# Welcome to the Dark Side: The Effect of Switching on CFL Measure Life

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**ABSTRACT**

The recent adoption of a shareholder risk-reward mechanism by the California PUC for the investor owned utilities (IOUs) has left possible shareholder earnings or penalties highly dependent on inputs to the resource net benefit calculations, including savings, costs, and measure life estimates. This is especially true as the California IOU portfolios are heavily reliant on certain compact fluorescent lamps (CFLs) measures. This paper focuses on how one critical cost-effectiveness input can affect the overall cost-effectiveness of a CFL program.

A few years ago, the California DEER adopted a measure life estimation approach for screw-in CFL measures that is based on two parameters: manufacturer rated life and hours of operation. The lighting industry rates lamp life using a three hours "on" and twenty minutes "off" cycle. Consequently, the DEER rated life-based methodology is different from prior years' retention data-based measure life estimates typically known as the effective useful life (EUL)[1]. The DEER rated life-based estimate provides only a proxy EUL for CFLs, and does not account for other factors that can affect the measure life including "burn time" (the length of on time per on/off cycle), lamp base orientation, placement in an open or closed fixture, use with timers, dimmers, and motion sensors, early removal, or burnout. This paper critiques the DEER rated life-based methodologies and shows that the length of on time per on/off cycle leads to a different "observed" life expectancy for CFLs than the manufacturers' rated life.

## Introduction

For a decade efficiency programs have promoted the benefits of CFLs to customers through a variety of program strategies. The West Coast energy crisis in 2000/2001 coupled with rising fuel prices in recent years turned public attention to strategies for reducing the use of electricity. The work of early CFL programs to address quality and supply issues, promote the lamps to customers and encourage stocking among retailers paid off. CFL familiarity and purchasing increased dramatically in 2001, and after a slight dip in 2002, has continued to steadily increase as large retailers work with energy efficiency programs to stock and promote the lamps (KEMA 2007, Itron 2007).

While CFL programs and promotions have resulted in significant increases in familiarity and market share in many parts of the country, purchasing a CFL remains more difficult than purchasing an incandescent lamp only because it requires thought on the part of consumers in a purchase most consumers are not used to thinking about. Deciphering the incandescent

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[1] The definition of Effective Useful Life as used in the California EM&V Protocol is "the proportion of measures retained in place and that are operable." Effective useful life (EUL) is thus an estimate of the median number of years that the measures installed under the program are still in place and operable (retained).

equivalency, understanding lumens and assessing the appropriateness of a particular lamp for a particular fixture are all complicating aspects of the CFL purchase.

The large volume of energy savings potential represented by converting the lighting load to the more efficient CFL technology continues to make CFL programs extremely popular, representing between eighty and ninety percent of all residential program energy savings claimed by the California IOUs (2006-2007 IOU filings with CPUC). This focus on CFLs has increased the need to establish accurate cost effectiveness estimates and to continually assess lessons learned in program design and implementation to ensure that programs are able to accurately estimate energy savings resulting from these efforts, while adapting programs to a rapidly transforming marketplace.

In this paper we first set the context of these issues. We then provide results of data collection from previous studies, and re-analysis and aggregation of those data for cost effectiveness estimates. In the long term, more detailed and larger sample size studies should be undertaken to increase the accuracy and confidence in the reported results. Considerations for future program and evaluation planning are provided in the conclusion section.

## Cost-Effectiveness Considerations

Establishing an accurate cost-effectiveness (CE) estimate for the replacement of a less efficient lamp with a compact fluorescent lamp (CFL) requires that, exclusive of free rider effects, at least five parameters be established to a reasonable degree of certainty for the CFL and the lamp replaced:

1. The operating power use (wattage) of the pre-existing lamp and the replacement CFL;
2. The energy interactive effects with the space conditioning system of the pre-existing lamp and the replacement CFL;
3. The usage profile (load shape) of the pre-existing lamp and the replacement CFL;
4. The life expectancy (total on-time) of the pre-existing lamp and the replacement CFL;
5. The cost of the CFL and the cost, over the expected life of the CFL, that continued use of the replaced lamp would have required.

When performing CE calculations for a "population" of replaced lamps all these parameters become distributions rather than point values. Thus, these parameters must be measured or observed in a large enough sample such that a statistically valid average values can be determined.

