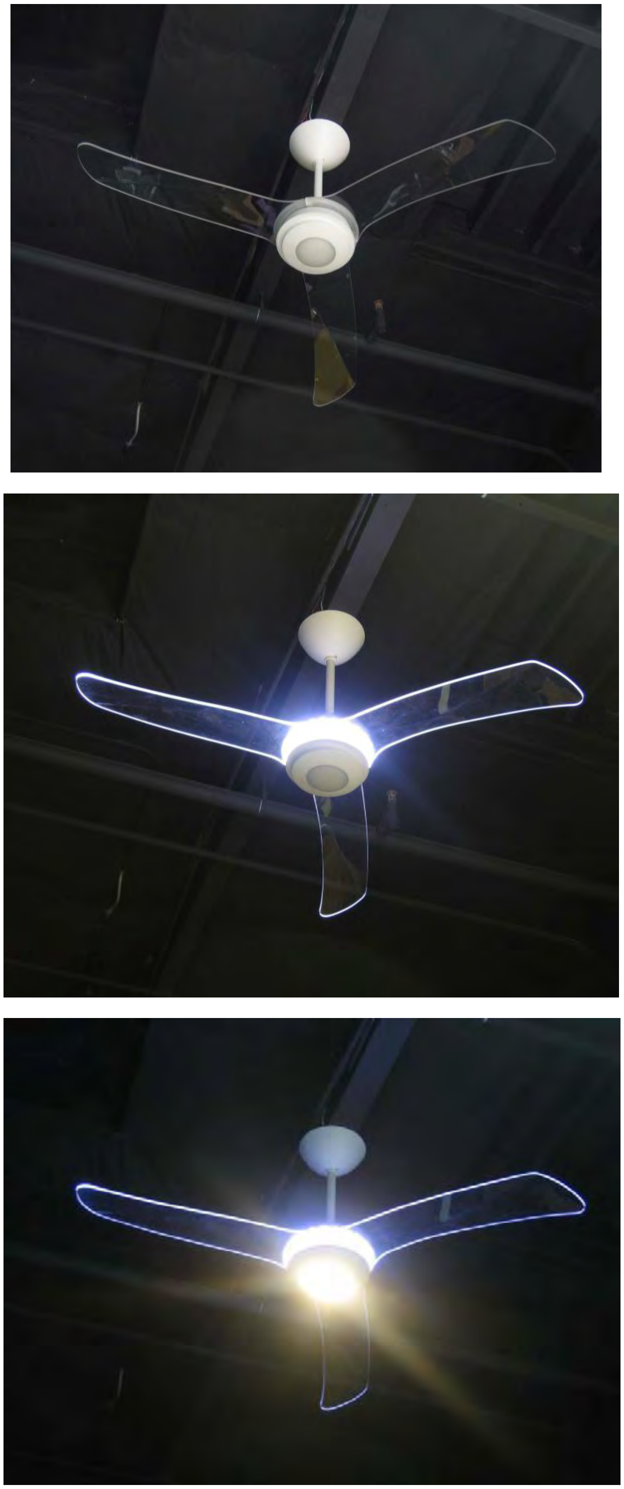

Figure 13. The CLTC transparent blade LED fan in three views: LEDs off, blade illumination on, and blade illumination and downlight on

Photo Credit: California Lighting Technology Center

The transparent blade LED fan was not characterized in the integrating sphere as it does not serve as a general illumination source. The blade elements are decorative and create a unique aesthetic. Because of this, it was decided this design would have minimum impact on the energy usage in a residential homes. The CLTC then focused efforts on the ceiling fan light kit.

The industry partner pursued comercializing this concept but concluded the design would be cost prohibitive.

2.4.3. Exhaust Fan LED Light Kit Results

Figure 14 shows the prototype of the LED bathroom exhaust fan that the CLTC designed, and Figure 15 shows the prototype components. The exhaust fan design was approached with the idea that the forced convection inherent in the fan function would be utilized to improve LED thermal management performance. The exhaust fan LED light kit was designed to fit into a narrow portion of the exhaust fan opening to utilize the air flow while minimizing the negative impact on fan functionality.

