Final Report

C&I Lighting Measure Life and Persistence Project

Prepared for the Regional Evaluation, Measurement & Verification Forum

Middletown, Connecticut June 29, 2011

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Preface

The Regional EM&V Forum

The Regional EM&V Forum (Forum) is a project managed and facilitated by Northeast Energy Efficiency Partnerships, Inc. The Forum's purpose is to provide a framework for the development and use of common and/or consistent protocols to measure, verify, track and report energy efficiency and other demand resource savings, costs and emission impacts to support the role and credibility of these resources in current and emerging energy and environmental policies and markets in the Northeast, New York, and Mid-Atlantic region. Jointly sponsored research is conducted as part of this effort. For more information, see http: www.neep.org/emv-forum.

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Subcommittee for the Commercial Lighting Persistence Project

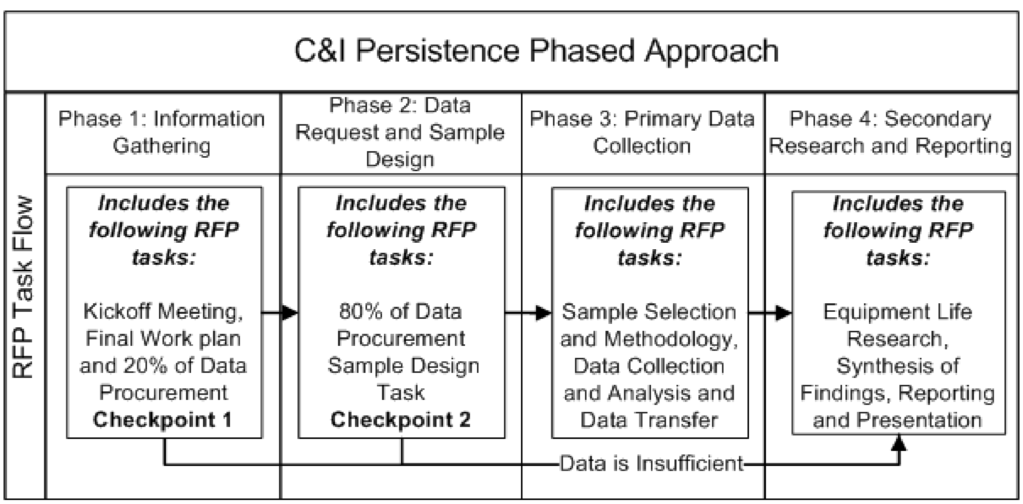
A special thanks and acknowledgment from Elizabeth Titus on behalf of EM&V Forum staff and contractors is extended to this project's subcommittee members and other Forum sponsors from Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, and New York, many of whom provided input, including data from a range of lighting programs, during the development of this project: Bill Blake and Dave Jacobson, National Grid; Judeen Byrne and Victoria Engel-Fowles, NYSERDA; Mary Cahill , Maribel Cruz-Brown and Josu Omaechevarria, NYPA; Mark Churchill and Dave Weber, NSTAR; Elizabeth Crabtree, Efficiency Maine; Gene Fry, Northeast Utilities; Dimple Gandhi, representing Long Island Power Authority; Lisa Glover, Unitil; Paul Gray, United Illuminating; Paul Horowitz, independent consultant; Nikola Janjic, Efficiency Vermont; Kathryn Mammen and Bill Saxonis, NY Public Service Commission; Kim Oswald, consultant to Connecticut Energy Efficiency Board; Mark Sclafani, Central Hudson; Earle Taylor, consultant to Northeast Utilities; John Zabliski, Rochester Gas and Electric.

1. Executive Summary

The primary objective of this study was to conduct primary and secondary research and analysis to provide the sponsors with estimates of measure lifetimes that included on-site verification of CFL bulbs and fixtures, LED exit signs, HID fixtures, and T8 fixtures installed by commercial and industrial lighting programs in New England and New York. A second objective was to determine the expected operating lives (in hours) for the same equipment categories; based on secondary data. A primary driver of this study was the need for lighting measure lives for use in submitting demand resources into the ISO-NE Forward Capacity Market.

Table 1-1 presents an overview of the study design. The original RFP had sequential tasks that included primary data collection and the subsequent analyses of that data. In the work plan KEMA divided the work into four phases and inserted two checkpoints to provide the forum with the authority to approve and modify the work scope. These checkpoints occurred at the conclusion of Phase 1 and the conclusion of Phase 2. This phased approach was developed as a mechanism to deal with potential data availability challenges in the opening study tasks. In this manner, there were clear opportunities for the study to become dependent on secondary research if insufficient data was not available to perform primary data collection, but this ended up not being necessary.

Table 1-1: Phases of Study Approach



1.1 Sample Frame Development

The sponsors provided tracking system data for C&I program lighting installations that occurred from 1999-2009. Using this data, KEMA developed a representative sample of installations from which primary data collection was gathered and used to determine measure persistence in years of survival and other statistical modeling analyses.

Due to the fact that projects often had more than one measure type installed through a given program, measure combination groups were created in order of their weighted probability (proportion of total estimated savings) in the population. Using these probabilities the measure goals in Table 1-2 were created for these groups (or strata), which were defined as CFL fixtures with any other technology, CFL bulbs with or without HIDs or T8s but without CFL fixtures, HIDs with or without T8s but without CFL fixtures and bulbs, and T8s only.

The sample was designed to ensure coverage of each of the measure goals in Table 1-2 beginning with CFLF and working to the left. For instance, 23 projects that occurred between 1999 and 2002 (Year Category 1) ***and*** consisted of at least CFL fixture installations (according to sponsor tracking systems) were selected to satisfy the sample size in that cell (CFLF, Year Category 1). If three of these projects also had CFL bulbs installed, then only 18 more projects which had CFL bulb installations that occurred from 1999-2002 would need to be pulled to reach our sampling quota in that cell (CFLB, Year Category 1).

Table 1-2: Sample Design Coverage by Year Category and Measure Type

	Goals				
Year Category	Projects	T8	HID	CFLB	CFLF
1 (1999-2002)	112	87	45	21	23
2 (2003-2006)	91	71	21	22	23
3 (2007-2009)	49	40	14	15	12
Totals	**252**	**198**	**80**	**58**	**58**

Due to better measure coverage per sample point than was initially anticipated and the time required of the sponsors to repeatedly provide detailed files, the sponsors decided to conclude the on-site effort short of the initial goal of 252 projects. Table 1-3 shows that even though on-sites were performed to only 224 projects, the sample design goals were reached for all but a few cells. The cells for which the goals were not met (shaded) came very close to the initial targets.

Table 1-3: Final Sample Compared to Sample Design

Year Category	Projects	T8	HID	CFLB	CFLF
Sample Design					
1 (1999-2002)	112	87	45	21	23
2 (2003-2006)	91	71	21	22	23
3 (2007-2009)	49	40	14	15	12
Sample Design Totals	252	198	80	58	58
Final Sample					
1 (1999-2002)	108	92	49	28	35
2 (2003-2006)	73	66	22	28	34
3 (2007-2009)	43	34	12	15	12
Final Sample Totals	224	192	83	71	81

1.2 Site Survey Methodology

The objective for the site survey task was to develop and execute a recruitment and data collection protocol to capture and report the data required for successful implementation of the survival models. The recruitment protocol (found in Appendix C) was designed to reduce non-response bias by allowing for the exploration of all possible avenues to gain access to the sampled sites. The on-site data collection form was designed so that information on measure type, quantity, model details (where available from the sample frame), and location could be prefilled on the form. We provide an example of an on-site form as Appendix A. The detailed data on what was installed became the reference point from which the on-site was performed. The site survey was designed to collect the following levels of data on each unit of equipment identified as installed through the program.

- **Status of unit at time of visit.** KEMA staff sought to determine if the original measures were still installed and operating at the time of the on-site visit. This was achieved through visual inspection (including random ballast checks) combined with site contact input.
- **End of service for units not present.** For all measures that were not installed at the time of the on-site visit, KEMA staff sought to identify when they were removed from the site contact. Date ranges were accepted when contacts could not provide the exact year of removal.
- **Reason for end of service.** KEMA auditors also sought to identify the reasons why program measures were removed. Understanding these reasons allowed for an important distinction between failure and removal/replacement prior to failure. KEMA also tracked whether

businesses were no longer in operation and if there was a new business in its place or if the building is vacant.

Nearly 1,000 ballasts were checked during the on-site visits; including 740 T8 ballast checks. When ballast checks suggested burn out rates[1], those estimates were applied to locations with the same schedule within the facility. That is, if an unchecked fixture was of the same fixture type and had the same reported annual hours of use as another fixture that was checked in the same facility, it was considered to be represented by the fixtures that were checked.

1.3 Survival Analysis Methods

A measure's Effective Useful Life (EUL) is defined as its median retention time; that is, the time at which half the units of the measure installed during a program year are not retained. Typically, a retention study is conducted when more than half the units of a measure installed during a program year are still retained. Therefore, it is necessary to employ statistical methods to estimate the measure's EUL. To analyze retention, this study employs a method commonly referred to as Survival Analysis. The set of techniques referred to as Survival Analysis are widely employed to analyze data representing a period of time.

Kaplan-Meier Estimator

Combining the non-persistence data from multiple program years requires a way to take into consideration unknown future events. Put another way, we need a method that can handle data that is installed at the time of the site visit, but that will experience a removal event at some unknown point in the future (*right censoring*). Life-test or Kaplan-Meier (KM) survival curves are a simple yet powerful way to summarize date-specific and right censored data.

If measures have been installed long enough that more than 50 percent of the measures are no longer in place, a non-parametric approach such as a KM approach, can offer a characterization of measure persistence. The limitation to the non-parametric approaches is that they cannot be projected beyond the limits of the maximum elapsed years. In many cases where estimates of measure persistence are sought, over 50 percent of the measures are still in the field, thereby limiting the ability to use KM.

[1] Burnout in this study refers to when a fixture has failed or died due to its normal use over time (i.e., it was not removed before failure).

Parametric Survival Analyses

In order to estimate a measure's EUL, this study assumes the number of years a unit of the measure is retained, or the time to non-retention of a unit, follows some general path. Technically, this path is referred to as a distribution. Therefore, the general method of study is to collect data on the times to non-retention of units and use those data to estimate the specific path or parameters of the distribution. The estimated path or parameters of the distribution of the time to non-retention of a unit of a measure are then used to estimate the measure's median retention time or EUL.

Given the variety of reasons a unit of a measure may not be retained, the general path the time to non-retention of a unit follows is unclear. Therefore, this study considers a variety of distributional assumptions, including Gamma, Weibull, Log-normal, and Log-logistic. These are common distributional assumptions made when conducting Survival Analysis. The Weibull model was selected as most appropriate for use to provide final EUL estimates.

1.4 Results

All technology level results are presented in the same manner and include a plot of the data that shows the predicted measure survival over time. In each plot, the y-axis shows the probability of survival and the x-axis measures time in years. The EUL is indicated with a horizontal line and is the time at which half of the units are expected to survive. The vertical line indicates the EUL for the Weibull model.

Table 1-4 provides a summary of the survival model results by technology. More details on each result is provided in the body of the report, including how we handled an HID outlier site as well as plots of the survival models. The error at the 80% confidence interval is provided in the final two columns of this table. The estimated EULs extend from a low of 5.1 years for CFL bulbs to a high of nearly 22 years for LED exit signs. T8 fixtures have an estimated EUL of just over 16 years.

Table 1-4: EUL Estimates by Technology

Technology	Number of Units	Estimated EUL	80% CI Lower	80% CI Upper
CFL Bulb	7,777	5.1	4.3	6.0
CFL Fixture	4,203	7.0	6.4	7.7
LED Exit	1,955	21.9	12.9	37.0
HID	6,732	9.1	8.3	10.1
T8 Fixtures	84,517	16.2	12.8	20.5

Figure 1-1 compares the secondary research estimates discussed above to the Weibull Model estimates that were derived from the on-site data. We further include the recent estimates of lifetime provided by GDS on behalf of NEEP as we understand those assumptions have generally been accepted by the study sponsors. The CFL bulb and T8 estimates are very comparable with approximately 1 year of difference between each source for both measures. The secondary CFL fixture and HID estimates are approximately 5-6 years longer than the Weibull estimates, while the Weibull estimate for LED exit signs is approximately eight years longer than its secondary counterpart. The error bars show the upper and lower bounds are the Weibull estimate at the 80% confidence interval.

Figure 1-1: Weibull EULs vs. Secondary EULs

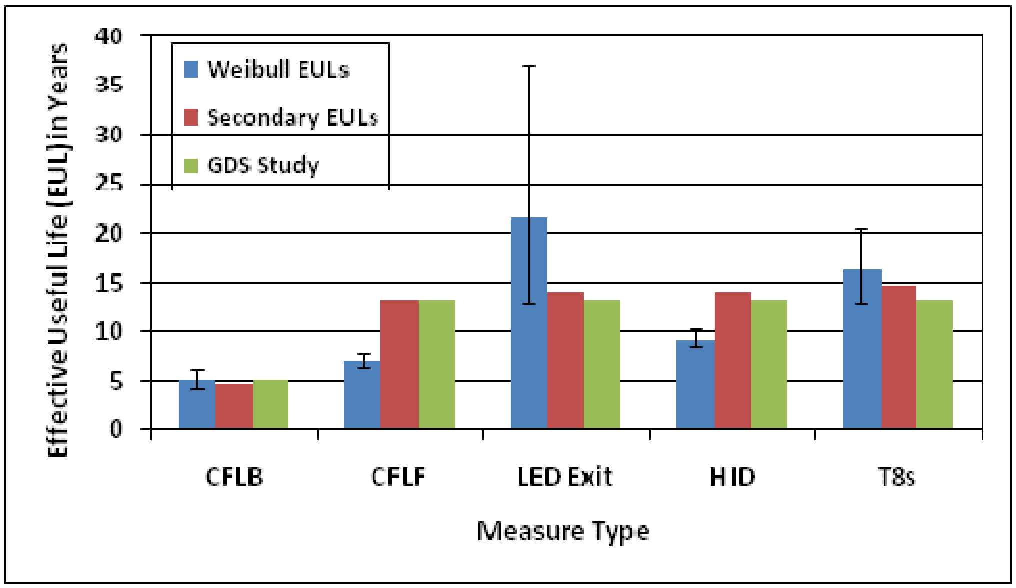


Table 1-5 presents all EUL results by technology and by various sub samples that were explored and analyzed. Cells are shaded gray to illustrate statistically different results. We provide a two-tailed, 80% confidence interval around each result. The use of an 80% confidence interval is consistent with other studies of this nature, including the Retention Study of Pacific Gas and Electric companies Industrial Program performed in 2003. We also provide results at the 90% confidence interval in the body of the report. The top row provides overall EULs by technology, with subsequent rows presenting EULs by program size, annual hours of use and building type.

