Illuminating Current CFL Usage Patterns

Results from a CFL Metering Study

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ABSTRACT

Compact fluorescent lamp (CFL) saturation in residential homes has dramatically increased in recent years, particularly in California, due to improvements in CFL technology and a significant reduction in prices. Existing prior data on CFL usage patterns, collected in the early 1990s, may not provide reliable estimates of the energy and peak savings for this important residential energy-efficiency measure. Program planners need up-to-date information on how consumers are currently using CFLs.

This paper describes the results of a 2003 California investor-owned utility (IOU) CFL metering study, which included 375 participating homes representing the state's varied demographics, dwelling types, and climate zones. A total of 1,200 interior CFLs were monitored from 6 months to 1 year. In addition to CFL hours of usage and peak diversity factors, lighting inventory results from an on-site survey that was conducted at each participating home will also be provided in this paper.

Introduction

CFL saturation in residential homes has dramatically increased in recent years, particularly in California, due to improvements in CFL technology and a significant reduction in prices. Existing prior data on CFL usage patterns, collected in the early 1990s, may not provide reliable estimates of the energy and peak savings for this important residential energy-efficiency measure. Most of these earlier studies were conducted to support protocol-driven CFL program impact evaluations; most did not rely on on-site data collection; and even fewer involved collection of metered time-of-use data. Those that did were conducted to evaluate specific utility programs (i.e., not statewide). In addition, these studies were conducted over 7 years ago, reflecting different patterns of CFL use and saturation. Moreover, these studies were designed to meter only one CFL per home.

Program planners need up-to-date information on how customers are currently using CFLs, i.e., where are they being installed? How many hours on average are CFLs being used? How often are CFLs being used during peak hours? How do hours of usage vary as CFL saturation increases? In 2003, the California IOUs commissioned a CFL metering study to provide this needed information.

This paper will focus on the results of the CFL metering study and provide updated ex post savings assumptions, including CFL hours of usage and peak diversity factors. In this study, 1,200 interior CFLs were metered for a period of 6 months to 1 year. The sample of homes included in the study represents the state's varied demographics, dwelling types, and climate zones. The monitoring period began in the summer of 2003 and was concluded in late fall of 2004. An on-site survey, including a complete lighting inventory, was conducted in conjunction with the installation of meters, and results from this survey will also be provided in this paper.

Methodology

Sample Development

The metering sample that supported this study was developed in two phases. The first phase was initiated in the summer of 2003 as part of a broader evaluation of the California IOUs' 2002 Upstream Residential Lighting program. The first sample included 100 homes, and meters were installed on all interior fixtures containing CFLs (where installation was feasible) for 6 months.

The second phase of the study began in the spring of 2004 when the IOUs authorized use of the 2003 Upstream Residential Lighting program evaluation budget to augment the metering study sample size and monitoring period. A total of 78 of the first phase's sites agreed to extend their monitoring period an additional 6 months, for a total monitoring period of 1 year. An additional 275 sites were recruited, and their interior fixtures with CFLs were monitored for 6 months.

The sample was geographically clustered to control for survey implementation costs. A total of 7 clusters were selected that represented the major rural/urban and geographic distinctions within the IOU service territories. Table 1 shows how the study sample was distributed across the seven clusters.

Table 1. Total Study Sample

Cluster	Geographic Region	Location of Region	IOU	Number of Sites
1	San Francisco Bay Area	North	PG&E	75
2	Fresno	Central Valley	PG&E	50
3	Los Angeles and Orange Counties	South	SCE	50
4	San Diego County	South	SDG&E	50
5	San Bernardino	South	SCE	50
6	Chico/Red Bluff	North	PG&E	50
7	Bakersfield	Central Valley	SCE	50
Total				375

On-Site Survey Development

An on-site survey was conducted in conjunction with the installation of loggers at each participant's home. During the on-site survey, the following information about the home and its lighting fixtures was collected:

- House type (i.e., single-family detached, single-family attached, apartment, etc.)
- Use area or room type (i.e., living room, kitchen, etc.)
- CFL wattage, fixture and bulb type (e.g, 20-Watt CFL ceiling fixture)
- Control type (dimmer switch, dual switching, occupancy sensor, etc.)
- Self-reported wattage and type of previous bulb (e.g., 100-Watt incandescent).

