# Updated Measure Lifetime Estimates: EULs Based on 10 Years of Studies

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## Abstract

As part of a project for the California Public Utilities Commission (CPUC), the authors conducted a detailed assessment of more than 100 measure retention / lifetime studies to identify the real-world lifetimes for numerous measures used in an array of residential and non-residential buildings.

Estimated useful lifetimes (EULs, or measure lifetimes), in conjunction with energy savings estimates, are the key elements in computing energy savings for a program or intervention. These savings estimates are used to plan programs, and are also critical inputs used to determine the shareholder earnings for the utilities in relation to investment in programs.

Many of the EULs had not been updated for more than a decade, and this project used results from 10 years of studies to identify updated EULs that could be supported by real-world program experience, as well as identifying those EULs in need of additional studies to support their values. For each study, the authors conducted an exhaustive review of program measures, sampling methodologies and approach; field work; data validation; and analysis steps to determine whether reliable lifetime information could be gleaned. The authors conducted a detailed evaluation of the statistical techniques used in each study, and in some cases, re-estimated EULs using more reliable techniques.

The paper provides information on updated / recommended EUL estimates for a wide array of residential, and non-residential energy efficiency equipment. The implications related to gaps in available EUL information – especially as it relates to key equipment – and reliable estimates of EUL values for planning for future programs are presented. These results are currently being used in for State and utility program planning.

## Introduction

Measure lifetimes are inputs to computations of shareholder returns for investor-owned utilities (IOUs) in California. Protocols prepared by the state regulatory agency prescribed the *a priori* lifetimes that could be assumed for each measure or measure type, as well as a whole set of rules regarding measure life validation study schedule and associated analytical and reporting methods. Measure lifetimes, or "expected useful lifetimes" (EULs) provide an estimate of the median number of years that an energy efficiency measure can be expected to remain in place and operational in the field. This figure represents a critical component in the computation of total energy savings that can be attributed to the measures installed under a program – the shorter the assumed lifetime, the smaller the total savings for the measure.

The CPUC contracted with the authors to conduct a detailed analysis of more than 100 EUL / validation studies that had been performed over a ten year period through 2004 in conjunction with a large review of the shareholder claims put forward by the utilities.[2]

The 100 studies reviewed covered residential, low income, commercial, industrial, agricultural, and military programs and measures. For each study, the consultant team conducted an exhaustive review and scored the studies on factors related to conformance with the protocols and

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[1] Quantec LLC served as a subcontractor to SERA for portions of this work.

[2] The study also examined "technical degradation" studies, which examined the pattern of degradation of incremental savings performance by measures over time.

documentation; sampling methodologies and approach; field work and data collection procedures; data validation; modeling approach, estimation method, and consideration of alternative models, and analytical conclusions. We assessed:

- Program information and documentation, share of program savings covered by the analysis, measures included, and other topics related to justification and context for the studies;
- Sampling methodologies, sample quality and justification, quality of field work – including data collection approach, treatment of sample, quality of program records and field work practices; and
- Data validation and verification, treatment of sample attrition and sample, statistical approach, consideration of alternative models and treatments, and the justifiability of the results reported.

The study provides quantitative information on updated measure lifetimes for scores of commonly-installed program measures, and noted measures for which reliable lifetime information is not currently available. As a consequence of the analyses – and the review of studies over time – we were able to identify "best practices" for measure lifetime analyses. The results have implications for others conducting retention analyses, as well as those considering or revising protocols or standards related to these studies.

## "Best Practices" for Measure Life Studies

The assessments of the quality of the studies were based on a number of criteria. We reviewed the studies to:

- Assess conformance with prescribed protocols, and review the methods, quality, and the justifiability of results. The analysis allowed us to identify methodological problems with past studies and develop "best practices" for the conduct of EUL studies.
- Assemble the EUL results for the various measure types and identify measures that require updates to the assumed measure lifetimes. These results of this review of 9 years of studies were used to update the EULs for a large database used extensively in planning and evaluation protocols.
- Identify measures for which insufficient retention study information is available to guide program planning.

The analysis showed that the majority of the studies attempted to follow the guidelines and suggestions from the protocols, and the studies were generally able to provide reasonable and useful EUL estimates. However, there was significant variation in the quality and thoroughness of the studies. As a consequence, we were able to summarize several common weaknesses in the studies, which are presented in Table 1.