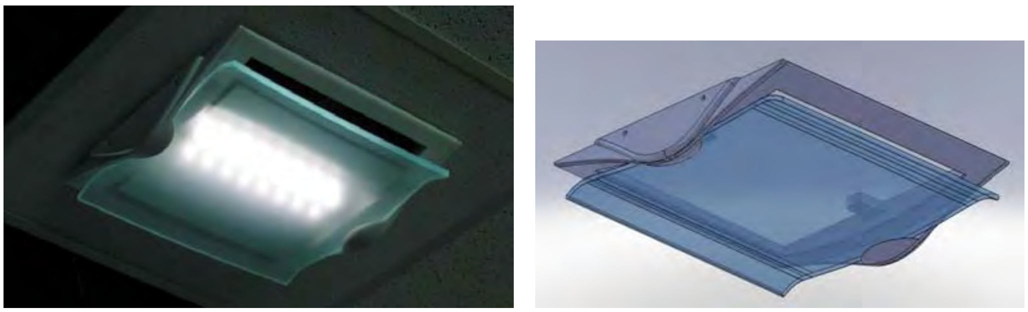

Figure 14. LED bathroom exhaust fan prototype and CAD rendering
Source: California Lighting Technology Center

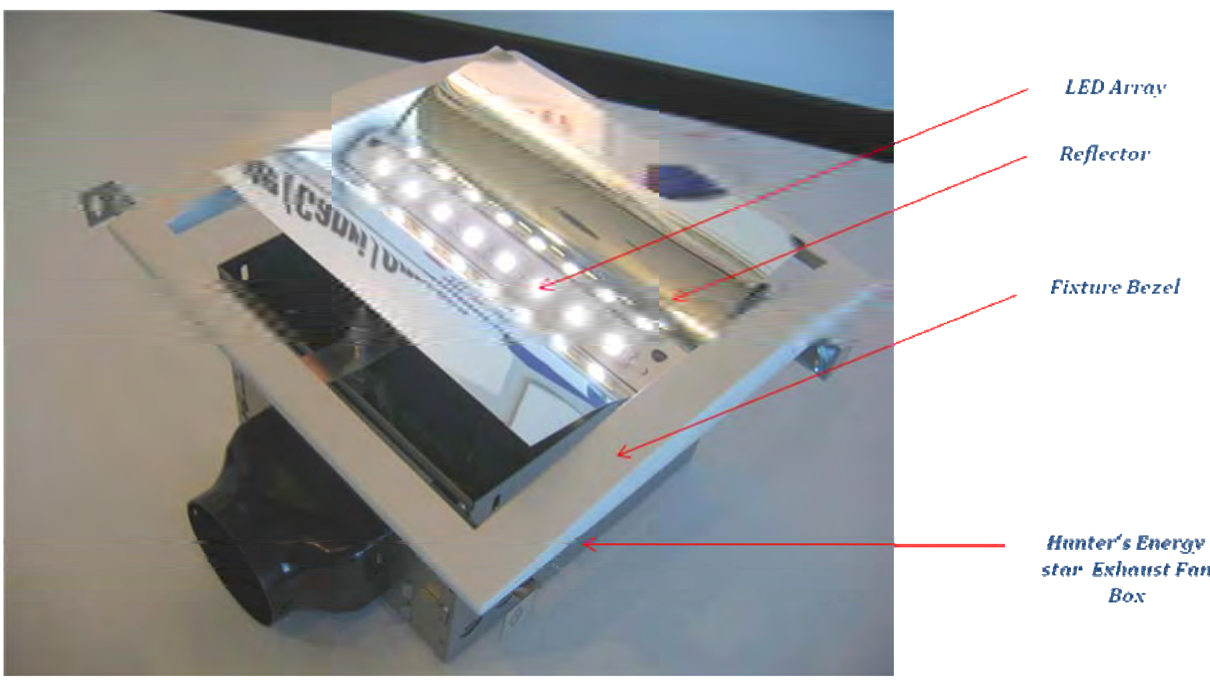

Figure 15. LED bathroom exhaust fan components
Source: California Lighting Technology Center