Table 1-5: Summary of all EUL Results at 80% CI

		CFL bulbs	CFL Fixtures	HID	LED Exit	T8 Fixtures
Overall (80% CI)		**5.1** ***(4.3-6.0)***	**7.0** ***(6.4-7.7)***	**9.1** ***(8.3-10.1)***	**21.9** ***(12.9-37.0)***	**16.2** ***(12.8-20.5)***
Program Size	Large (n=92) (80% CI)	6.3 *(4.9-8.2)*	11.3 *(8.6-14.8)*	8.7 *(7.7-9.8)*	20.4 *(12.0-34.9)*	16.7 *(13.0-21.6)*
	Small (n=132) (80% CI)	4.4 *(3.6-5.5)*	5.9 *(5.3-6.5)*	9.6 *(8.3-11.2)*	25.3 *(12.0-53.0)*	14.2 *(9.8-20.8)*
Annual HOU Bin	High HOU (n=166) (80% CI)	6.9 *(3.9.12.1)*	25.4 *(5.9-108.6)*	10.2 *(8.9-11.7)*	N/A	13.6 *(10.6-17.3)*
	Low HOU (n=138) (80% CI)	4.7 *(3.7-6.0)*	9.5 *(7.7-11.8)*	12.1 *(8.4-17.4)*	N/A	22.3 *(15.2-32.5)*
Building Type	Retail/Wholesale (n=70) (80% CI)	3.2 *(2.2-4.5)*	5.2 *(4.3-6.2)*	11.2 *(8.6-14.6)*	12.0 *(6.1-23.4)*	11.0 *(8.7-13.9)*
	Services (n=106) (80% CI)	6.5 *(5.1-8.1)*	7.3 *(6.6-8.1)*	10.4 *(8.6-12.6)*	22.4 *(12.8-39.1)*	19.4 *(14.0-26.9)*
	Other (n=51) (80% CI)	5.6 *(3.9-8.2)*	14.8 *(5.2-42.5)*	7.5 *(6.6-8.5)*	47.6 *(8.7-262.0)*	28.0 *(14.2-54.9)*

Note: Annual HOU and Building Type sample sizes may exceed the total sample size of 224. Self-reported annual HOU were gathered by space so sites that had areas of both high and low use will be represented in each bin. With regard to building type, two projects were performed in school districts for which visits to multiple building types were performed (services and other).

1.5 Conclusions and Recommendations

We recommend that the sponsors utilize the overall EULs by technology as provided in the top row of Table 1-5 above. This includes the use of a CFL bulb lifetime of 5.1 years, CFL fixture lifetime of 7 years, HID of 9.1 years, LED exit signs of 21.9 years and T8 fixtures of 16.2 years. While some sub sample results are statistically different, we have concerns that despite finding these differences, the sample sizes they are based on are not as robust as the overall EUL estimates provided. Given the size of some of the sub sample populations, there is an opportunity for chance events to drive the observed differences in results as opposed to the results being caused by actual differences between the sub sample groups. For example, a single remodeled site accounts for 21% of the fixtures removed among small business customers in that sub-sample, which drives much of the difference between the small CFL fixture measure life result and the overall result. In addition, it should be noted that the dis-aggregation of some results (such as EUL by hours of use) are dependent upon self reported hours of operation, upon which a distinction between groups is made that might not be entirely accurate.

Recently, sponsor programs have included T5 and high performance T8 technologies. While these were not included in the primary research effort of this study, they were included in the secondary data research to assess the possibility of transferring the primary EUL results to these technologies. Indeed, T8 fixture hours and lifetimes as noted in the secondary data are very similar to T5 and high performance T8 estimates. In our experience, the application and location of high performance T8 fixtures can be expected to be similar to those of standard T8 fixtures. To a lesser extent this is also true of T5, although a common application for T5 fixtures is to replace HID fixtures which can have different operating conditions and locations than standard T8 fixtures might have.

We believe the T8 EUL results are transferable to T5 and high performance T8 lighting until a more definitive measure life study on those specific technologies is performed. We conclude this for two primary reasons. First, much of the T8 fixture lifetimes in our sample were driven by events in which fixtures were removed before their natural failure, which we believe would also be the primary driver of T5 and high performance T8 lifetimes. Second, the similarity between the secondary data on lifetimes and rated hours between T5, HP T8 and T8 fixtures suggests that to the extent natural failure events do occur, they would likely impact these technologies the same as that observed in this study.

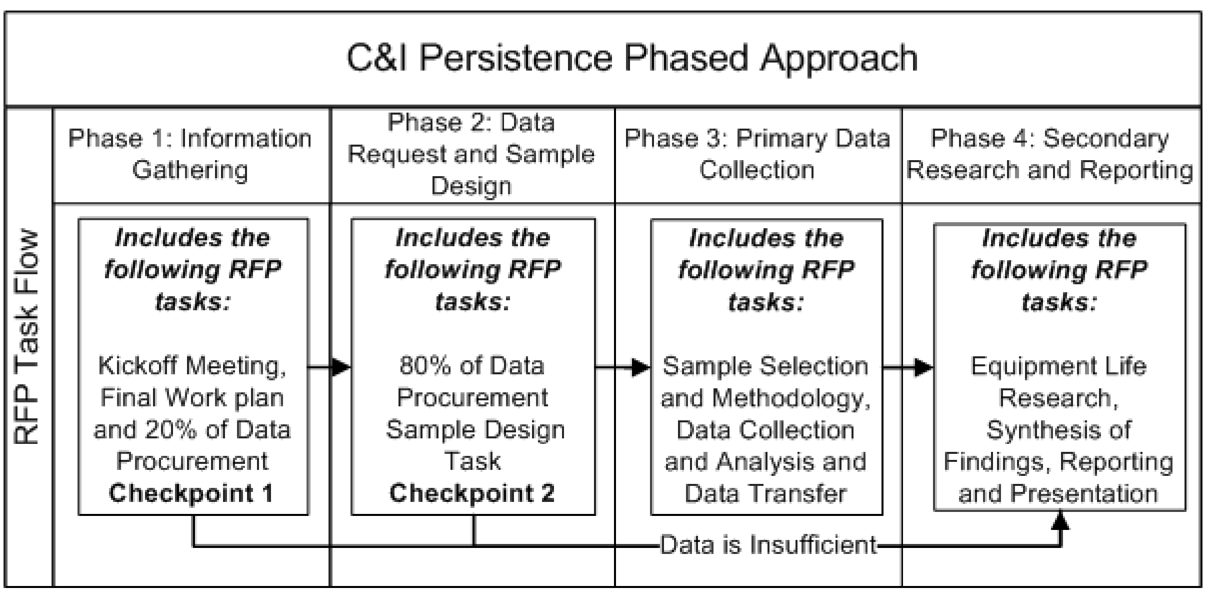
Finally, while T5 applications are often in place of HID fixtures, we do not recommend the use of the HID lifetime estimates for T5 fixtures. This is due to the fact that many HID removal events were replacements of the HID fixture to a linear fluorescent fixture. This removal cause heavily influenced the HID measure life calculated in this study and is not expected to occur with the T5 lighting technology.

2. Introduction and Study Overview

The primary objective of this study was to conduct primary and secondary research and analysis to provide the sponsors with estimates of measure persistence. This research included on-site verification of CFL bulbs and fixtures, LED exit signs, HID fixtures, and T8 fixtures installed by commercial and industrial lighting programs in New England and New York. The secondary objective was to determine the expected operating lives (in hours) for the same equipment categories; based on secondary data.

Figure 2-1 presents an overview of the study design. The original RFP had sequential tasks that included primary data collection and the subsequent analyses of that data. In the work plan KEMA divided the work into four phases and inserted two checkpoints to provide the forum with the authority to approve and modify the work scope. These checkpoints occurred at the conclusion of Phase 1 and the conclusion of Phase 2. This phased approach was developed as a mechanism to deal with potential data availability challenges in the opening study tasks. In this manner, there were clear opportunities for the study to become dependent on secondary research if insufficient data was available to perform primary data collection, but this ended up not being necessary.

Figure 2-1: Phases of Study Approach



The remainder of this report presents study methods, findings and recommendations. The next section of this report, Section 2, describes the participant information gathered from the sponsors and the sampling that was performed. Section 3 discusses the methods employed to estimate a measure's EUL and the standard error of the estimate. The calculation of both the confidence interval for a measure's EUL and hypothesis tests about the value of a measure's EUL are also discussed in Section 3. Section 4 presents the results for each lighting technology, including both summaries of the raw field results and the survival analysis results. Section 5 provides study conclusions and recommendations. Appendix A contains the on-site data collection instrument. Appendix B provides the mapping of building types into the groupings utilized in the report.

3. Methodology

This section of the report provides the methods used to approach each task of the study. We begin with a discussion of the sample design followed by our on-site methodology. We conclude this section with a discussion of the various survival analyses undertaken.

3.1 Sample Frame Development

Early in the study, an important task was to build the most comprehensive possible sample frame for the primary data collection effort. This included an initial effort to assess the availability of information upon which the study could rest followed by an effort to gather the specific data needed to perform the sampling. Recall from the figure above that if the PA information was deemed as not sufficient at the conclusion of these activities, then the study could be redirected and based upon secondary research alone.

Table 3-1 below provides a summary of the approximate number of projects from each state that were provided in this task by the sponsors. This information is presented by program type (combining C&I new construction and retrofit) and year. They are data that were available electronically and that minimally included a proxy for lighting size, but ideally included the type of lighting equipment type installed and quantity. Although some assumptions had to be made and some gaps in the data had to be informed by other sources, the number of lighting projects and the longitudinal nature of the available data were clearly sufficient for sampling and primary data collection.

Table 3-1: Preliminary Assessment of Project Data by Program Type, State and Year

[redacted]

The actual PA data received on lighting projects available from 1999 through 2009 are summarized in Table 3-2 below. This includes a count of projects for each state. It is important to note that this table is not a distribution of number of projects, but a count of projects that contain each measure type; which is why the sum of the utility-level proportions add up to 100%. This look also provides project counts as a percentage of the total number of projects with that measure across all utilities. It is easy to see that a higher percentage of projects include T8s than any other measure category across all but one state.

At the conclusion of gathering and exploring this information, it was decided to focus the study on four primary technologies. These included HIDs, T8 fixtures, CFL bulbs and CFL fixtures. Although it was not explicitly focused on in the sampling, it was also agreed that we would gather information on LED exist signs, which had accumulated significant levels of installations among several sponsors. While some consideration was made to include T5 fixtures, it was decided that they were more recently installed measures, so modeling these would not be ideal since there would not be much evidence of failure.

Table 3-2: Summary of Projects by Technology in Sample Frame

State	Technology Category	Number of Projects with a Measure in Category	Percent of All Projects with each Measure Type by Utility	Percent of All Projects with Measure Category
New York*	CFL	109	4%	0.2%
	LED Exit Sign	322	11%	0.5%
	HID	266	9%	0.4%
	Occupancy Sensors	160	5%	0.2%
	Other	57	2%	0.1%
	T5	151	5%	0.2%
	T8	1,898	64%	2.8%
CT (CL&P Only)	CFL	3,441	15%	5.0%
	LED Exit Sign	2,824	12%	4.1%
	HID	1,250	5%	1.8%
	Occupancy Sensors	5,163	23%	7.5%
	Other	4,172	18%	6.0%
	T5	932	4%	1.4%
	T8	5,152	22%	7.5%
Maine (EME)	CFL	218	6%	0.3%
	LED Exit Sign	86	2%	0.1%
	HID	35	1%	0.1%
	Occupancy Sensors	493	13%	0.7%
	Other	250	7%	0.4%
	T5	707	19%	1.0%
	T8	1,868	51%	2.7%
VT (EVT)	CFL	1,542	24%	2.2%
	LED Exit Sign	615	9%	0.9%
	HID	447	7%	0.6%
	Occupancy Sensors	1,031	16%	1.5%
	Other	391	6%	0.6%
	T5	418	6%	0.6%
	T8	2,030	31%	2.9%
MA**	CFL	7,359	22%	10.7%
	LED Exit Sign	5,741	17%	8.3%
	HID	1,906	6%	2.8%
	Occupancy Sensors	1,445	4%	2.1%
	Other	254	1%	0.4%
	T5	1,190	4%	1.7%
	T8	15,089	46%	21.9%
Total		69,012	N/A	N/A

*ConEd, Central Hudson, NYPA, NYSEG, O&R, RGE

** NSTAR and National Grid

3.2 Sample Design

Using the data provided by the sponsors through the data request, KEMA developed a representative sample of installations from which primary data were gathered and used to determine measure persistence in terms of the years of survival and other statistical modeling analyses. The survival model approach puts a premium on model fit, which defined the goal of the sample design.

Due to the fact that projects often had more than one measure type installed through a given program, measure combination groups were created in order of their weighted probability (proportion of total estimated savings) in the population. Using these probabilities the measure goals in Table 3-3 were created for these groups (or strata), which were defined as follows:

- Strata A: CFL fixtures with any other technology
- Strata B: CFL bulbs with or without HIDs or T8s but without CFL fixtures
- Strata C: HIDs with or without T8s but without CFL fixtures and bulbs
- Strata D: T8s only

The sample was originally designed based on a target of 300 total projects. The final allocations, developed with input from the PAs, included the approximate equalization of the two CFL measures (combined) with HIDs, with a greater number of projects including only T8s. Table 3-3 summarizes the overall population from which the sample was developed as well as the proposed targets from that population. These allocations were based on the expected distribution of specific measures across the strata which include multiple measure types.

