Energy Efficient Downlights for California Kitchens

CONSULTANT REPORT

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Legal Notice

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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 Energy Efficient Downlights for California Kitchens, Contract Number 500-98-020, conducted by the Lawrence Berkeley National Laboratory. The report is entitled Energy Efficient Downlights for California Kitchens. This project contributes to the Building End-Use Energy Efficiency program.

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

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Executive Summary

While energy efficient lighting has made significant inroads in commercial lighting applications, this success has not carried over to the residential sector. In particular, the compact fluorescent (CFL) downlights common to commercial applications have not been widely accepted or adopted by residential builders and homeowners. This is because significant barriers not present in commercial applications have limited the acceptance of compact fluorescent downlights in the residential arena. These include:

- High cost of dedicated CFL downlights
- Poor performance of residential-grade or retrofit CFL downlights
- Thermal management issues related to electronic ballast
- Difficulty in installation of CFL downlights
- Lack of availability

Objectives

The overall goal of this project was to develop a novel, low cost, high performance and high efficiency kitchen lighting system (KLS). The specific technical and economic objectives of this project were as follows:

- Develop a fully dimmable (10-100%) downlight system with a centralized control architecture serving four to eight compact fluorescent lights (CFLs).
- Develop fixtures for this application that have an efficacy of greater than 50 lumens per watt.
- Develop fixtures that cost 25-50% less to produce and install than current high performance commercial grade CFL downlights.

Approach

Upon initiation of the project, background research into both existing downlight products and current downlighting practice was begun. We characterized the photometrics of both the existing incandescent and CFL downlight designs to determine candlepower distribution, fixture efficiency, fixture efficacy, and fixture lumen output. We also conducted numerous interviews with professionals in the building industry and undertook a number of building site visits to observe the installation process for kitchen downlighting. In approaching the development of the KLS itself, we proposed and even prototyped many different systems. The project partners continually evaluated these systems in order to determine how well they balanced energy efficiency, performance, and ease of use with manufacturability and cost. The final prototype system described in this report is the one that most appropriately these requirements.

Outcomes

Of the objectives listed above, this project had the following primary outcomes:

- Developed fixtures with a final efficacy of 50 lumens per watt.
- Reduced fixture costs by over 50%. Comparable high performance commercial grade CFL downlights cost $150-200, while the initial target price for the KLS system is only $50-70.

The objective of developing a fully dimmable downlight system was not realized. This objective was abandoned early in the design phase of the project for the following reasons:

1) It was determined that dimming systems are rarely used in kitchens common in high-production housing.
2) Adding dimming capability could as much as double the final product cost of the system.
3) The added cost of dimming was unacceptable to production homebuilders.

These factors led to a new approach regarding the ballast in which a standard, off-the-shelf ballast could be utilized in a master-slave arrangement. This approach allowed ballast costs to be greatly reduced while opening a number of options for existing ballast products to choose from. Homebuilders strongly encouraged adoption of an approach in which industry standard ballasts with proven track records for reliability could be used, rather than an approach in which a new customized, proprietary ballast was developed.

The key features of the final prototype KLS are as follows.

- **Thermally enhanced ballast configuration.** The KLS ballast has been thermally optimized by connecting it to the main metallic housing for the downlight pan itself.
- **Master-slave ballast geometry.** This approach greatly reduces material and installation costs.
- **Plug-and-play wire connections.** This flexible and removable connection significantly simplifies the wiring to the slave fixture.
- **Simplified housing and reduced components.** These reductions should lead to associated reductions the cost of the downlighting system.
- **Institutionally transparent/builder-friendly.** The installation of the KLS follows the same process that builders are familiar with.
- **Improved maintenance.** There are several features of the KLS that should improve the maintenance of the overall system, including accessible ballasts, plug-and-play design, and flexible fixture whips.
- **High performance optics.** The reflector optics for the KLS are based on existing commercial grade CFL products that maximize output while minimizing glare.

- **High quality CFL.** The CFLs included with the KLS are 26W high quality, high output lamps.
- **High quality ballast.** The ballast chosen for the KLS is produced by Advance Transformer. This ballast is approved for residential applications (FCC Class B), and features a quick startup characteristic.

Conclusions

The KLS is a very strong performer, comparing favorably to even the much more expensive commercial-grade CFL systems. Economically, the KLS measures up very well against both incandescent and CFL downlight alternatives. The system offers 75% energy savings with negligible cost increase compared to standard incandescent downlighting. Thus the KLS provides a 0.4 year simple payback compared to incandescent systems and 4.2 year payback compared to standard residential CFL units, all while providing high, more-uniform illumination levels.

Commercialization Potential

LBNL has selected Lithonia Lighting as the manufacturer best suited to quickly and effectively penetrate the lighting market with the novel KLS technology and they are planning a summer 2004 product introduction. Lithonia has three key capabilities that are favorable indicators for KLS production. These are:

- **Pre-existing components.** Nearly all the components on the KLS are pre-existing components from other Lithonia lines. This limits the risks inherent in transitioning from prototyping quantities to manufacturing quantities.
- **UL-Certified Prototypes.** In the rigorous process of designing and building a number of prototype units to a level appropriate for UL-certification, Lithonia has already addressed the most important details of KLS production.
- **Large Production Capability.** Because of their significant size, Lithonia should be able to meet any foreseeable required production ramp-up through their existing production facilities.

The California electric utilities will likely play a significant role in the commercialization of the KLS. Sacramento Municipal Utility District (SMUD) continues to lead the transition of this project from research to market, and has integrated the KLS into their "Advantage Homes" program encouraging homebuilders to adopt energy saving devices in new homes. Southern California Edison and Pacific Gas and Electric also plan to acquire KLS units for demonstration purposes. All California utilities will likely initiate incentive programs in 2004 to more broadly prepare the homebuilders in their service territories for the changes to Title 24 that will take effect in 2005.

Benefits to California

The KLS system has the potential to generate significant energy and demand savings in California. Assuming that the KLS achieves 25% market penetration in kitchens in the 120,000 new homes constructed annually in California (but no penetration elsewhere in the home or in any retrofit applications), the first year energy savings would exceed 12 million kWh, while the load reduction would represent about 1.2 MW. By year five, the cumulative energy savings would exceed 185 million kWh, saving about $22 million/year with a corresponding load reduction of about 6 MW.

Abstract

The goal of this project was to develop a novel, low cost, high performance and high efficiency kitchen lighting system (KLS) that is fully dimmable, has fixture efficacy of at least 50 lumens per Watt, and costs 25-50% less to install than current high-performance commercial-grade CFL downlights.

The major accomplishment of this project was the development of a final prototype KLS that met the goals listed above. This prototype system has the following key features:

- Thermally enhanced ballast configuration
- Master-slave ballast geometry
- Plug-and-play wire connections
- Simplified housing and reduced components
- Institutionally transparent/builder-friendly
- Improved maintenance
- High performance optics
- High quality ballast

The system offers 75% energy savings with negligible cost increase compared to standard incandescent downlighting while offering higher, more uniform lighting levels. Economically, the KLS offers a 0.4 year simple payback compared to incandescent systems and 4.2 year payback compared to standard residential CFL units.

Lithonia is the commercialization partner and expects to announce the product in the summer of 2004.

This report details the background research into existing kitchen downlight products and practice as well as the process by which the final prototype was developed.

1.0 Introduction

1.1. Background and Overview

The State of California is the national leader in promoting efficient lighting technologies. While energy efficient lighting has made significant inroads in commercial lighting applications, this success has not carried over to the residential sector. In particular, the CFL downlights common to commercial applications have not been widely accepted or adopted by residential builders and homeowners.

The State of California has recognized the energy saving opportunity of CFL downlights in high-use areas such as kitchens. While the State has targeted kitchen lighting for conversion to energy efficient fixtures and even established Title 24 efficiency guidelines for these fixtures, their application is still limited because until the 2005 standards were established only a limited number of fixtures were required to be high efficiency.

Significant barriers not present in commercial applications have limited the acceptance of compact fluorescent downlights in the residential arena. The following is a list of the primary barriers and issues that have limited the success of energy efficient lighting approaches in residential kitchen applications.

- **High cost of dedicated CFL downlights**

  Current commercial-grade CFL downlights can be five to ten times the initial cost of conventional incandescent downlights. Even with volume purchases the CFL downlights will never approach the cost of traditional incandescent fixtures. Manufacturers' attempts to reduce fixture costs while emulating the traditional design and look of the incandescent downlight have further contributed to the perception of low quality and poor performance.

- **Poor performance of residential-grade or retrofit CFL downlights**

  Early market failures with inexpensive screw-based retrofits and downlights have biased the consumer and builder against this energy saving technology. Many of these failures relate to system life, lamp life, quality of components, and low lumen output. These retrofit packages have poor lumen output because of low fixture efficiencies that occur when using a lamp that is not originally designed for the luminaire. This shortcoming not only represents lost energy, but also causes consumer dissatisfaction in general with CFL technology based on low brightness.

- **Thermal management issues related to electronic ballast**

  Residential downlights are generally required to be rated for airtight, insulated ceiling environments. When a heat generating source, such as a lamp or ballast, is placed in this thermally restrictive environment, there is a significant thermal strain on the components. The most sensitive downlighting component to this environment is the electronic ballast. If the electronic ballasts are not maintained below certain critical temperatures, generally below 75° C - 90° C, they suffer premature failures. Existing CFL downlight products resolve this limitation by either using magnetic ballasts, which are much less efficient and slower starting, or limited to lower wattage ranges (generally 13 W) to reduce the heat generated by the system. Both of these approaches have a strong detrimental effect on the overall quality of the downlighting system.

- **Difficulty in installation of CFL downlights**

  Installation of incandescent downlights is a complicated and highly labor intensive process. Electricians and sheetrockers each have complicated multi-step processes to install downlights. This brings the installation costs per downlight to a level were it meets or exceeds the materials costs of a typical downlight. Relative to their incandescent counterparts, CFL downlights are even more complicated and thus more difficult to install. CFL downlights must have lamps, sockets, ballasting and control switches that are all designed to work together. Often some of these components are sold separately (i.e. the downlight does not include lamps and/or switch) requiring the homebuilder or homeowner to determine and acquire the appropriate missing parts.

- **Lack of availability**

  The low residential demand for CFL downlights can be traced directly to the above issues and the fact that aside from energy efficiency, they offer no increase in amenity. This lack of demand has led to a lack of availability, making this valuable energy saving technology even less appealing to homebuilders and contractors.

In juxtaposition to the lack of response in the residential market to products that are essentially commercial-grade CFL downlights has been a significant increase in the demand and sales of conventional incandescent recessed downlights. Marketing studies have indicated that downlight sales will continue to grow significantly during the next decade and that the vast majority of these sales will be low-cost, but highly inefficient, incandescents. Recessed downlights represent a popular consumer choice due to their "designer" aesthetic, high-end look and their general perception of providing "quality lighting." Builders have significantly increased the amount of downlighting in new homes in response to this consumer perception. Furthermore many homeowners are installing their own downlights as is evidenced by the increasing availability at many "do-it-yourself" hardware stores.

The high initial cost of commercial-grade CFL downlights in the residential market concerns builders and consumers to the point that the Title 24 guidelines for kitchen lighting are either overlooked or circumvented in creative manners.

Competitive market forces and advances in technology may modestly and incrementally lower the price of CFL downlights, but they will never push the cost of CFL downlights to a price point that approaches incandescent downlights. This is because CFLs cost more to manufacture, require more components (such as ballasts and starters), and necessitate additional structural components within the fixture.

California is at an impasse where CFLs are an energy conservation necessity, but builders are unfamiliar with the technology, dissatisfied with the lack of performance and amenity, and very concerned about the cost. Residential consumers, the ultimate market for homebuilders, have also failed to embrace CFL technologies due to early failures associated with poor performance and premature failure due to low quality.

