Residential Lighting Metering Study: Detailed Methods and Preliminary Lighting Inventory Results

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Abstract

California is currently conducting a large-scale comprehensive residential lighting inventory and metering study. The primary goal of the study is to produce estimates of lighting hours of use by dwelling type, room type and fixture/lamp type. In addition, the study will provide whole-house lighting inventory data that will be used to determine the remaining potential for energy efficient lighting applications in the residential sector. These results will be used by regulators, planners and implementers to design future strategies for residential lighting programs.

The current study includes 1,200 households recruited randomly throughout California. The study includes households currently using compact fluorescent lamps (CFLs) as well as households who are not using any, and a range of dwelling types (e.g., single family, multi-family, and mobile homes). Meters are installed for at least six months, with the monitoring period beginning in July 2008 and going until December 2009.

In addition to estimating average hours of use for CFLs vs. non-CFLs, the study will produce estimates of hours of use by level of CFL saturation (e.g., households with no CFLs, households with a few CFLs, and households with CFLs installed in nearly every applicable socket). These estimates will help program planners and implementers predict the likely energy savings impacts from programs targeting these different market segments. In addition, the study attempts to identify CFLs that were rebated through utility programs to support analyses of whether or not there are any differences between average hours of use for program- and non-program CFLs.

This paper will present the detailed protocol for data collection and meter installation, as well as the results from the whole-house lighting inventory. Metering results will be available in early 2010.

Study Background

This study was designed to support the evaluation of the California's 2006-2008 Upstream Lighting Program. The Upstream Lighting Program is sponsored by the three electric investor-owned utilities (IOUs) of California – Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E). The program provides financial incentives to compact fluorescent lamp (CFL) manufacturers who in turn offer discounted CFLs to their retail partners, who then sell the discounted CFLs to consumers at a reduced price. Consumers purchasing IOU-discounted CFLs do not have to fill out a rebate form and are often not aware that they are purchasing products that have been discounted by an IOU. Further, despite IOU efforts to offer discounted products only through retailer partner locations within their service territories, CFLs are available to all consumers, regardless of their electricity provider. This makes the energy savings from these discounted CFLs very difficult to track and verify.

Part of the evaluation of this program includes an in-home survey of 1,200 California households to characterize residential lighting use and determine average hours-of-use for CFLs through a comprehensive metering study. The surveys take place throughout the service territories of all three of the state's electric IOUs, specifically 40% of the sites are in PG&E's service territory, 40% in SCE, and 20% in SDG&E. The results of this research provide the most accurate and comprehensive data on residential lighting use in California to-date. In addition, the study provides a valuable baseline of lighting saturation

and efficiency characteristics for use in estimating the energy savings potential from future programs. Preliminary information on the characteristics of residential lighting use will be presented in this paper; however, the results from the full metering sample will not be available until early 2010.

Approach

Households were recruited from IOU customer databases by random sampling. Each of the three participating IOUs provided the name, address, and telephone information for a total of 20,000 randomly selected residential customers.[1] Targets for recruiting and scheduling were established for 37 different regions throughout the IOU's service territories. These regions consisted of groups of counties or groups of zip codes within a county, depending on population density. Targets were set for each region based on the percent of households within each region and the overall target for each IOU. Figure 1 displays the sampling targets for the full sample.

Households were recruited by a cold call during which they were informed of the study and invited to participate. Participants received $100 for their participation in the study – $50 after an initial inventory and installation visit, and another $50 after the meters were removed. Depending on the size of the home, the initial visit could last up to two hours. Up to seven meters were installed on different fixtures and the metering period was six months.

Lighting Inventory

A whole-house inventory was collected for each household recruited into the study. This involved recording information about every lamp[2] installed inside and outside of each home. For each lamp, the following characteristics were recorded:

- Location in home by room type
- Type of heating and cooling system serving space in which it is located
- How the fixture is controlled (by switch, dimmer etc)
- The type of fixture it is installed in
- Number of watts
- Lamp type (Incandescent, CFL, Halogen etc)
- Lamp shape type or Bulb type (Spiral, globe, tube, etc)
- Base type (small screw-in, pin, standard-medium screw, etc.)

In addition, information on incandescent lamps and CFLs contained in storage for future use was also collected (i.e., wattage, type, shape, and base type). Table 1 provides a full list of the lighting inventory characteristics data collected for all lamps included in this study.

[1] The surveys were conducted in three waves. In the first wave, 300 households were recruited and in the second wave another 300 households were recruited. A random sample of 10,000 IOU residential customers was used to recruit the first 600 households. In the final wave, a total of 600 households were recruited and a second random sample of 10,000 IOU residential customers was used for recruiting.

[2] Use of the word lamp in this paper is consistent with the lighting industry use. A lamp in this sense is also known as a bulb in colloquial language. Here, a bulb is the glass casing encapsulating the filament or cathode.