Table 3-3: Final Proposed Measure Combination Allocation (300 Project Target)

Strata (Measure Combination)	Population		Sample	# Projects in Sample				
	% of Projects	% of Savings	% of Savings	Total	CFL Fixture	CFL Bulb	HID	T8
A CFL Fixture with any other	32%	17%	23%	69	69	8	16	56
B CFL Bulb with or without HID and T8, no CFL fixture	14%	11%	20%	60		60	10	42
C HID with or without T8, no CFLs	10%	15%	37%	111			111	20
D T8 Only	44%	58%	20%	60				60
Totals	100%	100%	100%	300	69	68	137	178

The first two columns show the strata population percentages with respect to number of projects and savings. The remaining columns summarize the sample given the chosen allocation. The third column provides the sample percentages with respect to savings. The "Total" column gives the count of projects in each stratum. The remaining four columns show the expected count of projects within that stratum that include each fixture type.

The first line illustrates that 69 sample projects from CFL fixture with any other fixture stratum will be selected. Among those projects we expected 8 projects to have CFL bulbs, 16 projects to have HID fixtures and 56 projects to have T8 fixtures. Each subsequent line shows the counts of each measure selected for each stratum. The bottom line shows that a total of 300 were allocated but that those 300 projects represent 452 project-measure combinations. For any specific sample, the project-measure combinations will vary. These estimates were based on the average mix of measures across projects.

Table 3-4 provides the estimated sample pull performed as part of the sample design development. The strata level allocations were effectively the same[2]. The number of those allocated projects with each of the other measures was similar to the expected counts. Though exit lights were not explicitly included in the sample design, they were included in the analysis based on the project that had exit light measures.

Table 3-4: Preliminary Measure Combination Allocation (300 Project Target)

Strata (Measure Combination)	Projects in Strata	Projects with Measure Type Present				
		CFL Fixture	CFL Bulb	HID	T8	Exit
A CFL Fixture with any other	70	70	9	16	63	29
B CFL Bulb with or without HID and T8, no CFL fixture	60		60	15	42	28
C HID with or without T8, no CFL	111			111	27	27
D T8 Only	59				59	7
Total	300	70	69	142	191	91

The sample was also distributed across three time periods to force a reasonable distribution across the 11 years for which project information was available. The percentages in Table 3-5 were

[2] The shifting of one project from stratum D to stratum A was an unintended consequence of or rounding error.

applied to the sample size goal of 300 sites to determine the number of projects within each measure combination/year category we will select. These percentages were used to manage samples with regards to potential attrition issues.

Table 3-5: Proposed Measure Combination by Year Category Percentages

Strata (Measure Combination)	Time Period			
	1 (1999-2002)	2 (2003-2006)	3 (2007-2009)	Total
A) CFL Fixture with any other	9%	9%	5%	23%
B) CFL Bulb with or without HID and T8, no CFL fixture	8%	8%	4%	20%
C) HID with or without T8, no CFL	15%	15%	7%	37%
D) T8 Only	8%	8%	4%	20%
Total	40%	40%	20%	100%

The final sample produced reflects a number of priorities identified by the sponsors, including a desire to target results separately for CFL fixtures versus bulbs and the desire for minimum sample thresholds for each sponsor of the study. We tried to balance these needs amid the primary challenge of developing a sample design that provides sufficient representation of each measure group of interest in each installation year bin. In the survival modeling context, defining the sample in this manner is expected to provide as much quality data as possible to facilitate the most optimal model fit and resulting precisions.

To ensure that factors such as sample attrition or lack of detailed records would not affect our ability to perform on-sites, KEMA developed preliminary sample targets based on a sample size goal of 252 sites. The intent was to meet these minimum targets for all measure combination/year category bins before completing additional sites. KEMA then requested detailed project files for each project which, at a minimum, needed to include site and customer identification information, measure type, measure quantity, and measure location to be considered eligible for an on-site visit. If a particular project file did not contain adequate detail, it was replaced by another project which consisted of the installation of the same measure type within the same year category (not necessarily within the same sponsor's service territory). Throughout the detailed file review and recruitment processes, 329 projects needed to be replaced for various reasons. As Table 3-6 shows, more than 60% of the replacements were due to a lack of sufficient detail to support an on-site visit. While a high rate of sample replacement such as this may raise concerns regarding the potential for selection bias, there is no reason to believe that lighting measure retention at a site is correlated with the quality or completeness of the program documentation.

Table 3-6: Reasons for Sample Replacements

Reason for Replacement	Quantity	% of Replacements (n=329)
Lack of sufficient detail[3]	198	60.2%
Miscategorized measures[4]	73	22.2%
Sponsor dropped out of study[5]	38	11.6%
Refused[6]	16	4.9%
Vacant & inaccessible site[7]	4	1.2%
Total	329	100.0%

Another finding during the file review process was that some projects included the installation of more fixture types than the tracking systems initially reported. For instance, a project may have been selected because it ***only*** consisted of T8 installations according to the tracking system, but the detailed file revealed that CFL bulbs and CFL fixtures were also installed, which gave the sample more measure coverage per sample point than initially expected.

Due to the increased measure coverage per sample point described above and the time required of the sponsors to repeatedly provide detailed files, the sponsors decided to conclude the on-site effort short of the initial goal of 252 projects. Table 3-7 shows that even though on-sites were performed at only 224 projects, the sample design goals were reached for all but a few cells. The cells for which the goals were not met (shaded) came very close to the initial targets.

It is important to mention also that 16 projects consisted of installations that occurred at multiple locations. For these projects, it was decided that we would randomly select up to six locations to

[3] Most (85%) of these sites were replaced due to a lack of space-level information, while the remainder were replaced due to a lack of fixture detail.

[4] The large majority (85%) of these instances were of sites that were selected to fulfill an HID sample point according to the tracking system data that was provided, but the detailed files revealed that no HIDs were actually installed at these sites. The remainder of these instances consisted of similar situations that occurred with other measure types.

[5] Twenty of these were NYPA sites. NYPA decided to drop out of the study on November 8, 2010. The remaining 18 sites were VEIC sites. While VEIC was able to provide assistance with the initial group of sample points, they were unable to provide assistance with subsequent samples due to internal resource constraints.

[6] One of these sites was a site that VEIC requested not be contacted for an on-site visit because the customer had recently participated in an on-site evaluation and VEIC did not want to risk upsetting this customer.

[7] These four sites were replaced (in accordance with the recruitment protocol) because they were inaccessible and there was no way to verify if the measures in question were actually still installed. Two other vacant sites were included in the final sample because we were able to gain access through the property managers to verify that all program measures had been removed.

perform on-site visits (three projects consisted of seven locations so we visited all seven). To complete visits for 224 projects, we visited a total of 291 locations.

Table 3-7: Final Sample Measure Counts Compared to Sample Design

Year Category	Strata	D	C	B	A
	Projects	T8	HID	CFLB	CFLF
Sample Design					
1 (1999-2002)	112	87	45	21	23
2 (2003-2006)	91	71	21	22	23
3 (2007-2009)	49	40	14	15	12
Sample Design Totals	252	198	80	58	58
Final Sample					
1 (1999-2002)	108	92	49	28	35
2 (2003-2006)	73	66	22	28	34
3 (2007-2009)	43	34	12	15	12
Final Sample Measure Count	224	192	83	71	81

Table 3-8 presents the final sample by strata. Strata A was selected first so 81 sample points were needed to reach the strata A final measure count shown in Table 3-7 above. Sixteen of the strata A sites also had CFL bulbs so only 55 more sample points were needed to reach the strata B final measure count of 71. Thirty-six of the strata A and B sites had HIDs so only 47 more sample points were needed to reach the strata C final measure count of 83. One-hundred fifty-one strata A, B, and C sites also had T8s so only 41 more were needed to reach the strata D final measure count of 192.

Table 3-8: Final Sample Counts by Strata

Year Category	Total	Strata			
		D	C	B	A
1 (1999-2002)	108	20	30	23	35
2 (2003-2006)	73	10	9	20	34
3 (2007-2009)	43	11	8	12	12
Final Sample Total	224	41	47	55	81

Table 3-9 shows how the final sample compared to the population by number of projects and MWh savings. Like any sample, this final sample is just one snapshot of the population. There was, in fact, substantial movement on sponsor counts from sample to sample. The sample percentages by sponsor are not identical to the population percentages but are generally in line with them. Where sponsor percentages differ substantially between population and sample, it is primarily because we allocated to year categories based on set percentages rather than sponsor distributions across the year categories. In the final completed sample, all sponsors had at least eight sample points, with the largest quantity coming from NSTAR's service territory (90). The table also contains the number of products represented by each sponsor's sampled sites. As expected, the proportions of products fall in line with the proportions of projects and savings. The population product counts are not included as they were not present in all of the sponsors' tracking data provided for this study.

Table 3-9: Population and Sample, Sponsor Percentage of Projects, Savings and Products

	Population				Sample					
Sponsor	Projects	%	Savings (MWh)	%	Projects	%	Savings (MWh)	%	Product Count	%
EME	1,997	5%	32,070	2%	10	4%	1,147	1%	3,383	3%
EVT	2,540	7%	103,396	8%	8	4%	2,308	3%	6,688	5%
NGR	8,240	22%	85,870	6%	13	6%	778	1%	2,777	2%
NSR	14,629	39%	358,354	26%	90	40%	12,260	15%	14,441	12%
NU	5,987	16%	122,744	9%	48	21%	5,580	7%	30,740	25%
NYSERDA	3,490	9%	634,571	47%	47	21%	56,023	70%	62,787	52%
UIL	854	2%	19,067	1%	8	4%	1,936	2%	951	1%
Totals	37,737	100%	1,356,072	100%	224	100%	80,032	100%	121,767	100%

The KEMA Team followed a rigorous recruitment protocol that was designed to minimize non-response bias. If the original business/contact were no longer occupying the site of interest, a new business/contact was obtained through an internet search and recruited for an on-site visit. If a new business/contact could not be found on-line, the auditor would drive by the site and attempt to perform the visit. If the auditor could not complete the visit during a drive-by he/she would gather information on the new business/contact, which was used to recruit via telephone.

Six of the sampled sites were found to be vacant during the drive-by. Consistent with the recruitment protocol established at the beginning of this study (see Appendix C), KEMA staff utilized all of the information available on these six sites so that they could be accessed and included in the sample. For two of these sites, the auditor was able to gather information on the management company, which was recruited to gain access to the site to perform the visit, resulting in our ability to include these vacancies in our analysis. For the remaining four sites, no management company information was available and the site was replaced, as it was not possible to see if the program measures were still installed. This rigorous recruiting approach resulted in a replacement rate of only 6.9%, among sites where recruitment was attempted.

Table 3-10 presents the final status of all 291 projects we attempted to recruit in support of this study. More than three-quarters (77.0%) became part of the final sample. Sixteen sites refused to participate in the study (5.5%) and four (1.4%) were vacant and inaccessible. The remaining sites (16.2%) were still in the recruitment "pipeline" when the on-site effort concluded.

Table 3-10: Final Status of All Recruited Projects

Final Status	Quantity	% of All Sampled Projects
Completed	224	77.0%
Calling	47	16.2%
Refused	16	5.5%
Vacant & Inaccessible	4	1.4%
Total	291	100.0%

3.3 Site Survey Methodology

The objective for the site survey task was to develop and execute a data collection protocol to capture and report the data required for successful implementation of the survival models. The on-site data collection form was designed so that information on measure type, quantity, model details (where available from the sample frame), and location could be prefilled on the form. We provide an example of an on-site form as Appendix A. The detailed data on what was installed became the reference point from which the on-site was performed. The site survey was designed to collect the following levels of data on each unit of equipment identified as installed through the program.

- **Status of unit at time of visit.** KEMA staff sought to determine if the original measures were still installed and potentially operable, even if the space was not in use at the time of the on-site visit. This was achieved through visual inspection (including random ballast checks) combined with site contact input. Measures were classified as "installed" if the products listed in the program tracking system were found to be installed and operating at the time of the on-site visit and the site contact reported that they were the original products installed through the program. Measures were classified as "replaced in kind" if the site contact reported that the original products were replaced with like products.

- **End of service for units not present.** For all measures that were not installed at the time of the on-site visit, KEMA staff sought to identify when they were removed from the site contact. Date ranges were accepted when contacts could not provide the exact year of removal.

- **Reason for end of service.** KEMA auditors also sought to identify the reasons why program measures were removed. Understanding these reasons allowed for an important distinction between ballast failure and removal/replacement prior to failure. KEMA also tracked whether businesses were no longer in operation and if there was a new business in its place or if the building is vacant.

As discussed earlier, ballast checks were performed at the majority of sites visited. To perform a ballast check, auditors simply opened up randomly selected fixtures and recorded the ballast manufacturer and model number. A minimum of two fixtures was opened in each selected space. If the ballast manufacturer and model number of these two fixtures matched one another ***and*** the fixture information (type, wattage, etc.) matched the information in the tracking system, they were assumed to be the fixtures that were originally installed through the program unless the site contact reported otherwise. If the ballast manufacturer and model number did not match one another, three more were opened up in the selected space. Using this information in conjunction with feedback from the site contact, the auditor determined the proportion of fixtures that were no longer installed.

As Table 3-11 shows, nearly 1,000 ballast checks were performed in total, including 740 T8 fixture checks. When ballast checks suggested that fixtures had persisted or failed, those estimates were applied to locations with the same schedule within the same facility. That is, if an unchecked fixture was of the same fixture type and had the same reported annual hours of use as another fixture that was checked in the same facility, it was considered to be represented by the fixtures that were checked. Using this methodology, the ballasts that were checked represented almost 34,000 products.

Table 3-11: Proportions of Actual and Representative Products Checked

Fixture Type	Ballast Checks Performed	Fixtures Represented by Checks
T8 Fixtures	740	28,331
CFL Bulbs	155	4,928
CFL Fixtures	45	668
Total	**940**	**33,927**

3.4 Survival Analysis Methods

This section of the report discusses the methods employed to estimate measure persistence to date, each measure's EUL, the methods employed to estimate the standard error of the estimate, the calculation of the confidence interval for a measure's EUL, and hypothesis tests about the value of a measure's EUL. A measure's EUL is defined as its median retention time; that is, the time at which half the units of the measure installed during a program year are not retained. To analyze retention, this study employs a method commonly referred to as Survival Analysis. The set of techniques referred to as Survival Analysis are widely employed to analyze data representing the duration between observable events. These same approaches were used to disaggregate the analysis by various sub populations later in this report.