The project team refined the decorative bezel and diffuser design until the optimal product design was reached. The CLTC then led the design and procurement of 5 injected-molded plastic prototypes to be combined with glass provided by the industry partner. These 5 prototype exhaust fans were intended to be deployed in a field test. The prototype exhaust fan kit was tested in the integrating sphere and determined to have the following fixture characteristics:

- Light output - 310 Lumens
- CCT - 3605 K
- CRI – 77
- Power – 28 Watts
- Efficacy 11 L / W

Based on these test results, it was determined that an alternative LED vendor should be pursued. A concept design incorporating high brightness LEDs with light output performance at an industry leading level was proposed based on an existing heat sink manufacturers stock extrusion. This design was initially pursued but never realized due to complications in manufacturing. The designed system efficacy level was ~ 55 lumens / watt, which at the time of this report is a realistic LED system efficacy based on commercially available components. Additionally, a mode for night light functionality was explored and prototyped. Figure 16 shows the prototypes.

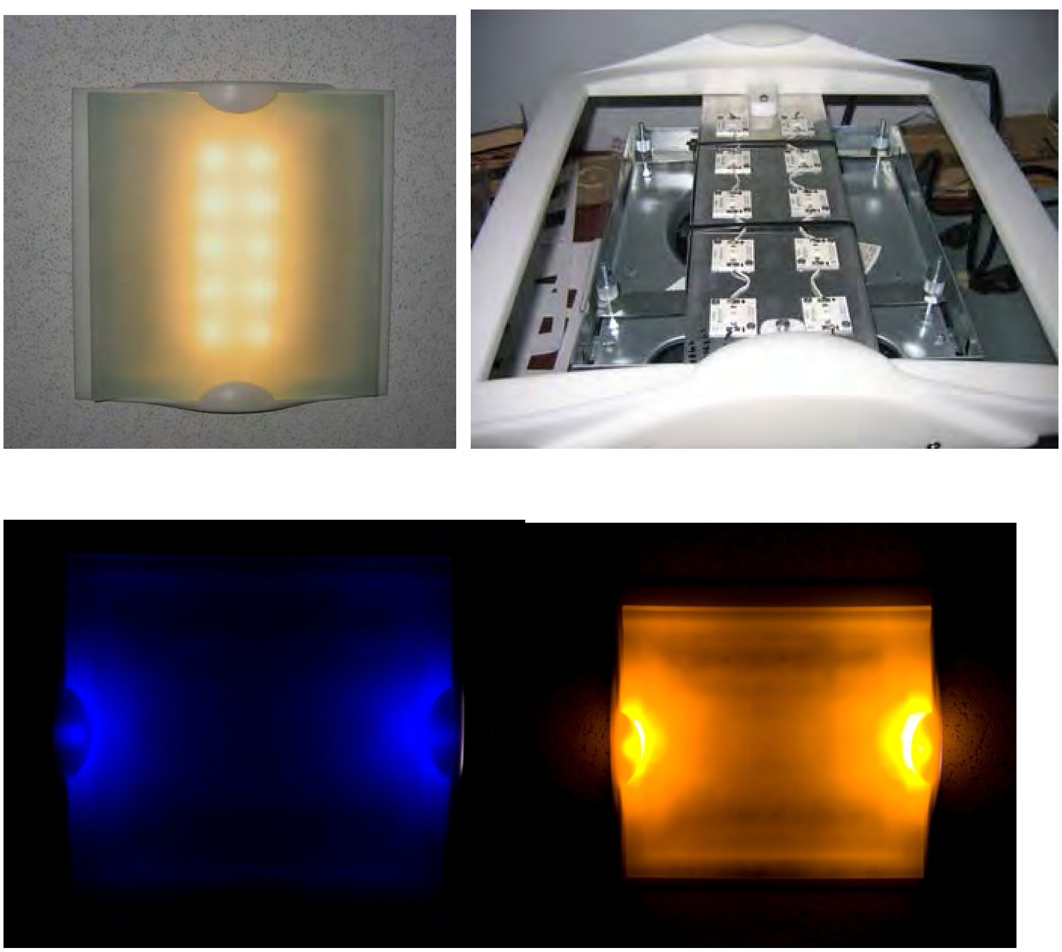

Figure 16. Exhaust fan concept design – High mode, LED module, blue night light, amber night light