The on-site survey was based on similar recent surveys of homes such as those used for the IOUs' Residential New Construction Program Evaluation. A detailed instruction form with survey guidelines was developed to accompany the survey, and auditors were trained on the guidelines, both in a classroom setting and in the field. KEMA's experienced senior field staff conducted the training and participated in the first 2 weeks of field visits to ensure a quality data collection process.

On-Site Monitoring and Survey Implementation

Recruitment. The sample for on-site data collection was recruited according to the following process:

- Potential phase 1 participants were identified during the 2002 program evaluation consumer telephone survey as having CFLs in the home and living in one of the study clusters. The sample was filled by KEMA representatives offering a $50 incentive for the 6-month study via a follow-up phone call.
- Phase 2 participants were recruited in three ways:
    - Phase 1 participants were offered the option to continue on to phase 2 for an additional 6 months and $25.
    - Potential participants that had not been contacted during phase 1 were recruited by KEMA representatives with the original incentive of $50 for a 6-month study.
    - The remainder of the sample was filled by KEMA staff recruiting from a new database of qualifying, potential participants developed by a survey research firm using telephone random-digit dialing. The original $50 incentive was offered.

Monitoring Period. Phase 1 meters were installed in June–July 2003 and were either removed in March–April 2004 (Group A) or remained until September–October of 2004 (Group B). Phase 2 meters were installed in March–April 2004 and were removed in September–October 2004 (Group C). Table 2 shows the monitoring period by phase and group.

Table 2. Monitoring Period by Phase/Group

			2003							2004									
	Phase	**# Sites**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
A	1	22																	
B	1	78																	
C	2	275																	

=installation or removal period
=monitoring period

Equipment. Time-of-use lighting loggers were used to capture all on/off switches of the selected fixtures during the monitoring period. Two models were used, one by DENT Instruments and one by Onset Computer Corporation. Both used a photocell with variable sensitivity, recorded a time and date for every on/off switch captured, and had their own software for data retrieval. The DENT model had a built-in magnet for simple installation.

Logger Installations. The loggers were installed in fixtures with CFLs while KEMA auditors conducted a complete lighting inventory of the home. The intent to monitor all CFLs in each home was not always achieved due to privacy, safety, and other concerns. The final cleaned dataset was weighted by room type to adjust for the fact that the monitored sample differed slightly from the CFL inventory with respect to the distribution of CFLs by room type.

Logger Removals. As program participants exited the study, they were offered the choice of either having pre-stamped padded envelopes sent to them for self-removal or setting up an appointment for an auditor to return and remove them. Once the loggers were returned, the dataset was downloaded from the logger to a hard drive, cleaned, and then analyzed.

Data Quality Assurance Procedures. Quality assurance procedures that have been developed and implemented in numerous prior metering studies were used throughout the survey implementation process to ensure that reliable, cost-effective data were gathered, processed, and analyzed.

An experienced KEMA auditing team was provided with thorough guidelines and detailed, customized training by the project manager and KEMA's equipment expert. During the phase 1 and 2 transition, the auditors were able to ensure that loggers were functioning properly at those sites continuing for the full year-long study and correct those that were not. Quality control of hard-copy documentation and data entry was ongoing during the logger installation and removal periods. KEMA staff reviewed one another's work during data cleaning and analysis. Customized Microsoft Access databases and the SAS system were used for storing, analyzing, and cleaning the data. KEMA software specialists provided quality control on their use.

Analysis

After data validation and cleaning, seasonality adjustment factors and weights were developed. Additionally, outdoor lighting usage was estimated at each site using a combination of lighting inventory data from the on-site survey and second source data.

Seasonality. Average daily usage estimates on a per-site basis were adjusted due to the seasonality affects associated with partial year monitoring. For fixtures in a given month that were either monitored for less than half the month or not monitored at all, seasonality factors were developed using regression analysis to impute the missing monthly usage values. Then the average daily usage for each site was calculated equal to the average of its 12 monthly usage values.