***Table 1. Issues and Suggestions Regarding EUL Study Method***

| ***Issue*** | ***Suggestion*** |
|---|---|
| ***Small Sample Size:*** The most common problem with the studies that we evaluated was an insufficient sample size. In some cases, a small sample size was the result of an inadequate data collection effort, and therefore easily avoidable. However, other studies worked from poor population lists (usually obtained from program tracking data). In such cases, sample size complications were far beyond the control of the research team. | Any possible effort should be taken to ensure a sufficient sample size. Inadequate samples can lead to several insurmountable analytical problems, from large confidence intervals to models that do not converge. Utilities need to maintain high quality lists – with a view toward evaluation and not just rebate or program invoicing applications. In addition, sample sizes need to vary based on the expected failure date; those items with long lifetimes will likely |

| Issue | Suggestion |
|---|---|
| | need extremely large sample sizes to detect failures.[3] |
| ***Failure to Test Other Models:*** Another common mistake was the failure to test several models using different statistical distributions when estimating survival functions. Often, this occurred when a research team tested different functions for one measure, then applied that function to the rest of the measures covered by the study. Because different measures act differently, the same model assumptions will not always be justifiable from one type of equipment to the next. This caveat is especially important when parametric models are being used. Although failure rates may accelerate with time for both refrigerators and air conditioners, they may not accelerate in the same way. | Statistical programs make it fairly easy to test log-logistic, weibull, gamma, and other distributions. Testing alternatives allows the researcher to identify the best "fit" for the failures over time, and improve the chance of identifying appropriate EULs. Failure rates for different types of measures, and for measures of different lifetimes may be expected to accelerate in different patterns, and the research should account for that. |
| ***Ambiguous Failure Dates:*** There is often a tendency for inspections and surveys to fall short in their attempts to obtain approximate failure dates. Even if the exact date of failure is unknown, any additional information regarding when the measure in question failed can be used to narrow the censoring interval. Follow-up questions, such as year of failure, season or month of failure may produce more accurate responses than simply asking whether the measure is still in place at the time of the interview. Accurate failure date responses are easier to obtain when the measure being studied is more noticeable. Even the maintenance supervisor for a large and busy building is likely to know approximately when an energy management control system stopped working. | The best remedy for large failure date intervals when measures are small and numerous (such as light bulbs) is more frequent surveys – though this course of action can be expensive. However, if the measure is common or responsible for a large share of savings (and potentially a large share of earnings claims) the extra investment may be well justified. If dates cannot be recalled, follow-up questions that identify the season and year of failure or removal is essential. In addition, utility records must also clearly note installation date (which did not always happen). |
| ***Poor Documentation:*** Reports need to clearly document the methods, procedures, and analyses conducted, and their justification. The biggest problem that we encountered in the review was documentation inadequate to determine exactly what procedures had been followed, hypotheses tested, modeling applied, coding adjustments made, weighting schemes used, etc. Some reports had included formulae that were not relevant to the models estimated. The documentation step is frequently overlooked but extremely important. | Simply put, the documentation must be sufficient to facilitate both (1) thorough understanding of the methods used to conduct the study (and justify methodological decisions), and (2) the conclusions drawn from the study. Regardless of whether a potential reader is reviewing the study for accuracy, to assess shareholder earnings claims, or simply trying to gain insights from its conclusions, documentation is critical. |
| ***Failure to examine results in context:*** Very few studies looked "outside themselves". There are now many retention studies that have been conducted across the nation for a large number of measures (including previous studies for the same program in many cases). | Discussion of results is improved if results are reviewed and compared to other studies – earlier studies of the same program, or for programs in other locations – to identify similarities, patterns, and differences, and provide a context or benchmark for the findings. |

## Analysis and Comparison of EUL Results by Measure Type

A key effort of the study was an assessment of whether there were differences between the *ex ante* EUL values and the estimated *ex post* estimates of EULs. Differences have implications for program planning and evaluation, as well as the program dollars and shareholder returns that are

