Residential Lighting: Shedding Light on the Remaining Savings Potential in California

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ABSTRACT

The California Public Utilities Commission (CPUC) conducted an impact evaluation of the 2006-2008 Upstream Lighting Program (ULP) in which onsite surveys were conducted with over 1,200 California households. All types of residential lighting were included in both the inventory and metering portion of the survey, providing a rich data set of residential lighting saturation levels and usage profiles. The inventory and metering results were analyzed as part of the CPUC's impact evaluation to provide average daily hours-of-use and wattage reduction estimates for compact fluorescent lamps (CFLs) rebated through the 2006-2008 ULP. However, subsequent analysis of the entire residential lighting inventory and metering database had not been completed until recently.

This paper presents results from this subsequent analysis, including quantification of the remaining technical potential for efficient lighting, as well as assessments of the remaining potential for different types of lighting measures and different household characterizations. The paper concludes with recommendations and next steps for designing and targeting future programs.

Introduction

The state of California has a long history of energy efficiency programs focused on decreasing the amount of energy consumed by lighting in the residential sector. Beginning in 1989, the first programs were launched in response to the introduction of integral-ballast compact fluorescent lamps (CFLs), and the California utilities experimented with various program design, outreach and delivery strategies over time. By 2004-2005, the upstream program model became the dominant delivery mechanism and, from 2004-2008, the California utilities provided upstream incentives to manufacturers and retailers which were then applied toward the sale of over 120 million compact fluorescent lamps (CFLs).

The California Public Utilities Commission (CPUC) conducted an impact evaluation of the 2006-2008 Upstream Lighting Program (ULP) in which onsite surveys were conducted with over 1,200 California households. These onsite surveys were conducted randomly through the service territories of Pacific Gas & Electric (PG&E), Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E). At each household, a whole-house lighting inventory was conducted and up to seven time-of-use meters were randomly installed – for a total of over 8,000 metering points over the course of the study. The study included three overlapping waves of data collection, beginning in July 2008 and completed in December of 2009. All types of residential lighting were included in both the inventory and metering portion of the study, providing a rich data set of residential lighting saturation levels and usage profiles.

The inventory and metering results were analyzed as part of the CPUC's impact evaluation to provide average daily hours-of-use and wattage reduction estimates for CFLs rebated through the 2006-2008 ULP. However, subsequent analysis of the entire residential lighting inventory and metering database had not been completed until recently. This paper presents results from this subsequent analysis, including quantification of the remaining technical potential for efficient lighting, as well as assessments of the remaining potential for different types of lighting measures and different household characterizations. The paper concludes with recommendations and next steps for designing and targeting future programs.

Methodology

The residential lighting inventory and metering database contains information on over 63,000 lighting sockets, including:

- Location in home (room type);
- Control type (on/off switch, dimmer, etc.);
- Fixture type;
- Lamp wattage;
- Lamp technology type (incandescent, CFL, halogen, etc.);
- Lamp shape (spiral, globe, tube, etc.); and
- Base type (small screw-base, pin, MSB, etc.).

Each socket was characterized according to its "potential" – i.e., if the socket already contained an efficient lamp, the socket was characterized as "efficient," and if the socket contained an inefficient lamp that could readily be converted based on products available in the market today, the socket was characterized as "inefficient." These "inefficient" sockets were further characterized into two subgroups based on the type of efficient lamp that could be installed (i.e., basic v. specialty). Finally, if the socket contained a lamp for which the researchers felt there was not a readily available efficient alternative, the socket was characterized as "not convertible." The specific definitions for each of these characterizations are summarized below.

Socket Characterization Definitions

Efficient Sockets

Efficient sockets are those for which an efficient lamp is already installed and include:

- All CFLs (all base types, including pin bases)
- T8 and T5 linear fluorescent tube lamps
- Fluorescent circline lamps
- All LEDs

Inefficient Sockets

Inefficient sockets are those for which an efficient lamp is not currently installed. For this analysis, the researchers assumed that inefficient lamps are most likely to be replaced by efficient lamps with similar characteristics (e.g., shape, dimmability, wattage). Inefficient sockets were thus further sub-divided into two groups: basic and specialty.

- ***Inefficient basic*** sockets are non-dimmable and contain single-wattage, A-line shaped medium screw base (MSB) incandescent or halogen lamps.
- ***Inefficient specialty*** sockets contain MSB incandescent or halogen lamps with at least one "specialty" feature:
    - Dimmer switch (socket)
    - 3-way switch (socket)
    - Specialty shape
        - Globe
        - Reflector
        - Decorative
        - Bullet/post
        - Linear tube.

In addition, inefficient specialty sockets include all candelabra or small screw base sockets, as well as inefficient (T12) linear fluorescent tube lamps.

Not Convertible Sockets

Not convertible sockets contain lamps for which no readily available efficient alternative for residential applications exists. Included in this category of sockets are:

- Pin-based halogen lamps (including linear tubes, MR-16 and bi-pin lamps)
- Other pin-based lamps (not CFL or LED)
- Other sockets with different base types (e.g., large screw base, bayonet base)
- Sockets with High Intensity Discharge (HID) lamps

Socket Characterization Results

Applying the definitions presented above results in the distribution of sockets presented in Figure 1. As shown, 26.0% of all sockets already contain efficient lamps. Inefficient specialty sockets represent about 43.2% of all sockets, and inefficient basic sockets represent another 26.1%. Only about 4.7% of all sockets are currently not convertible to efficient alternatives. For reference, the average household in California has 46.7 sockets.

Efficient sockets break down as follows: 86.5% contain CFLs, 13.1% contain efficient fluorescent lamps (e.g., circline lamps, T8 or T5 linear fluorescents), and 0.3% contain LEDs. Table 1 shows a distribution of the types of CFLs, as a percent of all sockets, all efficient sockets and of all CFLs. As shown, spiral-shaped CFLs are installed in 16.5% of all sockets and 63.5% of all efficient sockets, and overall represent 73.4% of all CFLs installed.

