Performance and Energy Efficiency Evaluation of Residential LED Downlighting

ET 07.15 Report

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Disclaimer

ABBREVIATIONS AND ACRONYMS

CCT	Correlated Color Temperature
CFL	Compact Fluorescent Lamp
CRI	Color Rendering Index
DOE	Department of Energy
kW	Kilowatt
kWh	Kilowatt Hour
LED	Light Emitting Diode
lm	Lumens
SCE	Southern California Edison
SCLTC	Southern California Lighting Technology Center
SSL	Solid State Lighting
W	Watt

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EXECUTIVE SUMMARY

The objective of this study is to assess the status of the light-emitting diode (LED) recessed can lighting and to measure any incremental energy and demand savings over their pin-based compact fluorescent and halogen counterparts. Photometric and power tests conducted in the Southern California Lighting Technology Center (SCLTC) demonstrate the differences and similarities of the baseline (fluorescent and halogen) vs. measure (LED) cases. To supplement the tests conducted at the SCLTC, a field study was conducted to understand how residences use their kitchen overhead lighting. This study consisted of monitoring 60 houses. Of the 60 houses, it was found that there were two predominant lighting configurations: kitchens with only overhead lighting and kitchens with both overhead and under cabinet lighting. The data was used to help gain an understanding of the yearly operation of the overhead lighting in kitchen applications. The photometric and power data obtained through lab testing was combined with hourly usage figures to obtain energy savings, demand savings, and efficacy figures for the technology.

Recent advances in LED technology have made them brighter and more efficient, thereby expanding the application of the LED to the various lighting markets. In addition to using high efficiency LED chips, some manufacturers have improved efficiency of the required AC-DC conversion process. This study assumes that the end user operates the LED lamp in the same way as the fluorescent and halogen lamps.

The measured lumen output of LED lamps ranged from 126 lumens (lm) to 1456 lm. The 26 Watt (W) pin-based fluorescent was tested both as a bare lamp and inside a recessed can fixture. The measured lumen output of the Compact Fluorescent Lamp (CFL) inside of a recessed can was 447 lm; most of the LED lamps exceeded this light output.

Test results demonstrate that there are some LEDs that can compete with both the CFL and halogen baselines. Since there was a range of tested efficacies and lumen outputs, the baseline cases were normalized to estimate the CFL and halogen wattage at different lumen outputs based on efficacy. Through the field evaluation, homes with only overhead lighting (Kitchen Configuration A) used it for 1180.2 hours annually. Homes with both overhead and under cabinet lighting (Kitchen Configuration B) used the overhead lighting for 963.9 hours annually. Combined with the average demand savings acquired through lab testing, it was found that on average tested LEDs save 16.47 kilowatt hours (kWh) annually in Kitchen Configuration A and 13.45 kWh annually in Kitchen Configuration B over the 26W CFL. The average tested LEDs save 38.61 kWh annually in Kitchen Configuration A and 31.53 kWh annually in Kitchen Configuration B over the 60W halogen. The LEDs tested had manufacturer ratings for wattage that ranged from 5 – 38W.

- Lab assessment included:
  - Lumen output
  - Correlated Color Temperature
  - Color Rendering Index
  - Power (kW)
  - Efficacy
- Field assessment included tracking kitchen overhead lighting usage.
- Assessment integration included combining power and overhead lighting usage to determine energy savings.

INTRODUCTION

In recent years, solid-state lighting (SSL) technology has progressed in terms of efficiency, quality, and cost. The United States is becoming more interested in lighting that uses less energy and delivering lighting that meets or exceeds current market products. Research and development performed by the Department of Energy (DOE) and manufacturers of SSL and light emitting diode (LED) technology has shown that LEDs are a good candidate to provide an efficient general lighting source. This technology can be applied to kitchen downlighting.

The focus of this project was to evaluate the currently available LED recessed can downlighting options and compare these downlights to their halogen and fluorescent counterparts. This includes screw-in and hardwired (GU24 base or equivalent) types shown in Figure 1[1]. However, LED directional lamps made more for track lighting and PAR lamp replacements were excluded. There are manufacturers that supply linear fluorescent LED replacement lamps; however, this technology was not covered in this project since it is not a recessed can type downlight fixture.

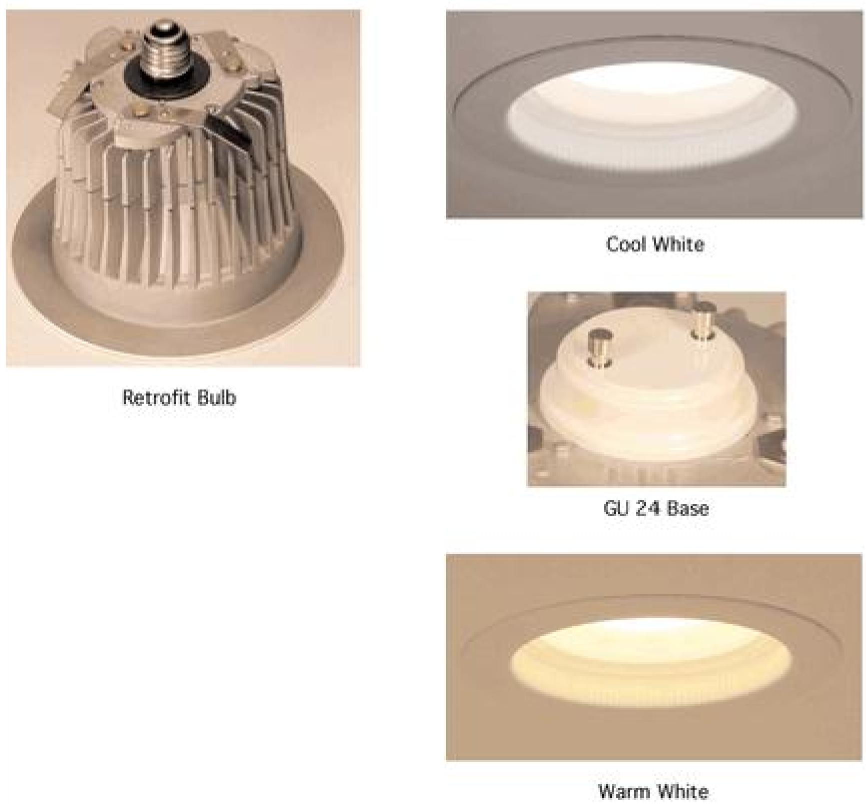

FIGURE 1. EXAMPLE OF SCREW-IN VS. HARDWIRED GU24 LED DOWNLIGHTING OPTIONS

Halogen bulbs use a tungsten filament which is heated and begins to glow in a low-pressure inert gas-filled bulb. Much of the energy required to operate a halogen light bulb is wasted in the form of heat.

Compact fluorescent lamps work on a different principle. Using a ballast to regulate the flow of power through the lamp, the electricity is used to excite mercury vapor. The excited mercury atoms produce short-wave ultraviolet light that causes phosphor located in the fluorescent tube to fluoresce. In turn, visible light is produced. This process is more efficient than the halogen method of lighting and uses less electricity.

LED lamps work differently from their traditional counterparts since it is a semiconductor diode. It consists of a chip of semi-conductor material treated to create a structure called a P-N (positive-negative) junction. When connected to a power source, current flows from the p-side or anode to the n-side, or cathode, but not in the reverse direction. Charge-carriers (electrons and electron holes) flow into the junction from electrodes. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon (light)[2]. Different semiconductor materials are used to create different colors. There are typically two ways that white light is created. The first is to combine red, green, and blue LED's to make white. The second is to coat a blue LED with yellow phosphor.

The goal of this project is to understand the energy and demand savings associated with LED downlighting technology over various types of kitchen lighting options in single family homes.

MARKET DESCRIPTION

Downlighting has become popular in kitchen applications. Nearly every residential customer in SCE service territory has a kitchen. Approximately 60% of customers' homes built since 1990 have downlights and this figure seems to be increasing. In addition, downlighting is a popular retrofit for existing kitchens. As with compact fluorescents when they were first introduced, the availability and cost of the LED downlight are significant market barriers for this energy efficient option.

2005 Title 24 considers all screw-type fixtures to be low efficacy. This means that California residences with downlighting built under the 2005 code can have pin-based compact fluorescents for at least 50% of their overhead kitchen lighting. In this case, pin-based compact fluorescent fixtures will need to be replaced with an appropriate LED fixture, also a significant market barrier.

For new construction applications, many LED downlighting manufacturers produce a hardwired fixture/luminaire combination that complies with the high efficacy requirements in 2005 Title 24. This style is most likely to be used in new construction applications. However, most LED downlighting manufacturers produce a screw-type downlighting retrofit that screws into the existing socket within the recessed can as shown in Figure 1. Screw type fixtures are considered low efficacy under 2005 Title 24, regardless whether or not the LED lamp saves energy.

Due to the change in residential building code, different vintage houses may have different kitchen lighting configurations. For retrofit applications, if the house was built after 2005, the replacement of existing high efficacy lighting with LED technology will require a fixture change, however if low efficacy (screw-type) recessed cans were used for up to 50% of the kitchen, consumers can use the screw-type LED retrofit. If the kitchen has linear fluorescent kitchen lighting the retrofit becomes more complicated. When switching to recessed cans, the lighting well that houses the linear fluorescents must be considered. This includes the addition of drywall to "fill-in" the old lighting well in addition to the fixture change.

If using this technology in a retrofit scenario, more significant market barriers are experienced. This is because a fixture change is necessary if pin-based or linear fluorescent fixtures exist.

Considering the various installation opportunities in residential kitchen settings, the LED downlight is most appropriate for applications in this order:

- Retrofit Applications: Kitchens with existing recessed cans (Screw Type).
- New-Construction Applications
- Retrofit Applications: Kitchens with existing recessed cans (Pin-Type Fluorescent). Requires fixture change.
- Retrofit Applications: Kitchens with other overhead lighting type considering a remodel and/or switch to recessed can lighting. (Requires fixture change, as well as some cosmetic work and wiring.)

BUILDING ENERGY CODE

The 2005 Title 24 requirement for kitchen lighting states that fixtures and lamps must be high efficacy or up to 50% of the total wattage can be low efficacy. Typically, pin based recessed can-type compact fluorescent lamps used for overhead downlighting are employed to satisfy the high-efficacy requirements, but high-efficacy under cabinet lighting may also be counted. The 2005 code allows up to 50% of kitchen lighting to be low-efficacy, as long as these luminaries are switched separately from the high-efficacy luminaries. Though uncommon, this creates a code-compliant case where low efficacy overhead lighting could be paired with high-efficacy under cabinet lighting. Figure 2 shows the Title 24 language.

Title 24 SECTION 150 – MANDATORY FEATURES AND DEVICES

(k) **Residential Lighting.**

1. **High Efficacy Luminaires.** High Efficacy Luminaires for residential lighting shall contain only high efficacy lamps and shall not contain a medium screw base socket (E24/E26). A high efficacy lamp has a lamp efficacy that is no lower than the efficacies contained in TABLE 150-C. Ballasts for lamps rated 13 Watts or greater shall be electronic and shall have an output frequency no less than 20 kHz.