Photo Credit: California Lighting Technology Center

2.5. Thermal Management Design and Development

The thermal management design for the high brightness LED arrays for both the ceiling fan and the exhaust fan were designed and developed by applying heat transfer principles and a working knowledge of LED thermal management. Targeting a conservative value of 8 square inches / watt of LED of useable heat sink surface area, the initial heat sink geometries were created. The LED fan light kit heat sink was designed to thermally manage up to 50 W of LED power. The exhaust fan heat sink was specified to manage up to 35 W of LED power. Upon refining these designs by applying a working knowledge of LED thermal management, the proposed geometries were prototyped and evaluated. The performance of these heat sinks was validated by measuring temperature off the LED circuit board as well as monitoring initial light output versus thermally stable light output. The prototype heat sinks were found to function within the ranges recommended by the LED manufacturers. Rigorous thermal evaluations of these concept designs were not pursued as the manufacturing partner was not interested in commercializing these designs.

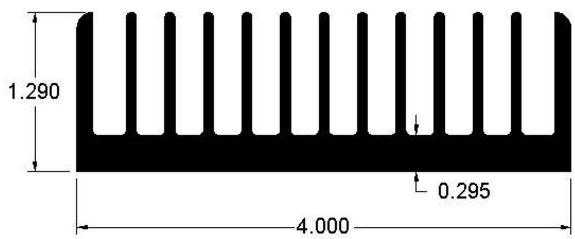

Figure 17. Exhaust fan heat sink cross section commercially available from Thermal Solutions International, Inc.

Source: www.thermal-solutions.us/

2.6. Controls

The initial product specification included designs for pull-chain dimming controls. The concept was to emulate existing ceiling fan light kits dimming functionality by providing 3 levels of light – high, low, and off. During the course of the project, it was determined that a continuous dimming light kit would provide added functionality, energy savings, and value to the customer. The ideal dimming functionality would allow the end user continuous dimming control in a smooth, linear fashion ranging from a 100% down to 5 % of initial light output. At the beginning of this project, typical dimmable LED power supplies required a 0 – 10 V controller that are traditionally intended for commercial or custom residential construction. These 0 – 10 V dimmer switches added significant cost to the system.

Over time, many LED power supply manufacturers have designed dimmable products that are compatible with traditional residential Triac-based dimmer switches that were originally intended for incandescent-based sources. Lightech Inc. is a progressive manufacturer that offers cost effective, Triac-compatible dimmable LED power supplies. The CLTC prototype design incorporated a Lightech Inc. dimmable driver with the mechanical constraint of fitting in a double gang junction box. It was determined that the design would provide the highest level of functionality while allowing for a replaceable power supply, should it require maintenance. It is also retrofitable in applications with existing Triac dimmers.

One of the primary control design concepts for the exhaust fan was to incorporate a night light functionality that would utilize the front diffuser plane to create a low level light source. The design could be realized with white LEDs or with a colored LEDs such as amber, green, blue, and red. The control concept incorporated a single pole, double throw switch to allow the end user to change the exhaust fan from night light mode to general mode. Additional energy savings could be realized by incorporating an occupancy sensor into the bezel depending on the behavior patterns of the user.

2.7. LED Fan Light and Controls Prototypes

Discussion of the prototypes is provided in previous Sections 2.4 and 2.6.

2.8. Field Testing

Because the concepts were not commercialized at the time of this report, formal field testing was not completed. A CLTC LED light kit was installed in SMUD's E-House to raise the public's awareness about LED products. This prototype installation has received positive feedback and is scheduled to remain installed indefinitely. Figure 18 shows the installation at SMUD.