A regression model was specified that determined the increase in CFL usage as a result of an decrease in daylight hours. Separate regressions were run by day type (weekend versus weekday) and room type (sensitive to daylight hours: kitchen, dining room, living room versus not sensitive: bathroom, bedroom, hallway). The regression results yielded a set of seasonality factors for each month, room type and day type combination. The regression equation indicated that a 1-hour decrease in daylight would result in less than 5 minutes per day additional CFL usage in a bathroom, bedroom, or hallway, but more than a 15-minute increase per day in CFL usage in a living room, kitchen, or dining room.

The seasonality factors were used to impute usage values over each site's missing months. For each day type and room type combination, the imputed monthly value for a fixture was calculated as follows:

$$m_{xi} = (M_x / S) * s_i$$

where:

m_{xi} = imputed usage value for month i and fixture x

M_x = the sum of monthly monitored usage values for fixture x

s_i = Seasonal factor (one set per day type/room type combination) for month i

S = the sum of the seasonal factors that correspond to M_x

Weighting. The logger data were collected at the fixture level and were weighted by the number of lamps associated with that fixture. The final cleaned dataset was also weighted by room type to adjust for the fact that the monitored sample differed slightly from the CFL inventory with respect to the distribution of CFLs by room type.[1] In analyzing the monitoring data, it was found that the major driver of the variation in CFL usage is the location of the fixture. Since a detailed inventory was captured at every home, the monitored sample was compared to the actual distribution of CFLs across all participating homes. Small but significant differences were found and, as such, adjustment weights were developed.[2]

Outdoor Lighting. The monitored sample explicitly excluded outdoor CFLs since the meters employed for the study operate on the presence of light. That is, meters installed on outdoor fixtures would capture daylight in addition to the light emitted by the fixture. The results were adjusted to account for exclusion of outdoor CFLs in the sample by applying results from the California Baseline Lighting Efficiency Technology Report (Heschong Mahone Group 1997)[3] to the inventory sample on outdoor fixtures with CFLs.

The 1997 study provided average run-time hours for outdoor fixtures by fixture type and control type based on adjusted self-reported data. These values were applied to the inventory data on outdoor CFLs on a per-site basis, and run-time hour results were adjusted by including the inventoried outdoor CFLs in the analysis.[4] The study results by and large focus on indoor lighting since outdoor lighting results are not based on current metered data and may not be reliable.

Sample Disposition

Table 4 presents the final study disposition of the 375 participating sites.

Table 4. Disposition of Monitoring Sample Sites, Fixtures, and CFLs

Disposition Category	Number of Monitored Fixtures	Number of Monitored CFLs
Initial sample	891	1,167
Dropped out	12	23
Unreturned loggers	57	71
Logger failure	70	90
Included in analysis	752	983

Tables 5 and 6 show the number of fixtures and CFLs included in this analysis by utility service territory and room type.

[1] While the study attempted to monitor all interior fixtures with CFLs installed, for a variety of reasons (e.g., infeasibility, respondent complaint regarding aesthetics, etc.) there were many fixtures that were not monitored. However, the inventory that was taken of each participating home captured detailed information on every interior and exterior lighting fixture.

[2] Alternative estimates were also developed, using sample expansion weights that take into account the clustering of bulbs by household, and stratification of households by region. The alternative estimates were similar to those presented here, with differences of 3 percent or less for the overall and service territory averages.

[3] This prior study analyzed data from 3 studies, including an SCE study with 477 time-of-use light meters installed in a balanced sample of homes in SCE territory, 1 fixture per household. (Due to attrition, malfunctions, and missing data, the final usable sample was 359 meters.) The meters ran for 4 to 8 months each, from the winter or spring to fall of 1993. Self-reported data on a larger sample were adjusted based on comparisons between the metered data and the self-reported data on the smaller sample.

[4] A second set of adjustment weights was created based on the lighting inventory data including outdoor fixtures. This set of weights was used whenever the combined indoor and outdoor estimates were presented.