Many past and recent evaluations that focused on the measurement of one or more cost-effectiveness input assumptions were not always designed to provide data for both current and future program designs. By focusing on evaluation of a specific program or program year in question, the CFL studies suffered from the following data limitations:

A. Insufficient sample size to allow flexibility in assessing average values applicable to a variety of pre-replacement and post-replacement conditions and their impact when considering all the above parameters in the field. This has led to insufficient data or lack of data to support assumptions such as:

- the use patterns of the replaced lamp and the CFL being identical or even similar;
- the pre-existing lamp likely being one with the shortest available life and the CFL likely being one with at least an average life;
- a CFL user being likely to accept a service decrease (lower average light/lumen output) compared to the replaced lamp;
- the differential (replaced vs. CFL) lamp purchase and storage habits of the user population (price sensitivity and its effect on storage times/rates) can be ignored;
- the differential product defect and breakage can be ignored; and
- any space condition requirement changes (decrease in cooling energy use and increase in heating energy) can be ignored.

B. An assumption that the advertised (rated) performance (input wattage, life, lumen output) for a CFL and the replaced lamp are comparable in definition, and are the values that are likely to be experienced in the field.

In what follows we address residential indoor applications of CFLs, and one important issue of the many field data issues identified above: the life expectancy (based on actual on-time per on/off cycle) of the replacement CFL.

## Methods for Assessing the Effects of Switching

In 2003-2004, KEMA conducted a statewide "CFL Metering Study" in support of the Statewide Crosscutting Upstream Residential Lighting Program implemented by the California IOUs (KEMA, 2005). One of the KEMA Study objectives was to provide an estimate of CFL hours of use per day. To achieve this objective KEMA used on-off event data from lighting loggers to estimate CFL hours of use as the average length of time for which the CFLs were switched on per day.[2] The data were weighted using the distribution of CFL lamps in the entire inventory, and were annualized to compensate for varying day lengths over the year. The final estimate of 2.3 hours of use per day agrees well with CFL hours of use estimated by previous studies (HMG, 1997)[3]. KEMA also estimated CFL hours of use by room type. These estimates varied from 1.2 hours per day for less-used rooms such as laundry rooms, to 3.6 hours per day for more used rooms such as kitchens.

The KEMA study did not attempt to calculate effective useful life (EUL.) However, the KEMA data on hours of operation was used in the DEER 2004-05 to estimate a CFL measure life as follows:

*EUL [years] = Lamp Rated Life [hours] / (365 * Hours of Use [h/day])*

Unlike the retention data-based EUL approaches[4], this DEER EUL calculation approach does not factor in how lamp switching patterns can affect lamp life. It has been known for close to sixty years that fluorescent lamps will fail when the emissive coating on its electrodes is dissipated by sputtering or evaporation, and that on/off cycling is a main cause (Vorlander and Raddin, 1950). As shown more recently in a study conducted by Rensselaer Polytechnic

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[2] This is a common method to estimate hours of use for any lamp type.