1.2. Project Goals and Objectives

The overall goal of this project was to develop a novel, low cost, high performance and high efficiency kitchen lighting system. The fundamental thesis of the project was that CFL downlighting must offer other amenities and advantages in addition to energy savings if consumers/homebuilders are to embrace it. The specific technical and economic objectives of this project were as follows:

- Develop a fully dimmable (10-100%) downlight system with a centralized control architecture serving four to eight compact fluorescent lights (CFLs).
- Develop fixtures for this application that have an efficacy of greater than 50 lumens per watt.
- Develop fixtures that cost 25-50% less to produce and install than current high performance commercial grade CFL downlights.

Kitchen applications were specifically targeted because of the large quantity of incandescent downlights and their significant energy use due to relatively long burn hours. 500 million incandescent downlights are already installed and over 30 million new incandescent downlights are sold in the United States each year.[1] Recessed ceiling downlights in the kitchen and dining areas account for 7.60% of California's residential lighting energy use. Furthermore, kitchen and dining areas account for 25% of lighting energy in California homes, making these spaces the largest lighting energy users in residential spaces.[2]

Even though efficient CFL recessed downlight alternatives are available, CFL downlights are not prolific because they are expensive, not as bright as incandescents, have poor color, lack a broad candlepower distribution and may flicker or hum during operation.

1.3. Report Organization

This report is organized as follows:

Section 1.0	Introduction
Section 2.0	Project Approach
Section 3.0	Project Outcomes
Section 4.0	Field Test Results
Section 5.0	Conclusions and Recommendations

There are no appendices.

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[1] Sardinsky, Hawthorne, Newcomb; E-Source Tech Update on High-Performance CFL Downlights, E News, May 1993.

[2] Heschong, Mahone, Parris, Sugar, Berryman; California Residential Lighting Baseline, Journal of the Illumination Engineering Society, Winter 1998.

2.0 Project Approach

Background Research

Upon initiation of the project, background research in two main areas was begun. This included research into:

- **Existing Products** – Identification, characterization and performance analysis of existing kitchen downlight products.
- **Existing Practice -** Investigation of how are existing products are installed in real world applications.

This information was then used to guide the development of a final prototype kitchen lighting system.

Development Approach

Throughout this development project, many different systems were proposed and even prototyped. The project partners continually evaluated these systems in order to determine how well they balanced energy efficiency, performance, and ease of use with manufacturability and cost. The system described here is the final prototype system developed and the one that most appropriately balances these requirements.

It should be noted that there were several prototype systems that were developed that represented a more "novel" overall approach. Some of these systems presented unique opportunities to reduce installation labor by slightly altering the sequence and processes of the tradesman during installation. Other systems included additional lighting components that enhanced the overall photometric performance of the system. Ultimately these approaches were set aside as it was recognized that the building industry is by and large slow moving, particularly in relation to lighting. A strategic decision was made that a system with several improvements that is familiar and understandable to homebuilders has a greater chance of gaining market share than a novel approach that requires a shift in the accepted lighting paradigm.

3.0 Project Outcomes

This project had the following primary outcomes:

- Developed fixtures with a final efficacy of 50 lumens per watt.
- Reduced fixture costs by over 50%. Comparable high performance commercial grade CFL downlights cost $150-200, while the initial target price for the KLS system is only $50-70.

The objective of developing a fully dimmable downlight system was not realized. This objective was abandoned early in the design phase of the project for the following reasons:

1) It was determined that dimming systems are rarely used in kitchens.
2) Adding dimming capability could as much as double the final product cost of the system.
3) The added cost of dimming was unacceptable to homebuilders.

These factors led to a new approach regarding the ballast in which a standard, off-the-shelf ballast could be utilized in a master-slave arrangement. This approach allowed ballast costs to be greatly reduced while opening a number of options for existing ballast products to choose from. Homebuilders strongly encouraged adoption of an approach in which industry standard ballasts with proven track records for reliability could be used, rather than an approach in which a new customized, proprietary ballast was developed.

The rest of this section details the results of the background research into existing products and current practice, in addition to the findings from the development process for the KLS prototype.

3.1. Existing Products

Nationwide, incandescent downlights are the most popular luminaire choice for residential kitchens. In California this trend is moderated only slightly by Title 24, the energy section of the California Building Code. **Title 24 requires that the primary switch in the kitchen must control an energy efficient fixture.** This code requirement is generally satisfied either by having one CFL downlight controlled by the “primary” switch or with the installation of less expensive fluorescent under-cabinet lighting. In either case, the “secondary” switch still controls, on average, six or more downlights that operate with 65W or 75W R-Lamps. As a result, a typical kitchen—usually the room with the longest number of operating hours in the home—has nearly a half a kilowatt of load but is still compliant with the energy code. There is thus significant potential to reduce energy use in kitchens through the use of more efficient technology.

One of the initial efforts on this project was the photometric characterization of both the existing incandescent and CFL downlight designs. While there are a wide variety of incandescent downlighting products available, these products generally exhibit only minor photometric differences. This is because the main optical element is the reflector lamp itself, which typically sends 90% of its flux out of the fixture without the use of any internal reflections from the fixture. The differences in incandescent downlights are largely aesthetic, with various types of trim rings, baffles, and other design features available. CFL downlights, however, offer much greater photometric variation as the use of different lamps, ballasts, and reflectors all have critical effects on the fixtures output.

To gather data on the various downlighting systems available, a partnership was formed with the Lighting Design Lab (LDL) in Seattle, WA. The LDL assembled a demonstration of existing CFL downlight technologies that included a mock-up of 14 unique CFL downlight models and 2 base-line incandescent downlights. The CFL downlights were of various cost and quality. They ranged in wattages from 9W to 32W and included systems with magnetic ballasts as well as systems with electric ballasts. While few of these CFL downlights were intended primarily for residential applications (they where primarily geared for small commercial uses), LDL's comprehensive collection of downlights presented an intriguing window into the industry. These 16 downlighting systems (shown in Figure 1) were sent to LBNL for photometric characterization where they were measured for candlepower distribution, fixture efficiency, fixture efficacy and fixture lumen output.

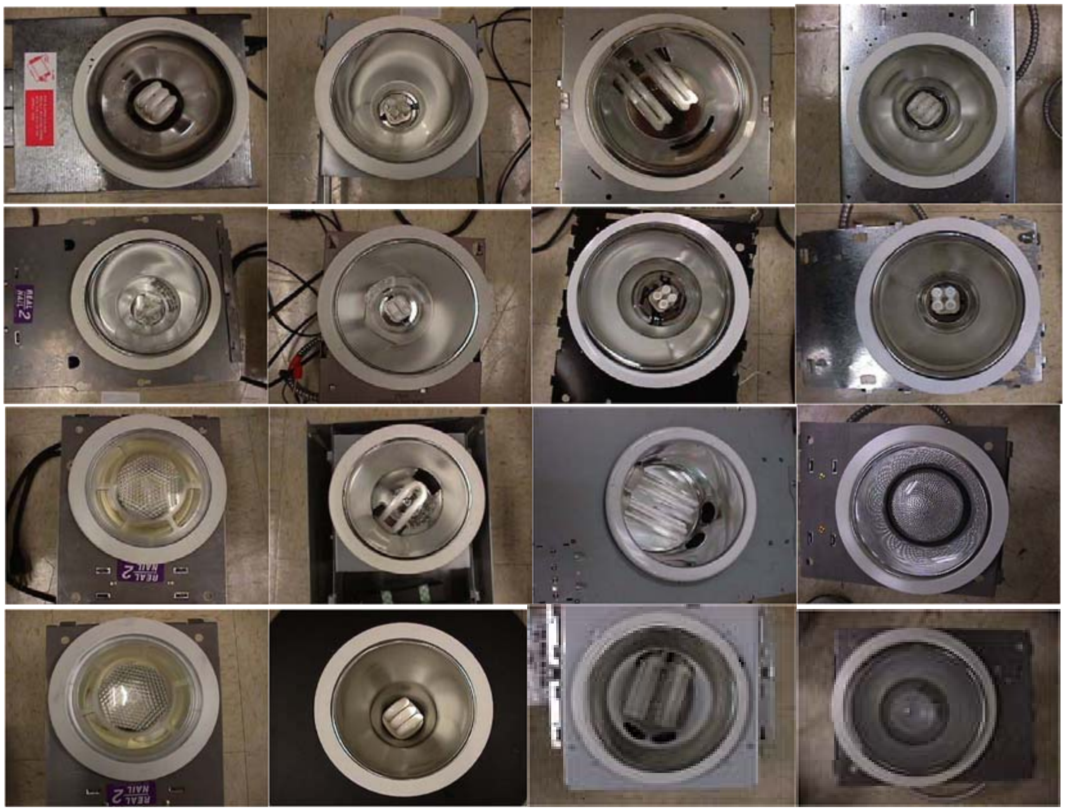

Figure 1. Downlighting Systems Evaluated by LBNL.

Photometric measurements were made using LBNL's gonio-photometer and integrating sphere (see Figure 2). The gonio-photometer measures the candlepower distribution (distributional output) of a fixture, as well as the total lumen output of the fixture. The integrating sphere measures the total lumen output of a light source. The fixture efficiencies of these systems are then calculated by comparing the percentage of the lumens produced by the light source (as measured in the integrating sphere) to that which exits the fixture (as measured in the gonio-photometer).

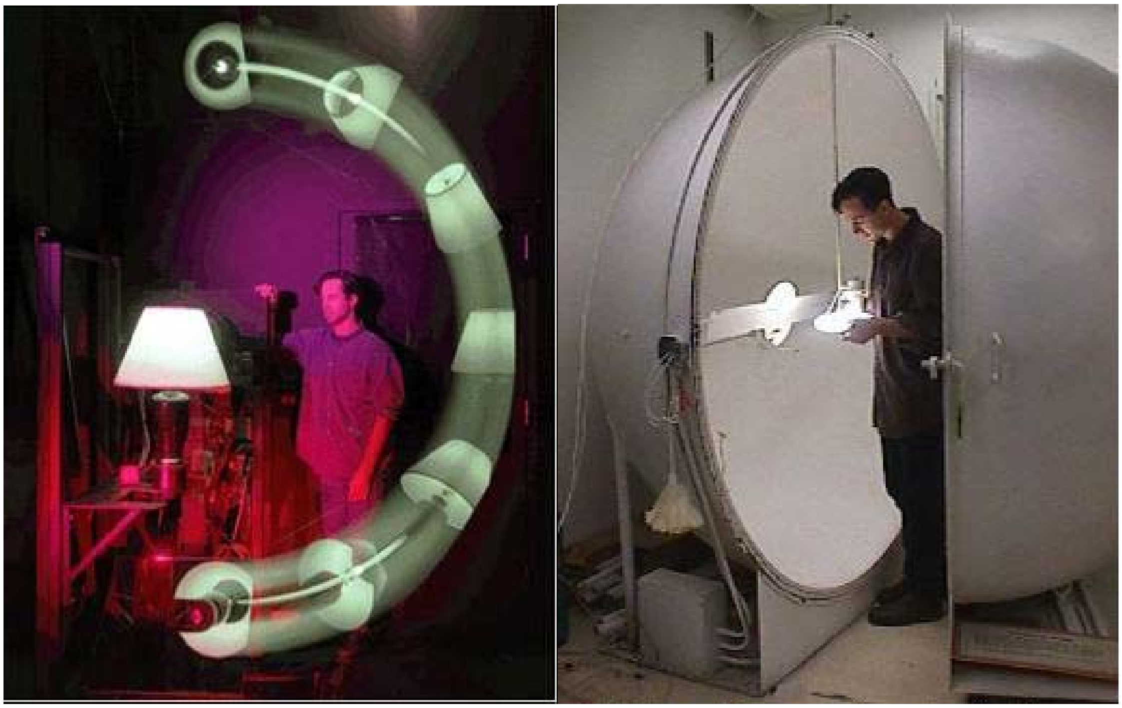

Figure 2. Measuring Candlepower Distribution by The Gonio-Photometer (Left) and Total Lumen Output by The Integrating Sphere (Right)

A striking finding from these photometric studies was the relative poor performance of the CFL downlights as a whole. The fixture efficiencies of the CFL downlights averaged 55% and ranged from as low as 30% to as high as 85% (Figure 3). There was a strong relationship between the cost of the CFL downlighting systems and their fixture efficiencies. The cheaper systems, which are the systems more likely to be used in residential applications, often contained inferior reflector optics. Some of the worst performers contained no optical elements at all and appeared to be housings originally intended for incandescent reflector lamps that had been refit for a ballast and CFL socket. The best performers of this group were clearly commercial grade systems that would be well over the price points required by residential homebuilders.