Inefficient specialty sockets represent 32.1% of all sockets, as shown in Figure 1 below. The vast majority of inefficient specialty sockets contain incandescent lamps (71.9%), while 19.8% contain inefficient linear fluorescents (nearly all T12s) and 7.1% contain halogens (nearly all reflectors). Another 1.2% of inefficient specialty sockets are "empty" (i.e., did not contain a lamp at the time of the household survey). However, these sockets had some sort of specialty feature (e.g., small-screw base, dimmable, three-way switch, etc.) and were designated as "inefficient" for the purposes of this analysis.

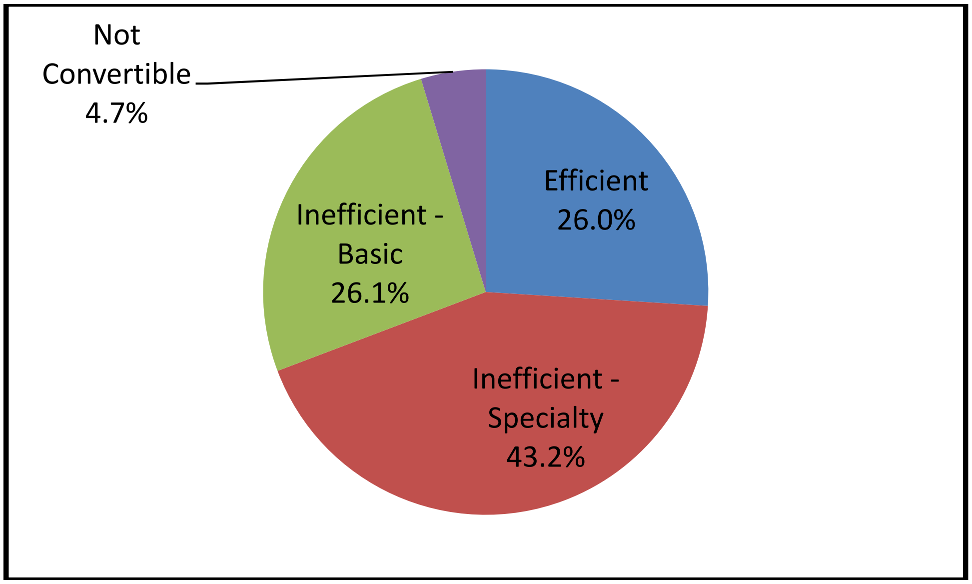


Figure 1. Socket Characterization Results (Percent of All Sockets)

Table 1. Distribution of CFLs by CFL Type

CFL Type	Percent of All Sockets	Percent of Efficient Sockets	Percent of CFLs
A-type	0.6%	2.2%	2.5%
Bullet or Post	0.2%	0.8%	0.9%
Decorative	0.4%	1.7%	2.0%
Globe	0.9%	3.3%	3.8%
Linear Tube	0.7%	2.8%	3.3%
Reflector	1.6%	6.2%	7.2%
Spiral	16.5%	63.5%	73.4%
U-Bend	1.6%	6.1%	7.1%
All CFLs	22.5%	86.5%	100.0%

Table 2 shows a distribution of the types incandescent lamps contained in all inefficient specialty sockets, presenting the types of specialty incandescents as a percent of all sockets, all inefficient sockets, all inefficient specialty sockets and of all incandescents. As shown, inefficient specialty incandescents represent 31.1% of all sockets and 44.9% of all inefficient sockets. Most inefficient specialty incandescent lamps are decorative lamps (34.8%), followed by reflectors and globes (25.7% and 24.0% respectively), and A-line shaped lamps (14.2%).

Table 2. Distribution of Inefficient Specialty Incandescents by Incandescent Type

Incandescent Type	Percent of All Sockets	Percent of Inefficient Sockets	Percent of Inefficient Specialty Sockets	Percent of Inefficient Specialty Incandescent Sockets
A-line	4.4%	6.4%	10.2%	14.2%
Decorative	10.8%	15.6%	25.0%	34.8%
Globe	7.5%	10.8%	17.3%	24.0%
Other	0.4%	0.6%	1.0%	1.4%
Reflector	8.0%	11.5%	18.5%	25.7%
All Inefficient Specialty Incandescents	31.1%	44.9%	71.9%	100.0%

Finally, overall, 84.6% of all sockets are controlled by on/off switches. About 10.3% of all sockets are controlled by dimmer switches, and 3.2% are controlled by three-way switches. As shown in Figure 2, sockets controlled by dimmer switches are most commonly found among the “not convertible sockets” (29.5%), although these sockets only represent about 4.7% of all sockets. Only 2.0% of all efficient sockets are controlled by dimmer switches, as compared to 19.5% of all inefficient specialty sockets.