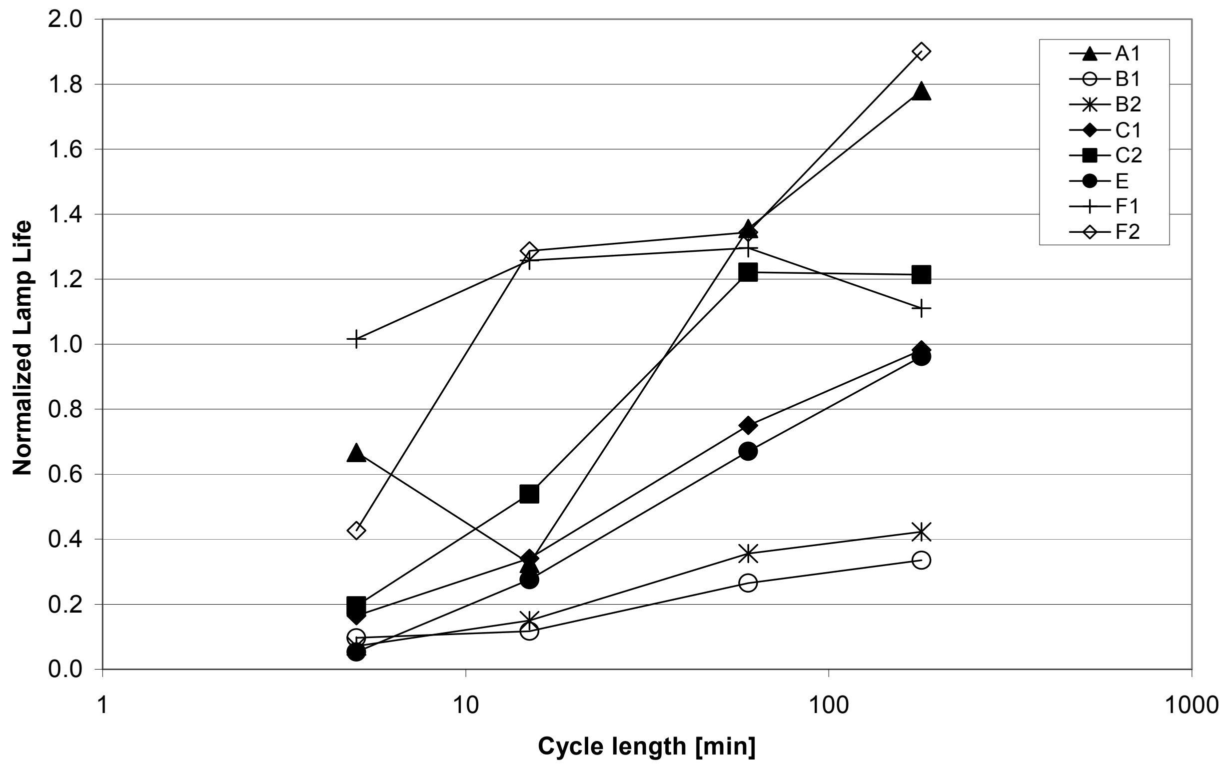
[3] The HMG study was a meta-analysis of previously collected hours of operation data.

[4] EUL studies use classic survival analysis of measure retention data collected earlier in a corresponding retention study.

Institute's Lighting Research Center (Ji et al, 1998 and SR, 1999), ignoring on/off cycling effects on lamp survival is likely not correct for CFLs. The Lighting Research Center's study started with the observation that CFL lamp life ratings are based on a laboratory test in which lamps are switched on for 3 hours and off for 20 minutes (IES, 1949). However, lamp switching patterns in the home vary by room, and very rarely match those in the laboratory. To study the effect of different on-time cycle lengths on lamp survival the LRC operated CFL lamps under different cycling strategies. The study estimated a relationship between normalized life (the ratio between measured lamp life and rated lamp life) and the length of the lamp on-time cycle.

Figure 1 shows the results of the LRC study for different types of lamps. Note that the results were derived by testing groups of 8 or 4 bulbs of 1996 or earlier vintage, which were "seasoned" for 1,000 hours before use in the study. The lamps were tested under computer-controlled cycling conditions and median results were reported.

**Figure 1: Normalized Lamp Life as a Function of On-Time**




The figure shows that CFL lamps that were operated by the LRC with a 5 minute on/ 5 minute off cycle (first set of points on the graph) had observed lamp survival rates of 5 to 100 percent of the rated lamp life. That translates to a range of 500 to 10,000 hours for a lamp originally rated to last 10,000 hours. This result shows the need to include on-time cycle length in estimates of CFL impacts, especially in the evaluation of lighting programs that claim savings beyond the first year of lamp operation.

For the purpose of this analysis we used the LRC results for lamps C1 and E only, for the following reasons:

1. The scope of this analysis is to explore the effects of switching on observed lamp life. Many of the lamps tested by the LRC either failed the rated life test (see results for lamps

B1 and B2 for the 3 hour cycle), or exceeded the rated life test (see results for lamps A1, C2, F2 for the 3 hour cycle.) These results incorporate an underlying statement about the adequacy of the manufacturer rated life tests, and we did not want to include that factor in an analysis of switching effects.

2. One lamp had counter-intuitive behavior across tests (see results for lamp F1); we did not want to include any underlying erratic behavior effects into the results of this analysis.
3. The 3 hour tests for lamps C1 and E came very close to lamp life ratings. Moreover, lamp C1 has coil shape, magnetic ballast, and preheat start. Lamp E has bullet shape, electronic ballast and instant start. Lamp C1 is very similar in shape, while lamp E is very similar in operation to the most popular lamps currently in use. We felt that these two lamps would be most representative of the current population of screw-base CFLs promoted through the California IOU upstream lighting programs.