   EXCEPTION to Section 150 (k) 1: High intensity discharge luminaires containing hardwired electromagnetic ballasts in medium screw base sockets shall be considered high efficacy luminaires for the purposes of meeting Section 150 (k) 6, provided they meet the efficacies contained in TABLE 150-C.

NOTE: To determine the minimum lamp efficacy category only the watts of the lamp (not the ballast) are to be considered.

2. **Lighting in Kitchens.** Permanently installed luminaires in kitchens shall be high efficacy luminaires.

   EXCEPTION to Section 150 (k) 2 Up to 50 percent of the total rated wattage of permanently installed luminaires in kitchens may be in luminaires that are not high efficacy luminaires, provided that these luminaires are controlled by switches separate from those controlling the high efficacy luminaires. The wattage of high efficacy luminaires shall be the total nominal rated wattage of the installed high efficacy lamp(s). The wattage of luminaires shall be determined as specified by Section 130 (c).

FIGURE 2. 2005 TITLE 24 LIGHTING REQUIREMENTS FOR KITCHEN LIGHTING

Since different types of kitchen overhead lighting are permitted by code, the two most popular types of overhead downlighting were investigated for this report. Furthermore, consumers have options when purchasing can type lamp or fixture replacements in retrofit applications. Considering new construction and retrofit applications, halogen and fluorescent type recessed can downlighting was selected as the baseline case.

Since the goal of this project is to determine the energy and demand savings as well as photometry of the LED recessed can light, it is considered the measure case. Using the information determined in the lab evaluation on energy use and photometry, the efficacy of the fixture could be determined.

Efficacy is a measure of light output to power input. Typically, efficacy is measured in lm/W, where lumens are a measure of light emitted by a fixture and watt is the unit of power required to operate the fixture. High-efficacy fixtures produce high lumens/watt. To be considered high efficacy per table 150-C in the 2005 Title 24, the lamp/fixture must meet the requirements listed in Table 1.

Lamp Power Rating	Minimum Lamp Efficacy
15W or less	40 lumens per Watt
Over 15W - 40W	50 lumens per Watt
Over 40W	60 lumens per Watt

TABLE 1. EFFICACY STANDARDS AS DEFINED IN TABLE 150-C FROM 2005 TITLE 24

Two baseline cases were evaluated during the lab assessment; a 26W compact fluorescent, and a 60W halogen. The fluorescent lamp's photometrics were tested with and without a metal can.

To determine energy demand and consumption savings of LED technology over the mentioned baseline cases, kW and kWh figures must be compared to a measure case. Thirteen LED recessed can fixtures were tested at the Southern California Lighting Technology Center (SCLTC). Each of these LED measure cases were compared against each of the baseline cases.

OBJECTIVES

The focus of this project is to determine the photometry, energy and demand savings associated with downlight LED technology when compared to other types of kitchen lighting. To do this, the project was broken into two phases.

The first phase consisted of a field evaluation performed by a third party consulting firm. This field evaluation included contacting residential customers and homebuilders in order to obtain sites, implement the technology, and track usage. The focus for this phase was to develop the usage profiles and annual usage for participating residences. Sites used to develop these profiles were located throughout California, Northern Nevada, and Idaho and varied by the number of occupants and their age. Though the focus of this study was on residential recessed can lighting, it was expected that kitchen overhead lighting usage profiles will be the same regardless of lighting type. Consequently, it was not required for participants to have recessed can lighting. A popular 2005 Title 24 compliant kitchen lighting configuration could also consist of a combination of both under cabinet and overhead lighting. Of the 60 residences monitored for this study, 26 had both under cabinet and overhead lighting.

The second phase consisted of a lab evaluation performed by SCE at the SCLTC. This lab assessment included the procurement of LED recessed can lighting from multiple manufacturers. This included both screw-in retrofit fixtures and hard-wired options for kitchen applications. This phase had two objectives. The first objective was to develop the power demand (kW) figures for the measure (LED technology) and baseline (fluorescent and halogen) cases. The second objective was to perform a photometric test to verify light output, color rendering index (CRI) and correlated color temperature (CCT). Using the lumen output combined with measured power data, the fixtures' efficacies can be determined.

These two phases were then integrated to develop the power consumption (kWh) figures of the measure and baseline cases. The end result is information on kW and kWh savings for the measure case vs. baseline cases, as well as efficacy which were the goals of this project.

At the time this study was performed, SCE offered rebates for LED downlight installations in commercial applications through SCE's Standard Performance Contract (SPC) rebate program. This rebate program requires the commercial customer to provide calculations on energy savings based on the installation. It is expected that results from this study will be used as a resource for utility programs to help make informed decisions for this technology in other market sectors, such as residential.

METHODOLOGY AND INSTRUMENTATION

FIELD ASSESSMENT

In order to determine the energy savings of the technology, it is necessary to understand how often overhead kitchen lighting is used in residential settings. Kitchen lighting can include a combination of one or more downlights, under cabinets, over-cabinets, pendants, and/or wall sconces. Based on interviews with homebuilders in SCE service territory and observation during the field assessment, the most popular kitchen lighting consists of solely overhead lighting (recessed-can type downlights or well-type linear fluorescents). Another popular lighting strategy found during this evaluation was a combination of overhead lighting and under cabinet lighting. These two kitchen lighting strategies were selected for monitoring in order to develop two separate usage profiles and to obtain the hour figure necessary to determine potential energy savings supplied by the measure case when compared to baseline cases.

For this evaluation, sites in SCE service territory were preferred. To obtain an acceptable number of sites, SCE and the third party consultant worked with homebuilders in the area to connect with recent buyers and homeowners associations whose members may be willing to participate.

To supplement data from SCE sites, a variety of locations outside of SCE service territory were also examined to understand if kitchen lighting use varies by location. Additional participants were located in the following service territories:

- Los Angeles Department of Water and Power
- Sacramento Municipal Utilities District
- Riverside Public Utilities District
- Truckee-Donner Public Utilities District
- Sierra Pacific Power Company
- Idaho Power

In order to track usage at these sites, the Onset HOBO® U9-002 Light On/Off Data Logger was used. This adjustable sensor contains a photocell that captures light and records a time and date stamp of the light being on or off. This information provides the amount of time per day homeowners use their kitchen lighting.

Installation of this logger includes mounting the logger close to a kitchen lamp with a hook and loop fastener. The installation requires field calibration which includes adjusting the sensitivity of the device to ensure that state changes are accurately tracked and to mitigate daylight from interfering.

The field assessment started in February 2009 with homes in the Southern California area. Thirty homes were found through industry contacts. This includes individuals and single-families that have participated in previous studies and those acquainted with the members of the project team willing to volunteer their home. A significant roadblock was encountered early in the project because most people weren't willing to participate without a significant incentive which is common in many residential studies.

This was most likely due to privacy and security issues. Of the 30 residents who initially participated in this project, all were acquainted in some way with the project team. Even with a small incentive, many people were not willing to give up their privacy and security to participate in a study that did not benefit them.

As a result, the project team contacted twelve homebuilders in the Southern California service territory through SCE account managers. Of the twelve homebuilders, 2 were interested in participating. The goal was to use the homebuilder's own housing developments as a connection to customers. The homebuilder provided labor for the LED conversion and SCE provided the LED technology installation. The idea behind this incentive is that the customers will allow the project team to monitor their usage and provide feedback on the technology while receiving high efficiency lighting.

It should be noted that the housing market in California during the time of this study was rapidly declining and homebuilders were having trouble selling new models. As a result of the declining housing market, the homebuilders shifted their efforts to reducing costs. Despite efforts to keep them interested, both homebuilders eventually backed out. According to the California Building Industry Organization, the number of new homes being built in California has been declining drastically since 2005. In 2005, 155,322 new single family homes were built. In 2008, only 33,050 new homes were built in California, roughly 1/5 the number built in 2005[3]. This situation made it difficult for homebuilders to allocate their share of resources for the project. A more significant impact will be on attainable kWh savings in new construction applications for the utility.

After targeting homebuilders, the project team's focus shifted to investigating the use of a third party energy efficiency contractor who specializes in utility programs and installations. The goal was to use their expertise to find homes interested in participating. The caveat is that the customer pays labor to the contractor while SCE provides the technology. In addition, the customer allows the project team to monitor their usage and provide feedback on the technology. Initially the contractor seemed interested but then declined participation in the project.

During the effort to obtain more homes in SCE territory, the project team continued installing loggers in houses outside of SCE territory. This was conducted by contacting homeowners associations and walking door to door in certain communities and lead to 60 homes participating spread over 7 electric utility service territories. A breakdown of participants by service territory is located in Figure 3.

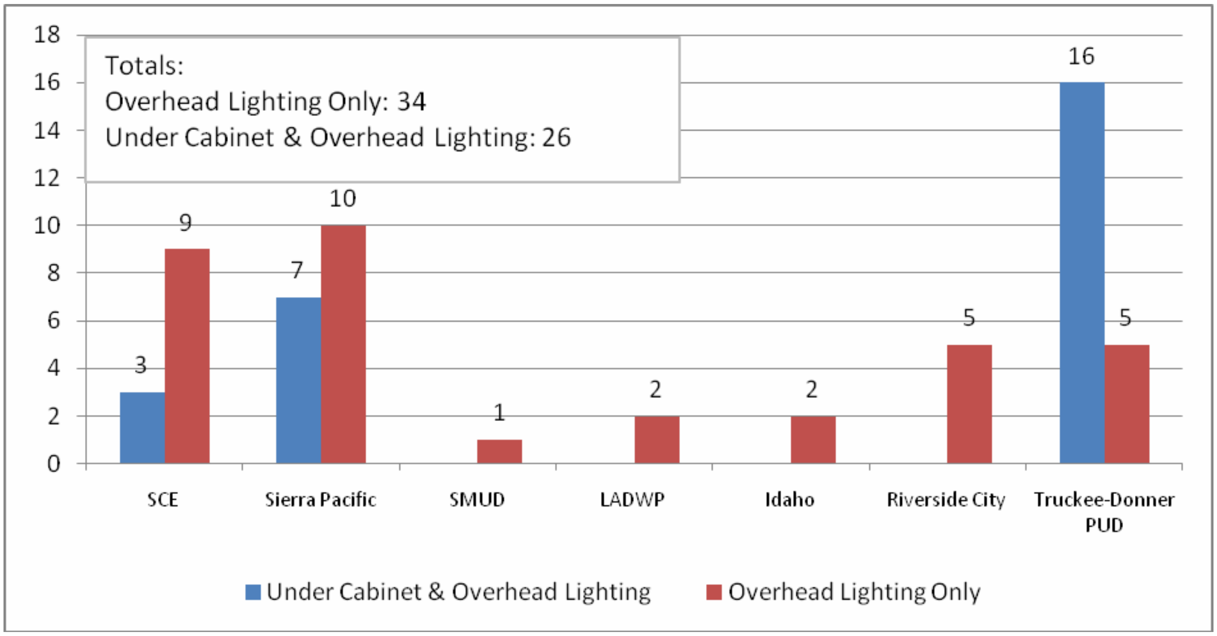

FIGURE 3. PROJECT PARTICPANTS BY SERVICE TERRRITORY

Households varied in size from 1,000 ft² to 10,000 ft² and ranged from 1 occupant to 5 occupants with varying living situations. Figure 4 shows the breakdown of participating households by square footage.