[3] For example, if multiple failures are desired to provide a reasonable chance for a model "fit" say 3 years after installation, and the lifetime of the measure is 15 years (median), and a "normal" curve is assumed for failures with a 5 year standard deviation, preliminary computations by the authors suggest it may take surveys (phone or on-site) of 450 sites to detect 2 failures. Different numbers of observations would be needed for different assumptions about measure lifetime, distribution, variance, and years after program installation, and the sample sizes are very sensitive to (unknown) standard deviations. The California Public Utilities protocols provide sample size and accuracy guidelines.

affected by the results. Variations in dollars affected occur when the estimated *ex post* or field-estimated lifetimes from the EUL studies differ from these *ex ante* "Protocol" values. The analyses:

- Reviewed differences between *ex ante* and *ex post* EULs by measure types, designed to bracket the potential dollars at risk from poorer quality EUL estimates.
- Used non-statistical analyses of the impact of the adjusted EULs on the final dollar amount claimed.
- Re-estimated EULs from studies with low scores for methodology using the original data collected by the utilities and their consultants.

Only those studies that were judged to have been completed with reasonable quality ("C" or better grades) were included in the remaining analyses. The results of the comparisons of ex post and ex ante EULs are provided in Figure 1 (residential measures) and Figure 2 (non-commercial measures) below.

The hypothesis testing performed by the EUL verification studies indicates that, for the majority of measures, the ex post values are not significantly different than the ex ante planning EUL values. Several exceptions arise. These include:

- Residential duct testing and high efficiency ducts, which appear to have quite a bit shorter lifetimes than originally estimated.
- Residential refrigerators, which appear to have somewhat shorter demonstrated median lifetimes than *ex ante* EULs would indicate.
- Residential T8 fixtures, which may have longer lifetimes in residential applications than indicated by *ex ante* values.
- On the commercial side, pump repair measures appear to have a longer *in situ* lifetime than indicated by *ex ante* values.