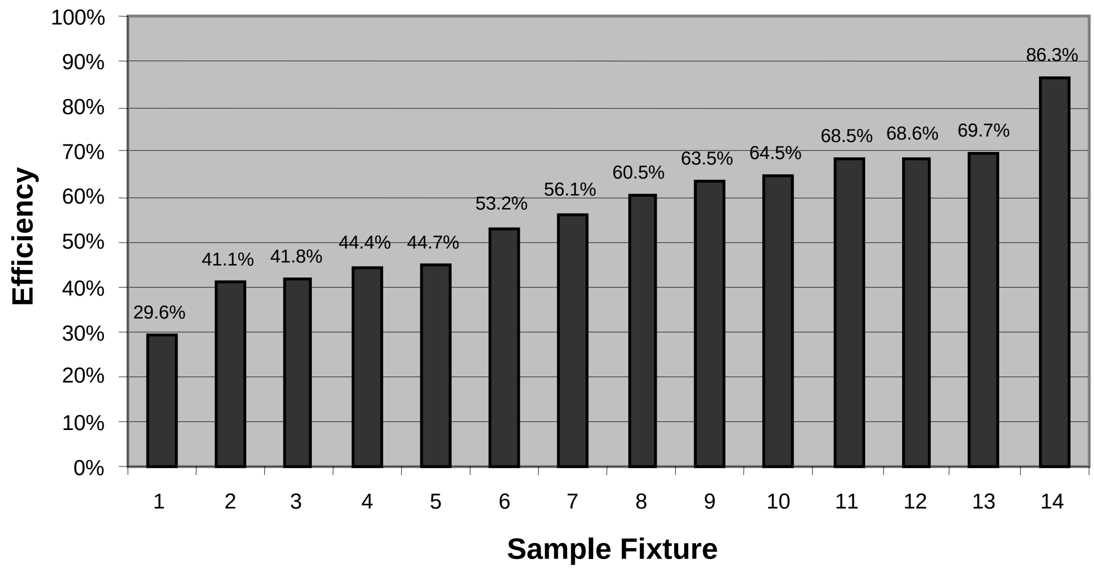

Figure 3. Distribution of CFL Downlight Efficiencies

An interesting observation from the tests was that in some cases the incandescent systems were actually more efficient than the "efficient" CFL systems. Table 1 demonstrates that a CFL system that has a source efficacy of 60 lm/W and a fixture efficiency of 30% yields a fixture efficacy of only 18 lm/W, while the incandescent counterpart might have a source efficacy of 20 lm/W and a fixture efficiency of 95% (both reasonable values for many halogen downlight systems) for an overall fixture efficacy of 19 lm/W.

Table 1. Worst Case Fixture Efficacy Comparison of CFL and Incandescent Downlighting Systems

	CFL	Incandescent
Source Efficacy	60 lm/W	20 lm/W
Fixture Efficacy	30%	95%
Fixture Efficacy	18 lm/W	19 lm/W

In addition to the laboratory photometric studies, in-situ photometric data was also measured in a model home. This was a model considered to have a very typical layout utilizing six 75W R-Lamp downlights and one 13W CFL downlight (See Figure 4).

Figure 4. A Representative Model Kitchen Chosen For In-Situ Photometric Characterization Of The Baseline (Incandescent) Condition

Illuminance distributions were gathered for this model kitchen by collecting a grid of light readings from all vertical and horizontal surfaces in the room. Daylighting components were blocked off for these measurements so that the illuminance distributions represented only the electrical lighting effect.

Figure 5 and Figure 6 present the illuminance distributions of the horizontal work plane (countertops) and vertical plane (cabinet faces) respectively. The most striking result from these tests is that overall, in nearly all vertical and horizontal areas, the illuminances were extremely low. Typically, in areas where detailed work is performed, illuminance should be maintained above 50 foot-candles (FC). Field measurements yielded a maximum horizontal illuminance of 32 FC and maximum vertical foot-candles of 20 FC. These readings suggest that, even though there are many downlight fixtures and a combined load of nearly ½ kW in the kitchen, the lighting levels are still quite poor. It was further observed that due to the relatively tight directional distributions from the downlights, vertical illuminances dropped significantly inside the kitchen cabinets. Readings of less than 1 FC were typical in the middle or back of the kitchen cabinets. At these levels it would be very difficult to identify items inside these cabinets.

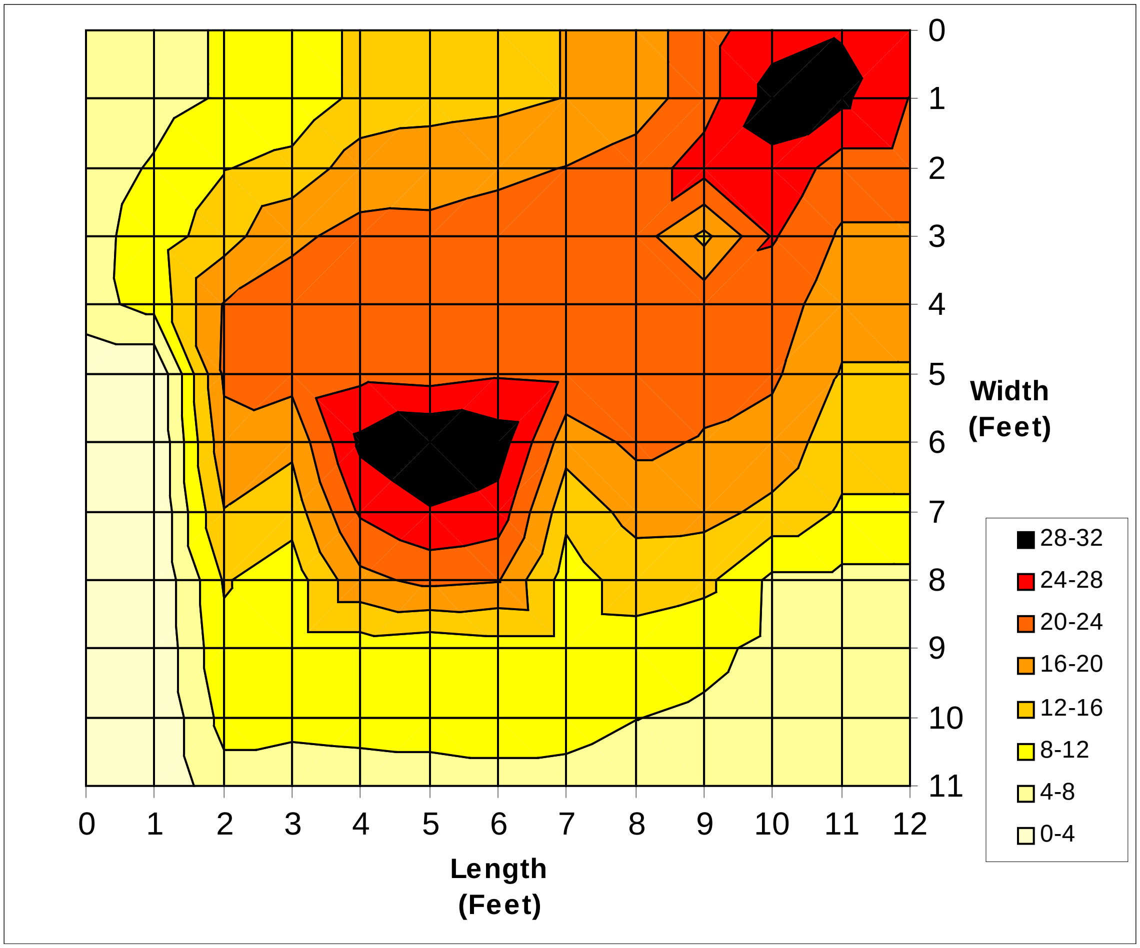

Figure 5. Horizontal Illuminance Distribution of Downlight on (Foot-Candles)

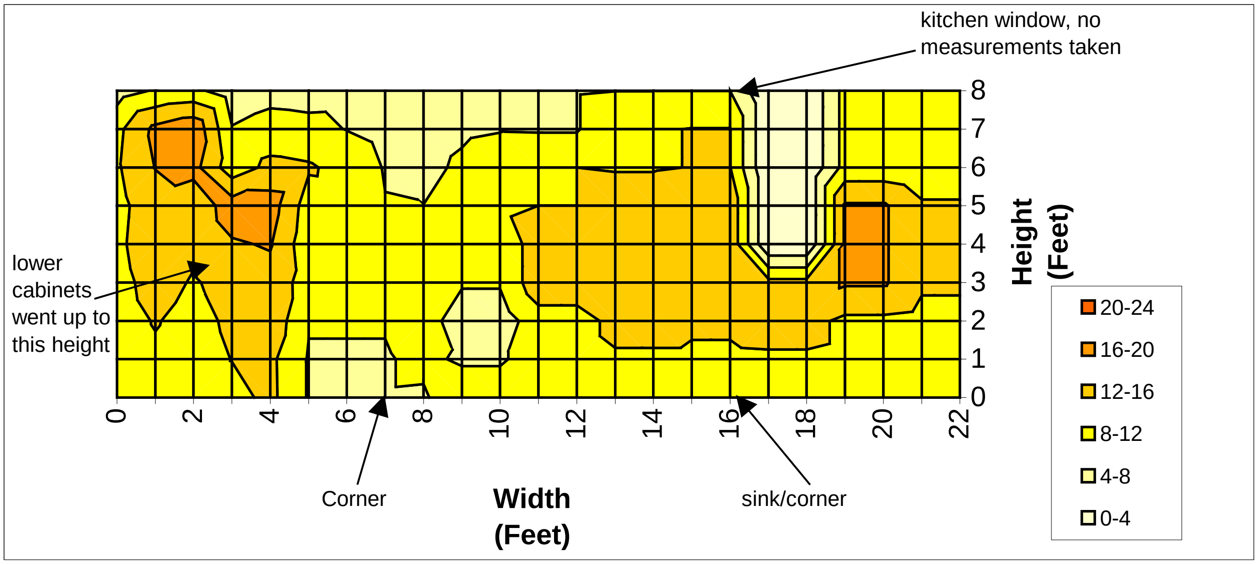

Figure 6. Vertical Work Plane Illuminance Distribution; All Three Walls Wrapped Around (Foot Candles)

3.2. Existing Practice

A significant effort was undertaken in the early phases of this project to identify and analyze the existing methods and practice in the installation of downlighting in kitchens. This effort included numerous interviews with builder executives, purchasing agents, housing sales people, interior designers, building superintendents, energy code consultants, general contractors, electricians, architects, utility representatives, and sheetrockers. These interviews sought the answers to the "how, what, why" of current practice for the installation of downlighting. These interviews also aimed to query the involved parties on what they would like to see in kitchen downlighting (or kitchen lighting more broadly) that is not currently satisfied by the products available today.