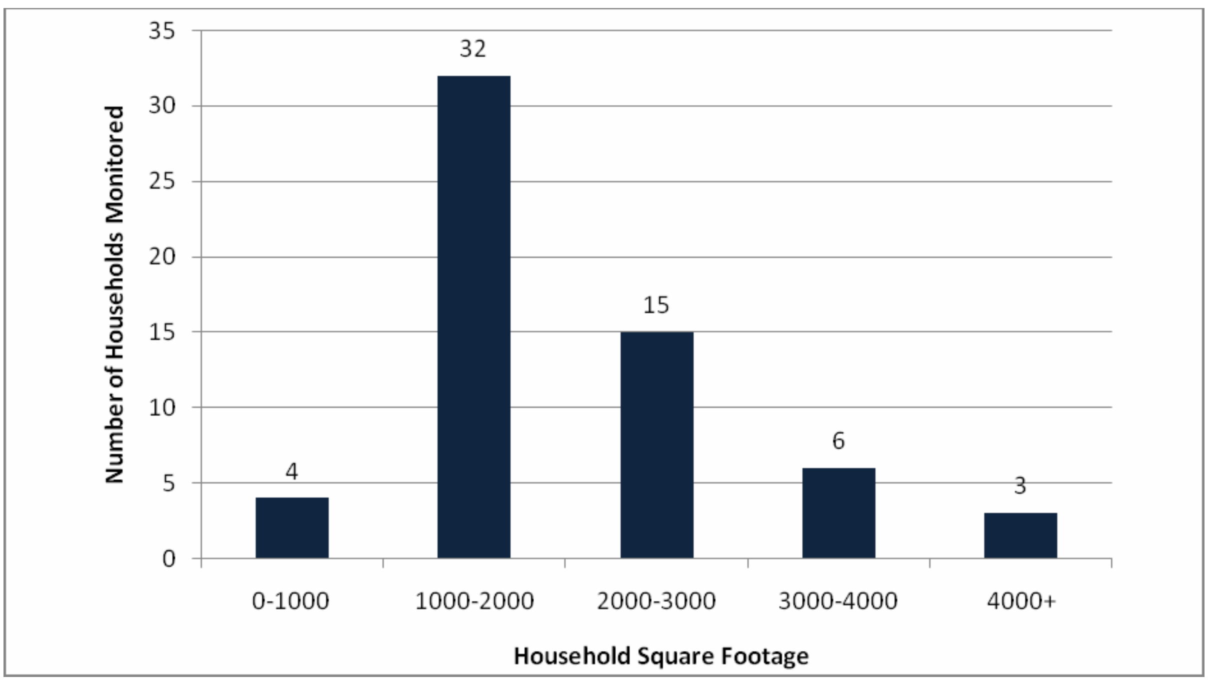

FIGURE 4. SQUARE FOOTABE BY HOUSEHOLD

Living situations include:

- One occupant living alone
- Two-Occupant non-related shared-living situation
- Two-Occupant married couple
- Two-Occupant single parent with child
- Three-Occupant non-related shared-living situation
- Three-Occupant married couple with child
- Four-Occupant non-related shared-living situation
- Four-Occupant married couple with children
- Five-Occupant non-related shared-living situation
- Five-Occupant married couple with children

Figure 5 shows the breakdown of participating households by the number of occupants. Occupants ranged in age from 8 to 70 years old. Each household was instructed to complete a brief survey about their home that included square footage, hours of occupancy, whether or not they have under cabinet lighting, and information about location and size of their kitchen windows.

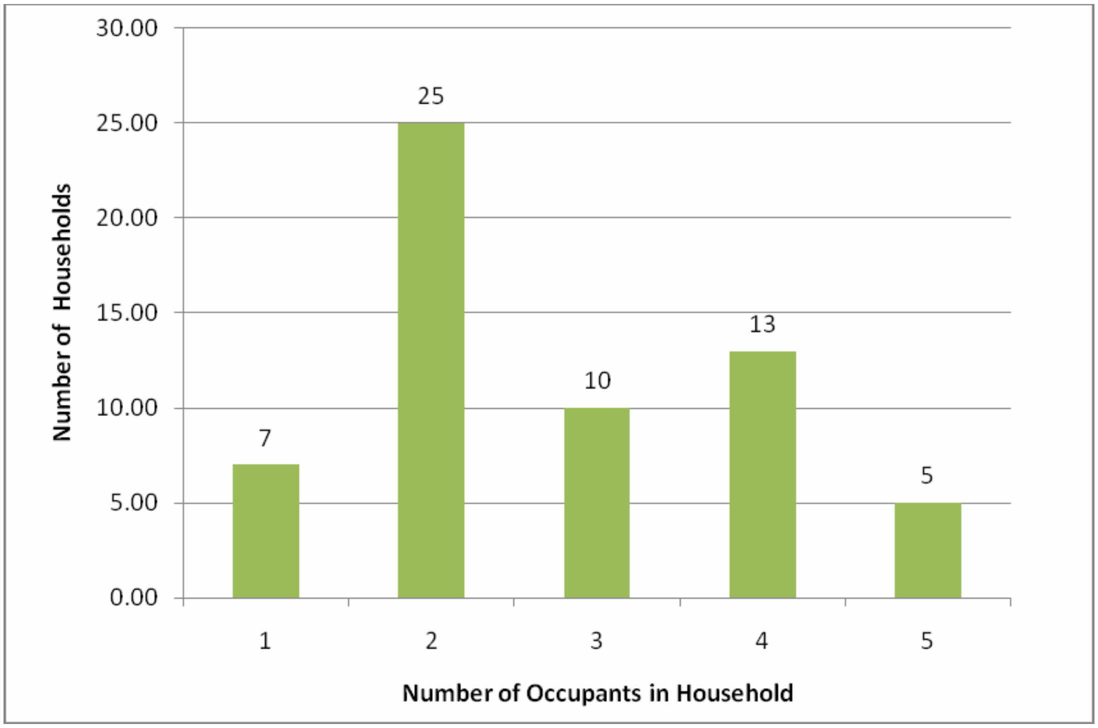

FIGURE 5. OCCUPANT COUNT PER HOUSEHOLD

LAB ASSESSMENT

The lab assessment was conducted concurrently with the field assessment. All lab tests were performed at the SCLTC in Irwindale, CA. Though energy savings figures are important for this evaluation, base and measure cases must be tested in terms of light output and quality to ensure the baseline and measure cases are similar. For the lab assessment, 13 LED measure cases were compared to two baseline cases. The baseline cases for this evaluation were a 26W compact fluorescent lamp and a 60W halogen lamp. The fluorescent lamp was first tested without a recessed can fixture. A subsequent test was performed to understand how the lamp performed when in a recessed can fixture that was made of a gray non-reflective metal. The following variables were tested in controlled environments to understand how baseline and measure cases compare.

LIGHT OUTPUT

Light output is the measure of light that a source can provide in lumens. Light output data was obtained from the Integrating Sphere test discussed in Lab Equipment section of this report.

CORRELATED COLOR TEMPERATURE

The correlated color temperature (CCT) describes the overall appearance of light. This figure indicates whether a light source appears more yellow with warmer temperatures or lower CCT, or bluer with colder temperatures or higher CCT. CCT refers to how the color of a theoretical black body heated to high temperatures will appear. The CCT of a light source is the temperature in Kelvin at which the heated black body matches the color of the light source in question[4]. CCT data was obtained from the Integrating Sphere test discussed in Lab Equipment of this report.

COLOR RENDERING INDEX

The color quality, measured as color rendering index (CRI), affects visual perception. The CRI is directly related to the colors or spectral characteristics that the lamp gives off. CRI data was obtained from the Integrating Sphere test discussed in Lab Equipment Section below.

CRI is an index which describes how well a light source renders color compared to a reference light source of similar color temperature. This index is scaled from 0-100.

CONNECTED LOAD

Power requirements for all test cases are determined by measuring current and voltage. Measurements for both current and voltage are taken between the driver and power source to understand AC power. This information is used to understand demand (kW) savings of the measure cases when compared to the baseline cases.

EFFICACY

An important indication of overall lamp performance is efficacy. This value, in lumens per Watt, is a measure of light output over power input. A higher efficacy lamp will provide more lumens of light output per Watt than a lower efficacy lamp. Though LED wattage may be lower than its fluorescent counterpart, it must do so while providing the same amount of light. A lamp with a higher efficacy will have the most energy savings potential.

LAB EQUIPMENT

LIGHT OUTPUT, CRI, AND CCT MEASUREMENTS

INTEGRATING SPHERE

The integrating sphere measures the total light output of a light source. This can be a lamp or a complete fixture. The light source being tested is placed in the center of the integrating sphere. At one side of the sphere is a light meter which measures the light output of the light source. A baffle is directly between the source and the light meter to prevent the meter from seeing any direct light from the source. This equipment is used to measure the light output of a light source, the CRI, and CCT. The temperature was regulated to approximately 77 degrees. Measurements were taken every 15 minutes until three consecutive measurements were within 0.5 percent of each other.

The entire inside of the sphere (including the baffle and mounting for the lamps) is coated with a highly reflective white paint that reflects all wavelengths equally and allows for accurate measurements. The calibrated power supply is connected to the lamp wiring on the outside of the sphere. Readings from the optical sensor are processed with the integrated software and displayed on the monitor.

FIGURE 6. THE INTEGRATING SPHERE

DEMAND DATA

The power aspects of the driver and LED downlights were measured using the Fluke 435 meter between regulated 120V power and the driver of the downlights.

ASSESSMENT INTEGRATION

After completion of the field and lab studies, it was necessary to integrate the two assessments to obtain energy savings and efficacy. Demand savings based on two baseline and thirteen measure cases were determined through lab testing. Usage profiles for different socioeconomic groups located throughout California, Northern Nevada, and Idaho were obtained through the field assessment. When combining demand savings with the amount of hours the typical household uses kitchen lights, energy savings can be determined. This integration was performed for each socioeconomic group assuming the replacement of a baseline case with the measure case in houses with both overhead and under cabinet lighting and those with only overhead lighting.

RESULTS AND DISCUSSION

FIELD ASSESSMENT

The field assessment for homes with under cabinet lighting consisted of a seven month period which began in mid-February 2009 and concluded in mid-September 2009. This field assessment consisted of tracking usage during the data acquisition period. Though 60 houses participated, problems with daylighting and installation of the instrumentation resulted in 50 good data sets. Ten of the sixty data sets had to be discarded.

There were two major kitchen lighting configurations investigated for this report: overhead and overhead with under cabinet lighting. Though the focus of this project is on the energy savings associated with LED recessed can (overhead) lighting, it is important to understand how overall usage of the overhead lighting is affected when under cabinet lighting is present. For this reason, usage data was separated for houses with and without kitchen under cabinet lighting.

Figure 7 shows how often different socioeconomic groups in different locations used their under cabinet lighting during this study. It was concluded that on average, homes with only kitchen overhead lighting use it more than homes with additional under cabinet lighting.

