One Analysis to Rule Them All and In the Darkness Give Them CFLs

Katie Albee, The Cadmus Group, Boulder, CO Brian Shepherd, The Cadmus Group, Boulder, CO Steve Cofer, The Cadmus Group, Portland, OR Lisa Wilson-Wright, NMR, Melrose, MA

ABSTRACT

Although CFLs have long been the staple of energy savings for residential programs, the landscape is changing. Upcoming legislation, if not repealed, will bring a new set of challenges for program planners and implementers to address in the coming years. Adding to these challenges are piecemeal evaluations without a holistic picture of program accomplishments that show where the greatest potential for CFLs remains. In this paper, we use primary data, which we collected from 1,500 households in 15 locations across the United States, to illustrate current lighting market conditions and to provide a more complete picture of residential lighting composition and the potential for greatest savings through hours-of-use (HOU) analysis.

The results of this evaluation show that CFL penetration and saturation are the highest among customers living in regions where CFL programs have been running for five years or more. There also still remains quite a bit of potential for CFLs, where the greatest opportunity continues to be for medium screw-base (MSB), A-lamp incandescent bulbs installed in sockets controlled by an on/off switch. More importantly, there remains good opportunity for specialty CFLs. Although each specialty bulb category by itself is relatively small compared to standard, twist CFLs, as a group they represent a large potential for replacement.

Our HOU analysis ranged from an annualized 1.98 to 2.98 HOU per day. Furthermore, we found very little correlation between HOU and CFL saturation levels.

Introduction and Study Goals

As part of a 2010 study estimating residential CFL program net-to-gross (NTG), The Cadmus Group, Inc. and NMR Group, Inc., working with additional evaluation consultants, conducted a series of lighting studies that explored the current conditions of the lighting market and provided a more complete picture of:

- 1. CFL penetration and saturation;
- 2. The remaining opportunities for CFLs;
- 3. Where CFLs are being purchased; and
- 4. How many hours per day CFLs are turned on.

The sponsors of this study included electric utilities, as well as energy service organizations, public service commissions, and state agencies. We collected data in each of the sponsors' service territories, as well as in four regions where there was no substantial or sustained CFL program.¹

¹ We were unable to obtain permission to use one of the sponsor's data for this paper, thus it is not included. The states that did have a lighting program and were used in this study include: Arizona, Illinois, Michigan, Missouri, Ohio, and Rhode Island. The four areas that did not have programs and were used in this study are in the states of Kansas, Indiana, South

Sponsored programs also ranged in the length of time they have been operating, which varied from just under one year to 12 years.

This paper represents one small portion of a series of much larger process and impact evaluations that specifically looked at utility lighting programs to address NTG and the effectiveness of program design. This paper allows for a greater understanding of the remaining market potential for CFLs, whether or not HOU is decreasing, and whether or not program assumptions about CFLs are accurate. Utility specific information regarding overall effectiveness and NTG work can be found in respective evaluation reports and is not presented in this paper.

Methods

Lighting Inventory

We drew upon several data sources for this study: utility customer data, random-digit dial (RDD) telephone surveys, on-site socket inventories, and metered lighting data.

To identify households to participate in the on-site socket inventories, we fielded telephone surveys in each of the program and non-program areas included in the analysis. During these surveys, we also asked respondents about their CFL purchasing habits, satisfaction, and demographics. After completing the telephone survey, we offered survey respondents an incentive to encourage them to allow a trained technician to perform an in-home lighting audit. We conducted most of the on-site visits in the first half of 2010.

The phone survey weighting scheme we used included two key demographic factors: homeownership and education. We weighted this distribution according to the *American Community Survey* (ACS) guidelines. We based the weighting scheme for the on-site participants, which were a subset of the phone survey participants, on their familiarity with CFLs and homeownership status. We then weighted this distribution to the phone survey participants for homeownership and stated familiarity with CFLs.

CFL HOU Estimation

Cadmus installed up to five loggers in each participant home, on randomly selected light fixtures following a whole-house lighting audit. The metering periods varied by utility and ranged from three months to one year. For homes where we identified five or fewer CFL fixture groups, we installed a logger on every CFL fixture. For homes with more than five CFL fixture groups, we used a random selection method to determine which five fixtures to meter. This random selection method identified a randomly assigned CFL fixture based on the number of total possible CFL fixtures, and then installed a logger on every nth CFL fixture from that randomly assigned fixture until five loggers were installed (the nth number was also based on the number of total possible CFL fixtures).