In addition to these interviews, many building sites were visited to observe the installation process for kitchen downlighting. Figure 7 illustrates the typical installation process for kitchen downlighting as observed at one site. This process consists of the ceiling service being wired (top left), the individual downlight housings being nailed to the ceiling joists (top right), followed by the downlights being wired together (middle left). Next the sheetrock is nailed up, holes are cut at the downlight locations and the seams and gaps in the sheetrock are taped and matted (middle right and bottom left). Finally the ceiling is painted and the finish electrical work is done, which includes the installation of the lamps and any other ceiling lighting fixtures (bottom right).

Figure 7. Typical Installation Process For Kitchen Downlighting

The follow is a summary of observations made based on the interviews with the homebuilder and site visits.

- The downlight installation process is multi-trade in nature involving electricians, sheetrockers, painters, insulation blowers and other tradespeople.
- The complicated and involved downlight installation process is error prone, as holes for downlights are often miscut or misaligned.
- Because of the above, there is a large labor savings potential in the downlight installation process.

- The downlights that are being installed (both incandescent and fluorescent) in new homes are generally the least expensive fixtures available.
- All CFL fixtures use magnetic ballasts.
- Consumers "usually replace" the installed CFL fixtures.
- 1/4 of kitchen lighting cost is due to Title 24 compliance.
- Homebuilders have major concerns about the amount of flux from CFL downlights.
- Homebuilders have major concerns about the quality of light from CFL downlights (hum, flicker, color, interference, etc.).
- Downlights are popular because of their clean look, flexibility, and consumer perceptions of a "quality" lighting system.
- There is strong support for a "system approach" that addresses the flux and the quality issues while satisfying Title 24 – even if it costs more.

3.2.1. Consol Drawings

In order to better understand the design application of downlighting systems, a broad review of construction drawings of new residential homes was undertaken. This review was undertaken with the cooperation of Consol, Inc, which reviews building plans from builders across California for Title 24 compliance. Consol made available hundreds of drawings for developments statewide that were currently under review. These drawings were then studied to identify the total number of downlights in the house as well as the number of downlights in the kitchen. Where available, information on the downlight layout patterns was analyzed. Figure 8 presents a summary of data gathered from these drawings. The figure shows that kitchens typically account for about 1/3 of the house's total number of downlights, or on average about 8 of the house's 24 total downlights.

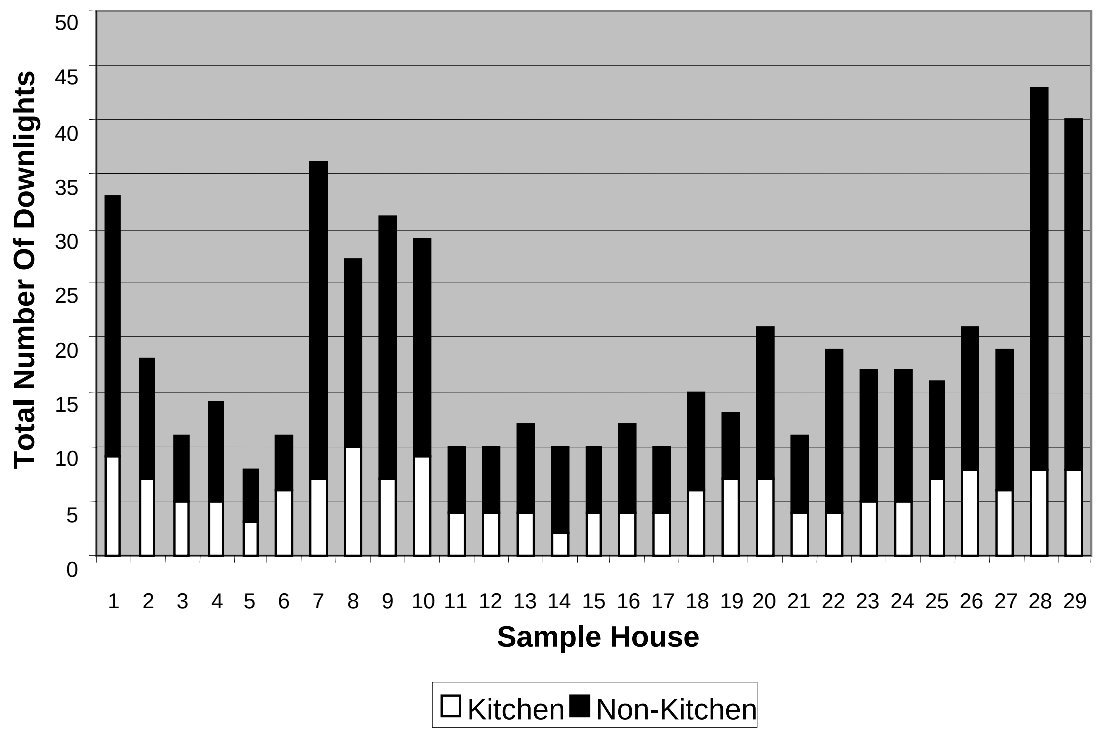

Figure 8. Kitchen vs. Non-Kitchen Downlights in California

The Consol data also showed that, not surprisingly, as the size of the homes increase, so does the number of downlights, as shown in Figure 9. This is an important point as the trend in new construction has been towards increasingly larger new homes.

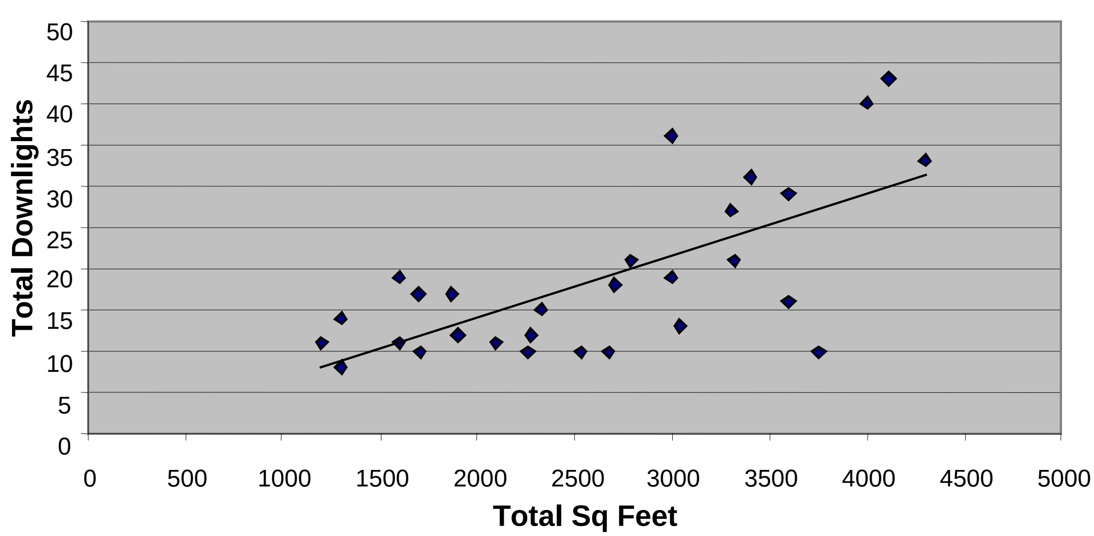

Figure 9. Total Downlights Vs Total Sq. Feet

3.2.2. RLW survey

Independent from this project, RLW Analytics conducted a study of selected lighting information based on on-site surveys of over 1250 California homes between December 1999 and March 2000. This work was performed under a contract with SMUD, PG&E, SCE and SDG&E. Prior to RLW Analytics' field work (and the initiation of this PIER project), LBNL and project partner NRDC worked with RLW Analytics to shape the type of data that was collected during their study. LBNL and NRDC were able to add many questions to this survey related to energy efficiency, downlighting, and kitchen lighting. This information, and the ability to selectively query this database, provided very useful information about existing practice and the market for kitchen lighting systems.

One of the important findings from this survey was that dimming was rarely available in existing kitchens. Only 6% of these 1250 homes had dimming capabilities. This finding, combined with feedback that builders would not accept additional cost for dimming, ultimately allowed the design team for this project to view dimming as an option rather than a requirement. This represented a significant shift in design criteria with important technical and economic repercussions.

Another important finding from the RLW data was the relative number of downlights in homes as a function of home age and remodel status. Newer homes were found to have much higher numbers of downlights. Additionally, homes that had been remodeled within the last ten years were found to have significantly more downlights than non-remodeled models of the same age (see Figure 10).

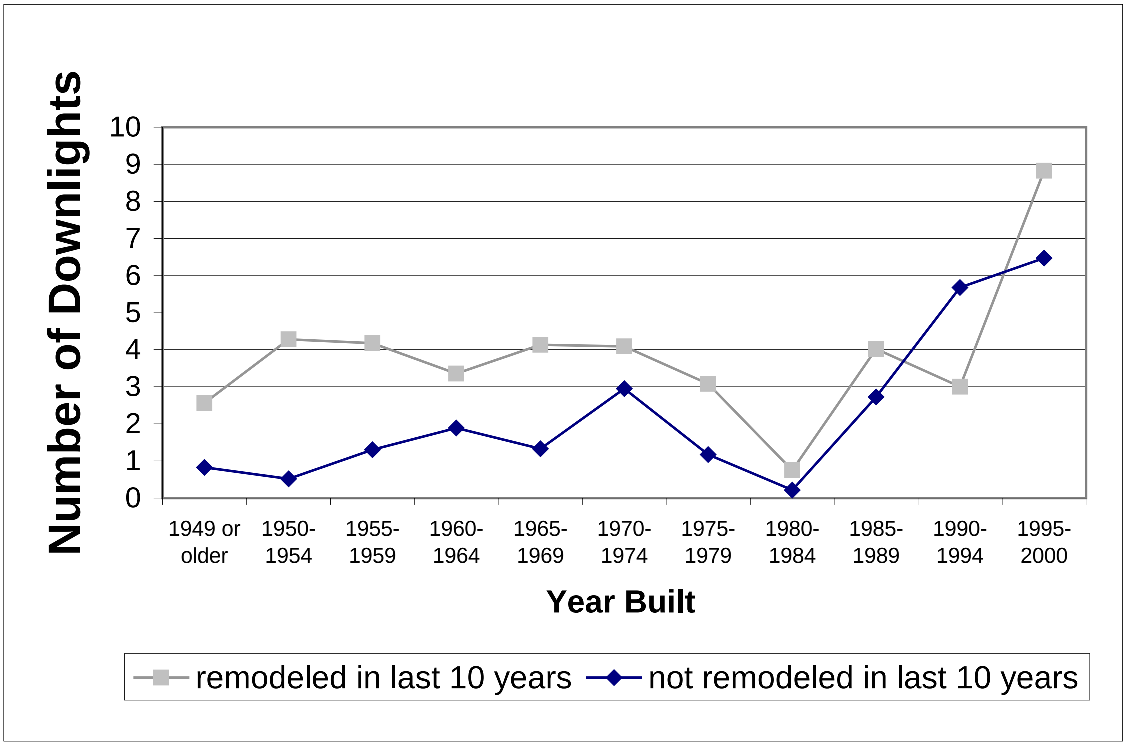

Figure 10. Number Of Downlights Per House By House Age

New homes (1980 and newer) contain many more downlights than older homes. Homes that have been remodeled (dark line) contain more downlights than homes that have not (light line).

Further data on remodeling found that:

- Kitchen remodels are the most common household renovations.
- Downlights are highly popular retrofits in kitchen remodels.

Kitchen Lighting System Overview

The final prototype kitchen lighting system (KLS) is shown in Figure 11. It consists of a master-slave fixture system in which the ballasts for the entire system are all present at a central location. This central location is thermally optimized to maintain the ballasts within acceptable ranges throughout their operation, in order to prevent premature failures. Plug and play wiring and simplified components are included in the system in order to facilitate a "builder-friendly" installation process. These features allow builders to install the system in a faster and less error prone manner than is possible with traditional systems. Finally, the system features many high quality components, such as 26W tri-phosphor triple tube CFLs, rapid start electronic ballasts and high-efficiency, low-glare reflector optics, all of which contribute favorably to the overall system performance.