- **Figure 1: Summary of Residential Lifetime Estimates – by Measure Type**

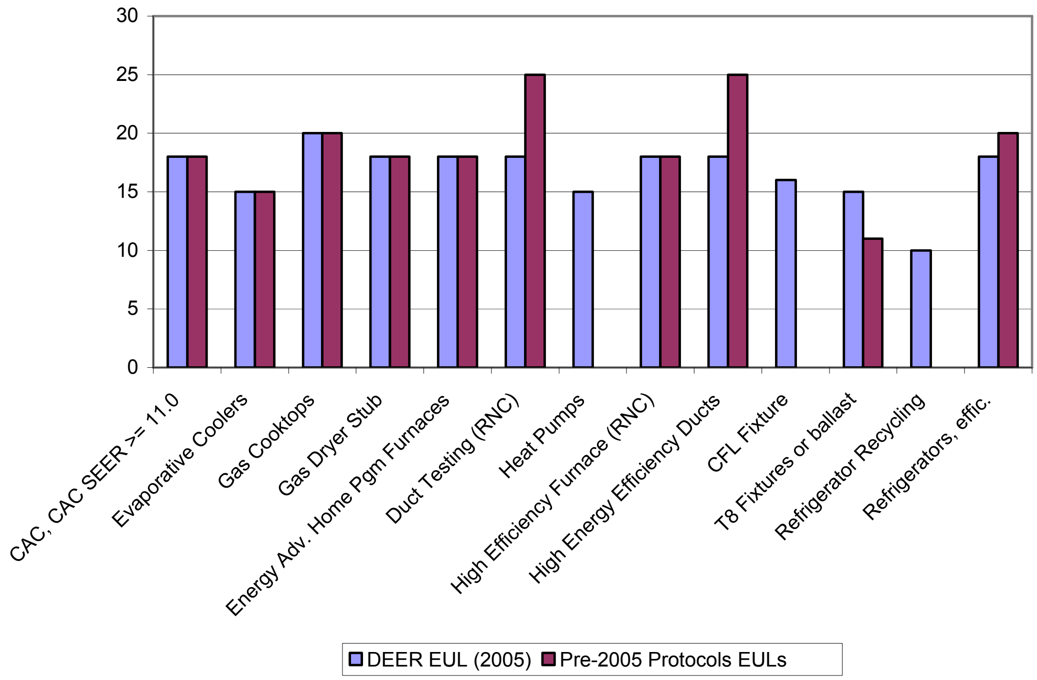
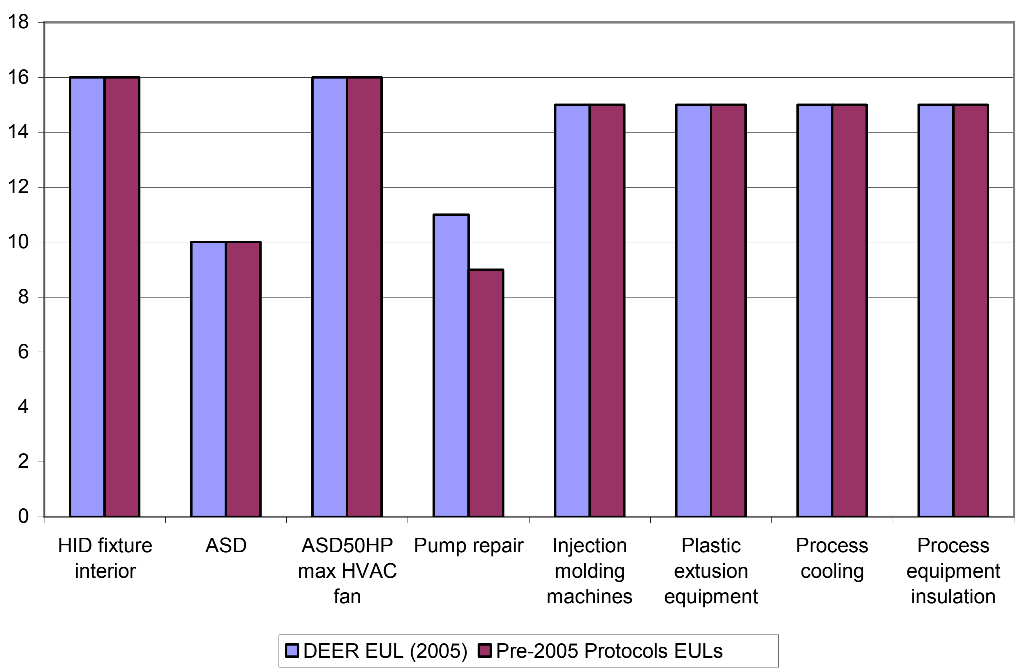



**Figure 2: Summary of Commercial Measure Lifetime Estimates – by Measure Type**



## Analysis of Lighting Measures

One of the most common end uses included in measure life studies was lighting; lighting was responsible for a very large percentage of the measures installed in California energy efficiency programs over the period. We were able to use these many studies to examine the difference in realization rates (the ratio of the in-field EUL experience compared to *ex ante* values, or the share of planned savings that are "realized"), which may provide a benchmark or proxy for EUL values for studies that were not well-performed.

The EULs were summarized across the retention studies based on sector, end use, and measure category. The examples presented in this paper represent the realization rates associated with measures with the most common end use and largest number of associated dollars – lighting in the commercial and industrial sectors. For each measure type the mean, minimum, and maximum EULs were reported for the *ex ante*, final (accepted) *ex post*, and computed realization rates. For example, there were eight commercial lighting programs that estimated EULs for electronic ballasts (Table 2). The mean ex ante EUL was 15 years, with a minimum of 10 years and a maximum of 16 years. The average accepted *ex post* EUL, however, was 14 years, as at least one study accepted the ex post EUL and rejected the initial *ex ante* EUL (the minimum realization rate was 0.8).

There are a number of measures that show dramatic increases in the *ex ante* to *ex post*. For example, commercial de-lamping / reflector projects increase from an average EUL of 13 years to an average of 33 years; T8 lamps increase from an average EUL of 15 years to an average of 33 years; finally, the one commercial project with occupancy sensors jumped from an *ex ante* EUL of eight years to an *ex post* EUL of 76 years (Figure 3). A number of realization rates, in fact, are over 9 times the *ex ante* value.

In the industrial sector most of the *ex post* lighting EULs were nearly identical to the *ex ante* values (Table 3 and Figure 4). Ballasts only showed a slight jump, from 12 to 16 years, while one study accepted an *ex post* EUL of 207 years for occupancy sensors, thus pushing this average to 113 years, well above any reasonable estimate (Figure 4).