During the logger removal process, we collected additional data for evaluating the quality of data and for determining if any loggers were tampered with, removed, or failed. For example, prior to removing each logger, we noted whether the logger was still installed correctly and the orientation of the sensor.

Dakota, and Texas. Except for Kansas, the non-program areas did not cover the entire state. For instance, Texas site visit participants were only in the Houston area and South Dakota participants were only in Pennington County.

After collecting meters, we performed a set of quality control reviews to ensure data integrity. These reviews consisted of multiple data checks which included: identifying and removing "flicker;"² determining whether the logger had been prematurely removed by a participant; and reviewing for data showing extreme usage or no usage at all. Where our field review notes could not provide an explanation, we contacted the participant for further confirmation.

After conducting the quality control reviews, we trimmed data points that occurred before the install date and time or after the removal date and time. This ensured that we only included data from the metering period. We eliminated data from meters that did not pass this review process from the final analysis.

CFL HOU Estimation Method

To calculate HOU estimates, Cadmus determined the total time "on" for each individual light logger per day using the following guidelines:

- If a light logger did not record any light for an entire day, that day's HOU was zero.
- If a light logger registered that a light was turned on at 8:30 p.m. on Monday, and turned off at 1:30 a.m. on Tuesday morning, we added 3.5 hours to Monday's HOU and 1.5 hours to Tuesday's HOU.

We calculated the average daily HOU as the average time "on" across the entire metering period and across all light loggers (daily from 12:00:00 a.m. to 11:59:59 p.m.). Next, we weighted the data using demographic information—such as homeownership status and educational attainment—to the ACS. (We had previously collected demographic data during lighting audits and phone surveys.)

We then applied an additional room-based CFL saturation weight. We calculated this weight as the percent of the sum of all CFLs associated with each room type by all CFLs in the total audit population. This weighting logic accounts for the fact that while loggers collect lighting data from only one CFL, there may be multiple CFLs associated with each metered fixture.

Lighting Inventory Findings

Across the study locations, CFL programs had been operating from just under one year to 12 years. In this paper, we grouped the data into three categories: long running (5+ years), new programs (<1-4 years), and no program. As expected, CFL penetration and saturation are the highest among customers living in regions where CFL programs are long running (Table 1).³

New program areas had higher penetration than non-program areas; however, contrary to expectations, CFL saturation in new program areas was lower than in non-program areas. This finding may indicate that people do not replace all of their light bulbs at one time, but do so gradually, likely when another bulb burns out. The data also indicate that the presence of CFLs in homes is highly common even without the presence of CFL programs, therefore natural adoption of CFLs is occurring.

 $^{^2}$ Dent Light Loggers require approximately three seconds for their status to change between on and off events. Events that occur less than three seconds apart are called "flicker," as they do not represent actual usage. Flicker typically occurs when a logger is exposed to ambient light sources, such as sunlight, passing car lights, and television screens. Flicker can also occur when the electrical components of a fixture are not functioning properly, causing the bulb to flicker multiple times when the switch is on. We deleted these flicker events from the logger data.

³ In this report, penetration is the percent of households that had at least one CFL installed in their home. Saturation is the percent of installed CFLs out of all installed bulbs.

Although not addressed in this paper and difficult to quantify, it is important to acknowledge that early CFL programs have had a cross-area spillover effect throughout the country. This spillover is likely due to long-running programs successfully encouraging people to adopt CFLs earlier than they would have in absence of the programs. However, the sheer number of programs that are now offering upstream incentives may also be causing manufacturers and retailers (who receive a large amount of program money) to accelerate offering their own promotion of CFLs in non-program areas.

Program	Average Penetration	Average Saturation
Long Running (5+ Years)	89%	23%
New Program (<1-4 Years)	86%	18%
No Program (0 Years)	81%	20%

Table 1. Saturation and Penetration

Total households: Long Running=648, New Program=451, No Program=35

Installed bulbs: Long Running=30,743, New Program=26,671, No Program=18,627

Note: Except for total households, all n's in this report reflect weighted values.