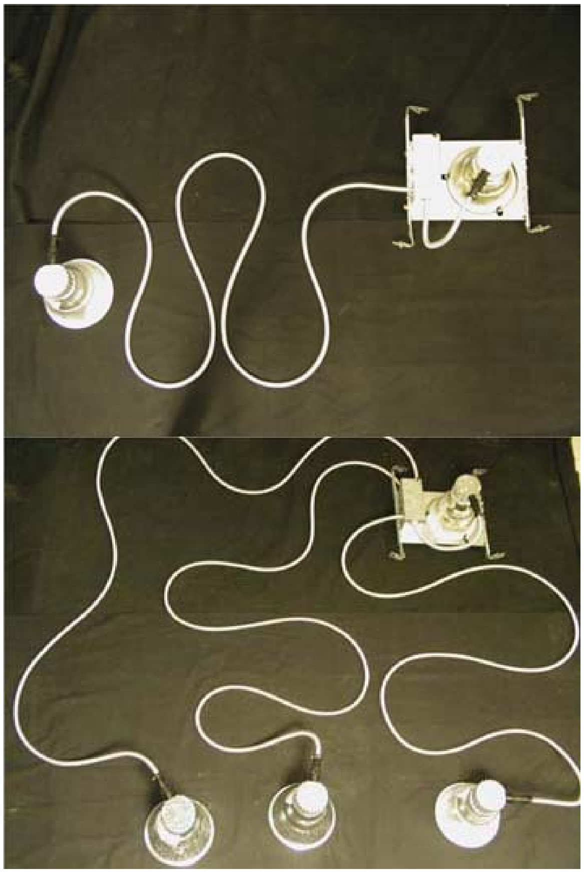

Figure 11. 2-Headed System (Left) and 4-Headed System (Right) Kitchen Lighting Systems.

There are two main factors that allow the KLS system to be cost competitive with traditional downlight systems even while providing a higher level of performance. The first is that the KLS utilize a "system approach" in that it is specifically designed for operation as a multiple downlighting head system. This allows for the cost-sharing of many components that otherwise would be too expensive to include in a single, stand-alone downlight. For example, the thermal management materials might be too expensive to include on every downlight head, but because of the centralized ballast in the KLS, the materials only need to be placed at one location. This effectively spreads the cost of these materials across all of the downlight heads in the system. The second key factor that benefits the cost evaluation of the KLS is the reduction in installation costs. Builders have indicated that 50% of the cost of installing downlighting systems is from labor. As their cost concerns are related to the "bottom line" costs of the system (materials + labor), the reduced labor requirements of the KLS can help afford incremental material cost increases.

3.3. Key Features

The key features of the KLS are discussed below in more detail:

- Thermally Enhanced Ballast Configuration

- Master-Slave Ballast Geometry
- Plug And Play Wire Connections
- Simplified Housing And Reduced Components
- Institutionally Transparent/ Builder Friendly
- Improved Maintenance
- High Performance Optics
- High Quality CFL
- High Quality Ballast

3.3.1. Thermally Enhanced Ballast Configuration

Thermal management of the electronic ballast for CFL downlights is critical. While incandescent downlights experience no problem in operating in super-heated environments, CFL downlights can have greatly shortened lives. The KLS "master" downlight locations have been thermally optimized to operate the ballast according to the manufacturer's guidelines. This includes situations in which the ballasts are operated for long periods of time while buried in ceiling insulation and/or placed in an extremely hot attic environment. This is achieved by thermally connecting the metallic casing of the ballast to the main metallic housing for the downlight pan itself (See Figure 12). The pan serves as a heat sink that siphons the heat off of the ballasts and spreads it across the pan housing. The thermal interaction between the pan and the sheetrock through conduction and/or convection transfers the heat from the pan to the sheetrock and finally into the kitchen. Because the attic may actually be hotter than the pan and/or the pan might be buried in insulation, the system was not designed to transfer into the attic or ceiling environment.

While the amount of heat transferred is significant terms of allowing the ballast to achieve sustained operation in an environment in which it would otherwise overheat, it has a negligible effect on the overall temperature of the room. The heat transferred for the ballast cooling for a 4-headed system (2 ballasts) is approximately 10W. By comparison, approximately 95% of an incandescent lamps power is transferred directly into heat. Thus, a comparable 4-headed incandescent system with 75W R-lamps would bring 285W of heat into the room.

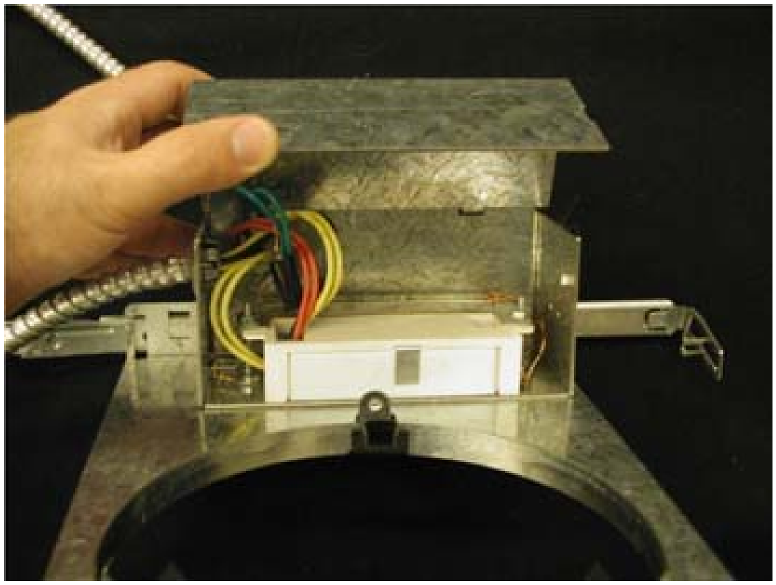

Figure 12. : The Ballasts Are Thermally Connected To The Fixture Pan For Optimized Heat Transfer.

3.3.2. Master-Slave Ballast Geometry

The master-slave geometry has several inherent advantages. The principle advantage of this approach is that it reduces material and installation costs in several key areas. The primary material cost for CFL downlighting is the electronic ballast. The master-slave geometry essentially cuts the ballast costs in half as two one-lamp ballasts (for the conventional approach) are replaced by one two-lamp ballast. Since the cost of two-lamp and one-lamp ballasts are essentially the same, this is a significant advantage.

The labor savings garnered by the master-slave geometry are also critically important. Perhaps the most time consuming step in the installation of downlights is the wiring at the junction box of the fixture. The master-slave geometry cuts the number of hardwire connections in half in 2-headed systems and by 75% in 4-headed systems.

3.3.3. Plug And Play Wire Connections

The electrical connections at the "slave" fixture are made with a plug and play connection (Figure 13). This flexible and removable connection significantly simplifies the wiring to the slave fixture. In addition to the labor savings that this offers, there are inherent safety benefits associated with the plug and play connections. The unidirectional connectors only allow the electrical connections between the ballast and the lamps to occur in the proper configuration. This reduces the likelihood of shorting, loose wire nuts, etc that can occur in standard hand-wired fixtures.

Figure 13. The KLS Plug And Play Connectors (Left) Offer More Simplified Electrical Connections Than Standard Hand Wired Fixtures (Right)

3.3.4. Simplified Housing And Reduced Components

The materials and part counts of the KLS are reduced from those of both incandescent and typical CFL downlighting systems (Figure 14). These reductions should lead to associated reductions the cost of the downlighting system.

Some of these parts reductions result from the "system approach" of the KLS, in which certain components can be shared as opposed to being present at each location. Other reductions are related to the unique thermal design of the KLS system. One significant reduction is the elimination of the "secondary can" that is present in most downlighting systems. Fire codes require that the hottest point on the outer surface of a downlight be below 90 C. Because of heat build-up produced by incandescent sources and most CFL sources and ballasts, this requirement is generally satisfied by utilizing an additional outer housing that insulates the outer jacket of the fixture from the hotter points inside. This housing contributes significantly to the overall cost of the fixture and accounts for approximately half of its weight. Because of the unique thermal management of the KLS system, even under the harshest conditions, the outer surfaces never approach 90 C. This allows for the elimination of the additional outer housing and its associated cost and weight.

Figure 14. The KLS Employs A Housing Design That Reduces The Fixtures Overall Cost And Weight.

3.3.5. Institutionally Transparent/ Builder Friendly

The installation of the KLS follows the same process that builders are familiar with. Certain steps have been made easier (such as replacing some hard-wired connections with plug and play connections) but the basic steps and sequence of installation have been maintained (Figure 15). Prior designs of the KLS involved more radical approaches that attempted to reap even greater labor savings by altering the sequence and/or task of the various trades-people. With significant guidance from the builders, it was determined that these approaches were not immediately practical because they required a significant level of training and/or reorganization. It was determined that a system that was "institutionally transparent" to builders would have a greater likelihood of being quickly accepted by the market.

Figure 15. The Installation Process Of The KLS Closely Matches The Process That Builders Currently Utilize For Traditional Downlight Systems.

3.3.6. Improved Maintenance

There are several features of the KLS that should improve the maintenance of the overall system. Foremost are those related to the ballasts. The ballasts are accessible and replaceable from the room side by the simple removal of the reflector (Figure 16). Many CFL downlight designs utilize ballast placements that require ceiling-side access for replacement. While this design may be appropriate for commercial settings, it has obvious drawbacks in residential settings. In certain applications where ceiling-side access is not possible (i.e., 2-story homes) replacing these ballasts may actually require cutting (then patching) the sheetrock to gain access. Because of the thermal management techniques utilized by the KLS, the frequency of ballast replacement should be much less than that of CFL systems that allow ballasts to reach elevated temperatures. Finally, because the KLS uses 2-lamp ballasts, there are half as many ballasts to maintain in the first place.

In addition to the ballast issues, the flexibility of the KLS offers other maintenance advantages. The plug and play design allows for the systems optical head to be easily unplugged and replaced should the head become damaged. The flexible fixture whips also should allow for easier relocation should a later remodel require a change in the fixture layout.

Figure 16. The KLS Ballasts Should Rarely Need Replacement, But When They Do, The Ballast Can Be Easily Accessed From Below.

3.3.7. High Performance Optics

The reflector optics for the KLS are based on existing Lithonia (the manufacturing partner for this project) commercial grade CFL products that maximize output while minimizing glare (Figure 17). The optics have been modified slightly to conform to the tighter vertical space limitations present in residential applications which require the overall fixture height to be less than 8 inches. The reflector's specular finish eliminates high angle glare while providing for an overall fixture efficiency of nearly 75%, which is significantly higher than most commercial and residential CFL downlight systems. This high fixture efficiency yields a total light output that is equal or greater to incandescent downlighting systems. More information on this topic is presented below in section titled Photometric and Electrical Performance of the System.

Figure 17. **The KLS Utilizes A High Quality Specular Reflector Optic That Maximizes Light Output While Minimizing Glare.**

3.3.8. High Quality CFL

The CFLs included with the KLS are high quality, high output lamps. The 26W triple tube, pin-based lamps (Figure 18) have an output that exceeds that of 75W R-lamps. They are available in a wide variety of color temperatures and have a CRI (color rendering index) in excess of 82, making them appropriate for kitchen applications that may require a high level of color recognition (incandescent CRI = 100). The 26W triple lamps are available with amalgam technology which allows maximum light output at the elevated temperatures common in downlights. In addition to their technical benefits, the 26W triple lamps were selected for the KLS because of their relative low cost and wide availability in the market (the 26W triple lamps is available from many different manufacturers, including all of the "Big 3" - General Electric, Sylvania, and Philips).

Figure 18. The 26W Triple Tube Lamp Offers A Large Lumen Package And Good Color Quality.