This work indicates that some of the most common measures in the high dollar studies are accepting *ex post* values that are well above the *ex ante* values. These high realization rates have potential dollar implications for programs. Differences between *ex ante* value and *ex post* values derived from strong studies are being used to bracket the dollars at risk from the poorer scoring measure life studies.

**Table 2: EULs and Computed Realization Rates for Commercial Lighting Projects**

| | | Ex ante | | | Final Ex post | | | Realization Rate | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **# Studies** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** |
| Ballast | 8 | 15 | 10 | 16 | 14 | 8 | 16 | 1.0 | 0.8 | 1.0 |
| CF Fixture | 7 | 13 | 10 | 16 | 13 | 10 | 16 | 1.0 | 1.0 | 1.0 |
| CF Lamp | 5 | 9 | 2 | 20 | 9 | 6 | 13 | 1.6 | 0.7 | 2.9 |
| Delamping/Reflectors | 7 | 13 | 10 | 16 | 33 | 10 | 154 | 2.2 | 1.0 | 9.6 |
| Exit signs (LED) | 1 | 20 | 20 | 20 | 20 | 20 | 20 | 1.0 | 1.0 | 1.0 |
| HID Lighting* | 1 | 16 | 16 | 16 | 16 | 16 | 16 | 1.0 | 1.0 | 1.0 |
| HP Lighting* | 2 | 18 | 15 | 20 | 18 | 15 | 20 | 1.0 | 1.0 | 1.0 |
| Occupancy Sensors | 1 | 8 | 8 | 8 | 76 | 76 | 76 | 9.5 | 9.5 | 9.5 |
| T8 Fixture | 3 | 13 | 11 | 16 | 13 | 11 | 16 | 1.0 | 1.0 | 1.0 |
| T8 Lamp | 9 | 15 | 5 | 20 | 33 | 5 | 91 | 1.9 | 1.0 | 4.5 |
| T8 Lighting* | 1 | 16 | 16 | 16 | 16 | 16 | 16 | 1.0 | 1.0 | 1.0 |

*Full lighting systems, with lamps and fixtures combined in same model

**Table 3: EULs and Computed Realization Rates for Industrial Lighting Projects**

| | | Ex ante | | | Final Ex post | | | Realization Rate | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | **# Studies** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** |
| Ballast | 5 | 12 | 10 | 16 | 16 | 10 | 33 | 1 | 1 | 2 |
| EMS | 1 | 15 | 15 | 15 | 15 | 15 | 15 | 1 | 1 | 1 |
| Exit signs (LED) | 2 | 20 | 20 | 20 | 113 | 20 | 207 | 6 | 1 | 10 |
| HID Fixture | 1 | 16 | 16 | 16 | 16 | 16 | 16 | 1 | 1 | 1 |
| HID Lighting* | 3 | 17 | 16 | 20 | 17 | 16 | 20 | 1 | 1 | 1 |
| T8 Fixture | 6 | 13 | 11 | 16 | 13 | 11 | 16 | 1 | 1 | 1 |
| T8 Lamp | 11 | 16 | 5 | 20 | 16 | 5 | 20 | 1 | 1 | 1 |
| T8 Lighting* | 3 | 16 | 16 | 16 | 16 | 16 | 16 | 1 | 1 | 1 |