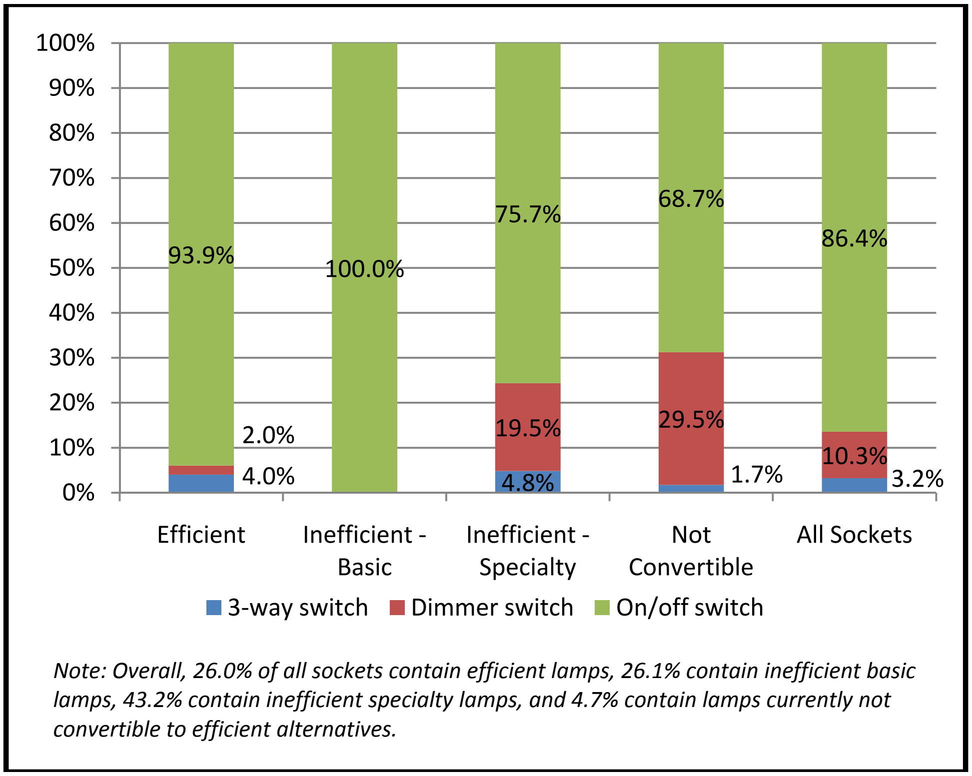


Figure 2. Socket Characterization Results by Type of Control/Switch (Percent of Sockets)

Energy Savings Potential Assessment

For all inefficient sockets, annual energy savings potential was calculated using the following formula:

$$Annual\ Savings\ Potential\ (kWh) = HOU * \Delta W * 365\ /1000$$

Where:

HOU = average daily hours-of-use

ΔW = assumed wattage reduction from converting inefficient to efficient lamps

Average Daily Hours of Use (HOU)

Based on the results of the 2006-2008 ULP Impact Evaluation, CFLs are estimated to be used about 1.9 hours per day on average. Subsequent analysis of the lighting inventory and metering data determined that, on average, non-CFLs are used about 10-15% less often as CFLs. Revised estimates of average daily HOU estimates were assigned to all inefficient sockets for the purposes of calculating the remaining energy savings potential.

HOU estimates varied by many factors, such as where the socket was located and in what type of fixture it was used. Each inefficient socket was compared to this overall mean and then assigned to an HOU bin as follows:

- “Average Use” – inefficient sockets assumed to be used between 1.15 and 2.15 hours per day;
- “High Use” – inefficient sockets assumed to be used more than 2.15 hours per day; or
- “Low Use” – inefficient sockets assumed to be used less than 1.15 hours per day.

Figure 3 displays the results from these HOU bin assignments. As shown, 16.0% of all inefficient sockets fell into the “high use” bin, 32.7% were assigned to the “low use” bin, and the remaining 51.3% were included in the “average use” bin.

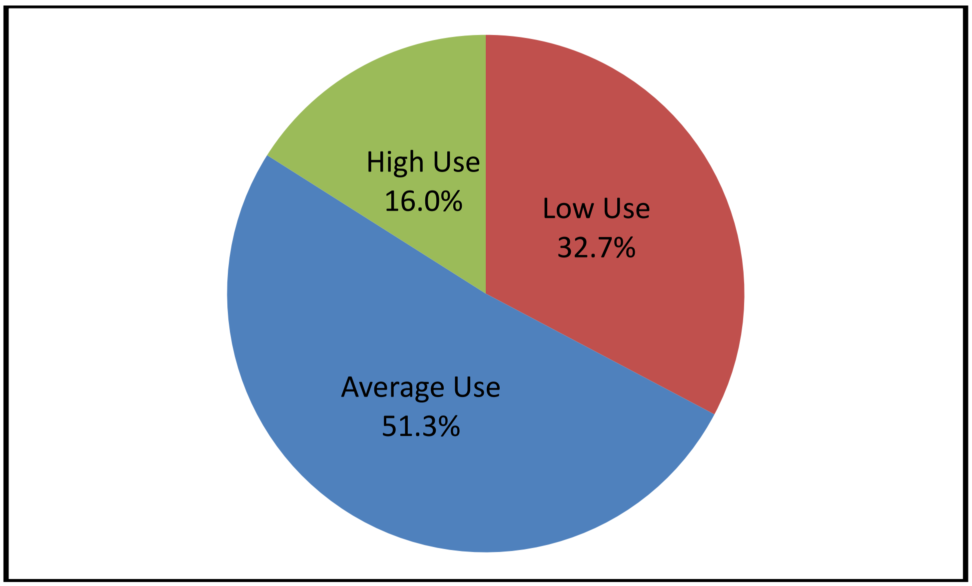
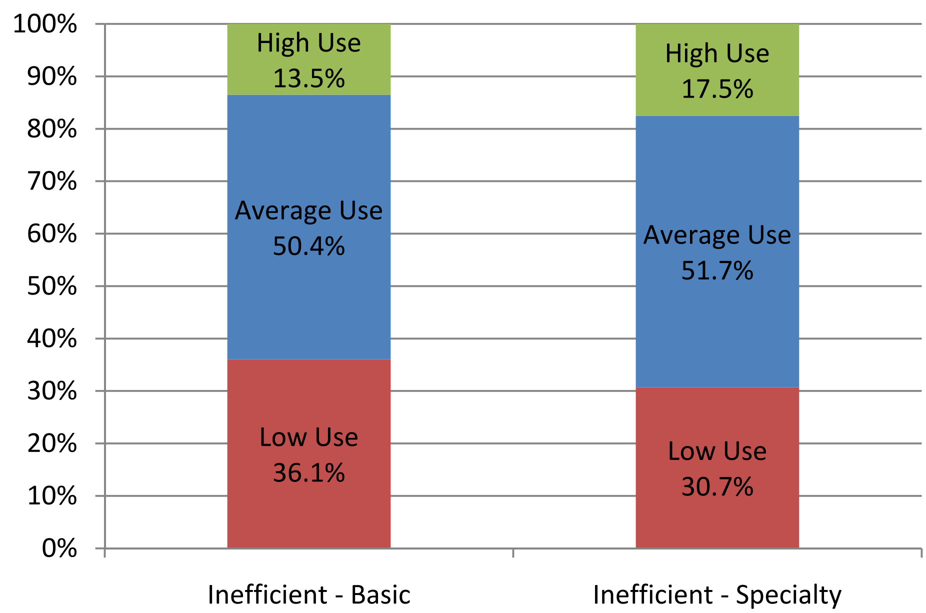