Kaplan-Meier Estimator

Combining the non-persistence data from multiple program years requires a way to take into consideration unknown future events. Put another way, we need a method that can handle observations of measures that are installed at the time of the site visit, but that will experience a removal event at some unknown point in the future (*right censoring*). Life-test or Kaplan-Meier (KM) survival curves are a simple yet powerful way to summarize date-specific and right censored data. These methods produce a non-parametric survival curve that reflects all the available information in both kinds of data.

If measures have been installed long enough that more than 50 percent of the measures are no longer in place, a non-parametric approach such as a KM approach, can offer a characterization of measure persistence. The limitation to the non-parametric approaches is that they cannot be projected beyond the limits of the maximum elapsed years. In many cases where estimates of measure persistence are sought, over 50 percent of the measures are still in the field, thereby limiting the ability to use KM for the EUL estimate. However, the KM approach is still useful for comparing with the parametric results.

The Kaplan-Meier (KM) estimator is also known as the Product-Limit estimator for reasons that will become clear shortly. In survival analysis it is common to estimate retention in terms of the survivor function, which measures the probability that an event time is greater than an arbitrary time. In the case of the KM estimator, the survivor function at time t_i is given by the cumulative product:

$$\hat{S}(t_i) = \prod_{j=1}^{i}\left(1 - \frac{d_j}{n_j}\right)$$

where $t_1 < t_2 < \cdots < t_D$ represent distinct event times; n_i is the number of units retained before time t_i; and d_i is the number of units that are not retained at time t_i. For periods prior to t_1, the KM formula reduces to 1, and for times after t_D, the survivor function is undefined. This is why it is not possible to produce out-of-sample estimates with the KM estimator.

When the data contains no censoring, the KM estimator possesses an intuitive interpretation: it corresponds to the proportion of observations with event times greater than t_i (Allison, 1995). Right-censored data, that is, cases in which the study ended before an event could be observed, can be handled properly by the KM estimator. However, unlike the parametric models presented in the next section, the KM estimator cannot handle left- and interval-censored data.

Parametric Survival Analyses

In order to estimate a measure's EUL, this study assumes the number of years a unit of the measure is retained, or the time to non-retention of a unit, follows some general path. Technically, this path is referred to as a distribution. Therefore, the general method of study is to collect data on the times to non-retention of units and use those data to estimate the specific path or parameters of the distribution. The estimated path or parameters of the distribution of the time to non-retention of a unit of a measure are then used to estimate the measure's median retention time or EUL.

The parameters of the distribution of the time to non-retention of a unit of a measure are estimated by fitting a general linear regression model to the natural log of the times to non-retention of units observed in the data. This model can be written as:

$$\log(T_j) = \mu + \sigma\varepsilon_j,$$

where

T_j = observed time to non-retention of unit j,

μ = location parameter or intercept,

σ = scale parameter, and

ε_j = random error term.

The exponential of the error term of this model (e^{ε_j}) is assumed to follow the standardized form of the distribution of the time to non-retention of a unit. The general linear regression model is fitted by maximizing the log-likelihood function for the assumed distribution.

To estimate a measure's EUL, the estimated parameters of the distribution of the time to non-retention of a unit of the measure are then employed in the survival function. This function is simply one minus the cumulative distribution function of the time to non-retention of a unit. The survival function $S(t;\theta)$ gives the probability of retaining a unit of a measure until at least time t, given the parameter vector θ. Therefore, the estimate of a measure's EUL is the time t* such that the survival probability $S(t^*; \hat{\theta}) = 0.50$, where $\hat{\theta}$ is the vector of parameter estimates.

Distribution Options

Given the variety of reasons a unit of a measure may be not retained, the general path the time to non-retention of a unit follows is unclear. Therefore, this study considers a variety of distributional assumptions, including Gamma, Weibull, Log-normal, and Log-logistic. These are common distributional assumptions made when conducting Survival Analysis.

The Gamma distribution is the most general of the distributions listed above. It has three free parameters, location (μ), scale (σ), and shape; whereas the other distributions have only one or two free parameters. The Gamma distribution includes the Weibull, and Log-normal distributions as special cases.

The Weibull, Log-normal, and Log-logistic distributions have two free parameters, location and scale; and the Exponential distribution has one free parameter, location. The Weibull and Log-normal distributions result as special cases of the Gamma distribution when the shape parameter equals one and zero, respectively.

The Gamma distribution places fewer constraints on the parameters than the Weibull and Log-normal distributions. As a result, the parameter estimates obtained assuming the Gamma distribution will be most based on the data. If one of the other distributions is a good description of the data, its results will be similar to those of the less constrained Gamma distribution.

Distribution Adopted

To select the most appropriate distribution, we reviewed three things. These are discussed below, and include implications for the non-retention rate over time; a likelihood ratio test; and maximum of the log-likelihood function.

Non-Retention Rate Over Time

The distributional assumption has implications for the non-retention rate over time. These implications are seen via the hazard function $h(t;\theta)$. Roughly, the hazard function can be thought of as the probability of not retaining a unit of a measure at time t, given the unit has been retained up to that time. Formally, it is the negative ratio of the survival probability density function dS/dt to the survival function,

$$h(t;\theta) = -\frac{dS/dt}{S(t;\theta)}.$$

An increasing hazard function means the non-retention rate increases as a unit of a measure ages, whereas a decreasing hazard function means the non-retention rate decreases as a unit of a measure ages. If the hazard function is constant, the non-retention rate remains constant as a unit of a measure ages. The hazard function of the Gamma distribution may have a variety of shapes. However, it is often difficult to determine which possible shape the hazard function of the Gamma distribution actually takes on.

The hazard function of the Weibull distribution may have one of three shapes: always decreasing, always increasing, or constant. If the scale parameter is greater than one then the hazard function is decreasing, whereas if the scale parameter is less than one then the hazard function is increasing. If the hazard function of the Weibull distribution is increasing (the scale parameter is less than one), the rate of increase depends on the value of the scale parameter. If the scale parameter is between 0.5 and 1, the hazard function is increasing at a decreasing rate; if the scale parameter equals 0.5, the hazard function is increasing at a constant rate; and if the scale parameter is between 0 and 0.5, the hazard function is increasing at an increasing rate.

The Log-normal distribution produces a hazard function that increases to a peak then decreases. The larger the scale parameter, the sooner the hazard function reaches its peak and begins to decrease. A hazard function that is increasing then decreasing means that for some period of time after a unit of a measure is installed, the non-retention rate increases as the unit of the measure ages then, after some point, the non-retention rate decreases as the unit of the measure ages.

The hazard function of the Log-logistic distribution may increase to a peak then decrease or it may be always decreasing. If the scale parameter is less than one then the hazard function is increasing then decreasing, whereas if the scale parameter is greater than or equal to one then the hazard function is always decreasing.

<u>Likelihood Ratio Test</u>

If a distribution is a special case of another distribution, the appropriateness of the former versus the latter can be formally tested using the likelihood ratio test. Therefore, likelihood ratio tests comparing the appropriateness of the Weibull, and Log-normal distributions versus the Gamma distribution were conducted.

Maximum of the Log-Likelihood Function

Recall, under each assumed distribution, the general linear regression model is fitted by maximizing the log-likelihood function. A larger maximum value of the log-likelihood function suggests a better model fit.

For CFL bulbs, CFL fixtures, and HIDs, the final choice of distribution was found to make very little difference to the EUL. The differences observed were well within the confidence intervals. For T8s and LED Exits, the choice of distribution does make a difference because we only observed a limited number of non-retained units. In both cases, the optimization procedure did not converge with the Gamma distribution. We again recommend the results from the Weibull distribution because it is standard in survival analysis and gave us lower estimates of EUL for T8s and LED Exits. We chose the Weibull because it is the standard distribution in survival analysis.

Standard Error of a Measure's EUL Estimate

In order to construct a confidence interval for a measure's EUL or conduct hypothesis tests about the value of a measure's EUL, the standard error of a measure's EUL estimate is necessary. To perform this, the general linear regression model is fitted to the log of the times to non-retention of units of a measure. Therefore, the parameters thus estimated and employed in the survival function directly produce the log of a measure's EUL estimate such that the survival probability is 0.50. A measure's EUL estimate is then obtained by calculating the exponential of this log value (elog(EUL estimate)). Calculating the standard error of a measure's EUL estimate, however, is not as simple because the logarithmic transformation is non-linear.

If the distribution of the log of a measure's EUL estimate is known, it may be possible to calculate the exact standard error of the measure's EUL estimate. However, this distribution is unknown in this study, as it is in most studies. Therefore, the approximate standard error is calculated by SAS® [8]using a first order Taylor expansion of the logarithmic function of the time to non-retention of a unit of a measure around the measure's EUL estimate. This approximation is a function of the log of the measure's EUL estimate and the standard errors of the parameter estimates of the general linear regression model.

[8] Proc lifereg is used for non-parametric survival analysis. Proc lifetest is the procedure used for the KM approach.

Adjustment to the Standard Error

When fitting a general linear regression model to the data for a given measure, an observation is the time to non-retention of a unit of the measure. The calculation of the standard errors of the parameter estimates assumes each observation is independent. This assumption, however, may be incorrect when sampling does not occur at the level of a unit of a measure. For example, as is the case in this study, when sampling occurs at the project level and a project may have obtained a rebate for more than one unit of a measure. In which case, the times to non-retention of units of a measure may not be independent because the times to non-retention of units may be more similar within a project than between projects. However, while the times to non-retention of units of a measure may be more similar within a project than between projects, they are not expected to be identical within a project. For example, remodeling, damage, dissatisfaction, or facility closure does not necessarily lead to the simultaneous removal of all units of a measure installed at a site.

Because the times to non-retention of units of a measure may be more similar within a project than between projects, the standard errors (of both the log of the measure's EUL estimate and its EUL estimate) are adjusted by the square root of the design effect (Kish 1965). If the times to non-retention of units of a measure are no more similar within a project than between projects, then the design effect equals one and the unadjusted and adjusted standard errors are equal. Generally, however, the design effect is greater than one.

The Design Effect

The design effect is used to adjust the standard error of an estimate when the sample that produced the estimate is not a simple random sample. Initially, as is typical, the standard error of an estimate of a measure's EUL is calculated assuming the sample that produced the estimate is a simple random sample, which it is not. In general, the design effect equals the ratio of the variance of the sample calculated consistent with the sample design to the variance of the sample calculated as if it were a simple random sample.

The samples employed in this study are not simple random samples. Rather, the samples employed in this study are unequal cluster samples. In sampling terminology, a project is a cluster. The clusters or projects are "unequal" because they contain different numbers of units of a measure.

While we are interested in the standard error of mean or median time to failure, the design effect is more easily calculated in the dimension of failure probability. Thus, we calculate the design effect as:

$$deff = \frac{\text{var}(p)}{(1-f)\frac{s^2}{n}},$$

where

var(p)	$= (1-f)\frac{c}{c-1}\frac{\sum_{i=1}^{c} A_i^2 (p_i - p_{y(i)})^2}{n^2}$,
f	= n/N,
n	= number of units in the sample,
n_y	= number of units in the sample in year *y,*
N	= number of units in the population,
c	= number of projects included in the sample,
A_i	= number of units in project *i*,
p_i	= proportion of units not retained to date in project *i*,
$p_{y(i)}$	= proportion of units not retained in the year of project *i,*
p_y	= proportion of units not retained in year *y*,
s^2	$= \frac{n}{n-1}\frac{\sum_y (n_y - 1) p_y (1-p_y)}{\sum_y (n_y - 1)}$.

This formula can be derived from Kish (1965)[9]. In this formula, var(p) in the numerator is the variance of the observed proportion failed at a given time. The observed proportion p_i reflects the random selection of a particular cluster (project) i with its particular underlying survival probability, and also the random failures of units within that project subject to that probability. Thus, the observed variability $p_i - p_{y(i)}$ reflects both the between-cluster variability of cluster-level survival proportions, and the variability of within-cluster random survival.

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[9] Kish, Leslie. 1965. *Survey sampling*. New York: John Wiley & Sons, Inc.

We take the deviations $p_i - p_{y(i)}$ with respect to the overall proportion p_y for each year y, rather than with respect to the overall survival proportion across all units. This within-year variability is used because the effect of year (time) is accounted for in the model, and we are interested in the design effect with respect to the remaining variability after time is accounted for. Thus, the numerator is a pooled estimate of variance, considering each year separately and pooling across years.

The term s^2 in the denominator is the variance of a single unit 0/1 observation, given the overall failure proportion. As for the numerator, this variance is a pooled estimate, pooling across years.

There are other approaches to translating design effect calculations into the survival analysis context. We have considered a few different approaches. The resulting design effects for different measures vary by factors up to approximately four, with results for some measures increasing and others showing a decrease moving from one method to another. The corresponding standard errors therefore vary by factors up to around two (square root of 4). Thus, the significance tests should be regarded as indicative, but not definitive. We believe the pooled estimates of design effects provide reasonable estimates, and the corresponding confidence interval calculations are useful indicators of the accuracy of the EUL estimates.

Adjusting for Outliers

Statistical analyses can be sensitive to the presence of outliers and survival analysis is no exception. In particular, one of the sites in the study removed nearly 1,900 HID fixtures before failure and replaced them with T8 fixtures[10]. In contrast, the average number of HID fixtures per site in the tracking system was about 107. It is natural to expect that this outlier site would have a strong influence on the results.

There are several strategies for dealing with outliers, ranging from excluding them from the analysis to including them without any adjustment. In the interest of assessing the sensitivity to the outlier, we produced results with and without that site. In addition, we also adjusted the results by assigning the average number of HID fixtures to the outlier and scaling back the number of replacements. By effectively down-weighting the outlier, the HID results turn out to be, as expected, between the extremes of including and excluding the site.

[10] These T8 fixtures were all installed at the same time approximately 7 years after the original HID fixtures were installed presumably for energy efficiency reasons. The site contact did not report any technical problems with the original equipment.

In the Technical Appendix (D), we provide details on how we calculated the confidence interval for a measure's EUL, including how it is done for the log of a measure's EUL.