Among new program areas, the average percent of CFLs among all bulbs found in storage was 37 percent. For the same areas, 21 percent of all CFLs found on the site were in storage. The average number of CFLs in storage was 2.7 in new program areas.⁴

Who is Using CFLs?

We investigated CFL saturation by educational achievement, homeownership status, and household income to understand if these demographics showed significant differences in who is using CFLs. There are differences between high school graduates (and those with less education) and those with some college or more education, but this was minimal in all areas except those with long-running programs, where those with some college or more education were 8 percent more likely to buy CFLs than those with no more than a high school diploma (Table 2). In fact, households with some college that are in long-running program areas stand apart from all other groups in terms of their CFL saturation.

Table 2. CFL Saturation by Educational Achievement

Program	High School Graduate or Less	Some College or Higher	
Long Running (5+ Years)	21%	29%	
New Program (<1-4 Years)	16%	19%	
No Program (0 years)	22%	19%	

High school graduate or less, total installed bulbs: Long Running=6,312, New Program=6,357, No Program=3,473 Some college or higher, total installed bulbs: Long Running=23,960, New Program=24,235, No Program=15,063

We also found that people who own their home were more likely than renters to have at least one CFL installed. On average, owners had more CFLs, but renters had slightly higher levels of CFL saturation. This is likely due to owners having a greater number of sockets than renters. We found little relationship between CFL saturation levels and household income.

⁴ Due to inconsistencies in the data collection process, we could only conduct such analyses for the new program areas.

Where People Purchase Light Bulbs

For both incandescent bulbs and CFLs, the most common purchasing places are home improvement stores, such as Lowe's or Home Depot, and mass merchandise stores, such as Target or Wal-Mart (Table 3). Interestingly, people purchase CFLs more often than incandescent light bulbs from home improvement stores; and purchase incandescents more often than CFLs from grocery stores. This may be attributed to the fact that grocery stores are not often a retail participant in utility CFL programs, and also the fact that even program-supported CFLs tend to be more expensive at grocery stores because they do not have the same sales volume as home improvement stores and mass merchandise stores.

Store	Long Running Programs	New Programs	No Program	
Incandescent				
Home Improvement	31%	22%	24%	
Mass Merchandise	22%	24%	39%	
Grocery Store	17%	15%	17%	
Hardware Store	16%	12%	12%	
Warehouse	6%	10%	4%	
Drugstore	6%	9%	4%	
Convenience Store	2%	8%	0.4%	
CFL				
Home Improvement	46%	39%	35%	
Mass Merchandise	19%	27%	35%	
Hardware Store	12%	10%	13%	
Grocery Store	12%	12%	9%	
Warehouse	8%	10%	7%	
Drugstore	4%	2%	1%	
Convenience Store	0%	0%	0.3%	

Table 3. Where People Purchase Incandescent and CFL Bulbs

Households reporting purchases of incandescent bulbs at each store type: Long Running=833, New Program=1.248, No Program=484

Households reporting purchases of CFLs at each store type: Long Running=587, New Program=491, No Program=349

Remaining Opportunities

The replacement of standard, incandescent bulbs still represents the largest remaining potential for CFLs. The saturation of incandescent bulbs, regardless of the bulb features, is over 60 percent (Table 4).

Table 4. Incandescent Bulb Saturation

Program	Incandescent Saturation
Long Running (5+ Years)	60%
New Program (<1-4 Years)	63%
No Program (0 years)	65%

Total installed bulbs: Long Running=32,131, New Program=26,629, No Program=18,319

Note: The data we used in this analysis came from the original, full data sets. The data we presented earlier in the paper were based on a slightly more limited data set used in the individual multistate reports, in which we excluded some outliers for modeling purposes.

The greatest levels of incandescent bulb saturation are among A-lamps,⁵ MSB,⁶ and bulbs installed in sockets controlled by an on/off switch (this excludes specialty features such as dimmable or three-way controls). Table 5 displays the incandescent bulb saturation (of all installed bulb types we inventoried on-site) by shape, socket type, and control type.