Table 5. Number of Monitored Fixtures/CFLs in Sample by Utility Service Territory

Utility	Monitored Fixtures		Monitored CFLs	
	Number	Percent	Number	Percent
PG&E	419	56%	572	58%
SCE	227	30%	281	29%
SDG&E	106	14%	130	13%
Total	752	100%	983	100%

Table 6. Number of Monitored Fixtures/CFLs in Sample by Room Type

Room	Monitored Fixtures		Monitored CFLs	
	Number	Percent	Number	Percent
Living room	174	23%	204	21%
Bedroom	152	20%	199	20%
Bathroom	103	14%	181	18%
Kitchen/Dining room	122	16%	170	17%
Family room	79	11%	93	10%
Hallway	54	7%	61	6%
Garage	27	4%	27	3%
Other room	15	2%	21	2%
Laundry/utility room	26	3%	27	3%
Total	752	100%	983	100%

Results

CFL Usage

The following CFL usage results are based on the cleaned, weighted and seasonally adjusted CFL metering data (with the exception of one mention of the outdoor lighting estimate).

CFL Hours of Usage. CFL usage assumptions are key factors in lighting program savings estimates. In the past, the utilities and other energy-efficiency program implementers relied on studies of residential lighting in general (not specifically CFLs) or specific impact evaluations of CFL programs. This study's approach is unique in that it provides estimates of CFL usage across all homes in the IOUs' service territories—a segment that has been directly (via point-of-sale rebates) or indirectly (via manufacturer buydown and macro effects of the program on product price, availability, and exposure) influenced by the Upstream Residential Lighting Program.

Based on this study's metering results, the average usage of indoor CFLs in California is 2.3 hours per day. The estimate does not change much when the estimate of outdoor lighting usage is included, increasing from 2.28 to 2.34. CFL usage varies by room type as shown in Figure 1, with CFLs located in kitchens, living rooms, outside, and in garages being used the most and those in laundry rooms, bathrooms and hallways being used the least. Other factors driving variation in CFL usage are fixture type (suspended, downlight, and torchiere fixtures are associated with higher usage mostly because they are installed in high-use locations), control type (use of timers/dimmers increases usage), and whether the CFL was purchased prior to 2001 (newer CFLs are used more often[5]). CFL hours of usage is shown for each of these categories in Table 7 below.

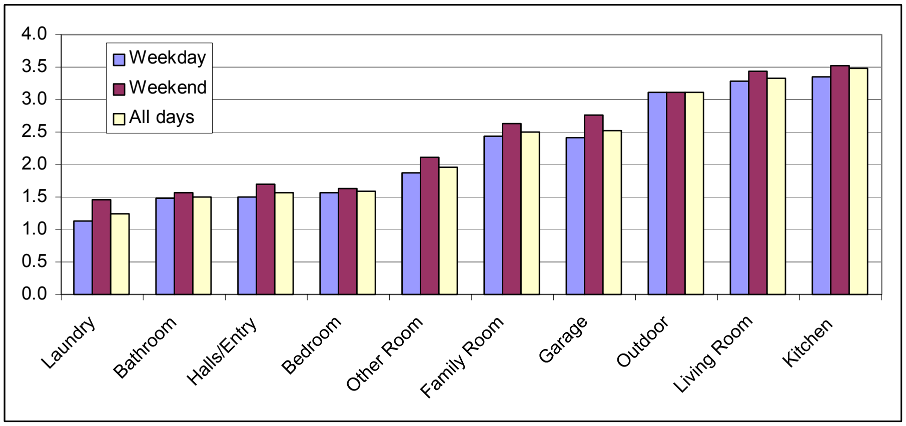

Figure 1. CFL Average Hours of Use Per Day by Room Type

Table 7. Indoor CFL Hours of Use Per Day by Monitored Fixture and CFL Characteristics

Segment	Category	Min # hours	Max # hours	Avg. # hours	# of obs
Fixture type	Ceiling mounted	0.0	15.6	1.7	221
	Ceiling Fan	0.0	11.2	2.7	86
	Downlights	0.0	12.0	2.8	69
	Floor/Table lamp	0.0	23.3	2.6	312
	Other	0.0	7.3	2.8	4
	Suspended	0.0	12.3	3.8	48
	Torchiere	0.1	9.2	2.9	48
	Wall-mounted	0.0	8.1	1.6	201
Control type	Switch	0.0	23.3	2.2	969
	Other (timer or dimmer)	0.3	16.3	5.5	14
CFL vintage	Purchased prior to 2001	0.0	9.0	1.8	91
	Purchased 2001 or later	0.0	23.3	2.3	834