Region	IOU		
	PG&E	SCE	SDG&E
Alameda Region	60		
Butte Region	24		
Contra Costa Region	40		
Desert South West Region		20	
El Dorado Region	20		
Fresno Region	36		
Humboldt Region	12		
Kern Region	24	8	
LA Central Region		64	
LA Coastal Region		44	
LA Inland Empire Region		76	
LA North Region		24	
Merced Region	12		
Monterey Region	24		
Orange North Region		72	
Orange South Region		12	16
Riverside West Region		36	
San Bernardino Region		64	
San Diego City Region			72
San Diego Coastal			36
San Diego NE Region			48
San Diego SE Region			36
San Diego South Region			32
San Francisco Region	36		
San Joaquin Region	16		
San Mateo Region	28		
Santa Barbara Region	16	8	
Santa Clara Region	60		
Solano Region	20		
Sonoma Region	36		
Tulare Region	4	16	
Tuolomne Region	12		
Ventura Region	x	36	
TOTAL	**480**	**480**	**240**

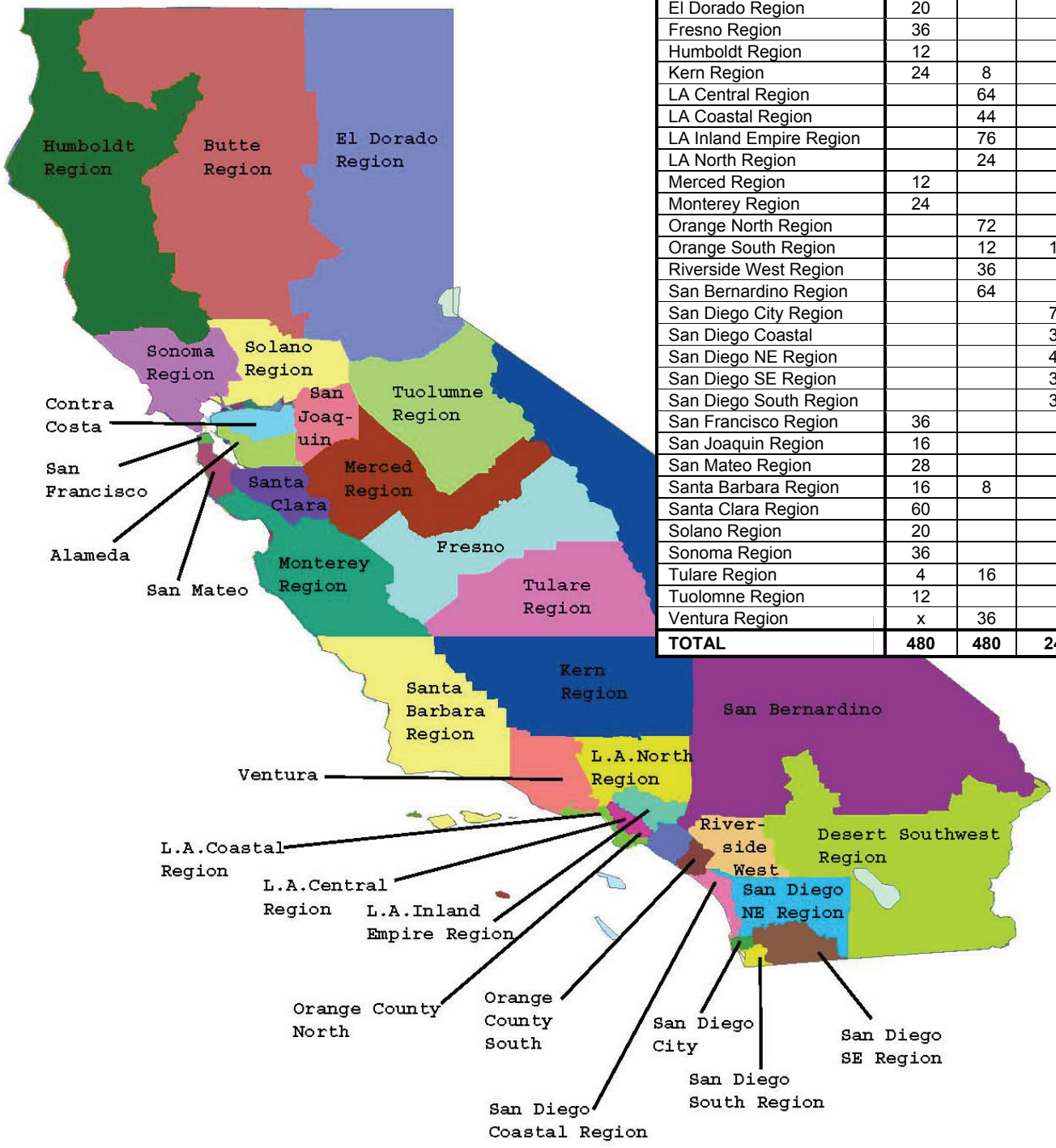


Figure 1: California Residential Lighting Metering Study Sample Design

Table 1. Lighting Inventory Characteristics Data

Room Types	Control Type	Fixture Type	Lamp Type (Primary)	Lamp Shape (Secondary-type)	Lamp Base Type
K=Kitchen **KE**=Kitchen w/ eat-in **L**=Living room **D**=Dining room **B**=Bedroom *Use number! **BA=**Bathroom **H**=Hall/Entry **OF=** Office **BS=**Basement **LN**=Laundry/Utility Rm **OL=** Other Living Room (Family Rm/Rec Rm/Den) **G**=Garage **C**=Closet **O**=Other room *DESCRIBE! **XP**=Outside porch/ patio **XE**=Outdoor entry lighting **XO**=Other outdoor lighting	**S**=Switch (on/off) **D**=Dimmer **3**= 3-way **L=**Lit Switch **M**=Motion sensor **P**=Photocell **T**=Timer **H**=Home Automation System **O**=Other (describe)	**C**=Ceiling-mounted **L**=Floor/table lamp **T**=Torchiere **W**=Wall–mounted **R**=Recessed **S**=Suspended **F**=Ceiling fan **K**=Track lighting **HW**=Other hard-wired **PI**=Other plug-in **G=** Garage door **U=** Under Counter **O=**Other (describe)	**I**=Incandescent **C**=Compact Fluorescent **F**=Fluorescent **H**=Halogen **L**=LED **HID**=High Density Discharge *Note type!	**A=** A-type standard (regular incandescent) (I, C, H) **S**=Spiral (C) **G**=Globe (I, C, L) **R**=Reflector/Flood (I, C, H, L) **U**=U-bend (C, F) **D**=Decorative (I, C, L) **CIR=**Circline (F) **B=**Bullet or Post **T**= Linear tube/Tubular(I, C, F, L, H) *If a fluorescent tube, note size and length Example: T8/4 **MR=** MR-16 pin based halogen **BP=** “G” type, bi-pin halogens **V=** Low Voltage (H) **SE=** Socket Empty **O**=Other (describe)	**SM**=Standard medium screw-base **SS**=Small screw-base **P**=Pin based **O**=Other (describe)

Meter Installation Protocols

Up to seven meters were installed in each household participating in the study – up to four meters per home were reserved for fixtures containing CFLs, and the remaining meters were installed on fixtures containing other types of lamps. When completing the lighting inventory, surveyors entered a room and started recording information about each fixture group in a clock-wise direction from the entrance where they first walked into the room. A fixture group was defined to consist of all fixtures in a room that are operated by the same switch.

A randomized meter installation protocol was used by the surveyor to determine which specific fixture groups to meter. First, the surveyor would determine the total number of fixture groups in the home. Then, the surveyor would look up a randomized starting number on a table created uniquely for each site and meter every n^{th} fixture group according to protocol.