Table 5. Saturation of Incandescent Bulbs by Feature

	Long Running Programs	New Programs	No Programs		
Shape					
Globe	5%	10%	9%		
A-Lamp	35%	35%	40%		
Bullet	11%	11%	10%		
Spot/Flood/Reflector	8%	6%	6%		
Socket Type					
Medium screw base	50%	54%	57%		
Small screw base	9%	8%	8%		
Control Type					
On/Off	54%	54%	61%		
Dimmable	5%	5%	3%		
Three-Way	2%	2%	1%		

Total installed bulbs: Long Running=32,131, New Program=26,629, No Program=18,319

As noted above, incandescent bulbs with an MSB that are connected to a standard on/off switch continue to represent the largest opportunity for CFL replacements. Although each specialty bulb⁷ category by itself is relatively small when compared to incandescent bulbs that can be replaced by a standard twist CFL, as a group they represent a large potential for specialty CFL replacement. This is

⁵ A-lamps are conventional light bulbs.

⁶ Medium, screw-base incandescent bulbs are the conventional household screw type bulb.

⁷ We define specialty bulbs as dimmable, three-way, floods, globe, A-shape, bug light, bullet/torpedo, and candelabra models.

noteworthy because many specialty bulbs are exempt from the efficiency restrictions set forth by the Energy Independence and Security Act legislation. For instance, our data indicate that CFL saturation in dining rooms is relatively low compared to saturation in other room types; as many dining rooms have special light fixtures or features that are not compatible with a standard twist CFL (Table 6).

Room	Long Running (5+ Years)	New Program (<1-4 Years)	No Program (0 Years)
Bedroom	33.2%	22.7%	23.0%
Living Space	28.1%	24.5%	25.0%
Kitchen	22.8%	21.3%	21.5%
Basement	22.5%	13.2%	20.9%
Garage	12.6%	13.4%	18.7%
Dining	12.4%	12.1%	15.1%

Table 6. Saturation of CFLs by Bulb Type and Room Type

Total installed bulbs in:

Bedroom: Long Running=6,562, New Program=4,372, No Program=3,654 Living space: Long Running=4,736, New Program=3,418, No Program=2,775 Kitchen: Long Running=4,314, New Program=2,970, No Program=2,163 Basement: Long Running=3,275, New Program=1,954, No Program=765 Garage: Long Running=1,299, New Program=1,475, No Program=1,190 Dining: Long Running=2,069, New Program=1,308, No Program=1,099

While we did not collect wattage data for linear fluorescent tubes (i.e., T12, T8, or T5s), they represent 10 percent of all installed bulbs. Saturation of these lamps is concentrated in areas where HOU tends to be high, such as garages, basements, and kitchens (see the CFL HOU Findings section below). Efficient fixtures and lamps, such as T8 electronic ballasts, may also represent a potential for energy saving opportunities in the near future.

CFL HOU Findings

For baseload lighting fixtures (CFLs used in windowless rooms or on timers), usage is independent of daylight hours. However, some residential CFL usage partially depends on the number of daylight hours. This type of HOU is expected to inversely correlate with daylight hours over the year. For example, the average HOU for all CFLs used around times of the summer solstice (where days are longest) is expected to be the lowest of the year, while HOU usage around times of the winter solstice (where days are shortest) is expected to be the highest of the year.

The variation in daylight hours from the average number of daylight hours across one year is represented as a sinusoid curve; with the peak and trough representing the winter and summer solstice. To estimate the annual HOU from metered data, we leveraged the Cadmus/KEMA California Lighting Study (KEMA and The Cadmus Group, 2010), and fit a sinusoid curve representing changes in daylight hours to the logger data. To adapt the California model to the three utilities represented in this paper (non California utilities), we modified the latitudinal adjustment factor (since daylight hours in a given area are a function of latitude; Figure 1).



Figure 1. Annualized HOU by Utility

The final annualized HOU estimates for Utility 1 and Utility 2 were very similar, and were much higher than the annualized estimate for Utility 3. Cadmus examined the sampling proportions of various demographics for each utility and determined that the sample for Utility 3 may not represent the underlying population. Additionally, the metering period for Utility 3 was the shortest of the three studies and did not encompass seasonal changes (i.e., summer to fall), which typically beget noticeable changes in lighting usage. The metering period for Utility 3 also coincided with the expected lowest HOU of the year. Table 7 presents the final annualized mean HOU for each utility.

 Table 7. Final Annualized HOU Estimates

Annual HOU	Utility 1	Utility 2	Utility 3	
Estimation	2.91*	2.98	1.96	
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*Cadmus collected an entire year of usage data for Utility 1; therefore, the final weighted HOU is the annualized HOU.