3.3.9. High Quality Ballast

It is critical that the ballast for the KLS is robust and reliable. The residential marketplace has been stained by premature ballast failures from cheap and/or inappropriately applied ballast technology in the past. The ballast chosen for the KLS (Figure 19) is produced by Advanced Transformer, one of the largest and most respected ballast companies. This ballast is approved for residential applications (FCC Class B). It features a quick startup characteristic, firing after 0.7 seconds (vs. 1.4 seconds for typical rapid start electronic ballasts and 1–3 seconds for rapid start magnetic ballasts). It is possible to include a high quality and more expensive ballast such as this on the KLS largely because of the cost savings that is generated by using 2-lamp ballasts.

Thermal issues were critical in the selection of the ballast. Advance Transformer's engineers worked closely with LBNL and Lithonia to confirm that the ballast would function within its guidelines for real-world downlight applications. One important feature of the ballast that allows it to achieve this is thermally connecting critical ballast components to a metal ballast case. This metal case is then thermally connected to the downlight housing allowing for efficient heat flow away from the sensitive ballast components.

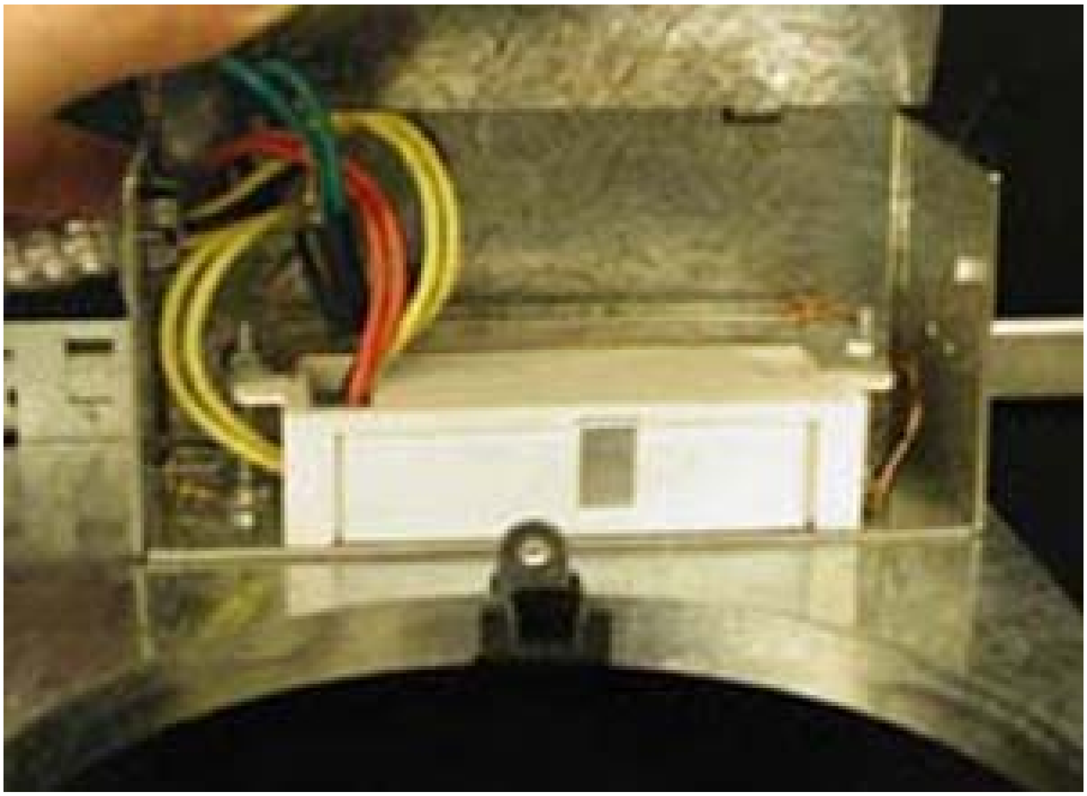

Figure 19. The KLS Utilizes A High-Quality Ballast That Should Be A Robust Performer In Harsh Thermal Environments.

3.4. Thermal Performance Of The System

As discussed above, thermal issues have traditionally been a critical barrier preventing the integration of high quality, efficient ballast systems into residential downlighting. In these applications, it is common on a hot summer day for the sun to beat down on the roof of a home for approximately twelve hours per day. Some of this heat is transferred through the roof and into the attic space. As the insulation that lines the ceiling prevents the heat from leaking into the home, this heat becomes trapped in the attic space. Ballasts also generate heat of their own during operation. Through background research, interviews with industry experts and laboratory testing, we concluded that the ambient attic temperature could be as much as 160°F. Certain components of the highly efficient electronic ballast are sensitive to high temperatures. As such, placement of electronic ballasts in the attic is a combination of formidable obstacles. (Downlights placed on the ground floor of multi-story houses have considerably fewer thermal issues because the heat from the attic and the ceiling insulation is not present. The KLS was designed, however, for the "worst case scenario" of the single story home.)

The problems described above have, until now, not been fully addressed. High temperature can actually be beneficial to the brightness of the cheaper incandescent bulbs. Among consumers who have transitioned into the more efficient compact fluorescent systems, older magnetic ballasts are common. Magnetic ballasts are not nearly as sensitive as electronic ballasts to thermal issues, but they offer a lower efficiency and lighting quality as compared to electronics. The newest "resolution" has been to use low-power lamps driven by electronic ballast; usually these lamps are equal to or less than thirteen watts to minimize the heat build up on the ballast's sensitive components. Using lamps of higher wattage significantly decreases the longevity of the ballast.

The KLS offers an industry-first solution. Utilizing a ballast with a metal jacket that is connected to bottom surface of the fixture which is in-turn thermally connected to the ceiling allows for efficient heat transfer and a more effective method of cooling (see Figure 20). By mounting the critical point of the ballast (a point identified by the ballast manufacturer as the most thermally sensitive) to a metal plate of significant surface area, placing the plate in close proximity to the attic side of the ceiling and providing a covering of insulation, we not only increase heat transfer away from the component, but give it a direction.

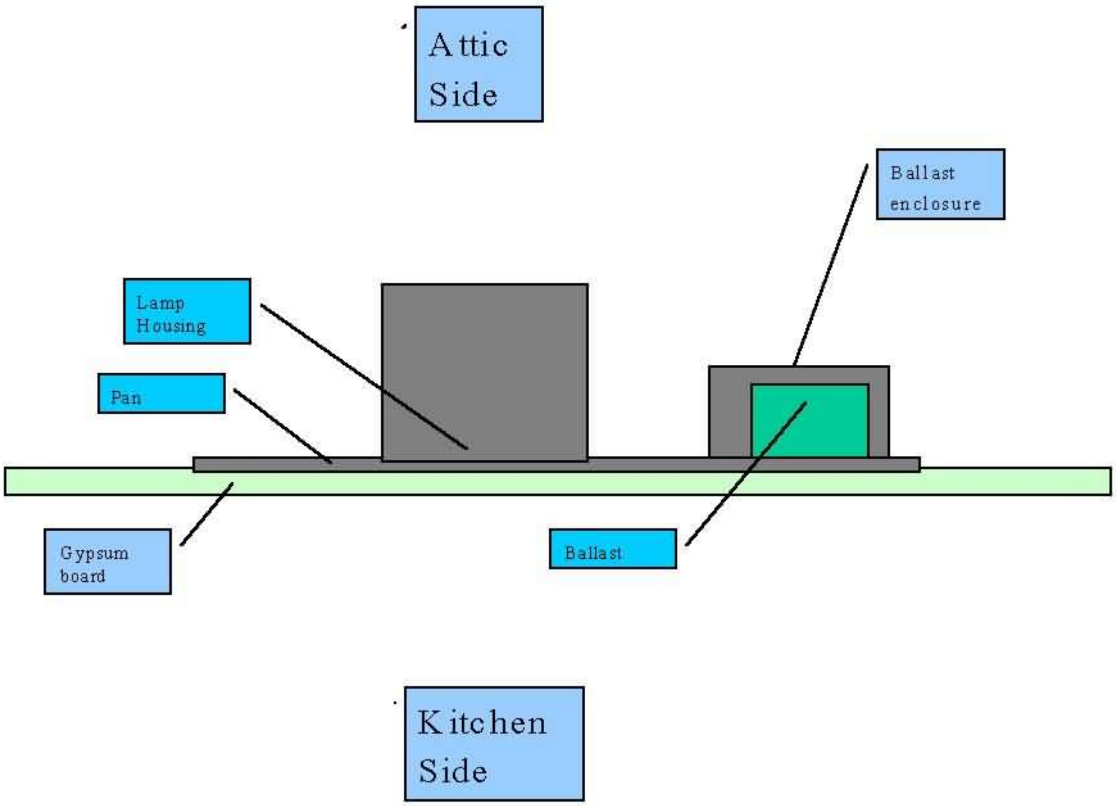

Figure 20. Schematic Of Thermal Elements Of KLS System

In order to test the KLS in harsh thermal environments, a ceiling-attic mockup was created (see Figure 21) in which ambient temperatures in excess of 160 F could be simulated. The thermal testing apparatus consisted of the "attic" chamber capable of holding the temperature at this elevated temperature, a mounting area for the KLS and ceiling panel, and an area underneath the ceiling panel that was held at room temperature. The thermal testing apparatus included a 200-watt tungsten filament A-lamp that was used as a resistive heat source to heat the "attic" space about the test subject.

Figure 21. The Thermal Testing Apparatus Used To Heat The "Attic" Space About The Test Subject.

During testing, temperature readings at several critical areas (including on the ballast, the exterior of the test fixture, the ceiling panel, and several air locations) were continuously monitored. Thermistors exposed to radiant energy from the heating element were shielded with aluminum foil or thin aluminum sheeting to prevent data corruption. Thermistors, in conjunction with a custom designed LabView-5.1 application, monitored and plotted temperatures, collecting data ever six seconds. A relatively thin layer of silicone thermal compound (0.60 watts/meter-K) was placed on the critical point of the ballast to provide a negligible temperature gradient between the critical point and the thermistors. The device was set beneath 9" of fiberglass insulation batting (R-30) in one set of tests and test with no insulation in another set. This variable was tested due to the possibility of incorrect field installation (i.e. no attic insulation). The insulation should serve both as a protective barrier from high attic temperatures and help as a way to direct heat flow through the sheetrock; the sheetrock provides less resistance to heat flow than does air. A piece of sheetrock, approximately 16"x 24", was used as the ceiling in this set of experiments. (See Schematic Figure 22.)