Figure 3. HOU Bin Assignments (Percent of Inefficient Sockets)

There is very little difference in the HOU bin assignments for inefficient basic versus inefficient specialty sockets, however inefficient specialty sockets are somewhat more likely to fall within the “high use” bin (17.5%) as compared to inefficient basic sockets (13.5%). (Figure 4)

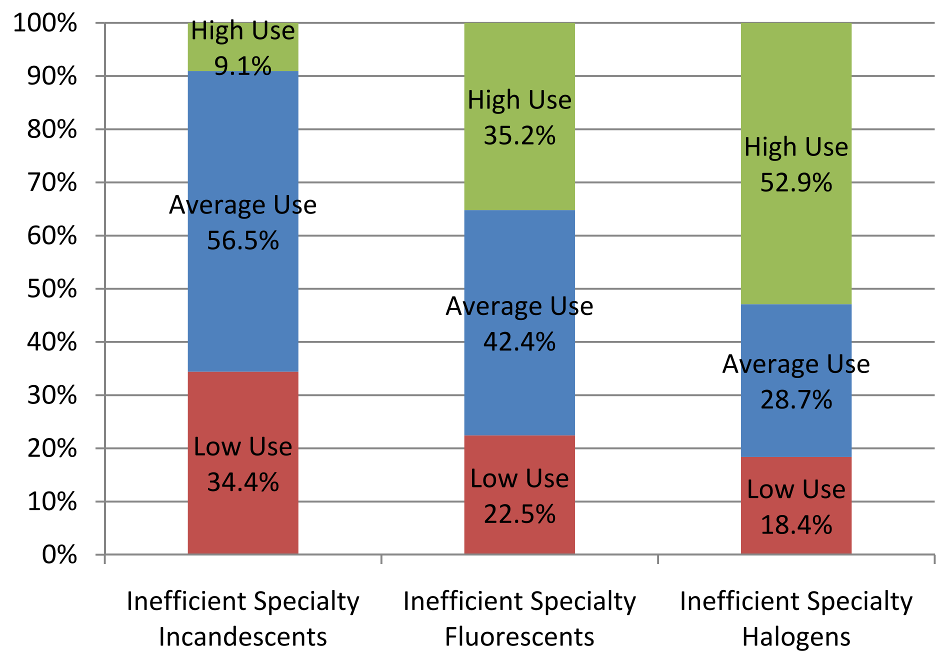
Even though incandescent lamps fill the majority of inefficient specialty sockets, it is interesting to note that relatively very few of them fall in the “high use” bin (9.1%). Comparatively, inefficient fluorescents and halogens are much more likely to fall in the “high use” bin (35.2% and 52.9%, respectively). (Figure 5)

Finally, sockets controlled by dimmers and three-way switches are less likely to fall within the “high use” bin when compared to sockets controlled by on/off switches. That is, about 10.3% of inefficient specialty sockets controlled by dimmer switches and 10.5% of inefficient specialty sockets controlled by three-way switches fall within the “high use” bin, whereas 19.8% of inefficient specialty sockets controlled by on/off switches fall within the “high use” bin.



Note: Overall, 26.1% of all sockets contain inefficient basic lamps and 43.2% contain inefficient specialty lamps.

Figure 4. HOU Bin Assignments by Type of Inefficient Socket (Percent of Inefficient Sockets)



Note: Overall, inefficient specialty incandescents represent 31.1% of all sockets, inefficient specialty fluorescents represent 8.5% of all sockets, and inefficient specialty halogens.

Figure 5. HOU Bin Assignments for Inefficient Specialty Sockets by Type of Lamp (Percent of Inefficient Specialty Sockets)

Wattage Reduction

Each inefficient socket was also assigned an assumed wattage reduction for converting from an inefficient to an efficient lamp (Table 3). Most of these wattage reduction assumptions were determined as part of the 2006-2008 ULP Impact Evaluation.

As shown, the average wattage reduction from replacing basic or specialty A-line shaped inefficient lamps with efficient alternatives (i.e., spiral or A-line shaped CFLs) was determined to be about 47-48 watts. Average wattage reductions for other inefficient specialty sockets ranged from 33-35 watts for globe-shaped or decorative style lamps and 52-53 watts for reflector style lamps. A reduction of 20 watts was assumed for replacing inefficient linear fluorescents with efficient linear fluorescents.

Table 3. Wattage Reduction Assumptions

Inefficient Socket Type	Inefficient Lamp Type	PG&E	SCE	SDG&E
Basic	A-line	47.2	47.8	47.7
Specialty	A-line	47.2	47.8	47.7
	Globe/Decorative	33.3	35.4	34.2
	Reflector	53.1	52.3	52.7
	Linear Fluorescent	20.0	20.0	20.0
	Other	44.3	44.8	44.5

Energy Savings Potential Results

Using the formula and inputs presented above, annual energy savings is estimated at about 6,521 GWh for all remaining inefficient sockets. Almost two thirds of this energy savings potential is available from inefficient specialty sockets (61.0%, or 3,978 GWh) and the remaining is from inefficient basic sockets (39.0%, or 2,543 GWh).

The vast majority of the energy savings potential from inefficient specialty sockets comes from replacing inefficient incandescents with more efficient lamps (72.5%, or 2,885 GWh). This breaks down by specialty incandescent lamp type as follows: reflectors (918 GWh), decorative (914 GWh), globe (534 GWh), A-line (475 GWh), and other (42 GWh). An additional 579 GWh in energy savings potential is available from replacing inefficient halogens with more efficient lamps, and 515 GWh in energy savings potential is available from replacing inefficient fluorescents with more efficient lamps.

Finally, about 13.0% of the overall energy savings potential (or 849 GWh) comes from inefficient lamps being used in sockets controlled by dimmer switches, another 3.3% (or 212 GWh) from sockets controlled by three-way switches. The majority of energy savings potential (83.7%, or 5,458 GWh) comes from sockets controlled with on/off switches, slightly more than half of which (53.4%) comes from inefficient specialty sockets and the rest from inefficient basic sockets (46.6%).