4. Results

This section of the report provides the results of the study. We begin with a discussion of the raw pre-modeling results we gathered in our observations and site work. We follow this by providing the results of the survival analyses overall and by sub group. We conclude with the provision and comparison of our secondary research results to the primary research results.

4.1 Pre-Modeling Results

One of the first steps taken in our analysis was to perform data characterization on each technology across program years. Plots of percentages of the non-persisting measures for each program year category provided a useful first step for understanding trends in the data and also provide a basic comparison and sanity check of the data across program years. These plots allow us to identify anomalous data. Below we present tables that characterize the information we gathered.

Table 4-1 presents the pre-modeling CFL bulb results by year category from the data gathered on-site. The proportions that were verified as still installed were relatively similar between year categories 1 and 2, but saw a large increase in year category 3. Overall, approximately one-third of the CFL bulbs were still installed across all study years. Almost 40% had failed, while 19% were removed before failure. The remaining 11% were not found by the auditor and were unknown by the site contact, were in inaccessible spaces, or were not found and were said to have never been installed by the site contact.

The overwhelming majority of those removed before failure were caused by upgrades to lower wattage CFLs than what was installed through the sponsors' programs (52.7%) or removals due to remodels (31.0%). It should be noted that the higher proportion of failures in the year category 2 as compared to year category 1, is due to one site which appeared to replace the 1,628 CFL bulbs with the same technology ("replaced in kind") that were installed through a sponsor program 5 years prior. These "replacements in kind" were identified through conversations with the most knowledgeable site contact that was available at the time of the visit.

Table 4-1: Pre-Modeling CFL Bulb Results[11]

Year Category	# of Sites	Tracking System Quantity	% Still Installed	Avg. Annual Hrs of Use	% that Failed	% Removed Before Failure	% Don't Know/ Unsure
1 (1999-2002)	28	3,420	32.0%	1,993	26.8%	14.8%	26.4%
2 (2003-2006)	28	9,508	26.4%	3,614	46.2%	22.7%	4.8%
3 (2007-2009)	15	1,577	72.8%	3,356	14.8%	1.7%	10.7%
Total	**71**	**14,505**	**32.7%**	**3,179**	**38.2%**	**18.6%**	**10.5%**

Table 4-2 shows that nearly 43% of program CFL fixtures were still installed at the time of the on-site visits. Approximately 39% were removed before they failed mostly due to remodels, but also due to dissatisfaction and upgrades. Only 3% of program CFL fixture installations were verified to have failed. It is important to note that the low year category 3 installation proportion (as compared to that of year category 2) was caused by one site which had removed 478 CFL fixtures during a remodel.

Table 4-2: Pre-Modeling CFL Fixture Results

Year Category	# of Sites	Tracking System Quantity	% Still Installed	Avg. Annual Hrs of Use	% that Failed	% Removed Before Failure	% Don't Know/ Unsure
1 (1999-2002)	35	2,289	27.9%	3,359	5.8%	56.6%	9.7%
2 (2003-2006)	34	1,892	61.4%	4,788	0.6%	9.5%	28.5%
3 (2007-2009)	12	891	40.0%	6,369	0.0%	53.6%	6.4%
Total	**81**	**5,072**	**42.5%**	**4,626**	**2.8%**	**38.5%**	**16.1%**

Table 4-3 shows that the majority (86%) of the LED exit signs installed through the program at the sampled sites are still installed and operating. Approximately 10% were removed before failure; mostly due to remodels, but also due to upgrades to lower wattage LEDs. None had failed by the time of the on-site visits. The lower year category 3 percent installed, as compared to year category 2, was due to one site that had 21 LED exit signs installed in inaccessible areas. These

[11] The formula that can be used to calculate a normalized installation rate for any row in any of the pre-modeling tables is: (Tracking System Quantity – (Tracking System Quantity * % Don't Know/Unsure)) * % Installed. Likewise, the normalized failure rate for each of these tables can be calculated using the following formula: (Tracking System Quantity – (Tracking System Quantity * % Don't Know/Unsure)) * % that Failed.

inaccessible exit signs are represented in the "% Don't Know/Unsure" column. All "Don't Know/Unsure" counts were not included in the modeled EUL results provided later in this report.

Table 4-3: Pre-Modeling LED Exit Sign Results

Year Category	# of Sites	Tracking System Quantity	% Still Installed	Avg. Annual Hrs of Use	% that Failed	% Removed Before Failure	% Don't Know/ Unsure
1 (1999-2002)	56	1,142	82.4%	8,760	0.0%	13.3%	4.3%
2 (2003-2006)	32	679	91.5%	8,760	0.0%	8.2%	0.3%
3 (2007-2009)	14	219	86.3%	8,760	0.0%	0.0%	13.7%
Total	**102**	**2,040**	**85.8%**	**8,760**	**0.0%**	**10.2%**	**4.0%**

Table 4-4 presents the pre-modeling HID results. It shows that 61% of the program HID fixtures are still installed and 35% were removed before failure. Most (86.4%) of those that were removed before failure were upgraded to more efficient technologies, but some (7.5%) were removed due to remodels. Only 2% were verified to have failed through the on-site visits. The very low proportion of installs in year category 2 was caused by one site that had upgraded 1,890 HID fixtures to T8s. We handled this site uniquely in our survival analyses due to its size and the observed magnitude of measure removal. This was previously discussed in the survival analysis method section. While some sites had significant removal events associated for other measure types, the HID outlier warranted special consideration because it accounts for over 21% of the sampled tracking system quantity. The other events accounted for no more than 11% of the tracking system quantities represented in the sample.

Table 4-4: Pre-Modeling HID Results

Year Category	# of Sites	Tracking System Quantity	% Still Installed	Avg. Annual Hrs of Use	% that Failed	% Removed Before Failure	% Don't Know/ Unsure
1 (1999-2002)	49	2,439	53.5%	5,979	6.6%	37.7%	2.2%
2 (2003-2006)	22	2,481	16.9%	4,358	0.8%	80.1%	2.2%
3 (2007-2009)	12	4,026	92.7%	4,736	0.0%	5.4%	1.8%
Total	**83**	**8,946**	**61.0%**	**5,004**	**2.0%**	**34.9%**	**2.0%**

Table 4-5 shows that 78% of program T8s were still installed at the time of the on-site visits. Approximately 14% were removed before they failed (mostly due to remodels but also due to upgrades) and 2% failed. Like the HID results in Table 4-4 few T8 burnouts were observed or reported in the site work.

Table 4-5: Pre-Modeling T8 Results

Year Category	# of Sites	Tracking System Quantity	% Still Installed	Avg. Annual Hrs of Use	% that Failed	% Removed Before Failure	% Don't Know/ Unsure
1 (1999-2002)	92	36,011	78.1%	4,502	3.8%	11.7%	6.3%
2 (2003-2006)	66	41,144	74.8%	4,286	1.1%	19.9%	4.2%
3 (2007-2009)	34	14,049	86.5%	3,640	0.6%	3.4%	9.5%
Total	**192**	**91,204**	**77.9%**	**4,261**	**2.1%**	**14.1%**	**5.8%**

4.2 Survival Analyses Results

The primary goal for this study was to produce estimates of measure lives for major measure groups that reflect the diversity of the included programs and geographies. We performed the core analysis at the technology level, and then where possible we examined the effect of more specific characteristics such as hours of operation and building type on measure persistence. All SAS procedure and Weibull model outputs are provided as a technical appendix (Appendix D) of this report. In addition, the analysis attempted to disaggregate the drivers of non-persistence, distinguishing between measure removal and failure.

To do this, we estimated time to failure using a competing risks approach, in which all but failure-related events are censored in the model. Unfortunately, the results were not consistent with expectations and were accompanied by large standard errors, undermining our confidence in the validity of the estimates. The main difficulty in measuring equipment lifetime lies in the fact that we only observed relatively few cases of failure among the data we collected. On the other hand, we observed plenty of other non-retention events, including replacements before failure. Table 4-6 presents overall proportions of units for non-retention and failure events. It is important to note that the “Don’t Know/Unsure” proportions from Table 4-1 through Table 4-5 above have been removed from the calculation of “Number of Units” provided in the table below. From the table, it is clear that we do not have sufficient information for producing reliable estimates of equipment lifetime, as none of the measure types reached a point where at least half of the installed products had failed.

Table 4-6: Non-retention and Failure Event Summary

Technology	Number of Units	Proportion of Non-Retained Units	Proportion of Units with Failure Event
CFL Bulb	12,981	63.4%	42.7%
CFL Fixture	4,253	49.3%	3.4%
LED Exit	1,959	10.6%	0.0%
HID	8,764	37.7%	2.1%
T8	85,885	17.2%	2.2%

All technology level results are presented in the same manner and include a plot of the data that shows the predicted measure survival over time. In each plot, the y-axis shows the probability of survival and the x-axis measures time in years. The EUL is indicated with a horizontal line and is the time at which half of the units are expected to survive. The vertical line indicates the EUL for the Weibull model.

Figure 4-1 below presents the CFL bulb results. The blue line shows the Kaplan-Meier result for which the 50% survival mark is at approximately 4.3 years. The parametric survival model produces slightly longer EULs but converge around the Weibull model result of 5.1 years. The Kaplan-Meier results and survival models are all tightly grouped where the decay crosses the 50% threshold.

Figure 4-1: Estimated EUL for CFL Bulbs

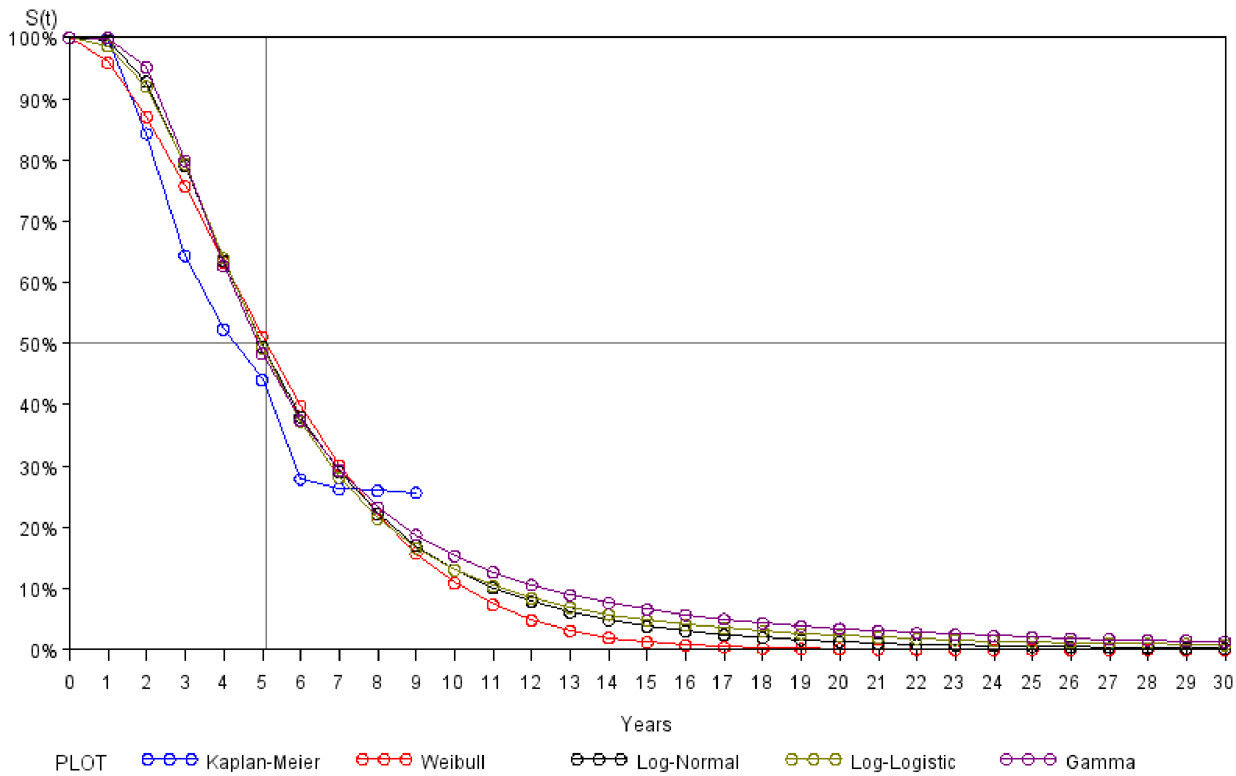
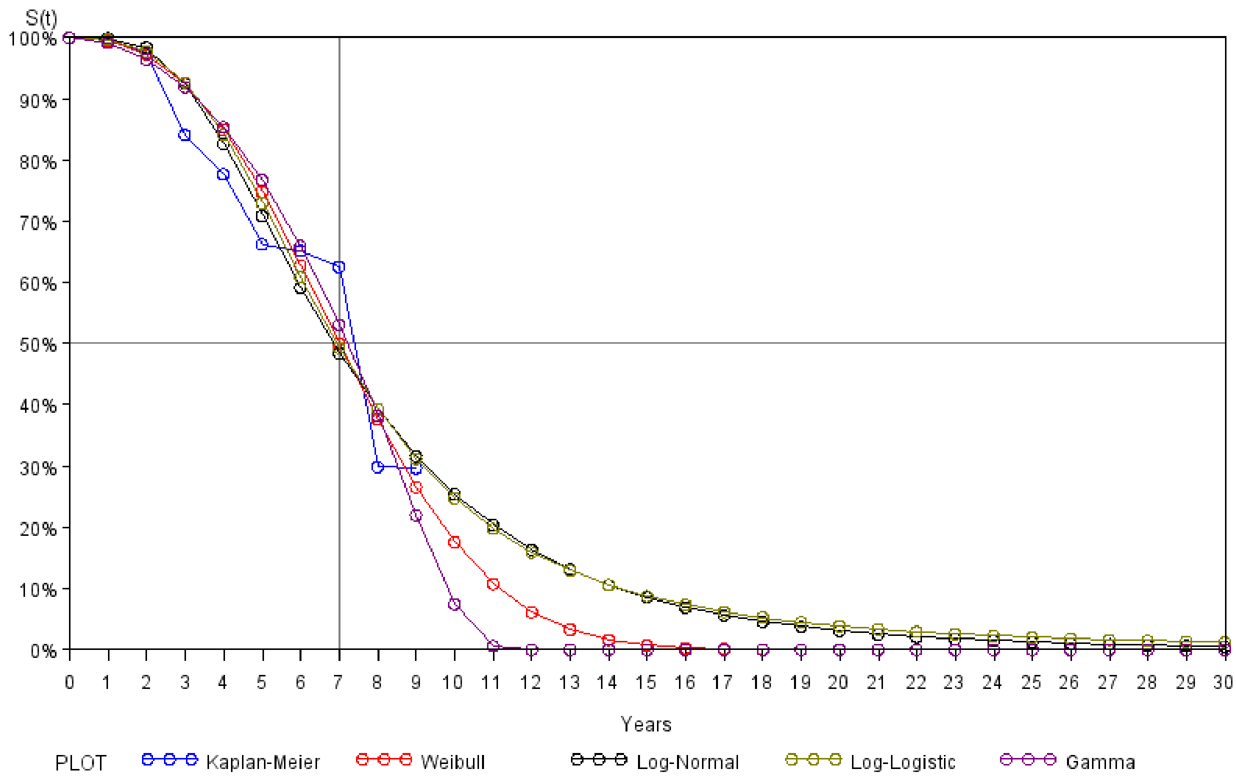


Figure 4-2 shows that the Kaplan-Meier EUL for CFL fixtures is approximately 7.4 years. The parametric survival model produces slightly shorter EULs than the Kaplan-Meier result, but converges around the Weibull model result of 7.0 years.