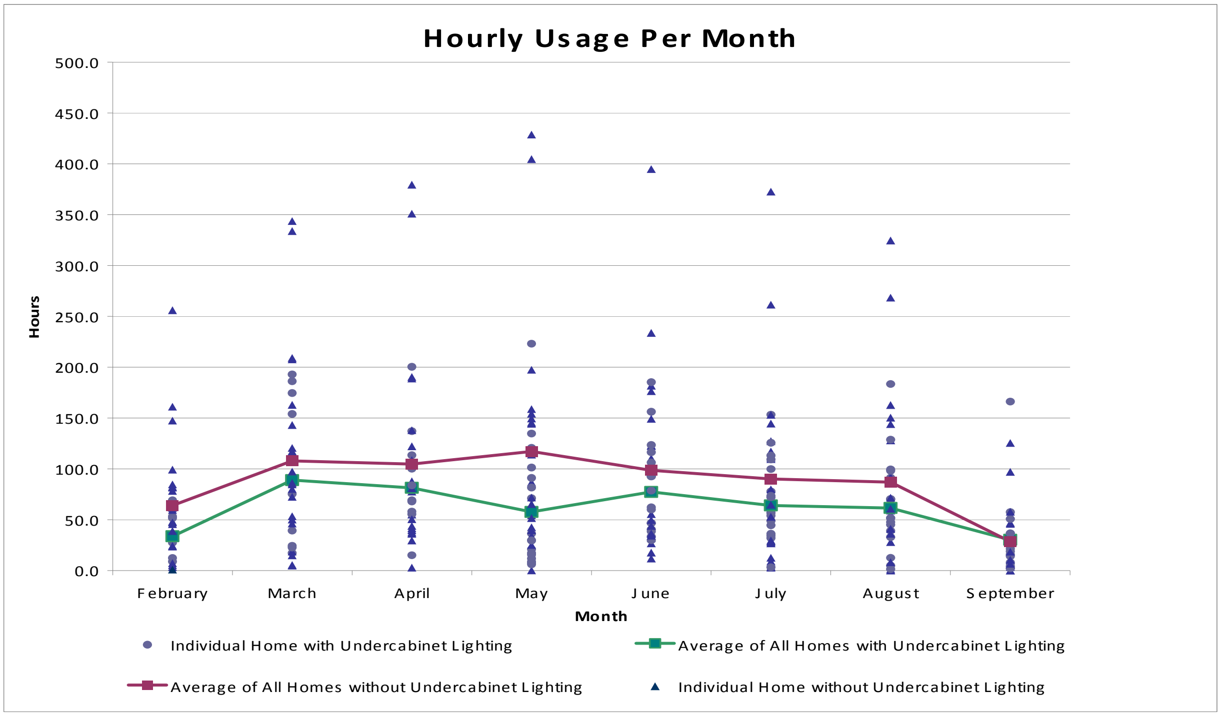

FIGURE 7. MEASURED HOURLY USAGE PER MONTH

Though this information is useful, February and September had only half of the month tracked. To address this issue, an average usage per day for the year was calculated over the entire data set. Since mid-September to mid-February data was not available for this study, measured data from the data set was averaged and applied to months where data was not available. This estimate should be considered conservative since it is expected that usage will be higher in winter months. Data from houses with kitchen under cabinet lighting was separated from those houses with only kitchen overhead lighting. Kitchens with overhead lighting only are referred to as Kitchen Configuration A. Kitchens with both overhead and under cabinet lighting are referred to as Kitchen Configuration B.

The hourly usage of each house can be compared to that of a percentage per hour for the data set. This percentage is useful to understand how frequently and during what time of the day participants used their kitchen lighting. For example, during the month of April 2009 which has 31 days; 22 days are weekdays, which means that there are 22 12:00 A.M. – 1:00 A.M. periods. If the participant has their under cabinet lighting on the entire hour for 11 of those 22 days or one half hour for all the 22 days, then the percentage for that hour for the data set will be 50%. Figure 8 shows an average percentage, for each hour over the entire data set, for houses with only overhead lighting that participated in the study. Most of the usage is during off-peak hours.

It was concluded during this study that kitchen overhead lighting usage is significantly reduced when the kitchen also has under cabinet lighting. Figure 9 shows the same “percentage” data for the kitchen overhead lighting for each hour over the entire data set for houses with both overhead and under cabinet lighting.

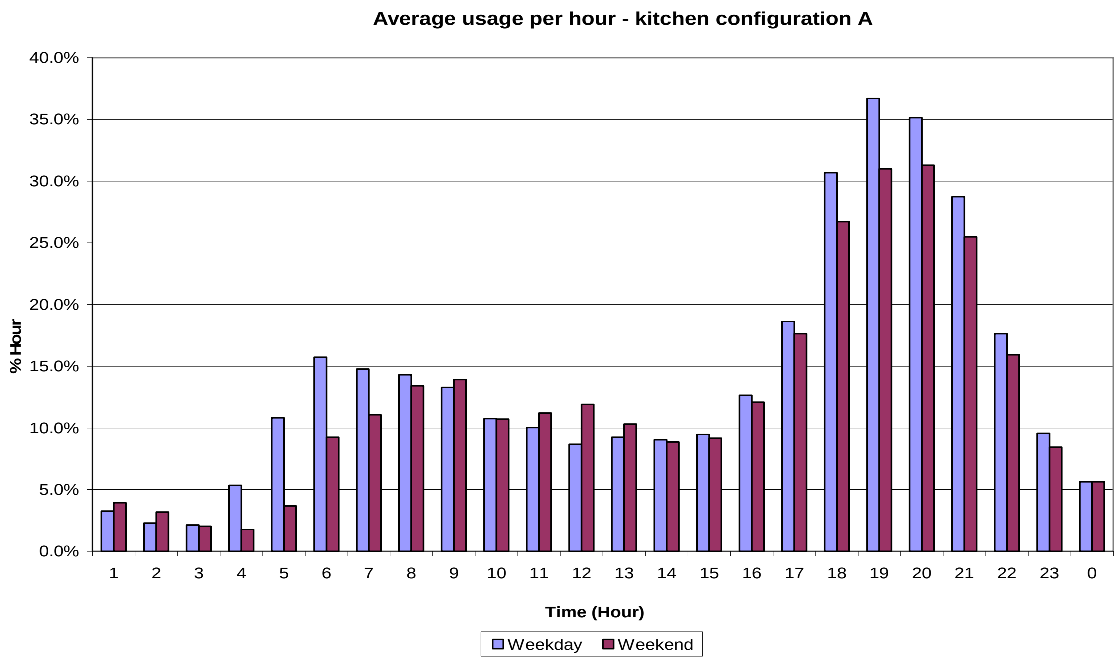

FIGURE 8. USAGE PROFILE OF KITCHEN OVERHEAD LIGHTING

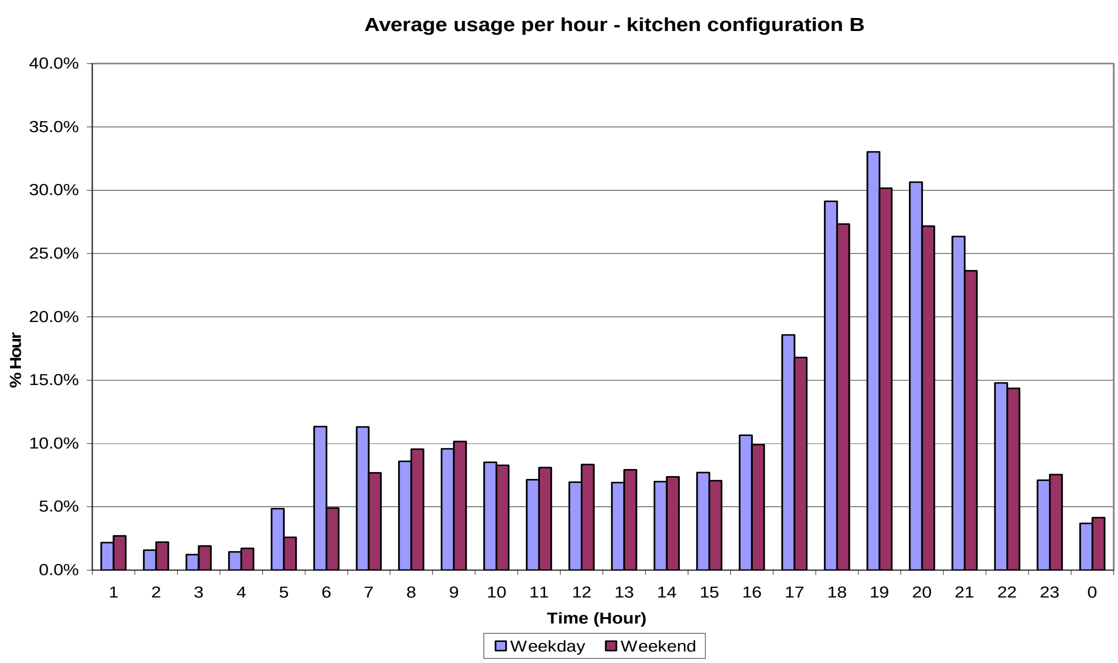

FIGURE 9. USAGE PROFILE OF KITCHEN OVERHEAD LIGHTING

Since usage profiles were found to be different depending on kitchen lighting configuration (e.g. kitchens with or without under cabinet lighting) two separate averages were calculated for hours per day for weekday peak, weekday off-peak, and weekend-off peak periods. Households participating in this study also varied in occupants and size adding diversity to each of the two data averages.

Based on results of this study, for kitchens with only overhead lighting (Kitchen Configuration A), it was found that that overhead lighting was used on average 1.19 hours per day during on-peak periods, 2.15 hours per day during weekday off-peak periods and 2.99 hours per day during weekend off-peak hours as shown in Figure 10. Using the average of the data set, it is estimated that overhead lighting in Kitchen Configuration A is used 1180.2 hours per year.