CFL “User Type”

To further assess the remaining energy savings potential available from different types of households, we created categories based on overall CFL saturation – that is, for each household, we calculated the percent of all MSB sockets that contain a CFL and then grouped each household into one of four CFL “user type” bins:

- “Non-user” – 0 CFLs installed in MSB sockets
- “Beginning user” – 1 to 25% of MSB sockets contain CFLs

- “Moderate user” – 26 to 50% of MSB sockets contain CFLs
- “Saturated user” – more than 50% of MSB sockets contain CFLs

Using these definitions, 12.3% of households were determined to be “Non-users”, 36.3% were classified as “Beginning users” and just over 50.0% were either “Moderate users” or “Saturated users,” as shown below in Figure 6. As shown in Table 4, diversity in type of CFL use expands as households become more saturated.

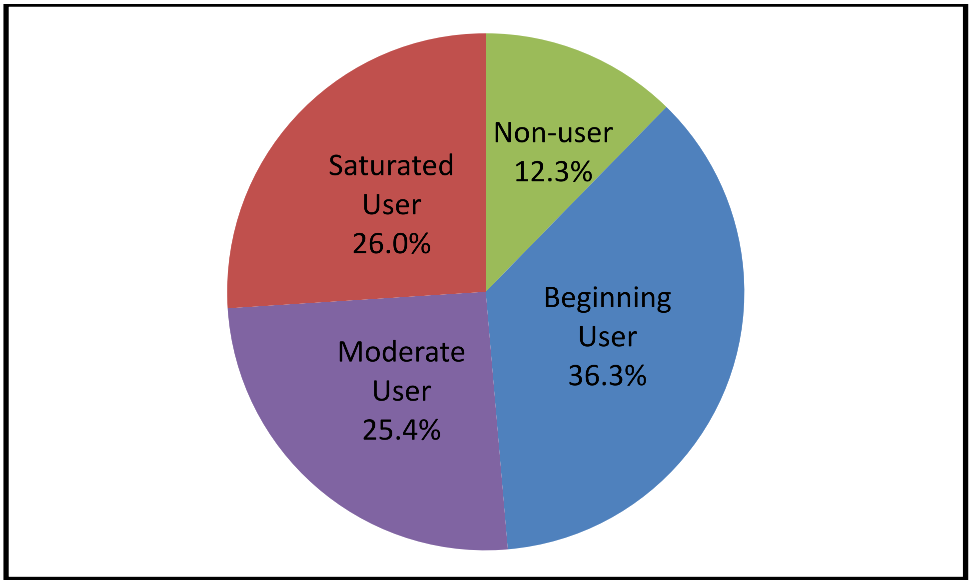


Figure 6. CFL “User Type” Bin Assignments (Percent of All Households)

Table 4. CFL Diversity by CFL “User Type” Bin Assignments (Percent of Sockets)

CFL Type	Beginning User	Moderate User	Saturated User
A-line	1.9%	2.0%	3.1%
Decorative	0.7%	2.2%	2.4%
Globe	2.2%	2.6%	5.3%
Reflector	5.8%	6.4%	8.3%
Spiral	72.4%	75.9%	74.1%
Tube	16.2%	9.6%	5.8%
Other	0.8%	1.4%	1.0%

Designing and Targeting Future Programs

As mentioned above, annual energy savings is estimated at nearly than 6,521 GWh for all remaining inefficient sockets. This is an extremely large number, representing six times the net annual energy saved as a result of California’s 2006-2008 ULP.

However, further analysis suggests that, going forward, achieving this level of available energy savings potential may be less cost-effective than it has been in the past, unless future programs are:

- Designed to address specialty applications within highest use sockets, and
- Targeted to reach households with low-to-moderate CFL saturation.

The first condition will maximize total gross energy savings achievable while the second attempts to maximize net energy savings (i.e., avoids potential free riders).

Maximize Gross Energy Savings Potential

Figure 7 shows that only about half (52.0%) of all "high use" sockets contain inefficient lamps, as compared to 80.6% of all "low use" sockets. This suggests that future programs will need to target "high use" inefficient sockets in order to maximize gross energy savings potential.

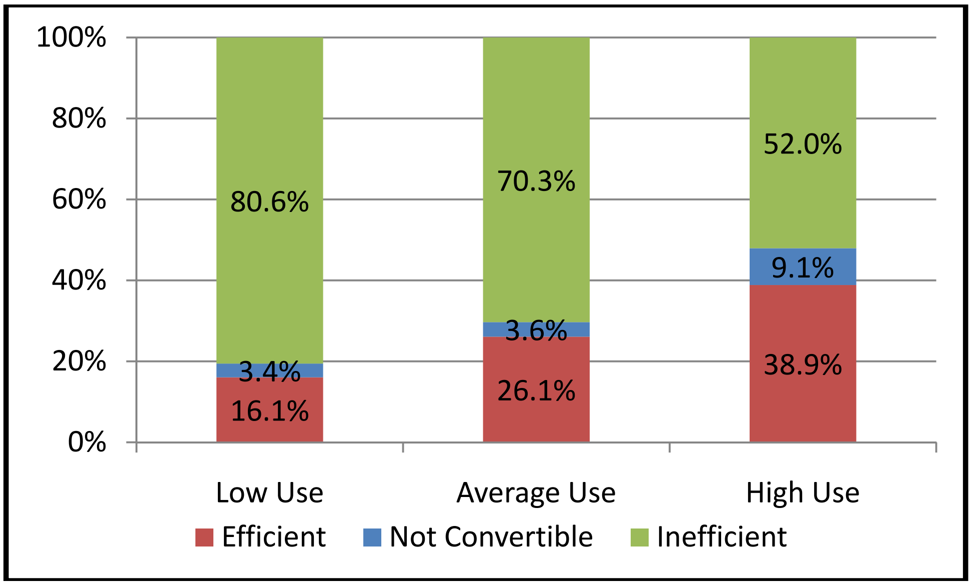


Figure 7. Socket Type by HOU Bin Assignment (Percent of Sockets)

In addition, Figure 8 shows that 68.3% of all "high use" inefficient sockets contain specialty lamps, as compared to 58.6% of all "low use" inefficient sockets. Basic lamps display the opposite pattern – only 31.7% of all "high use" inefficient sockets contain basic lamps, as compared to 41.4% of all "low use" inefficient sockets. This suggests that future programs designed to address specialty applications are more likely to maximize gross energy savings potential than programs designed to address basic applications.