Table 2 presents a sample protocol for one of the homes included in the study. In this example, there were 30 fixture groups in the home, 15 of which were CFL fixture groups and 15 of which were non-CFL fixture groups. The surveyor would find CFL fixture group number three and install the first meter on the fifth CFL fixture group after that (for up to four meters total). For non-CFL fixture groups, the surveyor would find non-CFL fixture group number two and install the first meter on the seventh non-CFL fixture group after that (for up to three meters total).

Table 2. Randomized Meter Installation Instructions

Number of Fixture Groups	CFL Fixture Groups		Non-CFL Fixture Groups	
	Random Start Number	Meter Every	Random Start Number	Meter Every
3-10	1	3rd	3	4th
11-20	3	5th	2	7th
21-30	2	8th	1	10th
31-40	9	10th	10	13th
41-50	6	13th	7	16th
More than 50	11	17th	16	17th

The protocol requires that only one meter is installed per fixture group, and a fixture group was not eligible for metering if all the sockets in the group were burned out or empty or the entire fixture group was not in use. In addition, if both CFLs and non-CFLs were being used within the same fixture group, then the fixture group was considered to be CFL fixture group. Surveyors provided documentation for cases where it was technically infeasible to install meters on fixture groups selected by the random protocol. In these cases, the surveyor used the protocol to select the replacement fixture group for the one that was infeasible. Finally, if a home did not have four CFL fixture groups, then the meters were installed on additional non-CFL fixture groups, again selected by the protocol. Appropriate weights will be developed when presenting the final metering results.

Equipment

Two types of meters were utilized for this study: (1) DENT Time of Use (TOU) SmartLogger lighting loggers (Figure 2), and (2) Watts Up PRO ES (Watts Up). The DENT loggers sense when the light is on and off and record a time stamp of each change of status (from on to off and off to on). They also track and display cumulative time on and percent time on. The newer SmartLogger model is much smaller than prior DENT TOU lighting loggers, and preliminary tests indicated that the newer models were easier to install in more locations (both indoors and outdoors) resulting in improved socket representativeness and reduced exposure to ambient light sources. Fiber optic eye attachments were also used with the DENT loggers in cases where temperature, moisture, and/or ambient light were of concern.

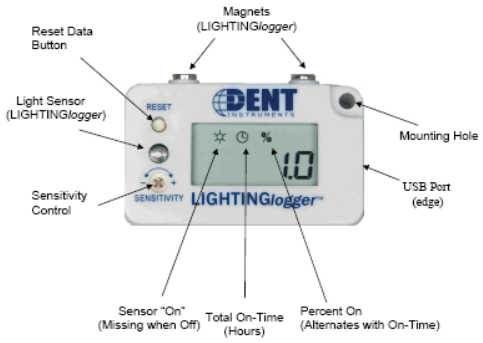


Figure 2. DENT Time of Use (TOU) SmartLogger Lighting Logger

The Watts Up meters were used because of their ability to measure actual power draw, as well as track hours of use. This was particularly important for fixture groups on dimmer and three-way switches. However, the Watts Up meters can only be used on plug-in fixtures, which limited their applicability. In addition, Watts Up meters have no internal clock and they do not keep track of time when power is cut to the meter during a power outage or when outlets controlled by switches are switched off. As a result, DENT TOU lighting loggers were required to be installed in addition to the Watts Up meters in order to verify the time-of-use information collected via the Watts Up meters.