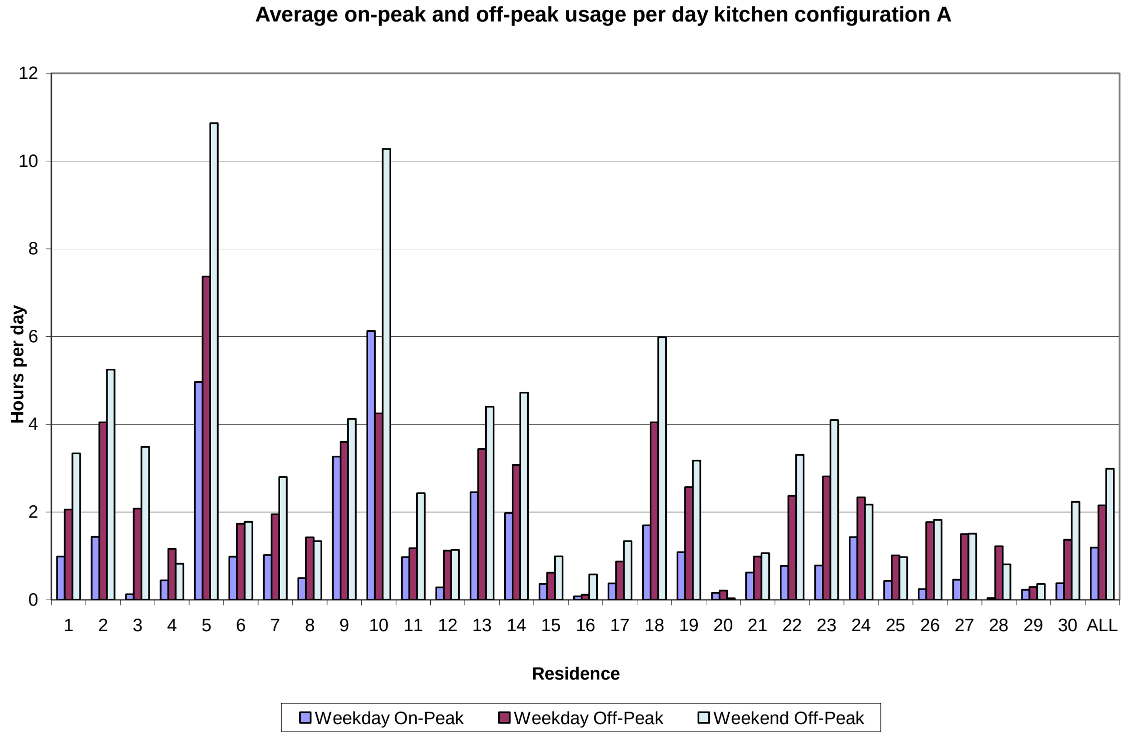

FIGURE 10. HOURLY USAGE PER DAY FOR EACH MONTH

A similar analysis was performed for kitchens with both under cabinet and overhead lighting (Kitchen Configuration B); it was found that overhead lighting was used on average 1.03 hours per day during on-peak periods, 1.68 hours per day during weekday off-peak periods and 2.51 hours per day during weekend off-peak hours as shown in Figure 11. Using the average of the data set, it is estimated that overhead lighting in Kitchen Configuration B is used 963.9 hours per year.

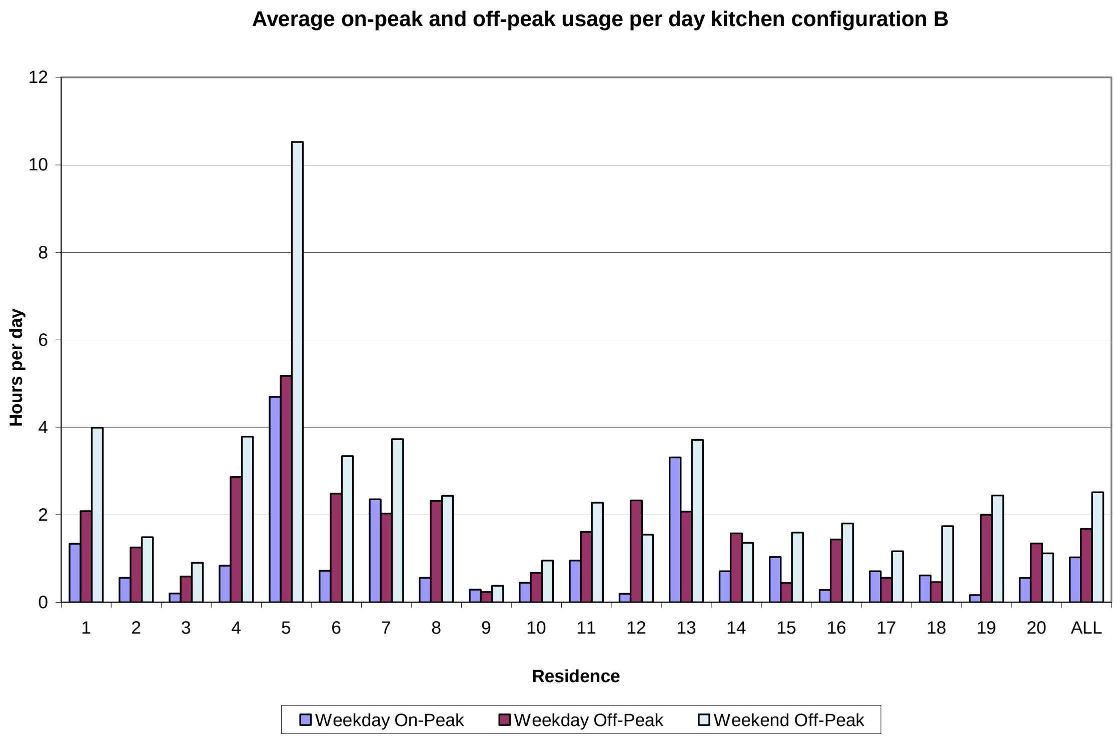

FIGURE 11. HOURLY USAGE PER DAY FOR EACH MONTH

The annual usage can be broken down into the different time periods that have been established by the utility. Since load on the utility grid has been found to be highest between the hours of 10:00 A.M – 6:00 P.M. on summer weekdays, it is considered "On-Peak". "Off-Peak" hours correspond to times when load on the utility grid is typically lower. The hours after 6:00 P.M. but before 10:00 A.M. on weekdays are considered "Off-Peak". Weekends are also considered "Off-Peak".

Utility Period	Hourly Usage / Year (Kitchen Configuration A)	Hourly Usage / Year (Kitchen Configuration B)
Weekday "On-Peak"	309.8	266.6
Weekday "Off-Peak"	559.9	435.8
Weekend "Off-Peak"	310.5	261.5
Total	1180.2	963.9

TABLE 2. ESTIMATED OVERHEAD LIGHTING HOURLY USAGE PER YEAR

Though participants in this study were spread throughout California, Northern Nevada and Idaho, location did not seem to affect the usage of kitchen lighting. Overhead kitchen lighting usage seemed to be most dependent on the amount of people in the house, square footage, and the occupants' schedules.

LAB ASSESSMENT

INTEGRATING SPHERE

LIGHT OUTPUT

The lumens of the halogen and fluorescent baseline cases and 13 measure cases were recorded at the intervals mentioned in the lab equipment section of this report. Figure 12 shows the measured lumen output for all the fixtures investigated for this study. The LED fixture results are arranged from high to low for easy comparison between the technologies and among the individual fixtures. The "CFL Fixture" data point includes the 26W fluorescent tested inside the described recessed can.

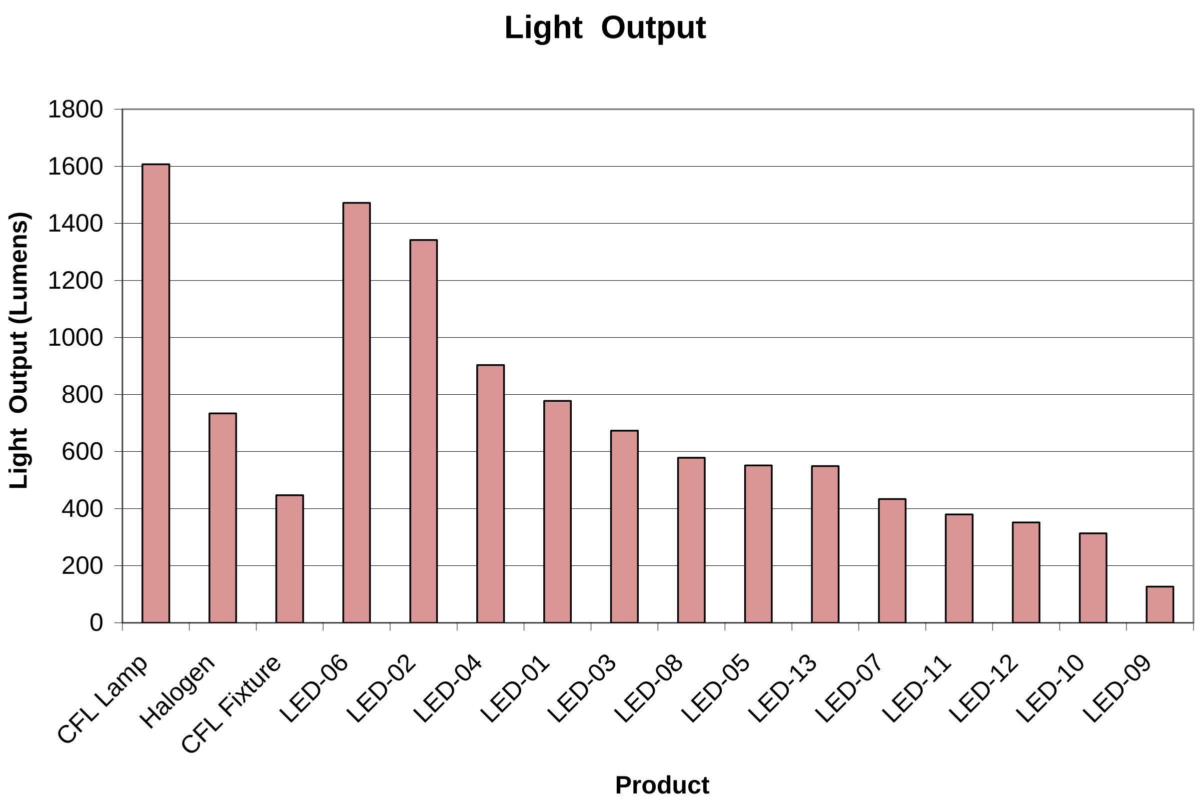

FIGURE 12. LUMEN OUTPUT RESULTS

As shown in Figure 12, none of the LED fixtures produce more light than the bare CFL lamp. However, once the lamp is placed in the test recessed can fixture, the light output is significantly reduced. The range between the CFL Lamp and the CFL Fixture data point is a good approximation of typical CFL fixtures. Most residential CFL fixtures have white baffles instead of the tested gray non-reflective metal. This range is a more appropriate comparison to the LEDs since it is common practice to mount the pin-based CFL in a recessed can fixture, especially in kitchen applications.

Four of the thirteen tested LED fixtures have light outputs greater than the halogen lamp. Eight of the thirteen exceeded the light output of the CFL fixture mounted in the recessed can fixture. Rated manufacturer values for the tested LEDs varied from 647-1500 lumens and for the most part tested close to advertised values. Five of the thirteen manufacturers did not make claims in terms of lumen output.

CORRELATED COLOR TEMPERATURE

The CCT for the LED downlights can vary. It can range from warm white, meaning the light appears more yellow, similar to halogen, to a very cool white, meaning the light source appears bluer. There is no "correct" CCT for displaying objects. Depending on the application, different color temperatures are preferred.

The CCT was measured for the fluorescent, halogen, and LED fixtures. Figure 13 shows the measured CCT for all LED, fluorescent, and halogen fixtures tested. The values are arranged in increasing CCT to allow for easier comparison to the baseline cases.