Figure 9 through Figure 11 present similar information, but quantify the total number of sockets available and the total energy savings potential, to provide high-level indicators of optimal future program volume and energy savings goals.

As shown, there are approximately 50 million inefficient, "high use" sockets remaining and available for replacement among California households. Twice as many sockets contain "high use" specialty lamps as compared to "high use" basic lamps (34 v. 16 million). Similarly, there is twice as much savings potential from "high use" specialty lamps as compared to "high use" basic lamps (1,224 GWh v. 569 GWh).

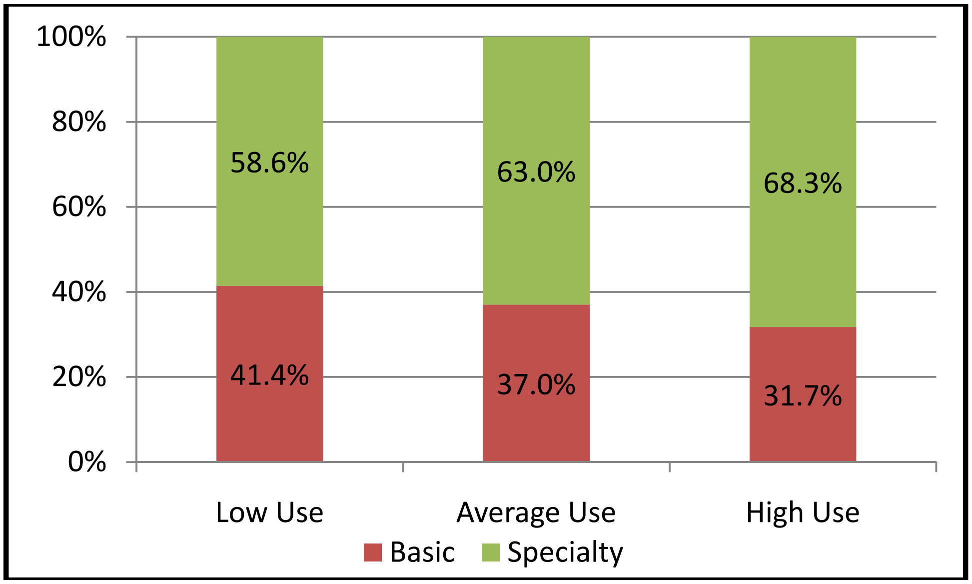


Figure 8. Inefficient Socket Type by HOU Bin Assignment (Percent of Inefficient Sockets)

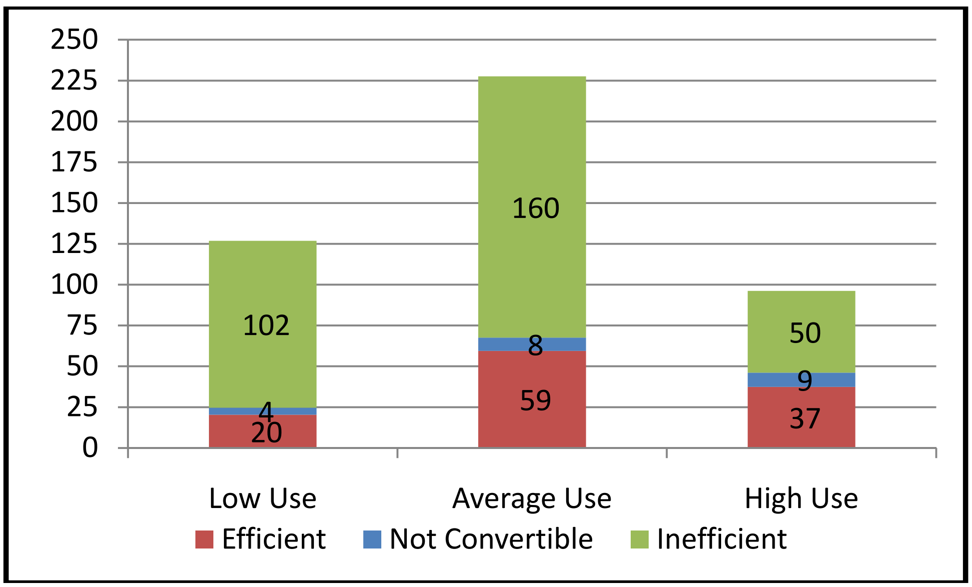


Figure 9. Socket Type by HOU Bin Assignment (Millions of Sockets)

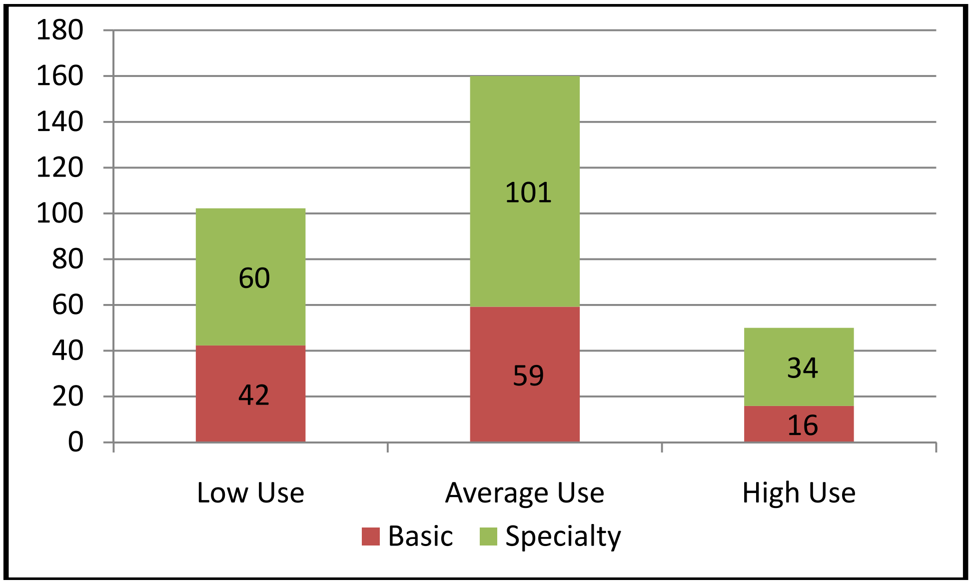


Figure 10. Inefficient Socket Type by HOU Bin Assignment (Millions of Inefficient Sockets)