To illustrate how the LRC results can be integrated with the traditional CFL analysis method, we re-analyzed the KEMA logger data so that the effect of short cycles is captured in the estimate of CFL observed life. In this re-analysis, the average length of time that a CFL lamp is switched on (i.e. its on-time cycle length) becomes a parameter in the estimate of the average number of hours that the CFL is used per day.

The re-analysis starts with the observation that the hours of CFL use per day can be calculated as the product of the average length of time that the CFL is on, and the average number of on-switches per day.

*Hours of Use [h/day] = On-time Cycle Length [min] * Number of On-Switches / 60*

The CFL hours of use estimated through this method should match KEMA's result, which was derived by using the logger data directly to estimate the average number of hours per day that each CFL is switched on. The advantage of this method is that CFL on-time cycle length can also be used in conjunction with the data from Figure 1 to calculate a normalized rated life factor. The normalized rated life factor is thus tied into the lamp's actual usage pattern and can adjust the rated life printed on a lamp's packaging into an "observed" lamp life. This in turn leads to a more realistic estimate for rated lamp life for use in the DEER EUL approach:

*Observed Lamp Life [in years] = Normalized Life * Lamp Rated Life [h]/(365* Hours of Use [h/day])*

## Assessment of Switching Results

### CFL On-Time Cycle Length

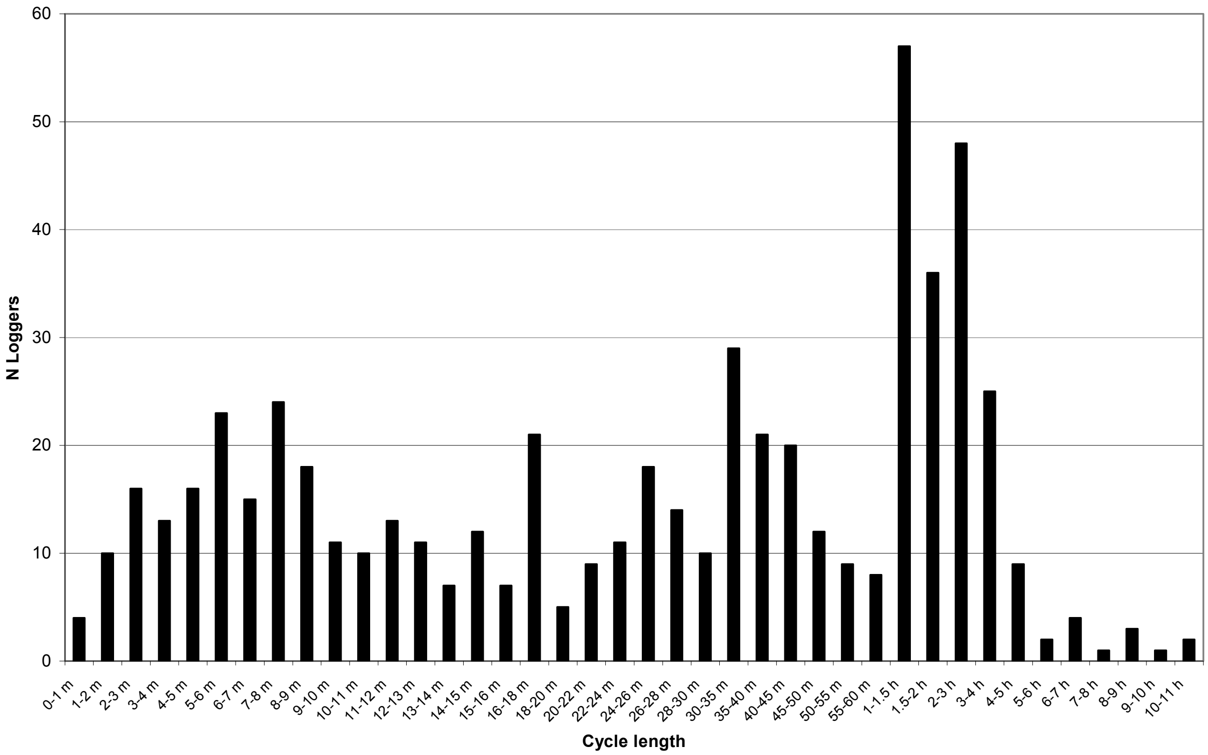
The on-off events recorded by KEMA loggers were used to calculate the total on-time for each monitored lamp, as well as the overall length of time for which each lamp was monitored[5]. The average on-time cycle for each lamp was then calculated as the ratio of those two numbers:

*On-Time Cycle Length [min/switch] = Total On-Time [min] / Total Number of Switches*

[5] The metering technology used in the KEMA study might be prone to failure to pick up on burning CFLs in rooms that receive regular sunlight.