*Full lighting systems, with lamps and fixtures combined in same model

**Figure 3. Ex ante and Final Ex post EULs for Commercial Lighting Projects**

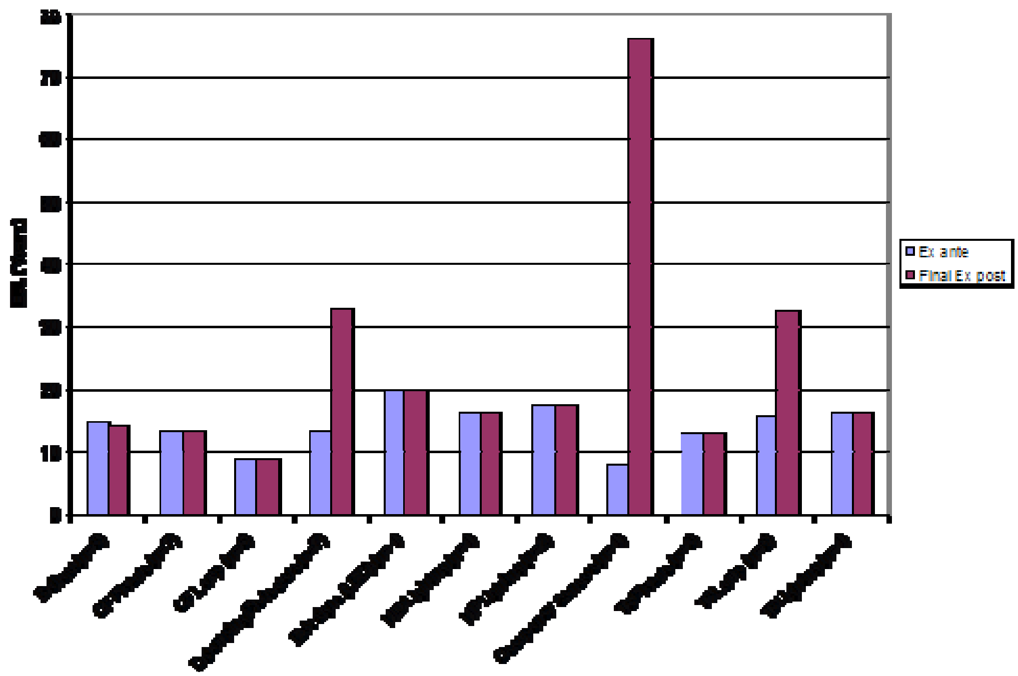
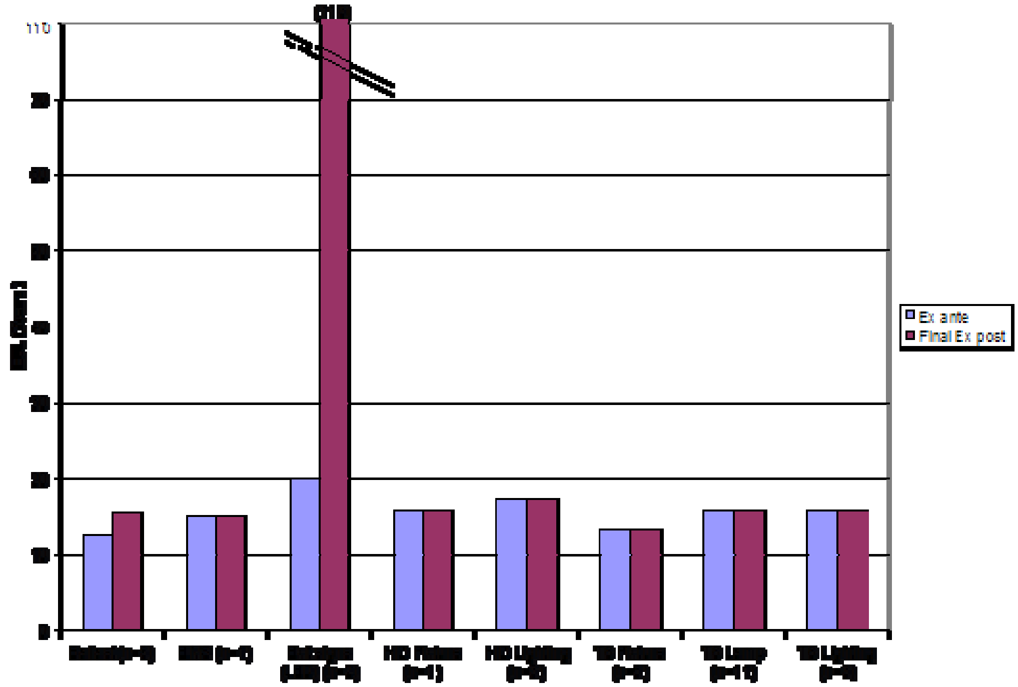