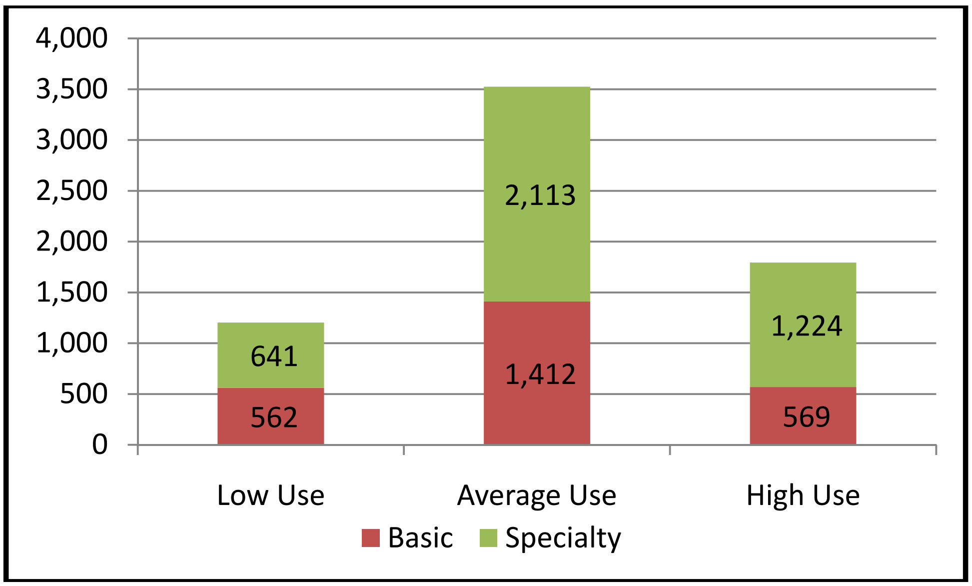


Figure 11. Inefficient Socket Type by HOU Bin Assignment (GWh Savings Potential)

Maximize Net Energy Savings Potential

Households with more than 50% of all MSB sockets already filled with CFLs may represent "free riders" for future programs since they have already overcome barriers to installing CFLs. Therefore, future programs targeted to reach households with low-to-moderate MSB CFL saturation should maximize net energy savings.

When MSB CFL saturation at the household level is considered, the total number of "high use" sockets and the associated energy savings potential is further reduced as shown in Figure 12 through Figure 14. As shown, there are only 41 million inefficient, "high use" sockets remaining and available for replacement among California households with low-to-moderate MSB CFL saturation. Just about twice as many sockets contain "high use" specialty lamps as compared to "high use" basic lamps among low-to-moderate MSB CFL saturation households (27 v. 13.6 million). Similarly, there is a little more than twice as much savings potential from "high use" specialty lamps as compared to "high use" basic lamps among low-to-moderate MSB CFL saturation households (1,003 GWh v. 514 GWh).

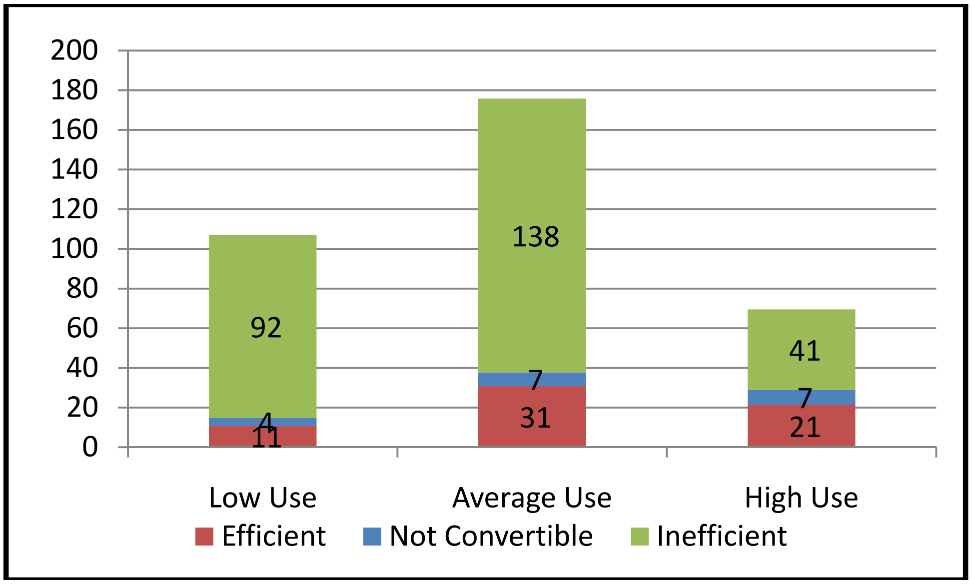


Figure 12. Socket Type by HOU Bin Assignment (Millions of Sockets Among Low to Moderate CFL Saturation Households)