Figure 2 shows a histogram of average on-time cycle lengths for all lamps monitored in the KEMA Study. 538 of the 585 lamps included in this analysis had average on-time cycles shorter than three hours per switch.

**Figure 2: Distribution of Average CFL On-Time Cycle Length for Monitored Lamps**




The estimated on-time cycle length is shown in Table 1 for all KEMA loggers, as well as for loggers installed in single family detached homes only. Due to sample constraints statistically valid results could not be obtained for single family attached and mobile homes.

**Table 1: Average CFL On-Time Cycle Length for Monitored Lamps, by Location**

| | All Homes | | Single-Family Detached | |
|---|---|---|---|---|
| Room Type | N loggers | On-Cycle Length (min/switch) | N loggers | On-Cycle Length (min/switch) |
| All Rooms | 585 | 32 | 447 | 30 |
| Bedroom | 138 | 29 | 102 | 28 |
| Bathroom | 89 | 11 | 71 | 12 |
| Family rm. | 59 | 51 | 52 | 54 |
| Garage | 12 | 28 | 11 | 28 |
| Hallway | 42 | 27 | 31 | 26 |
| Kitchen | 82 | 38 | 53 | 33 |
| Living rm. | 128 | 68 | 96 | 73 |
| Laundry rm. | 20 | 16 | 17 | 15 |
| Other rm. | 15 | 26 | 14 | 26 |

In Table 1 the average on-time cycle length of all KEMA loggers is 32 minutes. This is well below the three-hour cycle length that, according to the LRC results in Figure 1, would lead to an observed life equal to the lamp rated life. Average on-time cycle length varies by room, from 11 minutes for bathrooms to 68 minutes for living rooms. Note that the number of loggers available for the analysis of on-time cycle in garages, laundry rooms and other rooms is small, and more data should be collected in support of more robust results for these types of rooms.

## CFL Number of On-Switches per Day

The on-off events recorded by loggers were also used to calculate the average number of on-switches per day. The average number of on-switches per day was calculated by dividing the total number of switches by the total length of time for which each lamp was observed:

*On-Switches per Day = Total On-Switches / Total Observation Time [Days]*

Table 2 shows the average number of on-switches per day for all loggers, as well as for loggers installed in single family detached homes. On average, CFL lamps are switched on 4 times per day, but the number of on-switches varies between 3 per day in bedrooms and hallways and 8 per day in bathrooms. When assessing differences across room types, the reader is again cautioned to consider sample sizes.

**Table 2: Average CFL On-Switches per Day for Monitored Lamps, by Location**

| | All Homes | | Single-Family Detached | |
|---|---|---|---|---|
| Room Type | N loggers | On-switches/ day | N loggers | On-switches/ day |
| All Rooms | 585 | 4 | 447 | 4 |
| Bedroom | 138 | 3 | 102 | 4 |
| Bathroom | 89 | 8 | 71 | 8 |
| Family rm. | 59 | 3 | 52 | 3 |
| Garage | 12 | 7 | 11 | 7 |
| Hallway | 42 | 3 | 31 | 3 |
| Kitchen | 82 | 5 | 53 | 6 |
| Living rm. | 128 | 3 | 96 | 3 |
| Laundry rm. | 20 | 4 | 17 | 4 |
| Other rm. | 15 | 5 | 14 | 6 |

## CFL Hours of Use

The CFL hours of use per day can be estimated by multiplying on-time cycle length by the number of switches per day, and Table 3 shows the results of that calculation.