Household, dwelling and CFL characteristics that do not cause significant variation in CFL usage are geographic location (e.g., northern versus southern latitudes), dwelling type, household composition, size of home, electric utility service territory, and CFL base type and wattage category. Likewise, customer experience with CFLs (such as when they became aware, when they first purchased, the number installed, etc.) does not appear to drive CFL usage.

Estimated CFL usage from this study is similar to the estimated hours of usage of residential lighting in general (Heschong Mahone Group 1997). When broken out by room type, CFLs are operated for a longer period versus all lamp types in living rooms, family rooms, and garages, and operated for a shorter period in laundry rooms, bathrooms, and hallways, as shown in Figure 2.

[5] This result may be because CFLs are now available in a wider array of applications, sizes and color renditions, and as such they may be used more often in high use areas such as living rooms and kitchens where they may not have worked in the past.

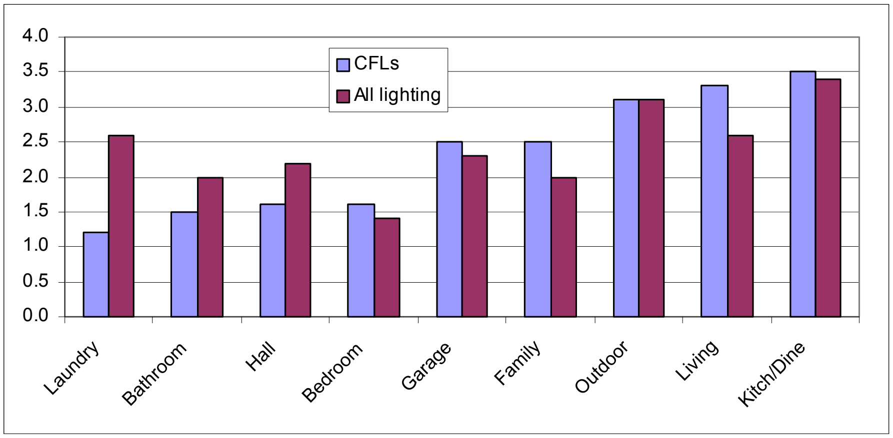

Figure 2. Average CFL versus All Residential Lighting Use Per Day by Room Type

Hourly Profile of CFL Usage. The metering data collected by this study were also used to develop load profiles of CFL usage over a 24-hour period. CFL load shapes show the average percentage that fixtures with CFLs are used for each hour of the day, averaged over the entire year. The study results indicate that less than 10 percent of CFL load occurs during the 12 to 6 pm summer weekday peak period. CFL usage peaks between 8:00 and 9:00 pm, and the time period associated with the lowest usage of CFLs is between 3:00 and 4:00 am. Note that CFL usage on weekends versus weekdays is lower in the morning, higher in the afternoon and evening, and about the same at night.

Figure 3 depicts indoor CFL load shapes by season and day type, with the x axis denoting the hour of the day, where 1 = 12 midnight to 1:00 am and 24 = 11:00 pm to 12 midnight. For this figure, winter refers to the month with the highest usage, which is December, and summer to the lowest usage month, which is June.