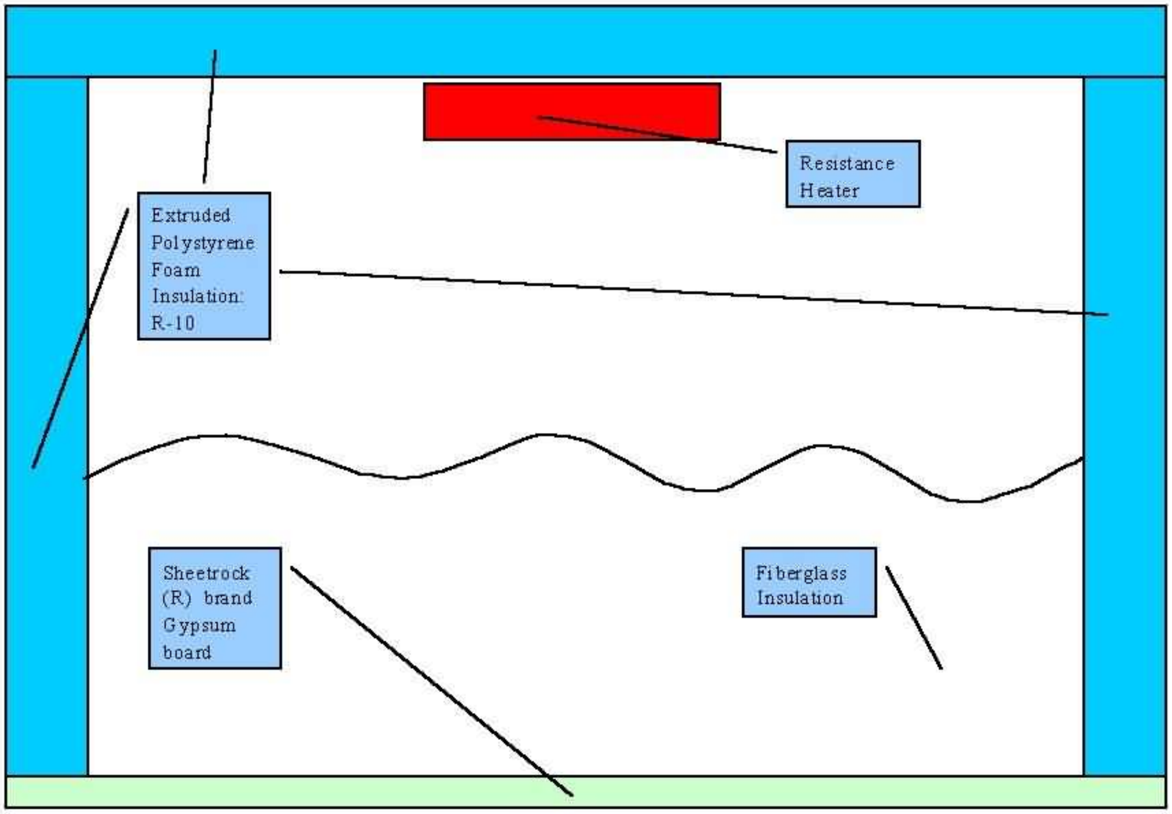

Figure 22. Schematic Drawing Of Thermal Test Apparatus

The first series of experiments involved placing the KLS fixture in good thermal contact with the sheetrock. The ambient temperature was controlled to 72°F ±2°F while the simulated attic space was held above 160°F. Thermistors were placed at pre-specified points prior to placing the apparatus in its operational orientation. The device and sheetrock were then shrouded with the fiberglass insulation. The space was sealed and preheated prior to striking the lamps. (Figure 23) Once the interior temperature was within five percent of the selected temperature the lamps were struck and documentation of the temperature begun.

Figure 23. The Thermal Testing Apparatus During Experimentation

The orientation of the device and the insulation were the only variable aspects of the experiment. To simulate conditions and perturbations that might occur in field implementation or manufacturing anomalies, we chose to change the height of the air layer between the device and sheetrock.

Following the analysis of the preliminary experiments mentioned earlier, it was realized that the duration should be determined in terms of temperature-time slopes to closely approximate equilibrium temperatures. An average slope of 1/500 was deemed adequate; this translates to two degrees Celsius per one and two-thirds hours. It was also decided that each experiment would need to be performed ten times each to reduce the possibility of corrupted data. The arithmetic mean temperatures on the critical point of the ballast in all tests conducted in each class are shown in Table 2 below.

Table 2. Overall Results Of Ballast Critical Point Temperature From KLS Thermal Testing

	With Insulation	Without Insulation
In Direct Contact	48° C	63° C
4/10” Air Layer	53° C	71° C

The Advance ballasts utilized on the KLS prototypes have a 3-year warrantee if critical point temperatures are maintained under 85°C and a 5-year warrantee if critical point temperatures are maintained under 75°C. Given this, the results above indicate that in an attic with standard insulation, the KLS performs exceedingly well. With the correct installation, the systems operated 27°C under the maximum temperature allowed by the 5-year warranty. It should be noted that this is the component's performance under the most extreme of conditions.

In non-insulated ceilings with heated attic spaces, the device did not perform as well as expected. When installed properly, the apparatus without the benefits of insulation, operated under the maximum allowable temperature by 15°C. If the apparatus was installed improperly as well, this figure would decrease to 4°C, and the ballast would be in jeopardy of breaching the first tier of its warranty. Again, it should be stressed that these are worst case conditions that should never really exist in practice. Non-insulated ceilings on lower floors of multi-story buildings will not have heated attic spaces while insulation should always be present in single story structures that do have attics with elevated temperatures. Even so, the KLS contained ballast temperatures within the manufacturer’s guidelines in these worst case scenario experiments.

Further tests should be performed over the long-term and in real-world field test applications, in order to measure the ballast reaction to conditions common to attic spaces. Tests should also be performed in which temperature and insulation type, thickness, and thermal resistance vary.

Overall, the KLS thermal management has shown excellent potential. These tests suggest that the KLS should expect to achieve long service operation from its electronic ballast package. If these findings prove to be true, then one of the most important technical barriers to residential CFL downlighting will have been addressed.

Photometric and Electrical Performance of the System

LBNL and Lithonia both performed photometric and electrical characterization of the KLS at their respective testing facilities. The test results were largely consistent and are summarized in Table 3 . These results indicated that the KLS optical heads achieved a fixture efficiency of nearly 75% while producing over 1300 lumens. At 1341 initial fixture lumens, the KLS system output is greater than that which can be expected from a 65 W R-Lamp downlight (1050 lumens) or a 75W R-Lamp downlight (1200 lumens). This significant result will likely have a beneficial effect on end-user perceptions of the brightness and overall lighting quality of the system.

Table 3. Photometric And Electrical Test Results For One KLS Fixture

Characteristic	Value
Power (Watts):	26.8
Lamp (Lumens):	1800
Fixture (Lumens)	1341
Fixture Efficacy (Lm/W)	50.04
Fixture Efficiency (%):	74.5%

The gonio-photometric characterization of the KLS yielded the candlepower plot that is presented in Figure 24. This plot shows that the distribution from the downlights yields fairly uniform light spread with a share cut-off (for glare mitigation) at angles above 45°. This distribution is typical of a well-designed downlight optic.

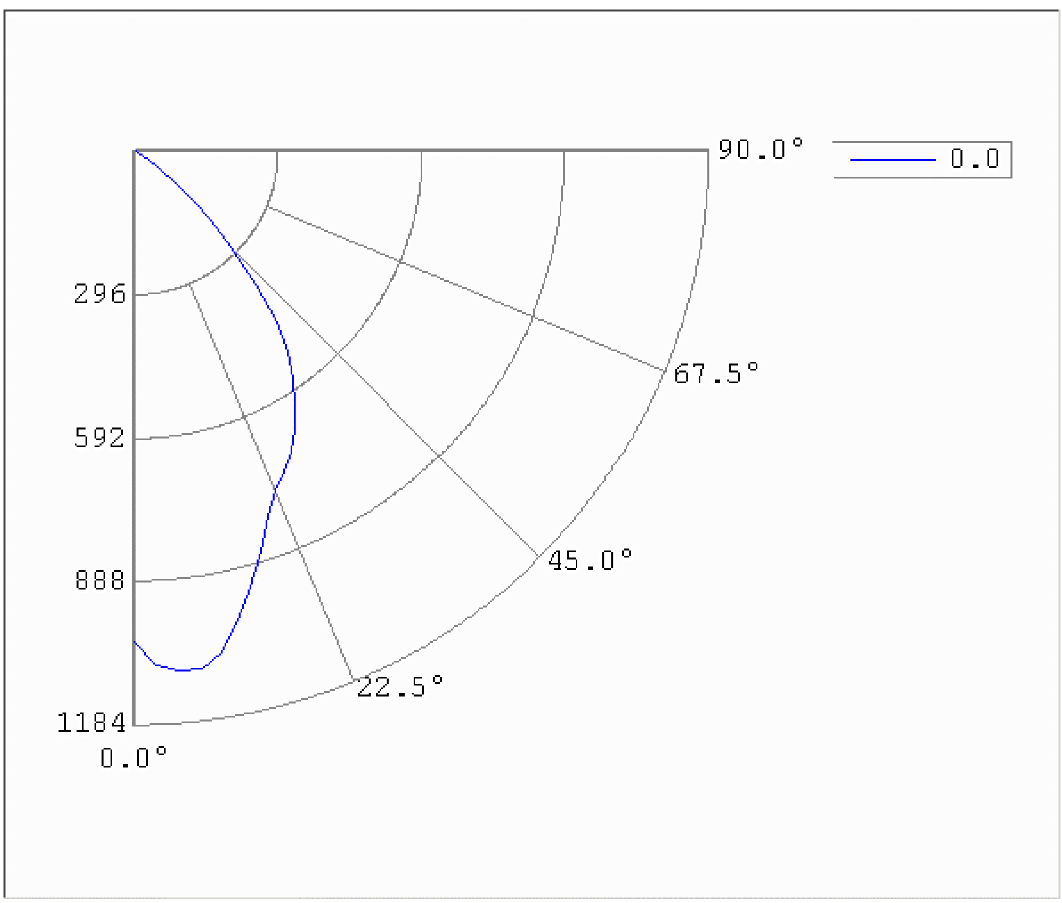

Figure 24. Candlepower Plot Of The Kitchen Lighting System

It is anticipated that, in application, the illuminance levels provided by this system will be higher than those of incandescent systems or of 13W CFL downlight systems. This follows directly from the fact that KLS produces significantly more total lumens than the alternative downlight systems. A homebuilder may decide to maintain their existing downlight layout as they transition from these other systems to the KLS, in which case the illuminance levels on the countertops and cabinets could be expected to be greatly enhanced. Alternatively, the homebuilder may desire to keep illuminance levels constant by simply installing fewer KLS downlights. It is anticipated that, because of the KLS's fairly wide light distribution, a wider-than-normal downlight spacing pattern will not lead to a noticeable increase in modulation (i.e. "hot spots" and shadows) in the kitchen.

4.0 Field Test Results

In order to test the functionality of the KLS in the field, LBNL worked with SMUD to deploy prototype systems in the residential sector. SMUD initially purchased enough prototype systems to install 276 downlight heads. As of December 1, 2003, 148 of these downlights had been deployed to our homebuilder partners for installation in new homes. The remaining systems have already been pledged to builders that will be installing the units in the coming months.

Several of the builders that did not receive the prototype systems have expressed continued interest in the system and SMUD intends to follow up with them. Some of these builders simply did not act in time to participate in SMUD initial deployment. Others were interested in the systems, but expressed a desire to see them installed inside a kitchen before they would commit to installing them themselves. SMUD plans to continue to work with these builders and has indicated that they are willing to purchase a second large batch of prototypes if there is enough builder interest to warrant it. Lithonia has indicated that they would be able to accommodate a follow-up purchase of prototypes.

The field test provided important information in three main areas of interest. These are:

- Photometric Characterization Of The Systems,
- Builder Response To The Systems, and
- Homeowner Response To The System.

4.1. Photometric Characterization

We had originally planned to perform in-situ photometric measurements in various kitchens to gather quantitative data on the KLS field performance. We were looking for situations where it would be possible to make side-by-side comparisons of a kitchen lit by the KLS and kitchens of similar layouts that are lit with standard downlighting systems. This comparison would allow us to evaluate the relative performance of the two systems with respect to room illumination, lighting uniformity, and electrical load.

Unfortunately, while a significant number of systems have been installed, as of December 1, 2003 none of the installations had reached a point in which a photometric characterization could be performed. That is, the sheetrocking and painting tasks had not yet been completed in the kitchens with an installed KLS. Because the photometric performance of these systems is highly dependent on the geometry and reflectance of the surface in the kitchen, it is necessary to wait for these features to be completed before in-situ photometric performances can be performed.

The sites that will be studied include both side-by-side comparisons (as discussed above) as well as potentially some retrofit applications. The retrofit applications would involve installing the systems into model homes that have already been constructed and currently use other kitchen lighting systems. While this obviously was not the original intent of the field test, doing a subset of the installations in this manner provides some unique advantages relative to photometric characterization. The main advantage is the ability to collect a very clean set of "before" and "after" photometric readings in these spaces. It is clearly more effective to compare two systems in an identical room, as opposed to evaluating the "before" and "after" systems in two "similar, but different rooms" (as would likely be the case in any side-by-side application).