**Table 3: Average CFL On-Hours per Day for Monitored Lamps, by Location**

| | All Homes | | Single-Family Detached | |
|---|---|---|---|---|
| Room Type | N loggers | On-hours per day | N loggers | On-hours per day |
| All Rooms | 585 | 2.2 | 447 | 2.2 |
| Bedroom | 138 | 1.6 | 102 | 1.7 |
| Bathroom | 89 | 1.6 | 71 | 1.5 |
| Family rm. | 59 | 2.5 | 52 | 2.5 |
| Garage | 12 | 3.1 | 11 | 3.3 |
| Hallway | 42 | 1.6 | 31 | 1.5 |
| Kitchen | 82 | 3.2 | 53 | 3.3 |
| Living rm. | 128 | 2.9 | 96 | 3.1 |
| Laundry rm. | 20 | 1.0 | 17 | 1.0 |
| Other rm. | 15 | 2.2 | 14 | 2.4 |

Even though this analysis has not annualized the logger data to compensate for varying day lengths over the year, as the KEMA Study did, the resulting 2.2 hours per day agrees very well with the KEMA result. Similar to the KEMA results, average CFL on-hours per day vary with location, from 1 hour in laundry rooms to 3.2 hours in kitchens.

## CFL Normalized Lamp Life

If the distribution of on-cycle length data from Figure 2 is used in conjunction with the survival data from Figure 1, an average normalized lamp life can be estimated for any group of monitored CFL lamps. The results reported in Table 4 below were obtained as follows:

1. The results corresponding to lamp “E” in Figure 1 were used to derive a regression of normalized lamp life value as a function of cycle length. This regression represents the “low” end of the normalized lamp life range of the representative lamps selected.
2. Similarly, the results corresponding to lamp “C1” in Figure 1 were used to derive a regression representing the “high” end of the normalized lamp life range of the representative lamps selected.
3. A “middle” regression was also derived, representing the average of the “high” and “low” ends of the normalized lamp life range.[6]
4. The distribution of average cycle lengths from KEMA loggers was used as weights to estimate an average normalized lamp life by room, and overall at home level.
5. Among the 585 lamps monitored in the KEMA study, 59 had average cycle lengths shorter than 5 minutes. In the LRC study, lamp survival was not tested for cycles shorter than 5 minutes. Because the survival curves in Figure 1 are highly non-linear, we felt it would not be prudent to extrapolate the regressions for estimating normalized lamp life for cycles shorter than 5 minutes. Instead, the normalized lamp life for the 5 minute cycle was applied to the lamps with cycles shorter than 5 minutes. As a result, the CFL life estimates recommended by this study are probably high compared to the results that would be observed in the field. Future work should be undertaken to establish normalized life factors for lamps subject to average on cycle times of less than 5 minutes.
6. Among the 585 lamps monitored, 47 had average cycle lengths longer than 3 hours. Again, the LRC did not study lamp survival for cycles longer than 3 hours. Since survival curve becomes more linear at the long cycle end, and because lamp survival longer than rated life has been observed in the field, we extrapolated the normalized lamp life regression beyond the 3 hour mark. The extrapolation applies 130% of the laboratory rated life to lamps that are operated with 12 hour cycles.
7. The on/off cycles for each individual lamp monitored was used to derive a mean cycle length and a mean number of switches per day, as discussed above. The distribution of mean lamp results was then used in conjunction with the survival regressions to derive a normalized lamp life factor by room, as shown in Table 4 below. Using each individual on/off event for each individual lamp, rather than a mean cycle length for each lamp, results in a lower factor than reported in Table 4 since each cycle now has equal weight,

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[6] Since the LRC reported median normalized life from testing of *groups* of bulbs under specific values of cycle length, it is possible that the LRC results introduce “aggregation bias” into the current analysis. In other words, the relationship inferred about normalized life as a function of cycle length may be different than what would be observed over individual bulbs.

and the cycle time to survival time relationship is highly non-linear. It should be noted that the LRC survival relationship is based on equal cycles for each cycle length, while the real-life data show that lamps usually have different cycle lengths per switch. Future lamp testing should examine the effects of varying cycle time on CFL survival.