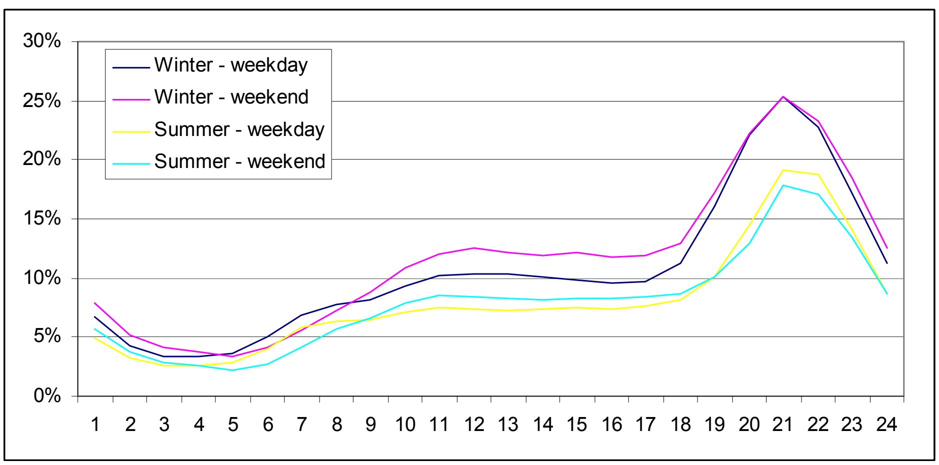

Figure 3. Indoor CFL Load Shapes by Season and Day Type

Self-Reported Hours of Use. In addition to using the CFL monitoring data to generate estimates of CFL usage and lifetime, respondent self-reported hours of usage were compared to actual monitored data to determine the extent of their correlation. If self-reported hours of usage were reliable and close to monitored data, collecting these types of data could be relied upon as an approach for future studies. In comparing self-reported CFL hours of usage to monitored hours of usage, it was found that self-reported values were overestimated by a factor of one-third.[6] The correlation coefficient between the two values was found to be 0.44, suggesting a moderately close relationship. Figure 4 shows a scatter plot of self-reported to monitored average CFL usage per day, with a trend line showing the approximate relationship between the two variables. If self-reported values were equivalent to monitored values across all fixtures (a perfect fit with a correlation coefficient of 1.0), then the points in the plot below would fall along a 45-degree line, starting from the junction of the two axes. Since self-reported usage is higher than monitored usage, the points tend to be closer to the self-reported usage axis. An approximation of the relationship between these two variables is the following equation: monitored usage = 0.66 + 0.59 * self-reported usage.

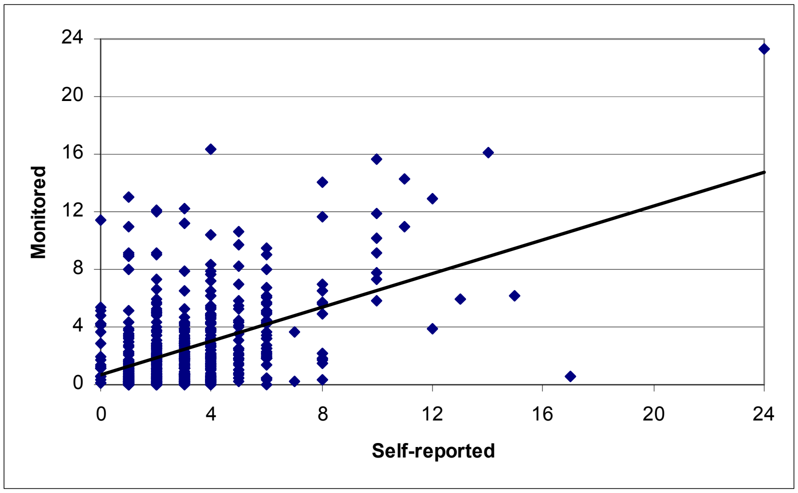

Figure 4. Relationship of Self-Reported to Monitored Average CFL Usage Per Day

CFL Installation Patterns

The following results are based on the detailed on-site survey and lighting inventory that was conducted at each participating site. Approximately 9,000 fixtures were inventoried across 375 homes, with about 6,000 fixtures containing incandescent lamps and 2,000 fixtures containing CFLs. Due to missing, inaccurate or inconsistent data, in some cases the number of fixtures reported is less than the total inventoried.

Installation/Retention Rate. The CFL installation rate is another input to determining the savings associated with CFL programs. This study attempted to determine an installation or retention rate for CFLs purchased since 2001. Of 2,739 CFLs purchased between January 2001 and June 2004, 1,794, or 65.5 percent of lamps, are presently being used. An additional 10 percent of CFLs purchased since 2001 are being stored for future use. A small but noteworthy percentage of CFL purchasers (13 percent) have had some of the lamps they purchased since 2001 burn out.