Sample Representativeness

Two aspects of representativeness were tracked for the Residential Lighting Metering Study. First, we tracked overall representativeness of the sample of households included in the study and, second, we specifically tracked representativeness of the use of CFLs.

In order to verify the representativeness of households, detailed dwelling and demographic characteristics data was collected during the initial visit. As shown in Table 3, households included in this sample were fairly representative of the underlying household population.

Table 3. Sample Representativeness – Dwelling and Demographic Characteristics

	Metering Sample [1]	CFL User Survey Sample [2]	CLASS [3]	
			2005	2000
Dwelling Type				
Single Family Home	71%	81%	72%	65%
Multi Family Home	28%	17%	24%	33%
Mobile Home	1%	1%	3%	2%
Other	1%	1%	1%	0%
Home Ownership				
Own	65%	73%	70%	61%
Rent	35%	27%	30%	39%
Other	1%	0%	0%	0%
Dwelling Size (Square Feet)				
<1,000	23%	13%	22%	28%
1,000-2,500	53%	51%	51% [4]	61% [4]
>2,500	9%	14%	23% [4]	9% [4]
Don't know	15%	22%	4%	2%
Annual Household Income				
<$20,000	15%	8%	12% [5]	22%
$20,000 to $49,999	24%	18%	21% [5]	25%
$50,000 to $74,999	17%	15%	17%	16%
$75,000 to $99,999	13%	12%	13%	11%
$100,000 to $149,999	12%	13%	18% [5]	9%
$150,000 to $199,999	6%	4%		
>=$200,000	3%	6%		
Don't Know/Refused	11%	23%	19%	18%
Household Composition				
Elderly-Only Household	17%	15%	na	na
Single Occupant Household	36%	Tbd	23%	28%
2-3 Occupant Household	57%	Tbd	68%	67%
4 or more Occupant Household	6%	Tbd	7%	5%

[1] Sample size of 623 homes distributed throughout the service territories of PG&E (40%), SCE (40%) and SDG&E (20%). Data collected between August and December 2008.
[2] Three waves of the CFL User Survey were completed in June 2008, October 2008 and February 2009. These surveys were completed with a random sample of PG&E, SCE and SDG&E customers. Combined, these telephone surveys produced a sample size of 2,263 customers.
[3] Two waves of the California Lighting and Appliance Saturation Survey (CLASS) were completed in 2000 and 2005. Sample sizes were 1,258 and 847 respectively, distributed proportionally within the service territories of PG&E, SCE and SDG&E.
[4] Comparable CLASS 2000 and 2005 square footage categories were 1,000-2,399 and 2,400 or greater.
[5] CLASS 2000 and 2005 income categories for the lowest two categories were <$25,000 and $25,001 to $50,000. The highest income category was $100,000 or more.

It was also important to ensure that the metering sample is representative of households overall and not biased toward households who are using CFLs. As shown in Table 4, it appears that the metering sample contains a smaller proportion of households who are not using any CFLs and a larger portion of households who are using 20 or more CFLs. However, these characteristics are representative of the first 623 homes included in the study; we plan to continue to monitor and make adjustments as necessary for the final wave of data collection.

Table 4. Sample Representativeness – CFL Usage

	Metering Sample	CFL User Survey Sample	CLASS	
			2005	2000
CFL Socket Penetration				
Average Number of Sockets	50.1	na	na	na
Average Number of Lamps	48.7	na	41.0	33.8
Average Number of Sockets Using CFLs	10.3	na	3.7	0.3
CFL Socket Penetration	21%	na	9%	1%
CFL Saturation				
Percentage of Households with 1+ CFLs	91%	81%	57%	12%
Percentage of Households with No CFLs	9%	19%	43%	88%
Percentage of Households with 1-5 CFLs	32%	27%	na	na
Percentage of Households with 6-10 CFLs	26%	28%	na	na
Percentage of Households with 11-20 CFLs	20%	21%	na	na
Percentage of Households with >20 CFLs	13%	6%	na	na
Average Number of CFLs Installed				
Among Households with 1+ CFLs	11.3	10.1	na	na
Among All Households	10.3	8.2	na	na

Lighting Inventory Characteristics

Figures 3 through 9 and Table 5 present detailed characteristics data for the more than 31,000 sockets captured in the detailed lighting inventory completed for the 623 homes included in the first half of this study. These results are preliminary as the full sample of 1,200 has not been completed yet. As shown:

- More than half of all sockets are currently filled with incandescent lamps (56%), and only 20% contain CFLs and 12% contain other fluorescent lamps (e.g., linear tube). Eight percent contain halogen lamps, less than 1% contain LEDs, and 3% of all sockets are empty.

- The majority of sockets are medium screw-base, especially those that contain incandescent lamps (82%) and CFLs (90%). All of the other fluorescent lamps are in pin-base sockets, and 59% of halogen lamps are in pin-base sockets. About one in five incandescent lamps (18%) are in small screw-base sockets.

- The majority of sockets are controlled by simple on/off switches – e.g., 82% of incandescent lamps are controlled by on/off switches, and 93% of CFLs. Nearly one in three halogen lamps (31%) are installed in dimmable sockets, 18% of incandescent lamps, and 3% of CFLs.