**Table 4: Average Normalized CFL Lamp Life for Monitored Lamps, by Location**

| | All Homes | | | | Single-Family Detached | | | |
|---|---|---|---|---|---|---|---|---|
| | | Normalized Lamp Life | | | | Normalized Lamp Life | | |
| Room Type | N loggers | Low (E) | Middle (C1,E) | High (C1) | N loggers | Low (E) | Middle (C1,E) | High (C1) |
| All Rooms | 585 | 0.491 | 0.526 | 0.561 | 447 | 0.486 | 0.521 | 0.556 |
| Bedroom | 138 | 0.430 | 0.467 | 0.505 | 102 | 0.418 | 0.456 | 0.494 |
| Bathroom | 89 | 0.210 | 0.257 | 0.304 | 71 | 0.220 | 0.266 | 0.312 |
| Family rm. | 59 | 0.664 | 0.692 | 0.720 | 52 | 0.670 | 0.698 | 0.725 |
| Garage | 12 | 0.434 | 0.472 | 0.510 | 11 | 0.440 | 0.478 | 0.515 |
| Hallway | 42 | 0.387 | 0.426 | 0.465 | 31 | 0.387 | 0.426 | 0.465 |
| Kitchen | 82 | 0.547 | 0.580 | 0.612 | 53 | 0.492 | 0.527 | 0.562 |
| Living rm. | 128 | 0.708 | 0.734 | 0.760 | 96 | 0.724 | 0.749 | 0.774 |
| Laundry rm. | 20 | 0.299 | 0.343 | 0.386 | 17 | 0.285 | 0.329 | 0.373 |
| Other rm. | 15 | 0.472 | 0.508 | 0.543 | 14 | 0.476 | 0.511 | 0.547 |

In Table 4 the average normalized lamp life at room level varies between 0.210 and 0.304 for laundry rooms, and between 0.708 and 0.760 for living rooms. The overall home average is 0.491 to 0.561, with an average of 0.526.[7] This result indicates that, because the average residential CFL lamp is switched on with cycles different than the three hours employed in the rating procedures, a lamp that was originally rated to 10,000 hours will have an "observed" life between 4,910 to 5,610 hours. Note that if the actual rated life values were available for each lamp in the KEMA sample, those values would have been used in this calculation instead of the constant 10,000 hours. For lamps currently promoted through the California IOU upstream programs, lamp rated life can be as low as 6,000 hours or as high as 12,000 hours.

**"Observed" CFL Lamp Life**

"Observed" lamp life for a CFL can be estimated by using the CFL hours of use from Table 3 together with the normalized lamp life from Table 4, and different values for CFL "rated" life. Again, had actual CFL lamp rated life been available for the monitored lamps, the use of those data would have been preferable to the use of a constant rated life for all lamps.

Table 5 shows that the average 10,000 hour rated CFL lamp has a lamp life of 6.1 to 6.9 years. Due to short on-cycles and many on-switches per day, the "observed" lamp life of 10,000 hour rated CFLs installed in bathrooms is 3.6 to 5.2 years. Due to longer on-cycles and fewer on-switches per day, the lamp life of CFL lamps installed in family rooms is 7.3 to 7.9 years.

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7 We conducted an analysis to assess the sensitivity of the normalized lamp life result on the type of regression used on the LRC data from Figure 1. The analysis shows that the normalized lamp life varies between 0.516 in a worst-case scenario and 0.532 in a best-case scenario. We concluded that the average normalized rated life derived through this method is not highly dependent on the regression used on the LRC data points. However, it is highly dependent on the bulbs included in the analysis. Obviously, LRC-type lamp performance results derived for lamps that are currently in use on the market would have been highly desirable for this analysis. Such lamp performance data are unfortunately not available.

**Table 5: CFL Observed Life for Monitored Lamps, by Location for Lamp Rated Life = 10,000 hours**

| | All Homes | | | | Single-Family Detached | | | |
|---|---|---|---|---|---|---|---|---|
| | | Observed Life [years] | | | | Observed Life [years] | | |
| Room Type | N loggers | Low (E) | Middle (C1,E) | High (C1) | N loggers | Low (E) | Middle (C1,E) | High (C1) |
| All Rooms | 585 | 6.1 | 6.5 | 6.9 | 447 | 6.0 | 6.4 | 6.8 |
| Bedroom | 138 | 7.2 | 7.8 | 8.4 | 102 | 6.7 | 7.3 | 7.9 |
| Bathroom | 89 | 3.6 | 4.4 | 5.2 | 71 | 3.9 | 4.7 | 5.5 |
| Family rm. | 59 | 7.3 | 7.6 | 7.9 | 52 | 7.3 | 7.6 | 7.9 |
| Garage | 12 | 3.8 | 4.1 | 4.5 | 11 | 3.6 | 3.9 | 4.3 |
| Hallway | 42 | 6.6 | 7.3 | 8.0 | 31 | 7.1 | 7.8 | 8.5 |
| Kitchen | 82 | 4.7 | 5.0 | 5.3 | 53 | 4.1 | 4.4 | 4.6 |
| Living rm. | 128 | 6.6 | 6.8 | 7.1 | 96 | 6.4 | 6.6 | 6.8 |
| Laundry rm. | 20 | 8.0 | 9.2 | 10.4 | 17 | 7.5 | 8.7 | 9.8 |
| Other rm. | 15 | 5.9 | 6.3 | 6.7 | 14 | 5.5 | 5.9 | 6.3 |