**Figure 4. Ex ante and Final Ex post EULs for Industrial Lighting Projects**



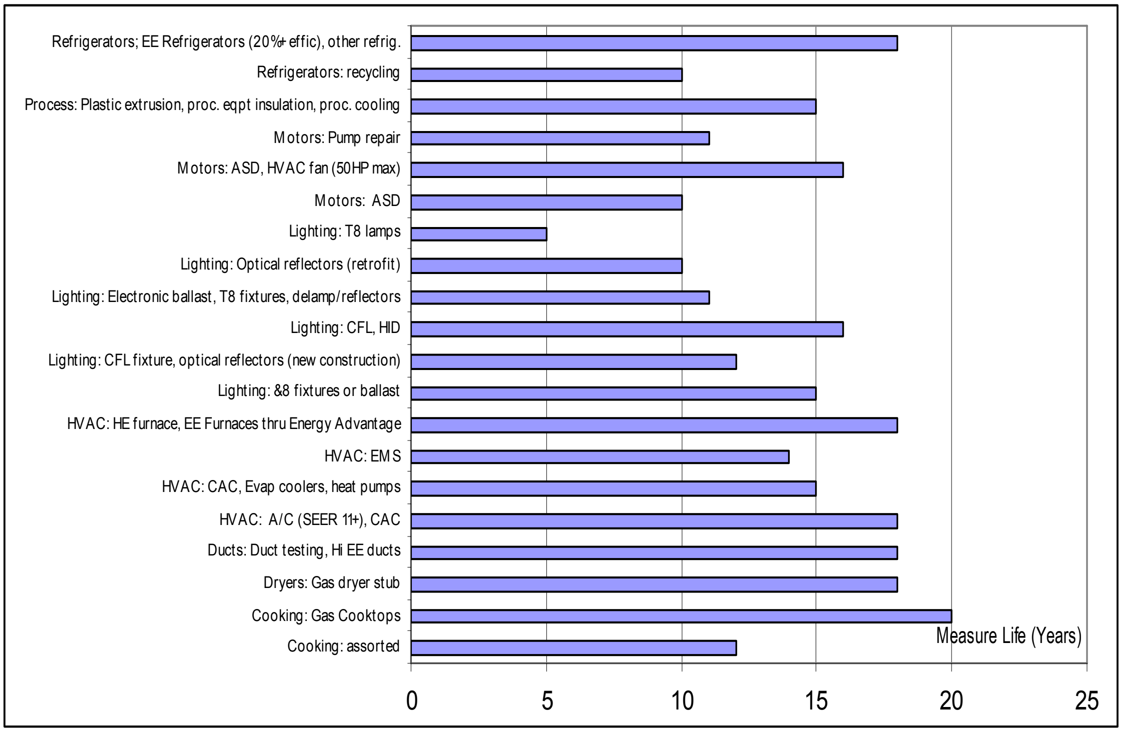

## EUL Lifetime Results

The Protocols call for EUL studies to be conducted on measures or measure combinations that account for half or more of the program's savings. Thus, many of the studies covered more than one measure. In total, the 100 studies covered 301 energy-efficiency measures. As part of our quality assessment activities, we "scored" each study in terms of the quality of its documentation, data, methods, and analysis. Studies that received a score of "C" or better (in a range of high of "A" to a low of "F") based on how well they conformed to "best practices" (above) were considered reliable sources of updated information about median EUL estimates. Figure 5 presents the EUL estimates that could be confirmed, justified, or revised based on the studies that we reviewed. The study provided conclusions on 43 common measures and variations, and the results computed by the authors were incorporated into the large California statewide DEER database.[4] DEER is a database used by the CPUC, utilities, consultants, and others as a common source for information on incremental savings, incremental costs, and lifetimes.[5]

[4] DEER stands for the Database for Energy Efficient Resources, and links can be found under energy.ca.gov/deer/.

[5] (1) Measures and results are presented without distinguishing between end use or sector. The end uses covered included: air conditioning; HVAC; clothes washers; EMS; lighting; motors, drives and pumps; process; and refrigeration. (2) The sectors covered included: commercial, industrial, residential, residential new construction and agricultural.

**Figure 5: Summary of Final Lifetime Estimates – by End Use Type**




## "Gaps" in EUL Results

The analysis also pointed out several "gaps" in EUL analyses, including some measures with only relatively weak measure lifetime studies (first column of Table 4) and some with no studies at all (column 2 of Table 4). .