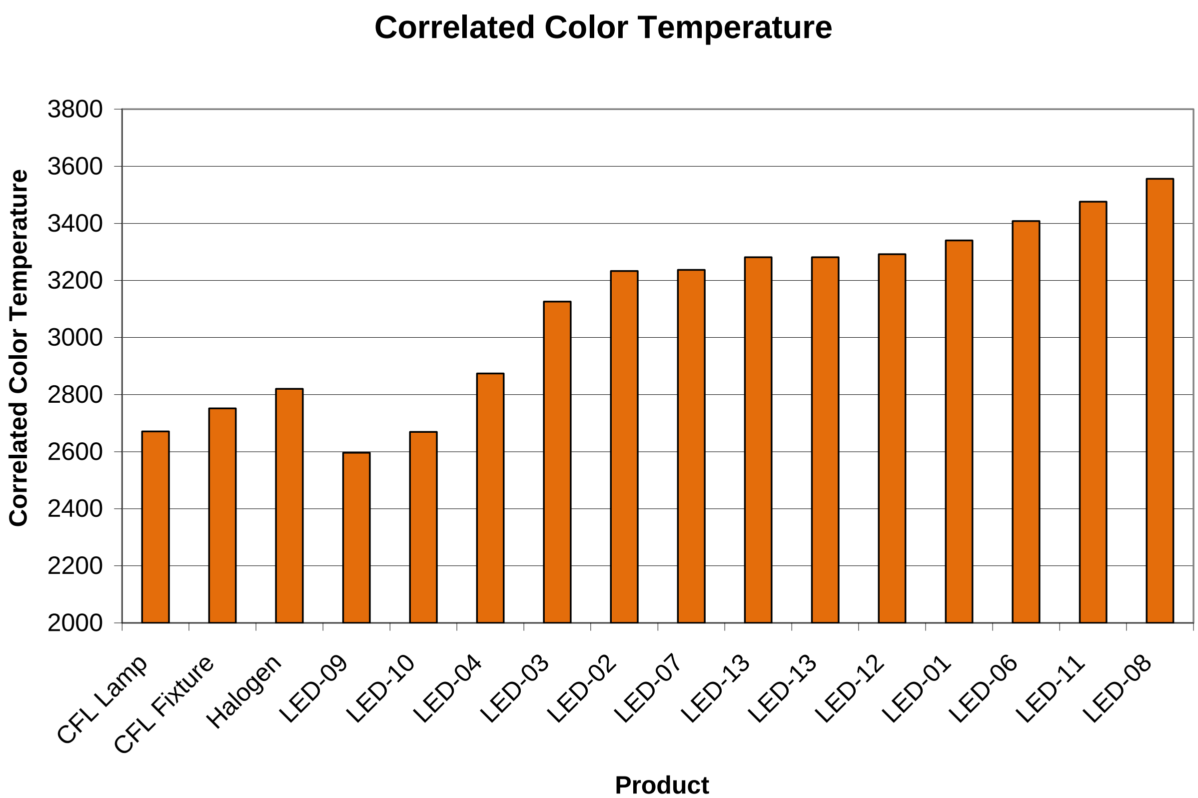

FIGURE 13. CCT RESULTS

The LED fixtures tested for this evaluation ranged from 2596K to 3556K. Though LED products are also available in higher temperatures of up to 6000K, none were tested for this evaluation. Lower CCT products were selected for the residential market sector. A benefit of the LED technology is the available range of CCT when compared to the compact fluorescent and halogen baseline cases. Manufacturer advertised values for CCT ranged from 2700K – 3500K and most tested values were close to these manufacturer ratings.

COLOR RENDERING INDEX

The CRI values for each of the LED measure cases were tested and compared with the baseline cases. Typically, a higher CRI is better and has a more positive impact on visual perception.

Figure 14 shows the measured CRI for all LED and baseline lamps tested. The values are arranged in decreasing CRI for easy comparison to the baseline lamps.

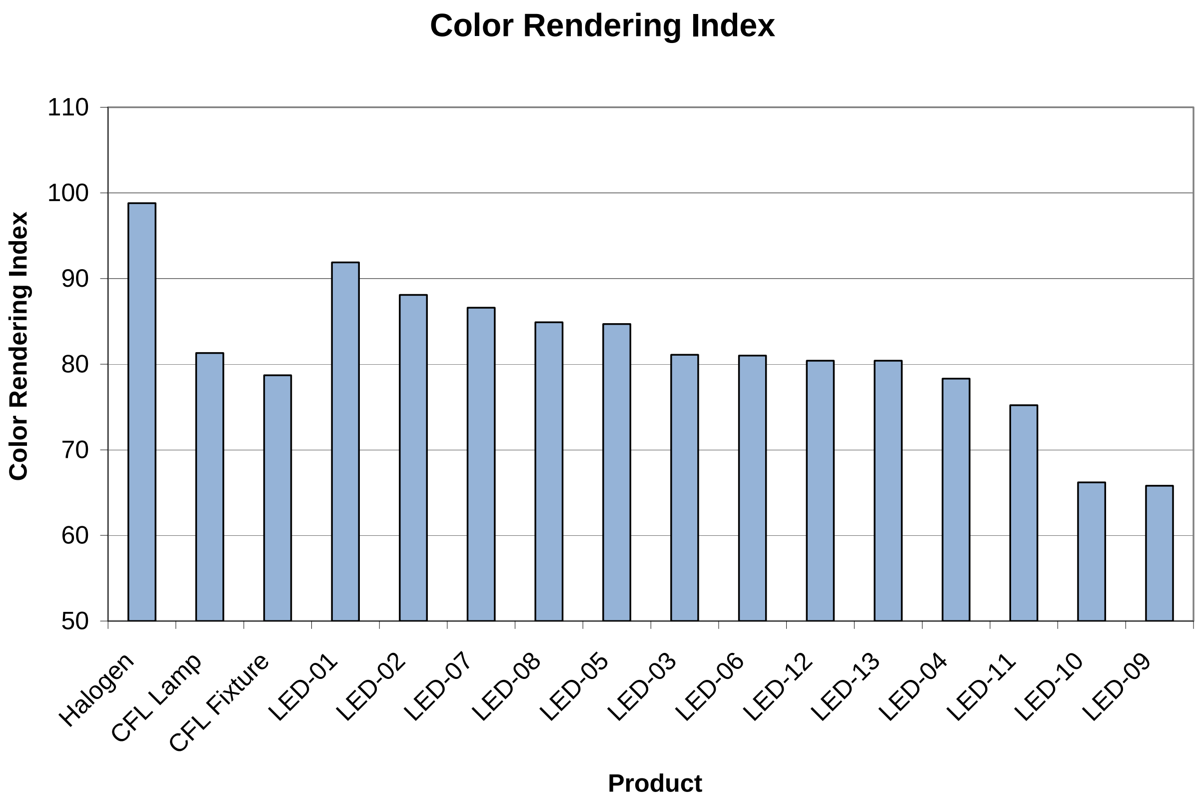

FIGURE 14. CRI RESULTS

The halogen lamp has the highest CRI value of 98.8. Of the tested LED measure cases, the closest comparable LED to the halogen lamp was LED-01 at 91.9. The tested compact fluorescent lamp has a CRI value of 78.7. The most comparable LED in terms of CRI is LED-04 with a value of 78.3. The CRI values for LED products tested in this evaluation ranged from 65.8 - 91.9 which shows that there are some LED lamps available that have similar CRIs to that of popular market options.

POWER MEASUREMENTS

One of the objectives of the LED recessed can fixture tests was to determine if replacing compact fluorescent or halogen lighting with LED style fixtures would result in energy savings without compromising light quantity. The efficacy comparison provides information to help to answer this question.

Unlike incandescent lamps LEDs typically require AC-DC drivers, similar to electronic ballasts for CFLs to control the voltage and current to the light source. DC power cannot be measured separately to understand the AC-DC efficiency since the driver is typically integrated within the lamp.

LED drivers are electronic power supplies that can have poor power factor. Higher power factor is more desirable than lower power factor, since power factor indicates how much more current is needed for the same amount of usable power delivered. A product with high power factor draws less current than a product with a lower power factor. Higher power factor minimizes transmission and distribution currents, which reduces transmission losses and equipment size. In turn, this makes the delivery of electricity more efficient and less costly. Figure 15 shows the measured power factor for each of the tested fixtures.

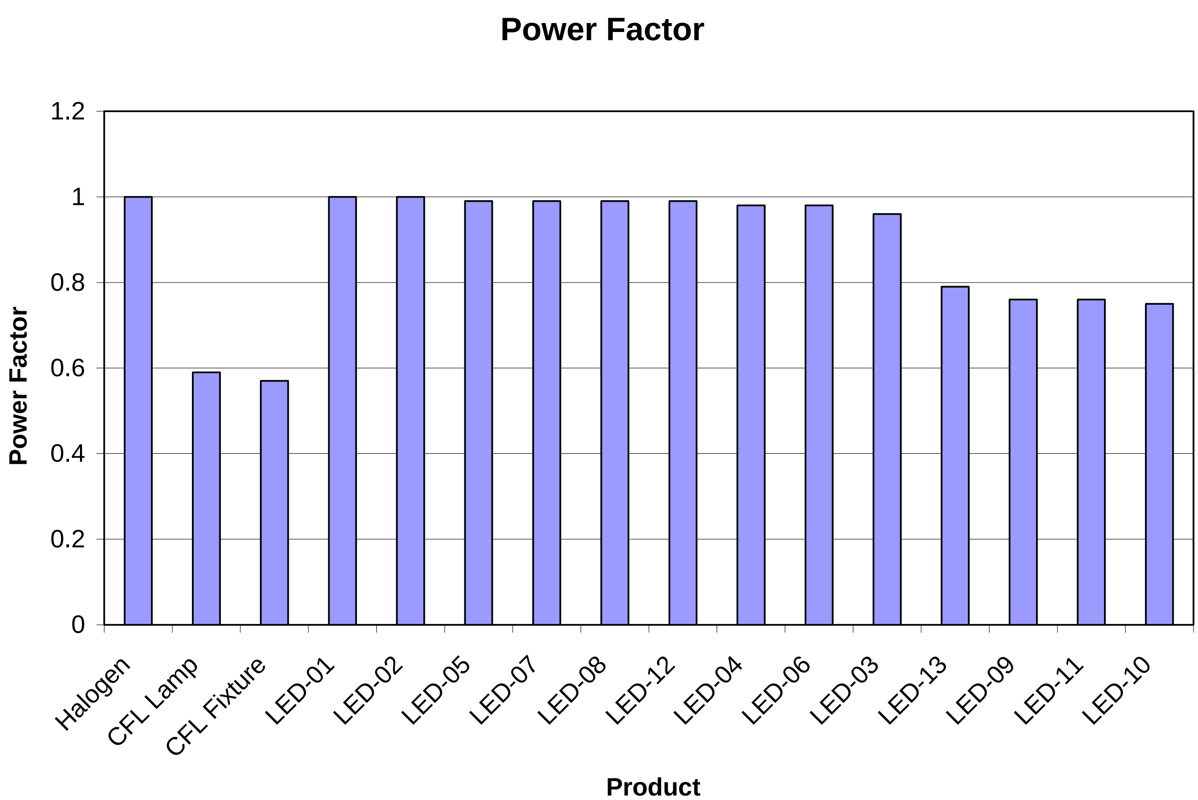

FIGURE 15. MEASURED POWER FACTOR RESULTS

All of the LEDs tested better than the tested CFL in terms of power factor. Most of the LED cases had power factors close to 1.