Figure 4-2: Estimated EUL for CFL Fixtures



The HID results are heavily influenced by one site which had replaced almost 1,900 HID fixtures with linear fluorescent fixtures before the HID fixtures failed. Due to the fact that this site carries so much weight, the HID results are presented both with and without it. Figure 4-3 presents the results with this site included and shows the Kaplan-Meier estimate to be approximately 6.8 years. The parametric survival model produces longer EULs but converge around the Weibull model result of 7.8 years.

Figure 4-3: Estimated EUL for HIDs with Outlier

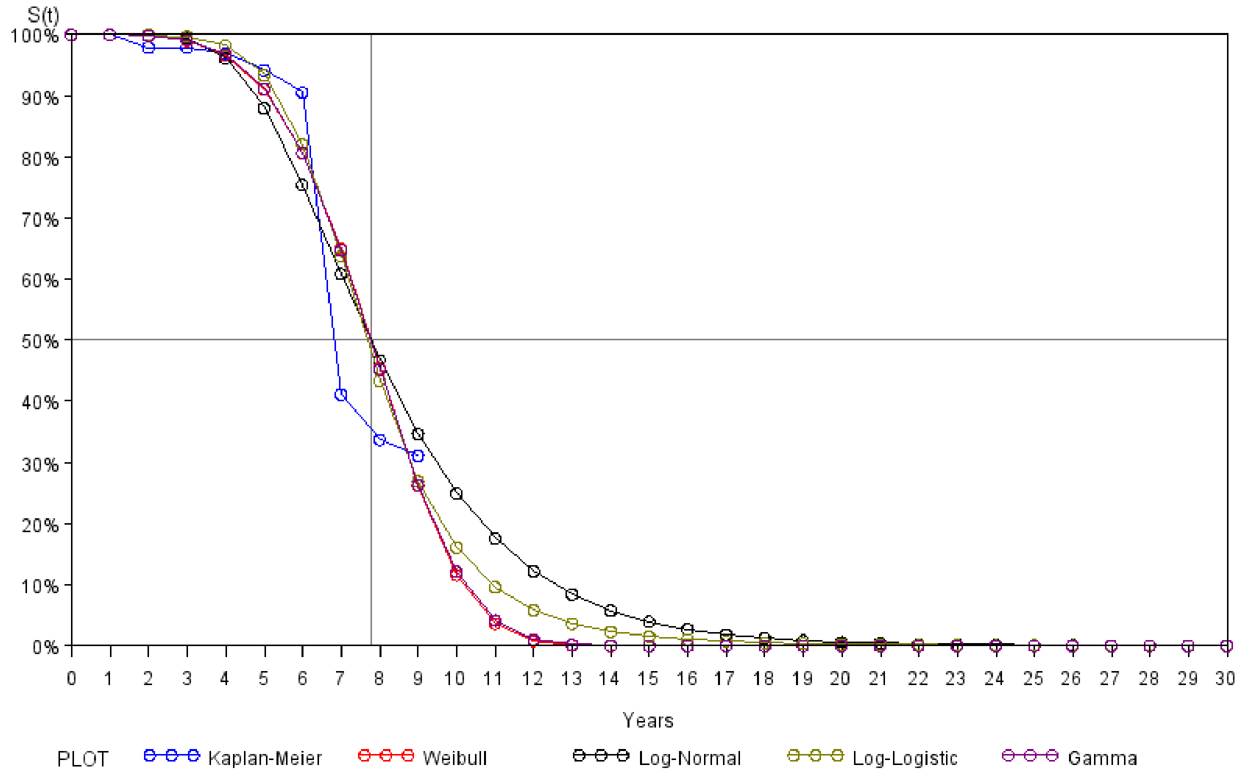
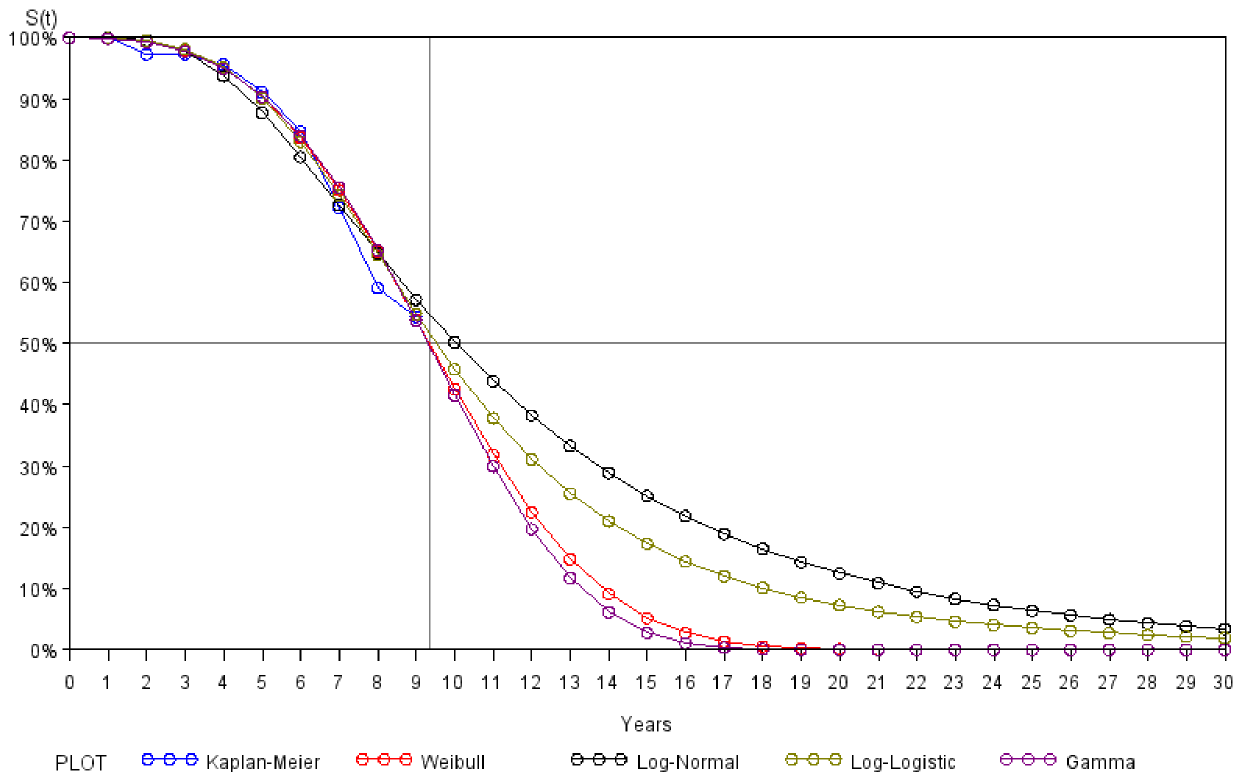


Figure 4-4 shows just how much the outlier influences the HID results. Without it HIDs do not reach the 50% non-retention mark, which is necessary to produce a Kaplan-Meier EUL. The parametric survival model result jumps from 7.8 years with the outlier to 9.4 years without it.

Figure 4-4: Estimated EUL for HIDs without Outlier



Ultimately KEMA handled the outlier by assigning the average number of HID fixtures to it and scaling back the number of replacements. Recall, the outlier site had removed nearly 1,900 HID fixtures before failure and replaced them with linear fluorescent fixtures. In contrast, the average number of HID fixtures per site in the tracking system was about 107. By effectively down-weighting the outlier, the HID results turn out to be, as expected, between the extremes of including and excluding the site. Figure 4-5 shows the HID result after assigning the average weight to the outlier site. The EUL, estimate resulting from this approach is at 9.1.

Figure 4-5: Estimated EUL for HIDs with down-weighted Outlier

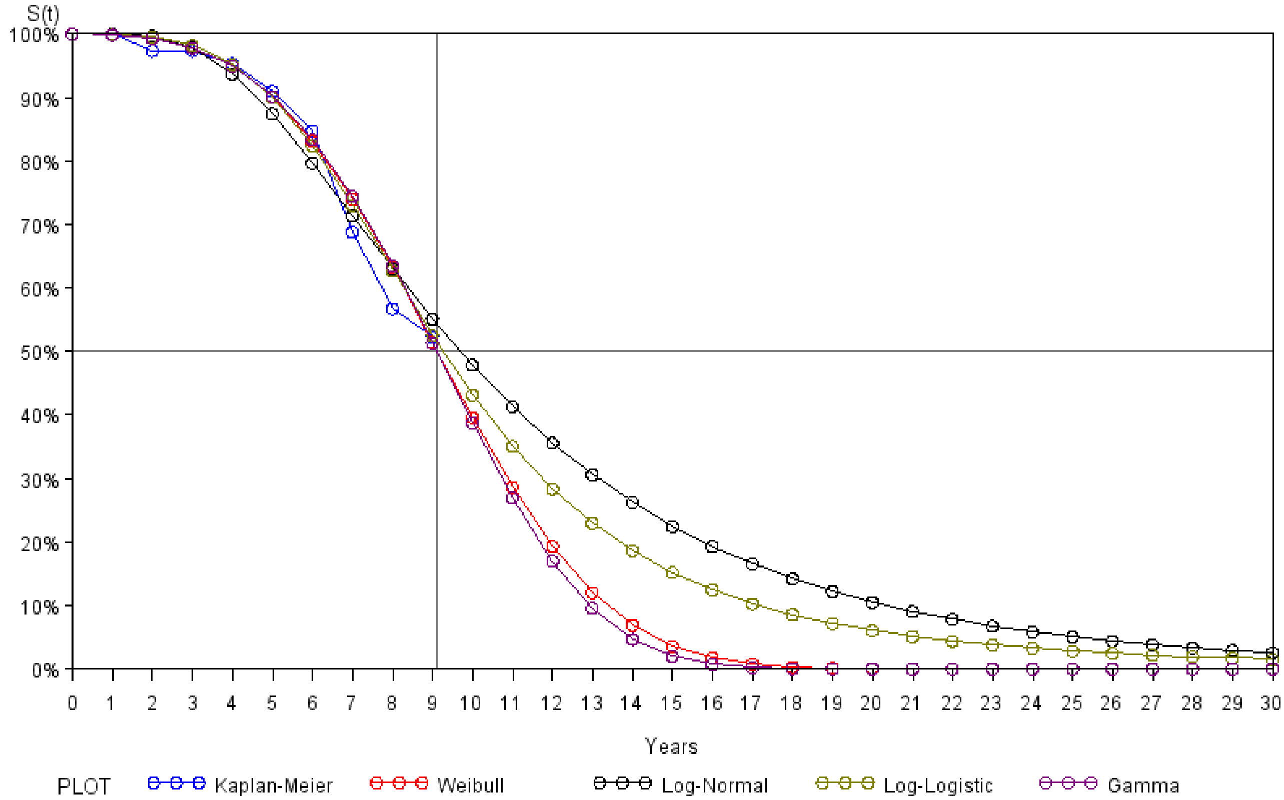


Figure 4-6 presents the LED exit sign results. As was the case in the previous figure, a Kaplan-Meier EUL cannot be produced because LED exit signs do not reach 50% non-retention. The parametric survival model produces results that are very different from one another due to the very low instances of non-retention. Given that the Weibull model provides the lowest EUL among the survival models, it can be considered a conservative estimate. The Weibull model produces an estimate of 21.9 years.