Several candidate sites have been identified for the in-situ photometric characterization that include both side-by-side and retrofit applications. These sites will be measured and analyzed between January 2004 and June 2004 and the results of this study will be summarized in a subsequent report for SMUD.

4.2. Builder Response

Working closely with the builders throughout the development process was thought to be critical to the successful commercialization of the KLS. Hence, the prototype design for the KLS evolved into its current state largely based on what our builder contacts indicated were their needs and desires. It was important to get feedback on the KLS system from a wide cross-section of players in the homebuilder community. It was also considered critically important to be able to make refinements based on the real-world experience of homebuilders, in order to further optimize the KLS before it enters into full production.

Initial feedback was collected from the electricians that installed the systems. After the homes are "finished" with sheetrock and paint, feedback will also be collected from other homebuilder sources such as purchasing agents, interior designers and homebuilder executives.

Lithonia, LBNL, and SMUD visited several field test sites to observe some of the installations and to gather feedback from the electricians. Overall, the feedback was very positive. Generally electricians felt that the system was easier to install (Figure 25) that a standard downlight. Additionally, they believed that the light output from these 26W systems would be far superior to 13W CFL systems.

There were several suggestions for improvements from the electricians, some of which had little to do with our actual research project (i.e., changes to the bar hangers on the housing) and some which did (changes to the J-box to make ballast access more straight forward). Lithonia felt that the recommended changes that were specific to the KLS system would be very straightforward and easy to implement in the final production.

Figure 25. Electrician Installs KLS System In Field Test Home

The electricians also expressed some interest in making these systems dimmable. Dimming was originally considered as an option for the KLS, but was considered too costly of a feature by the production builders surveyed early in the project. This decision was based on the fact that the KLS was being compared against the much cheaper incandescent downlight systems, as well as on gathered data that showed an overall lack of dimming capability in most kitchens. The discussions with the electricians raised two issues that suggested that it might perhaps be appropriate to reconsider the dimming issue. The first was their suggestion that in certain high-end applications, overall cost was not nearly as critical of an issue as performance and features. The electricians felt that in higher end houses, homebuilders and homeowners would be willing to pay a premium for the ability to dim the downlights. The second issue related directly to the design of the KLS as it relates to dimming. Because the KLS utilizes a single ballast to operate two downlights, the cost of "upgrading" to dimming of the KLS would only be half of that of standard one-ballast, one-downlight systems.

This is a subtle but important point that was not lost on the representatives at Lithonia. One of the primary advantages of the KLS is that it cuts in half the required number of the single expensive downlight component -- the ballast. Because a dimming ballast typically costs more than twice that of a standard ballast, this KLS ballast advantage is even more pronounced in dimming applications.

Interactions with homebuilders are ongoing and are expected to continue through June 2004.

4.3. Homeowner Response

The homeowner response to the KLS is critical as well. Ultimately, the homebuilders will not continue to install a system in their homes if it does not receive a favorable response from their customers, the homeowners.

Obviously, the homeowners are not yet living in the homes that have the KLS systems installed. However, SMUD and the homebuilders that have installed the systems have signed agreements committing to collecting survey data from the eventual homeowners to determine their opinions of these systems. This data will be collected later in the 2nd half of 2004 after the occupants have had an opportunity to become acquainted with the systems.

4.4. Retrofit Applications

The KLS was developed specifically for new construction applications. Significant effort was spent to identify the existing installation practice of downlights in new construction and to solicit feedback from homebuilders what their particular needs were.

During the course of this research project, it became apparent that the retrofit market also presented a significant opportunity for a high quality, energy efficient CFL downlighting system. The market opportunity was determined to quite large as the existing stock of incandescent downlights in California homes greatly exceeds the number of downlighting that are installed annually in new construction. And the addition of downlighting is one of the most common features when homeowners remodel or renovate their homes.

The Energy Commission's PIER program funded a new research project (#4.3 in contract 500-01-041) to adapt the KLS system for retrofit applications. Unlike the original project that was focused on residential kitchen applications, the retrofit project was open to all appropriate residential and commercial applications. This project was initiated in May 2003 and is scheduled to be completed by September 2004. It is anticipated that by project completion, one or more retrofit designs will have been developed, prototyped, and field-tested. These activities will be conducted to further the overall project goal of commercialization of a new CFL downlight retrofit system (see "Commercialization Potential in the Conclusions and Recommendations section).

5.0 Conclusions and Recommendations

5.1. Conclusions

The project goal to develop a novel, low cost, high-performance and highly efficient kitchen lighting system has been realized. The KLS is novel in many areas from unique master-slave ballast design to its builder-friendly installation process. It is low-cost, now appearing to have achieved a cost even lower than the original goal (mid-point between incandescent downlights and traditional CFL downlights). It is high-performance, with a low-glare optic that produces over 50% more flux that a standard incandescent downlight. And the KLS is highly efficient, utilizing state-of-the-art CFLs and electronic ballasts in combination with optical heads that boast superior fixture efficiencies.

Table 4 details the cost and payback information for the KLS as compared to standard incandescent and CFL systems.

Table 4. Cost And Payback Information For KLS As Compared To Conventional Systems

	Standard Incandescent		Standard CFL System		Improved CFL System	
Total # of Downlights	8		10		5	
Lamp Lumens per Downlight	1050	Lumens	600	Lumens	1300	Lumens
Lamp Power per Downlight	65	Watts	13	Watts	26	Watts
Material Cost per Downlight	$ 20		$ 35		$ 60	
Installation Cost per Downlight	$ 30		$ 30		$ 25	
Total Kitchen Lamp Lumens	6000	Lumens	6000	Lumens	6500	Lumens
Total Kitchen Power	520	Watts	130	Watts	130	Watts
Total Initial Installed Cost	$ 400		$ 650		$ 425	
Operating Cost per year	$79.72	/yr	$19.93	/yr	$19.93	/yr
Additional Initial Cost vs. Incandescent	n/a	n/a	$ 250		$ 25	
Annual Savings vs. Incandescent	n/a	n/a	$59.79	/yr	$59.79	/yr
Simple Payback	n/a	n/a	4.18	yrs	0.42	yrs
Notes: Calculations based on an average use of 3.5 hrs/day, an electricity cost of $0.12/kWhr, and initial lamp lumens						

The KLS is a very strong performer, able to compare favorably to even the much more expensive commercial-grade CFL systems. Economically, the KLS measures up very well against both incandescent and CFL downlight alternatives. Many potential market barriers have been addressed in the development of this system by the close and cooperative development process involving homebuilders. Changes to Title 24 to further promote efficient kitchen lighting are poised to take effect within the next 2 years. Finally, the manufacturer of the KLS (Lithonia Lighting) is one of the largest lighting equipment companies in North America, ready and able to ramp-up production of the KLS to meet whatever market demand its introduction generates.

5.2. Commercialization Potential

The KLS is in position to be a commercial success. All necessary steps to ensure success were taken during the development of the project. It is now up to market forces to determine what the commercial fate of this product will be.

LBNL has selected Lithonia Lighting as the manufacturer best suited to quickly and effectively penetrate the lighting market with the novel KLS technology. Lithonia Lighting of Acuity Brands is one of the premier lighting manufacturers in North America. They employ some 8,000 people and have extensive production and distribution capabilities. The company currently offers thirty-four categories of fixtures, controls, and wiring systems. The company is committed to the full-production of the KLS.

There are three key issues regarding production capability of Lithonia that are favorable indicators for KLS production.

- **Pre-existing components**: Nearly all the components on the KLS are pre-existing components from other Lithonia lines (such as the optical heads and can housings) or are existing off-the-self components from other manufacturers (such as the ballasts and lamps). This fact would seem to limit the risk that Lithonia would experience significant difficulties in transitioning from prototyping quantities to manufacturing quantities.
- **UL-Certified Prototypes**: Another favorable indicator is that Lithonia has already produced a significant number of UL-certified prototype systems. In the rigorous process of designing and building these prototype units to a level appropriate for UL-certification, Lithonia has already addressed the most important details of KLS production.
- **Large Production Capability**: Lithonia is one of the largest lighting manufacturers in North America. Because of their significant size, Lithonia should be able to meet any foreseeable required production ramp-up through their existing production facilities.

Distribution house price (i.e. cost to the homebuilders) of the KLS is expected to be between fifty and seventy dollars per head, with strong indications from Lithonia that it could drop to forty dollars per head with high production rates. In juxtaposition to current CFL-based, residential recessed downlights, this is a phenomenally economic package. At this price, the KLS will be substantially cheaper than the installed cost of traditional CFL recessed downlights and represent only a small cost adder to inferior incandescent systems.

The system is currently being field tested under an agreement between local homebuilders, the Sacramento Municipal Utility District (SMUD), and LBNL. The results of the field tests and feedback from electricians, installers, decorators and end-users will determine its final characteristics.

Following the definitive modifications of the KLS' design (to be concluded mid-2004), its introduction to the industry will begin. The first entities to be actively informed by LBNL will be the Californian utilities, in an attempt to both educate and elicit subsidies or rebate programs. Subsequently, LBNL, in conjunction with Lithonia, will hold colloquia and demonstrations for builders, contractors and installers to promote the features, advantages, payback time and Title 24 compliance of the KLS. The relationship between Lithonia and various lighting distributors and retailers will also aid in this aim. The established rapport provides an integrated segue into the company's new product offerings.

The plan builds to a crescendo in January of 2005. Orders will be taken beginning in August of 2004 and will be shipped beginning in October. This process will continue to through January 2005 when the new 2005 Title 24 regulations take effect. The plan capitalizes on the needs of builders and contractors to find high-quality energy-efficient lighting alternatives to previous methods, and there on the shelf, or there in the catalogue, will be the KLS.

The development of the KLS and the finalization of the new Title 24 kitchen lighting specifications have been parallel and complimentary efforts and LBNL has been intimately involved in both. The new 2005 Title 24 specification will require that 50% of kitchen lighting (by wattage) be energy efficient. This will, in effect, eliminate the incandescent downlight as the primary lighting system in kitchens.

LBNL and Lithonia believe that, due to photometric and aesthetic concerns, the homebuilders are very likely to maintain downlighting in kitchens. If the homebuilders are presented with a system that matches or exceeds the performance of an incandescent system with only a modest cost adder, then they would be inclined to spec this system. There will be other CFL downlighting systems that enter the market, but Lithonia plans to build market-share by convincing builders that they can provide the highest performance, most cost effective CFL downlights available.

Additionally, the California utilities will likely play a significant role in the commercialization of the KLS. SMUD has continued to take the leading role as this project transitions from the research phase into the market transformation phase. SMUD is introducing the system to new builders and has integrated the KLS into their "Advantage Homes" program, which encourages homebuilders to adopt energy saving devices in new homes. Southern California Edison has also recently initiated plans to acquire KLS systems to demonstrate the system to builders in their service area. Pacific Gas and Electric is also considering a similar proposal.

As significant changes to Title 24 related to kitchen lighting are slated to take effect in 2005, all California utilities will likely initiate programs in 2004 to more broadly prepare the homebuilders in their service territories. These programs will be likely to be designed to create incentives to homebuilders to voluntarily do in 2004 what they will be required to do in 2005. These programs will likely contain explicit incentives for the use of energy efficient kitchen lighting, which will have great benefits for the KLS.

5.3. Benefits to California

The KLS system has the potential to generate significant energy and demand savings in California. Assuming that the KLS achieves 25% market penetration in kitchens in the 120,000 new homes constructed annually in California (but no penetration elsewhere in the home or in any retrofit applications), the first years energy savings would exceed 12 million kWh, while the load reduction would represent nearly 1.2 MW. By year five, the cumulative energy savings would exceed 185 million kWh, saving about $22 million/year with a corresponding load reduction of about 6 MW.