- About half of all incandescent lamps (49%) have the traditional A-lamp shape, 18% are decorative lamps, 17% are reflector/flood lamps, and 15% are globe-shaped. The majority of CFLs are traditional spiral/twister style (73%), and another 7% are the typical U-shaped/U-bend shape. Altogether, about 15% of all CFLs have a specialty shape (e.g., A-lamp, globe, decorative or reflector/flood).

- CFLs and incandescent lamps are used fairly commonly in both ceiling and wall-mounted lighting fixtures. However, CFLs are more common in table/floor lamps and incandescent lamps are more common in suspended lighting fixtures.

- Over 85% of all sockets are found in the following locations: bedrooms, bathrooms, living rooms, kitchens, outdoors, hallways/entry ways, and dining rooms. CFLs are more common than incandescent lamps in living rooms and kitchens, whereas incandescent lamps are more common in dining rooms and hallways/entry ways.

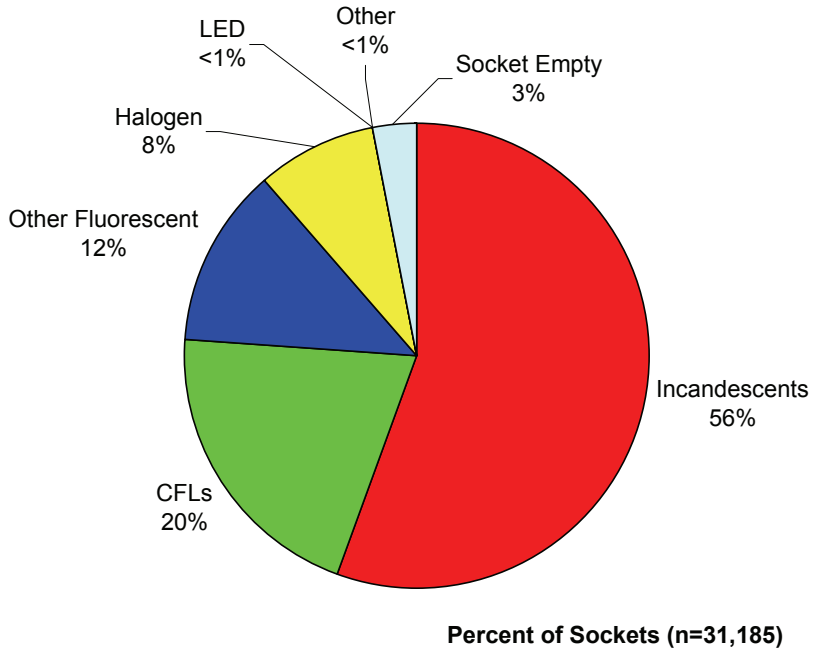