Figure 4-6: Estimated EUL for LED Exits

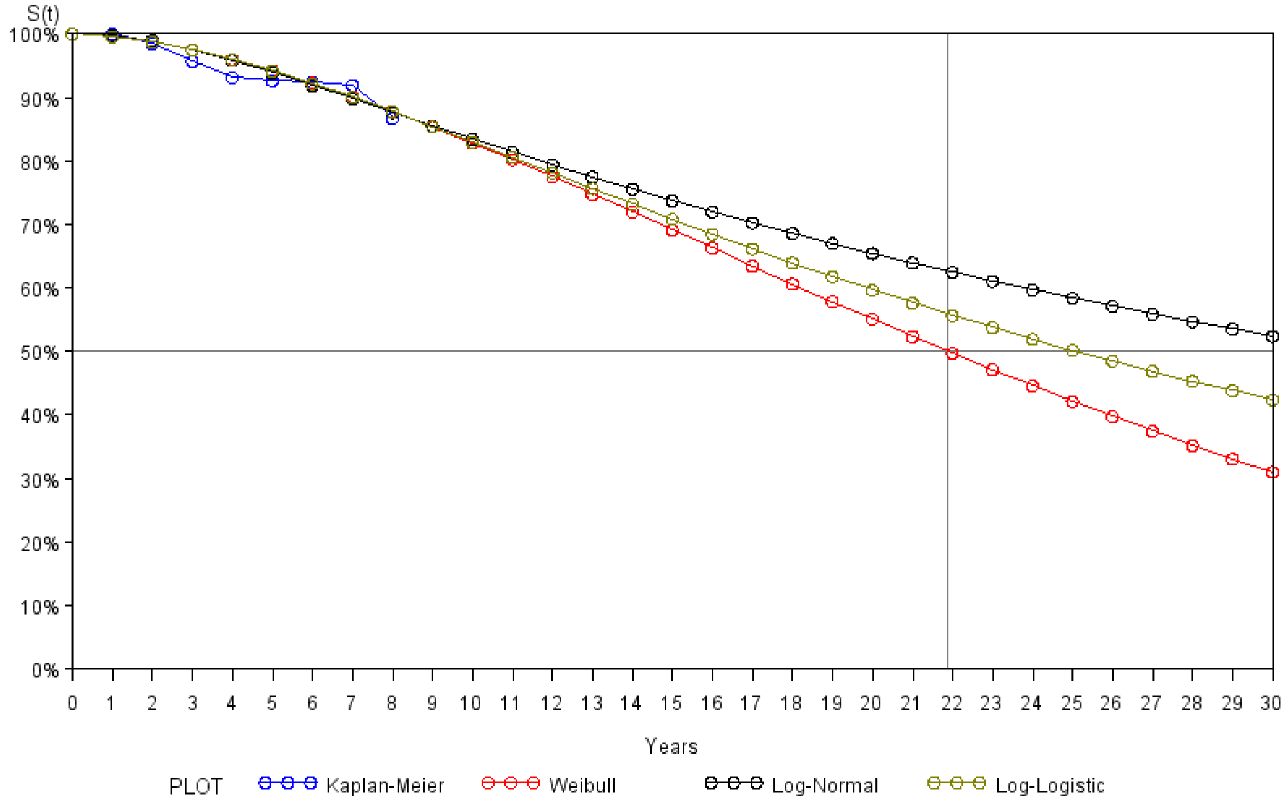
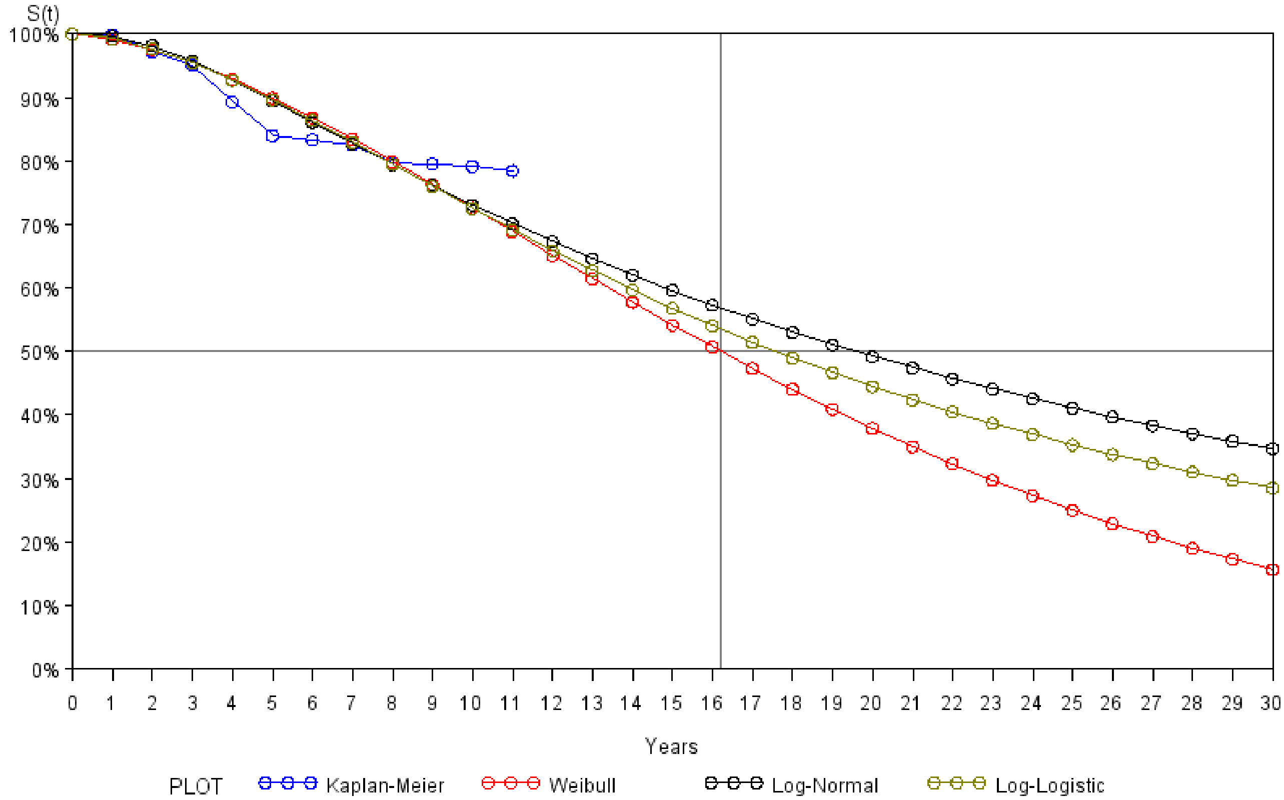


Figure 4-7 shows that T8s also did not experience enough non-retention to produce a Kaplan-Meier result. While not as different as the LED exit sign results above, the parametric survival model produces results for T8s that are different from one another due to the very low instances of non-retention. The Weibull model produces an estimate of 16.2 years.

Figure 4-7: Estimated EUL for T8 Fixtures



4.2.1 Overall Results by Technology

Table 4-7 provides a summary of the survival model results by technology. Note that the HID result is based upon the use of average weighting for the outlier site. The error at the 80% confidence interval is provided in the final two columns. The estimated EULs extend from a low of 5.1 years for CFL bulbs to a high of nearly 22 years for LED exit signs. T8 fixtures have an estimated EUL of just over 16 years.

Table 4-7: EUL Estimates by Technology

Technology	Number of Products	Estimated EUL	80% CI Lower	80% CI Upper
CFL Bulb	7,777	5.1	4.3	6.0
CFL Fixture	4,203	7.0	6.4	7.7
LED Exit	1,955	21.9	12.9	37.0
HID	6,732	9.1	8.3	10.1
T8 Fixtures	84,517	16.2	12.8	20.5

4.2.2 Results by Large and Small

Table 4-8 presents EUL results by program size and overall for each technology. Program size was defined as the program type that each sample point participated in. In broad terms, small business programs during this period primarily had thresholds of monthly demand of less than 200 kW, although at least one sponsor did use 100 kW as cut off. The Large program size results includes sample from both retrofit and new construction programs. Of the 92 sample points visits, 67 came from programs that were retrofit only, 24 came from programs with both retrofit and new construction eligibility and one came from a New Construction program.

The final column of this table presents the program size coefficient p-value. This value can be used as an indicator of whether the small and large results are statistically different from one another. If this value is under 0.20, the small versus large EUL results can be considered statistically different from the overall result at the 80% confidence interval and can be considered for application independently. If the p-value is over 0.20, then the small and large results are statistically the same at the 80% confidence interval. At the 90% confidence interval, the coefficient p-value threshold used to determine statistical similarity is 0.10. Any value under 0.10 identifies results that are statistically different and any value over 0.10 identifies results that are statistically the same.

Table 4-8: Estimated EUL by Program Size and Technology

Technology	Program Size	Number of Units	Estimated EUL	80% CI Range	90% CI Range	Coefficient p-value
CFL Bulb	Overall	7,777	5.1	4.3-6.0	4.1-6.3	
	Small	4,203	4.4	3.6-5.5	3.4-5.8	0.14
	Large	3,574	6.3	4.9-8.2	4.5-8.9	
CFL Fixture	Overall	4,203	7.0	6.4-7.7	6.2-7.9	
	Small	2,379	5.9	5.3-6.5	5.2-6.8	0.00
	Large	1,824	11.3	8.6-14.8	8.0-16.1	
LED Exit	Overall	1,955	21.9	12.9-37.0	11.1-43.1	
	Small	689	25.3	12.0-53.0	9.7-66.2	0.66
	Large	1,266	20.4	12.0-34.9	10.3-40.8	
HID	Overall	6,732	9.1	8.3-10.1	8.0-10.3	
	Small	1,268	9.6	8.3-11.2	7.9-11.8	0.48
	Large	5,464	8.7	7.7-9.8	7.5-10.2	
T8 Fixtures	Overall	84,517	16.2	12.8-20.5	12.0-22.0	
	Small	14,355	14.2	9.8-20.8	8.7-23.3	0.59
	Large	70,162	16.7	13.0-21.6	12.0-23.2	

4.2.3 Results by Building Type

At each of the on-sites, KEMA categorized the facility into one of 26 primary building types. of this report provides the means in which we categorized those 26 primary building type categories into the three categories in Table 4-9 below. Like Table 4-8 above, if the p-value is lower than 0.20, the results among the various business types can be considered statistically significant at the 80% confidence interval. Likewise, a p-value lower than 0.10 signifies that business type results are statistically different at the 90% confidence interval.

Table 4-9: **Estimated EUL by Building Type and Technology**

Technology	Business Type	Number of Units	Estimated EUL	80% CI Range	90% CI Range	Coefficient p-value
CFL Bulb	Overall	7,777	5.1	4.3-6.0	4.1-6.3	
	Retail/Wholesale	1,317	3.2	2.2-4.5	1.9-5.3	0.03
	Services	4,856	6.5	5.1-8.1	4.8-8.7	
	Other	1,604	5.6	3.9-8.2	3.4-9.5	
CFL Fixture	Overall	4,203	7.0	6.4-7.7	6.2-7.9	
	Retail/Wholesale	654	5.2	4.3-6.2	4.1-6.6	0.05
	Services	3,177	7.3	6.6-8.1	6.4-8.3	
	Other	372	14.8	5.2-42.5	3.5-63.1	
LED Exit	Overall	1,955	21.9	12.9-37.0	11.1-43.1	
	Retail/Wholesale	185	12.0	6.1-23.4	4.9-29.6	0.40
	Services	1,506	22.4	12.8-39.1	10.9-46.0	
	Other	264	47.6	8.7-262.0	5.0-456.5	
HID	Overall	6,732	9.1	8.3-10.1	8.0-10.3	
	Retail/Wholesale	3,734	11.2	8.6-14.6	7.9-15.8	0.10
	Services	1,232	10.4	8.6-12.6	8.1-13.3	
	Other	1,766	7.5	6.6-8.5	6.4-8.9	
T8	Overall	84,517	16.2	12.8-20.5	12.0-22.0	
	Retail/Wholesale	25,371	11.0	8.7-13.9	8.1-14.8	0.05
	Services	45,737	19.4	14.0-26.9	12.8-29.5	
	Other	13,409	28.0	14-2-54.9	11.6-67.1	

4.2.4 Results by Hours of Use

At each of the on-sites, KEMA gathered self-reported hours of use of the lighting in each facility area from the occupants of each building. Although not precise estimates, overall, these self reported estimates of hours are assumed to be fairly accurate. Table 4-10 presents these results. There are some instances where higher EULs correspond with higher hours of use, which is counterintuitive. This is due to many instances in which the removal of measures before burnout interfered with the expected relationship between hours of use and the estimated EULs for some measures.

We used the hour distribution midpoint of 3,500 annual hours to distinguish low versus high and calculated the EUL estimates using the same statistical approaches discussed previously. We consider all results split by hours of use to be statistically the same at both the 80% and 90% confidence intervals, with the exception of T8 fixtures, which have a P-value of 0.07 and are therefore statistically different at the 80% and 90% confidence intervals.

Table 4-10: Estimated EUL by Hours of Use and Technology

Technology	Load Factor	Number of Units	Estimated EUL	80% CI Range	90% CI Range	Coefficient p-value
CFL Bulb	Overall	7,777	**5.1**	4.3-6.0	4.1-6.3	
	Low	5,047	**4.7**	3.7-6.0	3.5-6.4	0.39
	High	2,089	**6.9**	3.9-12.1	3.2-14.8	
CFL Fixture	Overall	4,203	**7.0**	6.4-7.7	6.2-7.9	
	Low	1,589	**9.5**	7.7-11.8	7.2-12.6	0.35
	High	982	**25.4**	5.9-108.6	3.8-170.5	
HID	Overall	6,732	**9.1**	8.3-10.1	8.0-10.3	
	Low	490	**12.1**	8.4-17.4	7.4-19.8	0.53
	High	5,553	**10.2**	8.9-11.7	8.5-12.2	
T8	Overall	84,517	**16.2**	12.8-20.5	12.0-22.0	
	Low	42,925	**22.3**	15.2-32.5	13.7-36.3	0.07
	High	40,089	**13.6**	10.6-17.3	9.9-18.6	

4.3 Secondary Equipment Life Research

KEMA performed research to compile information on rated hours of operation, annual hours of operation, and other characteristics related to measure life for many lighting measure types, including those in this study. The following secondary sources were used:

- **Source 1:** California Database for Energy Efficiency Resources (DEER)[12].
- **Source 2:** Efficiency Vermont Technical Reference User Manual No. 2005-37, dated February 13, 2006[13].
- **Source 3:** Efficiency Maine Commercial Technical Reference Manual No. 2006-1, dated March 5, 2007[14].
- **Source 4:** CL&P & UI Program Savings Documentation for the 2011 Program Year, dated September 21, 2010[15].
- **Source 5:** Mid-Atlantic Technical Reference Manual, dated October 2010[16].
- **Source 6:** Massachusetts Technical Reference Manual, dated October 2010[17].
- **Source 7:** New England SPWG Residential & C/I Lighting and HVAC Measure Life Report, dated June 2007[18].
- **Source 8:** Lessons Learned and Next Steps in Energy Efficiency Measurement and Attribution: Energy Savings, Net to Gross, Non-Energy Benefits, and Persistence of Energy Efficiency Behavior, dated November 2009[19].
- **Source 9:** San Diego Gas & Electric 1996-97 Commercial Energy Efficiency Incentives Ninth Year Retention Study, dated March 2006[20].
- **Source 10:** Southern California Edison Energy Efficiency Incentives Ninth Year Retention Study, dated February 28, 2006[21].
- **Source 11:** Pacific Gas & Electric Energy Efficiency Incentives Ninth Year Retention Study, dated January 25, 2006[22].
- **Source 12:** Technical Reference Manual for Pennsylvania Act 129 Energy Efficiency and Conservation Program, dated June 2010[23].
- **Sources 13-17:** General Electric T8 and Compact Fluorescent Bulb Sell Sheets[24].