- CFLs and lighting measures are more complex to measure than other energy efficiency equipment because the lifetimes vary dramatically based on operating hours. As such, the retention studies / results are beginning to be revised to be stated in terms of operating hours, and detailed operating hour studies are being conducted.
- Many of the measures studied had only limited retention studies, or were only examined by retention studies that did not score well in our analysis. This is important because many of these measures are responsible for significant savings in programs across the State of California. Measures of this type include: air compressor equipment (9 equipment types, mostly industrial); air conditioning (8 types, including all sectors); cooking measures (2 types, commercial); controls and heating (9 measures, mostly commercial/industrial or agricultural); lighting (16 measures, many sectors); motors and pumps (25 measures, all sectors); process related equipment (12 specific industrial measures); refrigeration (several); shell measures (including insulation and glass); and several other types of measures.
- The study found no retention studies that addressed measure lifetimes for a number of other measures included in the statewide DEER database. These include: air conditioning equipment (more than 16 specific measure types in all sectors); dryers, washers, and water-related measures (about 25 measures), cooking measures (5 types), controls and heating (17 measures), lighting (12 measure types), motors and pumps (6 types), refrigerators (dozens of measures), shell measures (16 measures) and several other types.

**Table 4. "Gaps" in EULs – Measures with Poor or No Retention Studies**

| Poor studies | No studies |
|---|---|
| • Air compressors (industrial)<br>• Air conditioners (non-residential)<br>• Fryers & ovens (commercial)<br>• EMS / controls (commercial)<br>• Duct burners, sealing & testing<br>• HVAC process equipment (non-res)<br>• Heat curtains (agricultural)<br>• Humidifiers<br>• Various lighting<br>• Aeration blowers<br>• Various motors & pumps<br>• Adjustable speed drives, VAVs<br>• Various process equipment<br>• Some refrigeration categories<br>• Wall, attic insulation<br>• High performance glass<br>• Infiltration measures | • Centrifugal, reciprocating, VSD chillers (non-res)<br>• Evaporative coolers (residential)<br>• Point of use water heat (various)<br>• Aerators, showerheads (residential)<br>• Circulation pump time clocks<br>• High efficiency water heaters<br>• Pipe wrap<br>• Fryers, griddles, steamers, holding cabinets<br>• Heat exchangers, heat recovery, economizers<br>• Large boilers, water source heat pumps, hydronic<br>• Programmable thermostats<br>• Duct insulation, repair, leakage<br>• Timeclocks; vending machine controllers<br>• Various lighting, plug load measures<br>• Pool pumps, VSD supply fan motors; other motors<br>• Various freezers and compressors, condensers<br>• Many insulation, roof, glazing measures |

## Summary and Implications on Measure Lifetime Results

Computing energy savings from energy efficiency programs requires inputs in terms of estimates of: incremental savings per measure, number of measures installed, net to gross ratio[6], and measure lifetimes. Assumptions about these lifetimes – in combination with the per-measure savings –drive the benefits side of the benefit/cost ratios associated with programs and measures. This study provided a thorough and practical review of the more than 100 retention studies that had been conducted in California, and:

- Identified strengths and weaknesses of studies, and developed "best practices" recommendations for this type of study;
- Used the results to provide updated measure lifetimes for key measures, and provided information on realization rates for some measures that may be useful as proxies for programs with studies that are not strong; and
- Identified those measures for which inadequate retention information is available, indicating additional EUL research is needed.

The research provided an opportunity to examine "best practices" in retention studies based on the evolution of work in the area over a 10 year period. The paper provides highlights (and the full report provides detailed lists) of itemized suggestions on sample sizes, modeling approach, data collection, documentation, and the importance of reviewing the results in context – both over time and compared to results from other programs including similar measures. Most importantly, the results were used to provide updated EULs, and to provide information to help prioritize future research on measure lives with "gaps" due to poor or nonexistent studies.

[6] Net to gross ratio (NTG) can also be applied. This is the term for the refinement in savings estimates – turning gross computations of energy efficiency kWh installed into the kWh that are estimated to be attributable to the program's effects, above and beyond what would have happened without the program. NTG ratios represent the combined effects of free ridership and spillover. See, for example, Skumatz 2005.

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