Figure 3. Percent of Sockets by Lamp Type

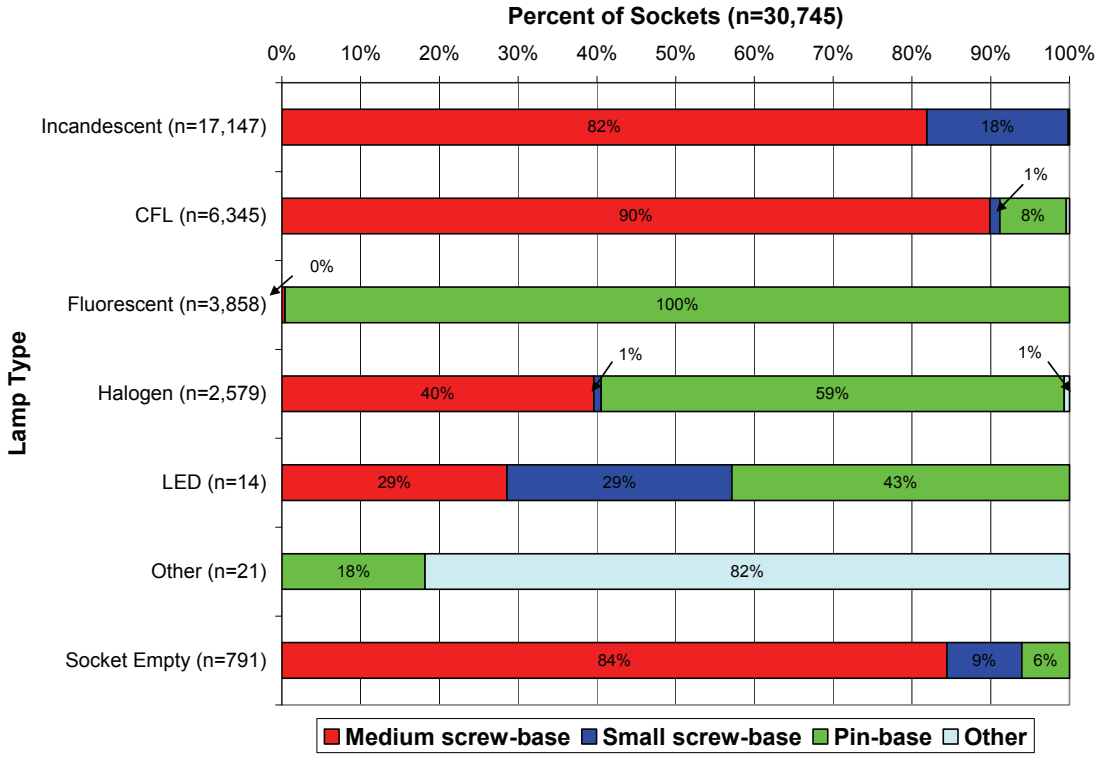


Figure 4. Base Type Distribution by Lamp Type

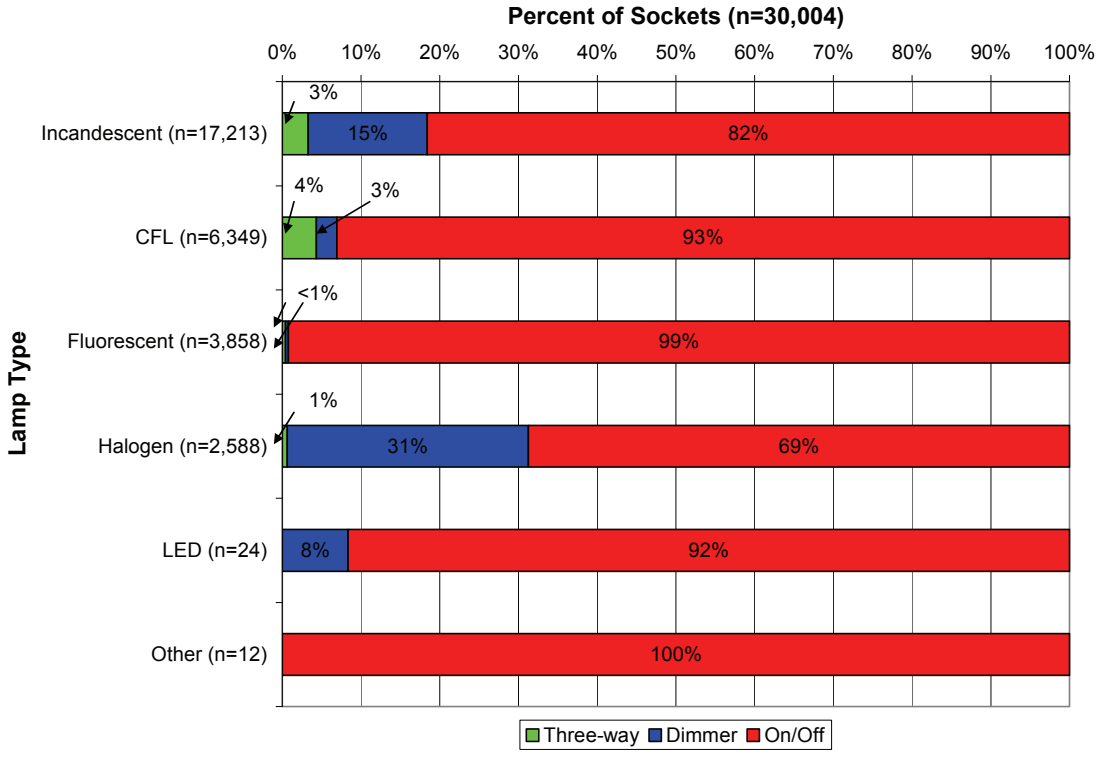


Figure 5. Control Type Distribution by Lamp Type

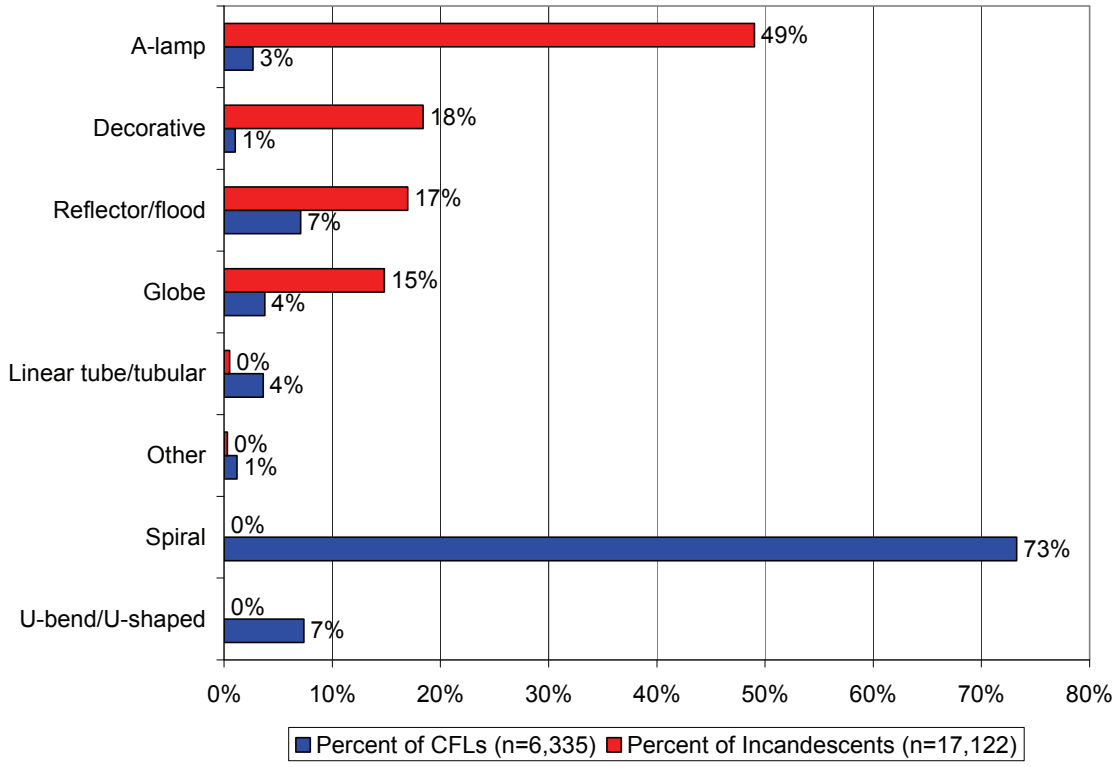


Figure 6. Lamp Type Distribution by Lamp Shape

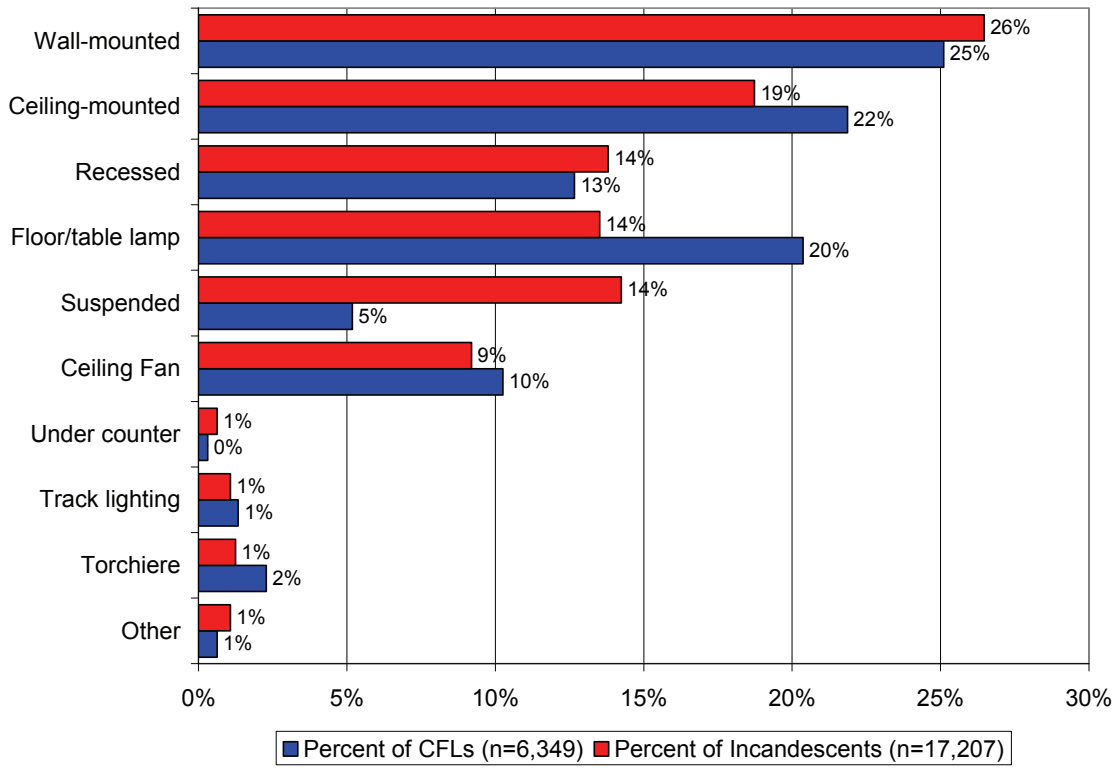


Figure 7. Lamp Type Distribution by Fixture Type

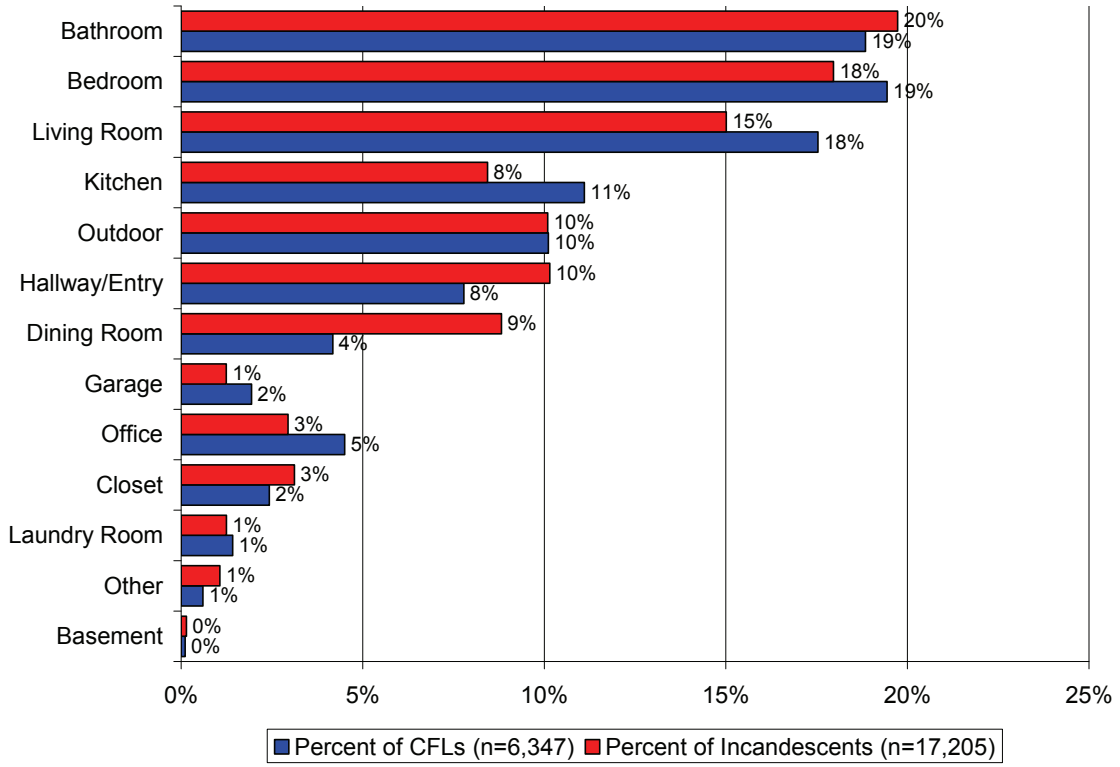
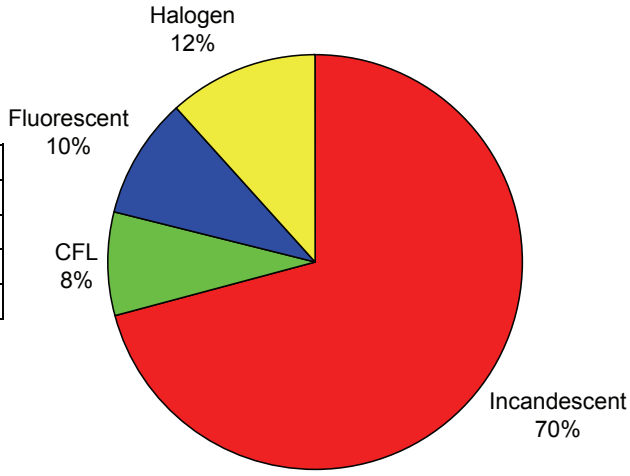