In retrofit applications, for recessed can applications, consumers will have three viable options to switch to LED technology. This includes a screw type LED retrofit for existing recessed can fixtures, or a fixture change from a pin-based type CFL to a hard-wired LED fixture. If a consumer is considering a kitchen remodel and is planning to switch to recessed can lighting, a hard-wired LED fixture is also an option in this scenario.

For new construction applications, there are Title 24 compliant hard-wired LED fixtures available from multiple manufacturers. These recessed can fixtures can be used as an alternative to compact fluorescent pin-based fixtures.

Since many kitchen configurations may exist in residences within SCE territory, it was necessary to identify the most popular lamp types for kitchen recessed cans. Since there are multiple options, it is important to understand each of the baseline and measure cases power demand. Figure 16 shows the measured power (in watts) for LED, compact fluorescent, and halogen lamps.

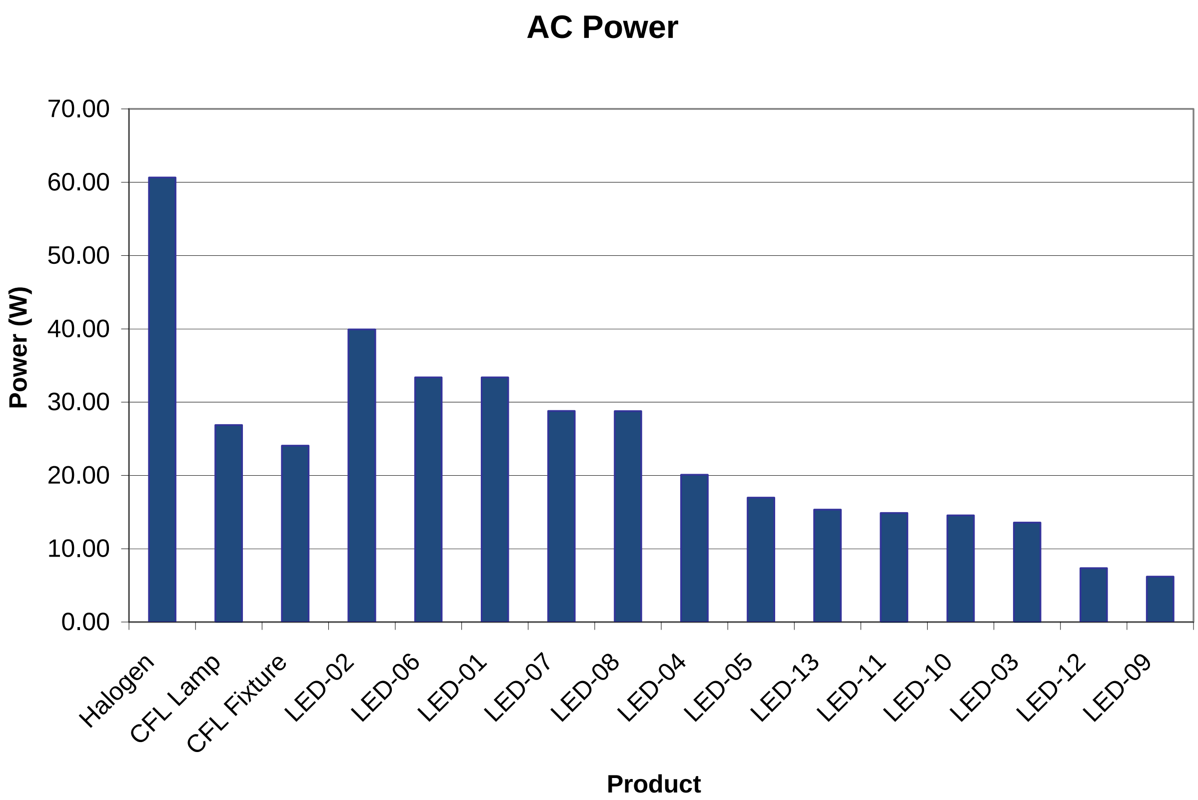

FIGURE 16. POWER DEMAND RESULTS

LED fixtures require less power than halogen baseline fixtures to operate. Manufactured advertised values for power consumption ranged from 5 - 35.8 watts. Most of the LEDs tested were close to their advertised values with the largest variance being +4.8 watts. Eight of the thirteen LED lamps required less power than the CFL baseline. In order to be considered more efficient, the lamp must use less electricity while providing the same or more light output. Measured power data is combined with lumen output to provide an efficacy value. If the efficacy is higher than that of the baseline cases it is considered more efficient.

EFFICACY

Efficacy is defined as the lumen output per Watt of power and provides a common unit for comparison between products. The downlight fixture's power data was measured during the Integrating Sphere test. The fixture power data was then combined with the sphere lumen data to determine efficacy.

Since CFL lamps are placed in recessed cans for most kitchen applications, the bare lamp efficacy does not apply to normal installed conditions. The bare lamp CFL and the CFL fixture values are used for high and low efficacy comparisons. Figure 17 shows the range of measured efficacy values for the fluorescent, halogen, and LED products. A higher efficacy is optimal.

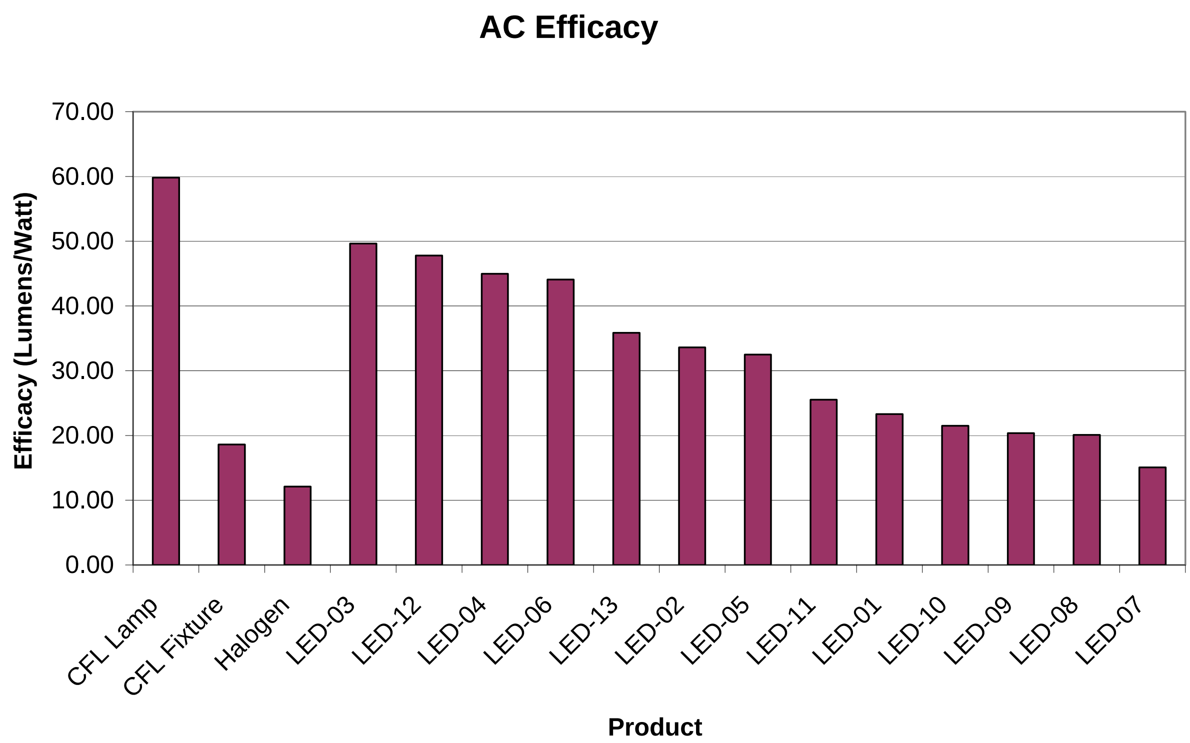

FIGURE 17. MEASURED EFFICACY VALUES

All but one of the tested LED lamps demonstrated better efficacies then the compact fluorescent baseline. All of the LED lamps demonstrated better efficacies than the halogen baseline. This means that most of the units use less electricity while providing the same or more light.

The highest LED product efficacy tested was LED-03 at 49.6 lm/W, which is 1.66 times more efficient than the CFL baseline and 3.09 times more efficient than the halogen baseline.

Figure 18 shows a plot of the efficacy and lumen output of LED, CFL, and halogen products. Points higher up provide higher light output and points further to the right are more efficacious.

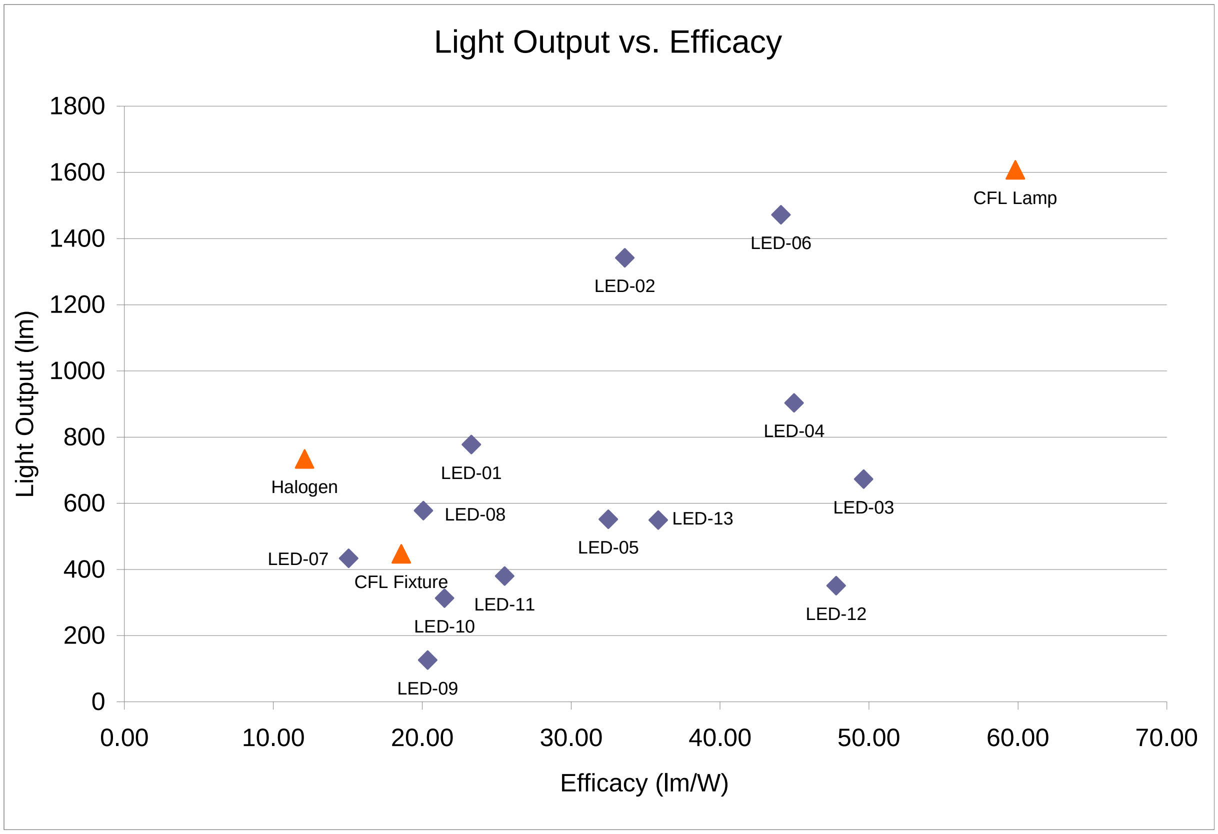

FIGURE 18. LIGHT OUTPUT VS. EFFICACY

Measured values of efficacy vs. lumen output for most of the LED fixtures were found to be better than the compact fluorescent baseline and the halogen baseline. The LED-08 product has a light output and efficacy similar to the bare compact fluorescent lamp. Though the light output of the LEDs vary, the efficacies of all but one LED product remain above that of the CFL baseline. All of the LED products performed better than the halogen baseline products.