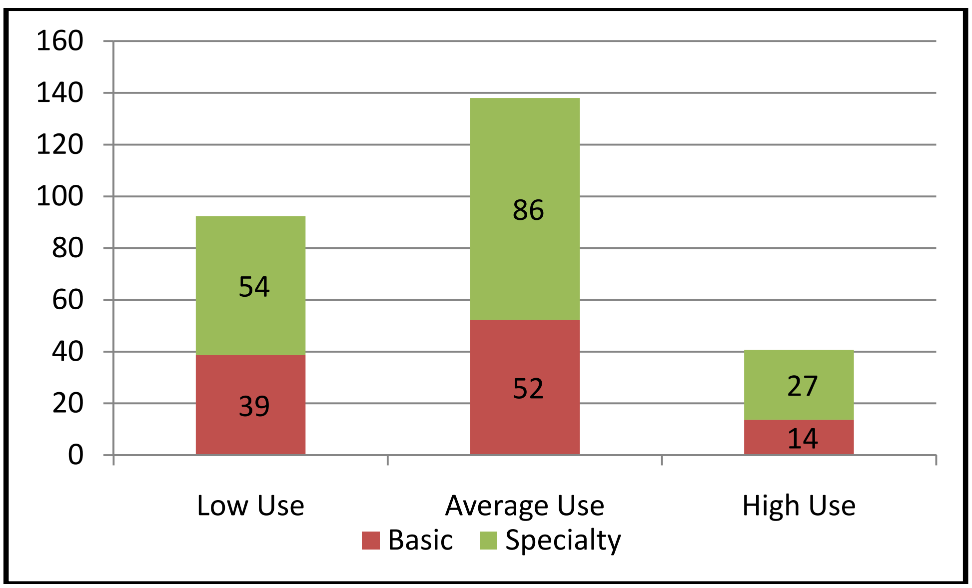


Figure 13. Inefficient Socket Type by HOU Bin Assignment (Millions of Inefficient Sockets Among Low to Moderate CFL Saturation Households)

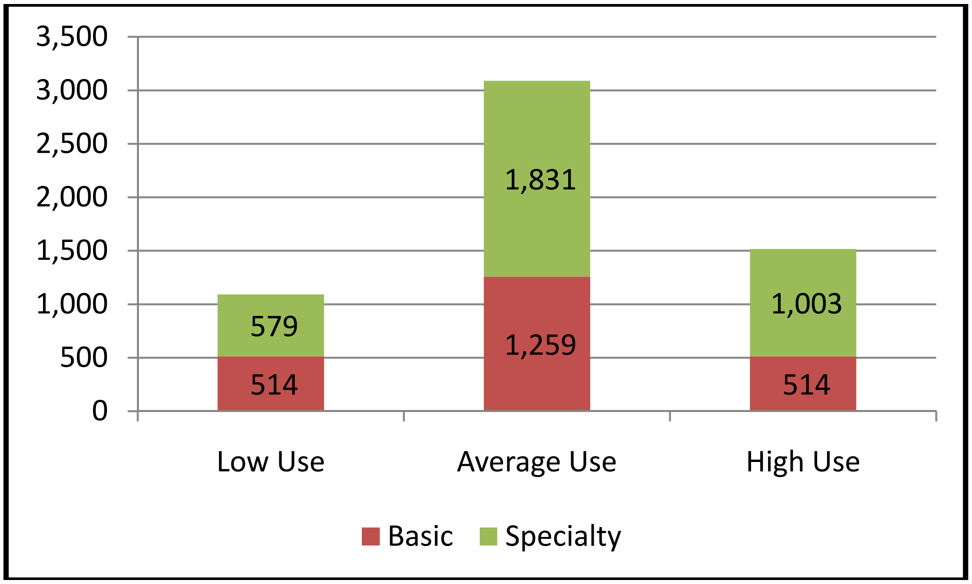


Figure 14. Inefficient Socket Type by HOU Bin Assignment (GWh Savings Potential Among Low to Moderate CFL Saturation Households)

Conclusions

The following summarizes some of the key conclusions from this analysis:

- One out of every four sockets contains a lamp that is already efficient.
- About one out of every three inefficient sockets is used, on average, less than 1.15 hours per day.
- Nearly two out of three inefficient sockets contain lamps with "specialty" features. Most common specialty lamp features include decorative, reflector and globe style lamps, and dimmable sockets.
- One out of every two California households already uses CFLs in more than 25% of all MSB sockets. Most common types of CFLs used by highly saturated users include spiral-shaped CFLs, followed by CFL reflectors, linear/bent tube-style CFLs and globe-shaped CFLs.

Finally, Table 5 shows the "order of magnitude" results from this analysis that provide guidelines for future program goals, both in terms "unit" volume (i.e., number of sockets) and total energy savings potential. This table shows the results for all households, as well as low-to-moderate CFL saturation households.

Recommendations

As Table 5 indicates, there are a considerable number of sockets containing inefficient lamps among California households, resulting in a significant remaining energy savings potential. However, there is considerably less potential when one excludes "low use," basic sockets among households that are already exhibiting high levels of MSB CFL saturation.

Table 5. Summary of Total Number of Sockets and Energy Savings Potential "Order of Magnitude" Results

Total Number of Sockets *(Millions of Sockets)*	**All Households**	**Low-to-Moderate CFL Saturation Households**
Total number of sockets	451	352
Total number of inefficient sockets	312	271
Total number of inefficient "high use" sockets	50	41
Total number of inefficient "high use" specialty sockets	34	27
Energy Savings Potential *(GWh)*	**All Households**	**Low-to-Moderate CFL Saturation Households**
Total energy savings potential from inefficient sockets	6,521	5,669
Total energy saving potential from inefficient "high use" sockets	1,793	1,517
Total energy savings potential from inefficient "high use" specialty sockets	1,224	1,003

Therefore, going forward, programs will need to be designed to address specialty applications within highest use sockets, and targeted to reach households with low-to-moderate CFL saturation. This is a significant departure from the mass market, upstream nature of the current programs included within California's 2010-2012 energy efficiency portfolio. Aside from limiting the number of incentives paid for basic CFLs, the upstream program design cannot effectively target specific households let alone specific sockets within households.

Further mining of the underlying data contained within the ULP inventory and metering database can provide additional guidance for future program design, outreach and delivery strategies. For example, similar analysis could be conducted for different dwelling characteristics (e.g., single- v. multi-family, square footage, HVAC system type, etc.), household compositions (e.g., number of occupants, distribution by age group, income level, etc.) and geographic locations (e.g., IOU, climate zone, urban v. rural, HTR) to help inform decisions related to future program planning, design, marketing, targeting and implementation.

References

KEMA, Inc., 2010. Final Evaluation Report: Upstream Lighting Program. Prepared for California Public Utilities Commission (CPUC); supported by The Cadmus Group, Inc., Itron, Inc., PA Consulting Group, and Jai J. Mitchell Analytics. February 8, 2010.