The behavior of CFL usage relative to daylight hours is best shown using the raw unadjusted metered data. Figure 2 shows the daily average HOU estimates for each utility, which generally corroborate our assumptions of the inverse relationship between HOU and daylight hours.



Figure 2. Unadjusted Mean Daily HOU by Utility

Table 8 presents the room-based average HOUs across all three utilities. In general, the rooms with highest usage were kitchens and living spaces. Utility 1 had the highest HOU for basements due to one participant who used their basement fixture for 24 hours each day of the metering period. Additionally, this fixture contained five CFLs, and therefore received a greater weight than other similar basement fixtures. This basement example demonstrates the importance of collecting additional data and making detailed *in-situ* observations. During the logger installation, this participant remarked to field technicians that he always left this particular basement fixture on. When analyzing logger data, we determined whether each logger collected accurate lighting data, and ultimately decided to keep this particular data in our analysis. This example also illustrates that such outliers are possible in randomly selected samples of participants and fixtures, and in this case that it should still be included.

	Utility 1	Utility 1		Utility 2		Utility 3
Room	HOU	# Rooms	Utility 2	# Rooms	Utility 3	# Rooms
Basement	5.76	55	2.62	45	1.23	31
Bathroom	1.68	167	1.65	151	1.31	127
Bedroom	1.32	223	1.23	199	1.10	185
Closet	0.80	84	0.16	29	0.06	110
Dining	1.21	47	4.40	68	1.44	47
Foyer	1.39	39	-	36	1.99	31
Garage	2.06	39	-	13	1.11	49
Hallway	1.32	77	1.78	89	0.22	93
Kitchen	4.32	92	5.26	82	2.75	72
Living Space	4.37	103	3.26	96	2.62	96
Office/Den	2.76	44	1.97	38	1.86	44
Other Room Type	0.32	29	-	23	0.00	24
Outdoor	3.20	71	6.18	67	1.07	61
Utility	0.47	47	1.65	39	3.01	59

Table 8. Average HOU by Room Type

Cadmus tested the relationship between HOU and CFL saturation of MSB sockets for each household in the study. Generally, we assumed that HOU and saturation are inversely related; the average HOU is expected to decrease as more CFLs are installed. This logic is based on the assumption that people will install CFLs in high-use fixtures first, where bulbs tend to burn out more frequently. As these high-use fixtures become saturated, people will install CFLs in low-use fixtures. These low-use fixtures will decrease the overall household average usage. In general, we assume that installation of CFLs at the margin results in a lower average HOU.

However, this study did not show a strong relationship between HOU and CFL saturation (see Figure 3).⁸ We combined HOU and saturation data for all three utilities and calculated a simple Pearson correlation coefficient, which was -0.073, indicating no statistical relationship between these two variables.

⁸ We also tested the relationship between HOU and saturation for each individual utility prior to combining the data, but did not find any statistical relationships.



Figure 3. HOU and CFL MSB Saturation Scatter Plot

Conclusion

Our study confirmed what was expected: CFL penetration and saturation is the highest among customers living in regions with long-running CFL programs. We did not expect the similar penetration and saturation levels that new program areas had with non-program areas. Our analysis also indicated that the proportions of those who are using CFLs was not greatly dependent on their common demographic variables, such as educational achievement, income, and homeownership status.

Our study also showed that people tend to purchase their CFL light bulbs at home improvement and mass merchandise stores, but tend to purchase incandescent light bulbs at grocery stores.

We also determined that there is still quite a bit of potential for energy savings through the use of CFLs. The greatest opportunity for CFLs continues to be for MSB, A-lamp incandescent bulbs installed in sockets controlled by an on/off switch. In addition, there is good opportunity for energy savings through specialty CFLs. Although each specialty bulb category by itself is relatively small when compared to incandescent bulbs that can be replaced by a standard, twist CFL, as a group they represent a large potential for replacement with specialty CFLs.

Of the three utilities that sponsored metered CFL HOU, two produced consistent results while one showed much lower usage. Our HOU analysis ranged from an annualized 1.98 to 2.98 HOU per day. Furthermore, we found very little correlation between HOU and CFL saturation levels. It also appeared that metering for less than six months and not metering across multiple seasons may produce estimates that are difficult to accurately annualize across the entire year.

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