With other LED products there has been a noticeable trend that an increase in efficacy results in an increase in light output. This is because more efficient LED chips can deliver more lumens at the same power[5].

ASSESSMENT INTEGRATION

The purpose of the assessment integration was to estimate the annual energy savings. This figure is directly dependent on the lamps' annual operating hours. For purposes of this study, the annual operating hours will be the figure determined through the field assessment. This figure is set at 1180.2 hours per year for houses with only overhead lighting and 963.9 hours per year for houses with both overhead and under cabinet lighting.

Though there are a few LED lamps that can be directly compared to the compact fluorescent baseline, the wattage of the fluorescent needs to be normalized to equal the light level of the available LEDs. To do this, the lumen output of each of the LEDs was divided by the measured efficacy of the compact fluorescent of 18.59 lm/W as shown in Equation 1. The equivalent Watts value reflects how much power is needed from the compact fluorescent to meet the lumen output of the LED lamp in question.

$$EquivalentWatts = \frac{(LEDMeasuredLumens)}{(CFLEfficacy)}$$

The example below shows the equivalent Watts of LED-01.

$$EquivalentWatts = \frac{(777.6lm)}{(18.59lm/W)}$$

$$EquivalentWatts = 41.83Watts$$

EQUATION 1. EQUIVALENT WATTS CALCULATION

After the compact fluorescent equivalent watts were determined, demand savings could be calculated. Assuming an 1180.2 hour annual operation for kitchens with only overhead lighting (Kitchen Configuration A), the energy savings was calculated as shown in Table 3. The same process was performed for kitchens with both overhead and under cabinet lighting (Kitchen Configuration B) using a 963.9 hour annual operation for the overhead lighting. Energy Savings for LED overhead lighting installed in Kitchen Configuration B as shown in Table 4. The same process was performed using Equation 1 to determine halogen equivalent watts. Values for annual operating hours were held constant to determine the energy savings of the tested LED vs. the halogen baseline. Energy savings for the tested LED products over the halogen baseline are shown in Table 5 and Table 6 for each kitchen configuration.

LED #	LUMENS	MEASURED WATTS	EQUIVALENT CFL WATTS	WATTS SAVED	OPERATING HOURS	KWH SAVED
LED-01	777.59	33.37	41.83	8.45	1180.2	9.98
LED-02	1341.79	39.94	72.18	32.24	1180.2	38.05
LED-03	673.12	13.56	36.21	22.65	1180.2	26.73
LED-04	903.64	20.10	48.61	28.51	1180.2	33.65
LED-05	551.72	16.98	29.68	12.70	1180.2	14.99
LED-06	1471.99	33.39	79.18	45.79	1180.2	54.05

LED #	Lumens	Measured Watts	Equivalent CFL Watts	Watts Saved	Operating Hours	kWh Saved
LED-07	433.71	28.80	23.33	-5.47	1180.2	-6.46
LED-08	578.06	28.78	31.10	2.31	1180.2	2.73
LED-09	126.20	6.20	6.79	0.59	1180.2	0.70
LED-10	313.14	14.56	16.84	2.28	1180.2	2.69
LED-11	380.02	14.88	20.44	5.56	1180.2	6.56
LED-12	351.54	7.36	18.91	11.55	1180.2	13.64
LED-13	549.50	15.33	29.56	14.23	1180.2	16.80
Averages				**13.95**		**16.47**

Table 3. Energy Savings LED vs. Compact Fluorescent (Kitchen Configuration A)

LED #	Lumens	Measured Watts	Equivalent CFL Watts	Watts Saved	Operating Hours	kWh Saved
LED-01	777.59	33.37	41.83	8.45	963.9	8.15
LED-02	1341.79	39.94	72.18	32.24	963.9	31.08
LED-03	673.12	13.56	36.21	22.65	963.9	21.83
LED-04	903.64	20.10	48.61	28.51	963.9	27.48
LED-05	551.72	16.98	29.68	12.70	963.9	12.24
LED-06	1471.99	33.39	79.18	45.79	963.9	44.14
LED-07	433.71	28.80	23.33	-5.47	963.9	-5.28
LED-08	578.06	28.78	31.10	2.31	963.9	2.23
LED-09	126.20	6.20	6.79	0.59	963.9	0.57
LED-10	313.14	14.56	16.84	2.28	963.9	2.20
LED-11	380.02	14.88	20.44	5.56	963.9	5.36
LED-12	351.54	7.36	18.91	11.55	963.9	11.14
LED-13	549.50	15.33	29.56	14.23	963.9	13.72
Averages				**13.95**		**13.45**

Table 4. Energy Savings LED vs. Compact Fluorescent (Configuration B)

LED #	Lumens	Measured Watts	Equivalent Halogen Watts	Watts Saved	Operating Hours	kWh Saved
LED-01	777.59	33.37	64.26	30.89	1180.2	36.46
LED-02	1341.79	39.94	110.89	70.96	1180.2	83.74
LED-03	673.12	13.56	55.63	42.07	1180.2	49.65
LED-04	903.64	20.10	74.68	54.58	1180.2	64.42
LED-05	551.72	16.98	45.60	28.62	1180.2	33.77

LED #	Lumens	Measured Watts	Equivalent Halogen Watts	Watts Saved	Operating Hours	kWh Saved
LED-06	1471.99	33.39	121.65	88.26	1180.2	104.17
LED-07	433.71	28.80	35.84	7.04	1180.2	8.31
LED-08	578.06	28.78	47.77	18.99	1180.2	22.41
LED-09	126.20	6.20	10.43	4.23	1180.2	5.00
LED-10	313.14	14.56	25.88	11.31	1180.2	13.35
LED-11	380.02	14.88	31.41	16.52	1180.2	19.50
LED-12	351.54	7.36	29.05	21.70	1180.2	25.61
LED-13	549.50	15.33	45.41	30.09	1180.2	35.51
Averages				**32.71**		**38.61**

Table 5. Energy Savings LED vs. Halogen (Kitchen Configuration A)

LED #	Lumens	Measured Watts	Equivalent Halogen Watts	Watts Saved	Operating Hours	kWh Saved
LED-01	777.59	33.37	64.26	30.89	963.9	29.77
LED-02	1341.79	39.94	110.89	70.96	963.9	68.39
LED-03	673.12	13.56	55.63	42.07	963.9	40.55
LED-04	903.64	20.10	74.68	54.58	963.9	52.61
LED-05	551.72	16.98	45.60	28.62	963.9	27.58
LED-06	1471.99	33.39	121.65	88.26	963.9	85.08
LED-07	433.71	28.80	35.84	7.04	963.9	6.79
LED-08	578.06	28.78	47.77	18.99	963.9	18.30
LED-09	126.20	6.20	10.43	4.23	963.9	4.08
LED-10	313.14	14.56	25.88	11.31	963.9	10.91
LED-11	380.02	14.88	31.41	16.52	963.9	15.93
LED-12	351.54	7.36	29.05	21.70	963.9	20.91
LED-13	549.50	15.33	45.41	30.09	963.9	29.00
Averages				**32.71**		**31.53**

Table 6. Energy Savings LED vs. Halogen (Kitchen Configuration B)

CONCLUSION

Overall, the LED recessed can lighting products tested during this study performed better than the pin-based CFL in terms of efficacy with the exception of one LED product. Though many of the LED lighting products require less power, most can still meet or exceed the CFL in terms of light output and power factor. After normalization of the CFL to determine equivalent Watts, all LED measure cases saved electricity with the exception of one LED product. Using the average energy savings over the 26W CFL for all LED cases, it is estimated that the typical LED will save 16.47 kWh annually in Kitchen Configuration A and 13.45 kWh annually in Kitchen Configuration B with under cabinet lights.

Though the tested LEDs did not meet or exceed the halogen baseline in terms of light output and CRI, they did exceed it in terms of power requirements and efficacy. After normalization of the halogen, all LED measure cases saved electricity with some providing a comparable CRI value. Using the average energy savings over the 60W halogen for all LED cases, it is estimated that the typical LED will save 38.61 kWh annually in Kitchen Configuration A and 31.53 kWh annually in Kitchen Configuration B with under cabinet lights.

Since the CFL baseline is rated at 26W, its required efficacy is 50 lm/W. The bare lamp tested at 59 lm/W, however when installed in the test recessed can fixture this efficacy dropped to 18 lm/W which demonstrates the importance of a well-designed can fixture. There is some concern that not all LED's tested met the minimum efficacy standards required by Title 24. Due to the design of the LED style lamps, can design will most likely not affect the efficacy of the overall fixture. There are some concerns that only two of the LED's tested met the minimum efficacy standards required by Title 24. The inability to meet Title 24 standards will prohibit the technology from being installed in new construction applications.

RECOMMENDATION

The field results of the study were limited in scope. It is recommended that a larger scale evaluation of usage profile be conducted to have a more reliable data set for the 'hour' portion of the energy savings calculations.

The results of this study show that the current state of LED downlight technology can more efficiently meet the technical requirements of the baseline CFL and incandescent halogen downlights. There are LED products that have sufficient light output to replace a baseline downlight fixture with similar CCT and CRI characteristics.

However, there are large variations in many aspects of LED downlight technology. The light output of LED downlights range from a level that is close to a CFL bare lamp, about 1600 lumens, down to less than 200 lumens. The CRI and CCT variation can be easily perceived. The power ranges from 40 watts to approximately 5 watts. There is much less variation in the standard halogen incandescent lamps. This difference in variation between the technologies can pose a threat to the acceptability of more energy efficient LED technology because of the expectation of minimal variation.

It is recommended that a set of criteria be established to reduce the risk of rejection in the market due to negative product variation. The criteria should include minimum efficacy and light output values as well as acceptable CRI and CCT ranges. The key to the long term success of energy efficient LED technology is high quality products that meet or exceed end-user expectation from the lighting quantity and quality standpoint. Concurrently, the technology should have a high level of efficiency to maximize energy savings and demand reduction.

LED technology progresses rapidly. It is recommended that a similar evaluation be conducted at a later time to understand the potential improvements in efficacy and efficiency. The results from this future study will potentially allow for additional energy savings and a better understanding of the advancement in the technology.

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