Figure 8. Lamp Type Distribution by Location

	Average Wattage/ Socket
Incandescent (n=16,169)	58.65
CFL (n=6,214)	17.17
Fluorescent (n=3,599)	35.40
Halogen (n=2,263)	68.22



Percent of Total Wattage, All Sockets (n=28,245)

Figure 9. Wattage Summary

Table 5. Lamp Storage Summary

	Avg. Number of Stored Lamps/Site (all households)	Avg. Number of Stored Lamps/Site (households with at least one)	Avg. Wattage/ Stored Lamp (households with at least one)
Incandescent	6.9	11.5	67.40
CFL	3.4	6.7	18.60
Fluorescent	0.2	4.1	26.10
Halogen	0.6	4.0	91.30

Conclusions and Next Steps

The preliminary results presented in this paper provide a reliable baseline for continuing to design effective lighting programs in 2009 and beyond. The California Public Utilities Commission (CPUC) and the California IOUs are beginning to use this preliminary information to estimate the remaining energy savings potential for lighting in the residential sector, and to identify new and/or emerging technologies that are most suitable to achieve this potential.

The preliminary results thus far suggest that, absent significant changes in program design and measure mix, there is considerable uncertainty in estimates of energy savings potential from upstream lighting programs going forward. For example, if one assumes that future lighting programs will be implemented similarly to the upstream programs that have been implemented in California in the past five years (i.e., 30-40 million rebated lighting products per year, 95% or more of these products were the traditional twister/spiral-style CFLs), then the savings from these measures is likely to be considerably lower than prior years for several reasons.

First, many of the sockets that are available to take CFLs are in locations with relatively lower hours-of-use and/or threats to long-term savings (e.g., high switch rates). Upstream lighting programs have been highly effective at reducing the price paid by consumers for CFLs, but they have not been particularly effectively at targeting specific applications at the household level. There is also evidence that the percentage of households replacing CFLs with CFLs is increasing, especially among households already highly saturated with CFLs. Upstream lighting programs have not been particularly effective in targeting households who have never used CFLs and/or have only used one or two.

One of most obvious recommendations to stem from the preliminary results of the detailed lighting inventory is that the California IOUs should encourage households to install the CFLs that they are currently holding in storage. The preliminary results indicate that nearly 40 million CFLs may currently be held in storage, which is more than enough to fill the remaining potential for CFLs in high-use sockets. An effective and highly publicized advertising campaign is required to get households to install these CFLs in their highest use sockets. Without this type of proactive messaging, these CFLs are likely to remain in storage until existing CFLs burn out and/or never get installed, further reducing the energy savings potential from prior program efforts.

Finally, past upstream lighting programs have not aggressively promoted energy efficient replacements for "specialty lamps" (e.g., reflector/flood lamps, globe or decorative style lamps, small screw-base lamps, dimmable or three-way lamps, etc.). During 2006-2008, the California IOUs Upstream Lighting Program rebated less than 5 million of these types of specialty CFLs. Preliminary estimates from this study indicate that nearly 200 million sockets currently contain incandescent equivalents of these lamp types, about half of which are being used in locations with relatively high expected hours-of-use and low switch rates. Clearly, there appears to be significant potential for future programs designed to encourage the increased manufacture, improved quality, expanded availability, and reduced price of a wide variety of specialty CFLs.

Next steps for this study include the development of preliminary estimates of hours-of-use by location for both CFLs and non-CFLs. The full set of weighted results should be available in early 2010.