Figure 18. The CLTC prototype light kit installed in SMUD E-House

Photo Credit: California Lighting Technology Center

3.0 Project Outcomes

Hunter Fan Company developed three successive iterations of a residential ceiling fan light kit during this project and continues to work towards commercialization. The CLTC developed a set of residential fan LED light kit specifications, and the prototypes to meet those specifications as well as designs for a decorative dedicated LED residential ceiling fan and a LED bathroom exhaust fan. To date, these products are not commercially available.

Hunter Fan Company and the CLTC developed prototypes of a LED exhaust fan with a night light mode. The exhaust fan bezel that houses the main LED light, the night light, and the power supply was designed such that it would be mountable to an existing exhaust fan or easily installed in new construction.

The CLTC developed a specification for a LED optical system that had a system efficacy of 40 lm/w. This system consists of 16 Cree XR-E LEDs driven at a drive current of 500 – 700 mA. This array also met the target 1000 lm output for the ceiling fan. This array should be properly mounted to a quality circuit board and attached to an appropriately designed heat sink. The fixture efficiency for the LED fan light kit is dependent on the transitivity of the decorative glass placed in front of it.

The CLTC also developed a specification for a LED exhaust fan. This system consisted of 10 Osram Opto Golden Dragon Plus warm white LEDs driven at a drive current of 500 mA. The light output of the initial prototype met the target of a 150 lumens for the exhaust fan light kit.

The efficacy and light output for these systems was characterized using an integrating sphere and a Xitron power analyzer. The light output and efficacy of the LED ceiling fan light kit met the 40 lm/w target while exceeding the 1000 lm output target by achieving ~1600 lm. The initial exhaust fan light kit exceeded the light output target of 150 lm by achieving ~ 300 lm. The initial exhaust fan light kit did not meet the target efficacy of 40 lm/w. The second exhaust fan light kit concept design is anticipated to exceed the efficacy target but was not measured.

Thermal management systems were designed based on specified wattages. A conservative heat sink design was developed and prototyped for both the ceiling fan light kit and the exhaust fan light kit. Both of these thermal systems were validated by measure solder point temperatures on the circuit board and comparing to LED manufacturers recommended. The solder point temperatures were found to be within the manufacturer’s recommendations.

4.0 Conclusions and Recommendations

The CLTC and the manufacturing partner worked to design and commercialize LED lighting for both a ceiling fan and an exhaust fan targeted at the residential marketplace. During the course of this project, it was determined that the residential marketplace is extremely cost-sensitive. This was observed in relation to the LED bill of materials, the heat sink design, and the light controls. While the performance targets were technically feasible, the cost constraints made achieving them in a commercial grade version impossible at the time this project was conducted. As the cost of LEDs and electronics continues to decrease, residential ceiling fan and exhaust fan LED light kits will become more affordable and improve in quality.

Recommendations stemming from this project include pursuing the development of a light kit for replacing candelabra style light kits, investigating the potential for wireless controls for both the ceiling fan light kit and the exhaust fan, and an in depth market analysis of existing Triac dimmer switches and their associated performance.

The benefits to California of cost-effective LED lighting in residential fans would be increased energy and peak demand savings. LED lights can also provide high efficacywith dimmability and increased product life. The widespread use of dedicated LED lighting systems in residential fan applications would increase energy savings and help meet future more stringent codes and standards.

Glossary

Acronym	Definition
AC	alternating current
CCT	correlated color temperature
CFL	compact fluorescent lamp
CLTC	California Lighting Technology Center
CRI	color rendering index
DC	direct current
GWh	gigawatt-hour
Hz	Hertz
I	current
IES	Illuminating Engineering Society
K	Kelvin
If	forward current draw
LCF	Lighting California's Future
LED	Light emitting diode
lm	lumen
lm/W	lumens per watt
mA	milliampere
MW	megawatt
nF	nanofarad
PCB	printed circuit board
PIER	Public Interest Energy Research
Pled	LED power dissipation
SMPS	switch mode power supply
SMUD	Sacramento Municipal Utility District
V	volt
VDC	direct current voltage
Vfd	forward voltage
W	watt