Wattage Differential. The pre-installation wattage is another important factor that is considered when determining energy savings associated with CFLs. Table 8 summarizes the results from the lighting inventory that was conducted during this study, with the wattage of the incandescent bulb that was in place before the CFL was installed and the typical wattage range of the CFL that was installed. The

[6] This finding is consistent with other similar studies (Ed Vine 2005).

most common CFL wattage is in the 13–17-Watt range, which is most often used to replace a 60-Watt incandescent bulb.

Table 8. Wattage of Incandescent Bulb Replaced with CFL

Original Incandescent Wattage	Monitored Fixtures w/ CFLs		Typical CFL Replacement Wattage
	Number	Percent	
40	55	12%	9-12
60	250	57%	13-17
75	84	19%	18-22
100	53	12%	23-26
Total	442	100%	

CFL Potential. The incandescent fixtures in the lighting inventory were each categorized as CFL-applicable or not to quantify the fraction of incandescent lamps that could technically be replaced with CFLs. Table 9 shows the results of this analysis. Cost and availability are the prevailing limiting factors in determining whether or not an incandescent bulb may be replaced by a CFL bulb. There are currently CFLs for sale on the Internet and specialty shops for nearly any incandescent fixture. Even small, dimmable, decorative candelabra-types can be found.

For standard incandescents the main factors are bulb size and dimmability. CFL-style flood lamp replacements are difficult to find and are often cost-prohibitive as well.

Table 9. Percentage of Incandescent Lamps that are Technically CFL-Applicable

Fixture Type	Incandescent Lamps that are Technically CFL-Applicable	
	Percent	Number
Standard	94%	6,864
Flood	81%	170
Globe	100%	82
Small base	49%	765
Reflector	86%	560
Decorative	100%	40
Total	86%	8,481

Miscellaneous Installation Pattern Results. Some additional results worth noting from the lighting inventory include:

- There is some evidence that as the number of CFLs installed increases, CFLs are more likely to be installed in lower-use areas of the home such as closets and hallways.[7] However, the average hours per usage per home is not significantly lower for homes with multiple CFLs installed.
- More than 90 percent of CFLs installed are in the 13–26-Watt range and have screw-in bases and integrated ballasts. The most common wattage range is the 13–17.

[7] This finding is consistent with a prior California lighting program evaluation (Rasmussen et al. 2002).

- CFLs that were purchased in 2001 or later are more likely to be in the 13–17-Watt or 23–26 range and are more likely to have an integrated ballast versus those that were purchased in 2000 or earlier.

Conclusions

This CFL study targeted a large diverse sample of residential homes with installed CFLs, and is designed to provide program planners with information on how residential customers use CFLs, which serves as an important update to prior residential lighting monitoring studies and CFL program impact evaluations. The study's monitoring results showed that residential customers operate their CFLs about the same length of time per day as other lamps (2.3 hours per day) but use them differently on a per-room basis. Moreover, the major driver of variation in the usage of CFLs is the room in which they are installed.

The lighting inventory results associated with the metering study concluded that on average 66 percent of lamps in residential homes with CFLs installed are incandescent. This percentage is likely higher in the 56 percent of homes that do not have CFLs (KEMA Inc., 2003). These results confirm what other recent studies have concluded that there remains a large untapped potential for residential CFL use. While the CFLs on the market today in theory could meet most of that potential, there remain cost and availability issues on the supply side, as well as consumer-related barriers such as lack of CFL awareness and attitudes towards CFL light quality and unwillingness to pay the higher up-front cost (KEMA Inc., 2003).

Residential lighting programs in California have been targeting these upstream and downstream barriers over the past several years and, along with national initiatives such as the Department of Energy's ENERGY STAR program, are critical in intervening in lighting markets to tap the remaining technical potential. The monitoring results from this study provide crucial program savings parameter estimates that will help program planners more accurately determine the energy savings associated with past and future programs, helping long-term decision-making regarding how to allocate program resources at the portfolio level.

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