Similarly, the "observed" CFL lamp life can be estimated assuming rated life values of 6,000, 8,000 and 12,000 hours. The results in Table 6 show how sensitive the observed life estimates are to the rated life input. The "middle" (C1,E) value for EULs varies between 3.9 years for lamps rated at 6,000 hours to 7.8 years for lamps rated at 12,000 hours. This indicates the importance of collecting manufacturer and model information from the field and using the rated life associated with each lamp in the sample in the calculation of "observed" life, as opposed to using a generic number for all lamps.

**Table 6: CFL Observed Life for Monitored Lamps for Different Lamp Rated Life Assumptions**

| | All Homes | | | | Single-Family Detached | | | |
|---|---|---|---|---|---|---|---|---|
| | | Observed Life [years] | | | | Observed Life [years] | | |
| Rated Life | N loggers | Low (E) | Middle (C1,E) | High (C1) | N loggers | Low (E) | Middle (C1,E) | High (C1) |
| 6,000 hours | 585 | 3.6 | 3.9 | 4.2 | 447 | 3.6 | 3.8 | 4.1 |
| 8,000 hours | | 4.8 | 5.2 | 5.5 | | 4.8 | 5.1 | 5.5 |
| 10,000 hours | | 6.1 | 6.5 | 6.9 | | 6.0 | 6.4 | 6.8 |
| 12,000 hours | | 7.3 | 7.8 | 8.3 | | 7.1 | 7.7 | 8.2 |

As a reference point, the California DEER Study uses a 9.4-year lamp life or EUL for CFL lamps based upon an 8,000 hour rated lamp life. The results in Table 6 show that lamps with 8,000 rated life have an observed life of 4.8 to 5.5 years. The "middle" estimate of 5.2 years "observed life" indicates that the current DEER approach of CFL measure life might over-estimate the actual measure life for 8,000 hour rated CFLs by at least 44%.

## Conclusions and Recommendations

CFL operation patterns highly influence observed lamp life, so understanding operation patterns should be an important component of any future CFL studies. The recommendations below are meant to provide a uniform framework for conducting future CFL studies.

1. Any study involving primary CFL data collection should be based on a sample that is large enough to support estimates of lamp usage by house type and room type. Single-

family attached homes, multifamily homes and mobile homes have been under-represented in past studies, as have family rooms, hallways and garages.

2. Primary CFL data collection should employ *devices that track on-off events with associated time stamps*. Loggers that only track average on-time per hour will not support an analysis of on-cycle length; those data are only partially useful to a comprehensive CFL study.
3. Complete *lamp-related information* such as manufacturer and model, base position (base up, base down, base sideways), fixture type (open, partially open, enclosed), control type (switch, dimmer, timer), location inside a room, type of room (bedroom, family room, etc.) and sensitivity to daylight should be collected when installing lighting loggers or devices on CFL fixtures.
4. A *complete lamp inventory* should be collected in each home in the sample, so that adequate weights can be developed for analysis purposes. For all CFL fixtures in the home, pre-CFL conditions (lamp type, wattage) should be collected as available. For all non-CFL fixtures in the home, CFL compatibility should be noted, as well as an indication of whether or not the homeowner would consider installing CFLs in those fixtures in the future.
5. *Demographics and home characteristics* (square footage, number of bedrooms, number of bathrooms, and number of rooms in the home) should be collected from the entire field sample; this is important for understanding differences among home types, and for inferring how those differences might affect results.
6. To address CFL product quality issues, laboratory-based studies similar to the LRC study should be conducted on a continuous basis, and for a large number of marketed lamps that are tested with random operating patterns, i.e., closer to field conditions. One of the many limitations of the LRC data is that lamps were operated under equal cycles, while in reality lamp cycle length varies at any location in the home.
7. EUL estimates for CFL measures should account for all factors that affect the life of the measures. Evaluation studies should collect retention data by initiating retention panels. The California impact evaluations for 2006-08 program cycle should consider adding this marginally costly, but critical data collection to the existing field work that would generate CFL survival data based on actual CFL usage in homes and businesses.

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