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[12] http://www.deeresources.com/deer0911planning/downloads/EUL_Summary_10-1-08.xls.
[13] http://www.state.vt.us/psb/eeurfp2005/trmusermanualno2004-31.doc#_Toc93807418.
[14] http://www.cee1.org/eval/db_pdf/565.pdf.
[15] http://neep.org/uploads/EMV%20Forum/EMV%20Studies/FINAL%202011%20CT%20PSD.pdf.
[16] http://neep.org/uploads/EMV%20Forum/EMV%20Products/Mid%20Atlantic%20TRM_V1.1.pdf.
[17] http://www.ma-eeac.org/docs/MA%20TRM_2011%20PLAN%20VERSION.PDF.
[18] http://neep.org/uploads/EMV%20Forum/EMV%20Studies/measure_life_GDS%5B1%5D.pdf.
[19] http://www.calmac.org/publications/Energy_Efficiency_Measurement_and_Attribution.pdf.
[20] http://www.calmac.org/publications/2006_PY96&PY97_CEEI_9th_Year_Retention_Evaluation.pdf.
[21] http://www.calmac.org/publications/SCE_9th_Year_Retention_Study_for_96-97_Commercial_Measures,_Final_Report.doc.
[22] http://www.calmac.org/publications/PGE_CI_Retention_Final.pdf.
[23] http://www.puc.state.pa.us/electric/docs/Act129/Act129_TRM-2010.doc.

- **Source 18:** US Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE)[25].
- **Sources 19 and 20:** ENERGY STAR qualifying CFL bulb and fixture lists[26].

Some of the sources listed above provided measure life estimates in years and some provided these estimates in hours, but none of the sources provided both. Six of the sources provided annual hours of use estimates by building type, but not by measure type.

Table 4-11 presents the number of sources, range, and average measure life estimates that were compiled through this secondary research task in both years and hours. Estimates in years were informed by a review of TRM and PSD documents. Based upon these sources, CFL bulb lifetimes averaged 4.6 years, CFL fixtures averaged 13.1, LED exit signs and HIDs averaged 14.0, and T8s averaged 14.7. Within these estimates are those from the GDS study which we understand to be the primary assumptions being used by many sponsors. The GDS study results provide a CFL bulb lifetime of 5 years and a lifetime of 13 years for CFL fixtures, LED exit signs, HIDs, and T8s.

The table also provides similar estimates for high performance T8s (HP T8s) and T5s, which are more efficient options for T8s and HIDs. For both HP T8s and T5s, the average lifetime estimates in years from the secondary sources are very close to those of the less efficient alternatives. The rated hours estimates for these technologies are also very similar to that of T8s, although we were only able to find one source for T5 and HP T8 hours.

The rated hours estimates provided in Table 4-11 are exclusively from manufacturer data, the DOE, and the ENERGY STAR web site. Except for CFL bulbs, they are the rated hours for ballasts and not lamps. As such, they represent hours of continuous operation until unit failure, not including events such as removal, whereas the estimates in years reflect annual hours of operation and, in some cases, may reflect removal before failure. The average rated hours from these sources was

[24] http://www.gelighting.com/na/business_lighting/education_resources/literature_library/sell_sheets/downloads/fluorescent/F32T8_SXL-SPX-ECO_Sell_sheet_74901.pdf, http://www.gelighting.com/na/business_lighting/education_resources/literature_library/sell_sheets/downloads/fluorescent/F28T8-XL_sell_sheet.pdf, http://www.gelighting.com/na/business_lighting/education_resources/literature_library/sell_sheets/downloads/fluorescent/LFL-F96T8-49W-SPX-63561.pdf, http://www.gelighting.com/na/business_lighting/education_resources/literature_library/sell_sheets/downloads/fluorescent/2-3Ft-T8_wm_sell_sheet.pdf, http://www.gelighting.com/na/business_lighting/education_resources/literature_library/sell_sheets/downloads/cfl/20563_cfl.pdf.

[25] http://www1.eere.energy.gov/buildings/ssl/life_measuring.html.

[26] http://www.energystar.gov/index.cfm?fuseaction=cfls.display_products_excel, http://downloads.energystar.gov/bi/qplist/fixtures_prod_list.xls.

9,437 hours for CFL bulbs, 9,800 hours for CFL fixtures, 13,750 hours for HIDs, and 27,333 hours for T8s.

Table 4-11: Secondary Source Measure Lifetimes

	Estimates in Years (TRMs)			Estimates in Rated Hours		
Measure	# of Sources	Range	Avg.	# of Sources	Range	Avg.
CFL Bulbs	8	3.4 to 10	4.6	3	6,000 to 15,000	9,437
CFL Fixt.	9	9.2 to 16	13.1	2	4,000 to 40,000	9,800
HIDs	8	13 to 15	14.0	1	7,500 to 20,000	13,750
HP T8s	7	13-15	13.6	1	N/A	25,000
LED Exits	7	10 to 20	14.0	0	-	-
T5s	8	11-16	13.8	1	N/A	25,000
T8s	11	11.2 to 20	14.7	5	18,000 to 40,000	27,333

4.4 Equipment Lifetime Hours Comparison

KEMA attempted to isolate technology failures from other removal events such as remodel or upgrades. We attempted this analysis in the interest of developing an independent estimate of rated hours of use that could be cleanly compared to industry-rated equipment life statistics. Unfortunately, we were not able to disaggregate the lifetimes based solely on unit failure as the confidence bands were too large around the final failure-only EUL estimates.

To perform an alternate comparison of lifetime hour results to secondary industry data, Table 4-12 presents calculated lifetime hours of each technology based on data gathered from TRMs and the primary data collected in this study. The secondary side of the table provides the assumed average hours of use as provided for lighting in the TRMs reviewed along with the TRM EUL estimates. The right side provides the EUL and self reported operating hours from the on-sites performed in this study. The calculated lifetime hours are the product of the annual hours of use and the EUL. While CFL bulb lifetime hour estimates are consistent between the two estimates, CFL and HID fixtures have notably lower lifetime hours in the current study than in the secondary data, although all of on-site hours are self reported. LED exits and T8 fixtures have considerably more hours in the current study than in the secondary data. Despite the fact that these hours are derived from both failure and non-failure removal events, all technologies have lifetime hours that exceed the average industry-rated equipment life statistics, which may be due to the self reporting of hours of use from the on-sites.

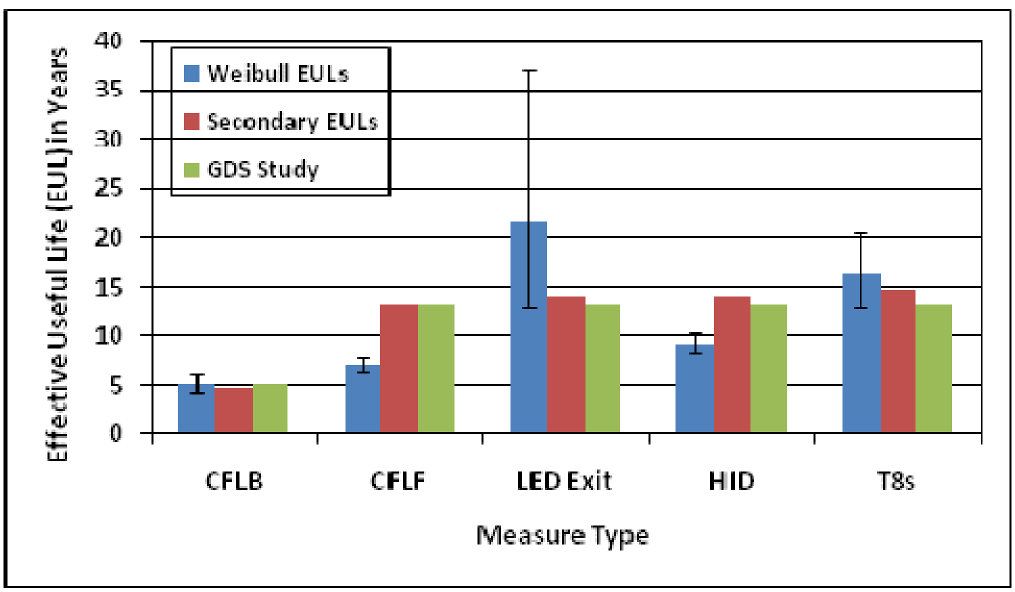
Table 4-12: Secondary T8 EULs

	Secondary				On-site		
Technology	# of Sources	EUL (in Yrs.)	Assumed AOH	Calculated Equipment Lifetimes (in Hrs.)	EUL (in Yrs.)	Reported AOH	Calculated Equipment Lifetimes (in Hrs.)
CFL Bulbs	8	4.6	4,008	18,437	5.1	3,179	16,213
CFL Fixtures	9	13.1	4,008	52,505	7.0	4,626	32,382
HID	8	14.0	4,008	56,112	9.1	5,004	45,536
LED Exits	7	14.0	8,760	122,640	21.9	8,760	191,844
T8 Fixtures	11	14.7	4,008	58,918	16.2	4,261	69,028

4.5 Secondary and Weibull Model EUL Comparison

Figure 4-8 compares the secondary research estimates discussed above to the Weibull Model estimates that were derived from the on-site data. We further include the recent estimates of lifetime provided by GDS on behalf of NEEP as we understand those assumptions have generally been accepted by the study sponsors. The CFL bulb and T8 estimates are very comparable with approximately 1 year of difference between each source for both measures. The secondary CFL fixture and HID estimates are approximately 5-6 years longer than the Weibull estimates, and appear to be statistically different. The Weibull estimate for LED exit signs is approximately 8 years longer than its secondary counterpart. The error bars show the upper and lower bounds around the Weibull estimate at the 80% confidence interval.

Figure 4-8: Weibull EULs vs. Secondary EULs



5. Conclusions and Recommendations

Table 5-1 presents all EUL results by technology and by various sub samples. Cells are shaded gray to illustrate statistically different results. We provide a two-tailed, 80% confidence interval around each result. The top row provides overall EULs by technology, with subsequent rows presenting EULs by program size, annual hours of use and building type.

We recommend that the sponsors utilize the overall EULs by technology. While some sub sample results are statistically different from one another, we have concerns that despite finding these differences, the sample sizes they are based on are not as robust as the overall EUL estimates provided. Given the size of some of the sub samples, there is an opportunity for chance events to drive the observed differences in results as opposed to the results being caused by actual differences between the sub sample groups. For example, a single remodeled site accounts for 21% of the fixtures removed among small business customers in that sub-sample, which drives much of the difference between the small CFL fixture measure life result and the overall result. In addition, it should be noted that the dis-aggregation of some results (such as EUL by hours of use) are dependent upon self reported hours of operation, upon which a distinction between groups is made that might not be entirely accurate.

Recently, sponsor programs have included T5 and high performance T8 technologies. While these were not included in the primary research effort of this study, they were included in the secondary data research to assess the possibility of transferring the primary results to these technologies. Indeed, T8 hours and lifetimes as noted in the secondary data are very similar to T5 and high performance T8 estimates. In our experience, the application and location of high performance T8 fixtures can be expected to be similar to those of standard T8 fixtures. To a lesser extent this is also true of T5, although a common application for T5 fixtures is to replace HID fixtures which can have different operating conditions and locations than standard T8 fixtures might have.

We believe the T8 EUL results are transferable to T5 and high performance T8 lighting until a more definitive measure life study on those specific technologies is performed. We conclude this for two primary reasons. First, much of the T8 fixture lifetimes in our sample were driven by events in which fixtures were removed before their natural failure, which we believe would also be the primary driver of T5 and high performance T8 lifetimes. Second, the similarity between the secondary data on lifetimes and rated hours between T5, HP T8 and T8 fixtures suggests that to the extent natural failure events do occur, they would likely impact these technologies the same as that observed in this study.

Finally, while T5 applications are often in place of HID fixtures, we do not recommend the use of the HID lifetime estimates for T5 fixtures. This is due to the fact that many HID removal events were replacements of the HID fixture to a linear fluorescent fixture. This removal cause heavily influenced the HID measure life calculated in this study and is not expected to occur with the T5 lighting technology.

Table 5-1: Summary of EUL Results at 80% CI

		CFL bulbs	CFL Fixtures	HID	LED Exit	T8 Fixtures
Overall **(80% CI)**		**5.1** ***(4.3-6.0)***	**7.0** ***(6.4-7.7)***	**9.1** ***(8.3-10.1)***	**21.9** ***(12.9-37.0)***	**16.2** ***(12.8-20.5)***
Program Size	Large (n=92) (80% CI)	6.3 *(4.9-8.2)*	11.3 *(8.6-14.8)*	8.7 *(7.7-9.8)*	20.4 *(12.0-34.9)*	16.7 *(13.0-21.6)*
	Small (n=132) (80% CI)	4.4 *(3.6-5.5)*	5.9 *(5.3-6.5)*	9.6 *(8.3-11.2)*	25.3 *(12.0-53.0)*	14.2 *(9.8-20.8)*
Annual HOU Bin	High HOU (n=166) (80% CI)	6.9 *(397-12.1)*	25.4 *(5.9-108.6)*	10.2 *(8.9-11.7)*	N/A	13.6 *(10.6-17.3)*
	Low HOU (n=138) (80% CI)	4.7 *(3.7-6.0)*	9.5 *(7.7-11.8)*	12.1 *(8.4-17.4)*	N/A	22.3 *(15.2-32.5)*
Building Type	Retail/Wholesale (n=70) (80% CI)	3.2 *(2.2-4.5)*	5.2 *(4.3-6.2)*	11.2 *(8.6-14.6)*	12.0 *(6.1-23.4)*	11.0 *(8.7-13.9)*
	Services (n=106) (80% CI)	6.5 *(5.1-8.1)*	7.3 *(6.6-8.1)*	10.4 *(8.6-12.6)*	22.4 *(12.8-39.1)*	19.4 *(14.0-26.9)*
	Other (n=51) (80% CI)	5.6 *(3.9-8.2)*	14.8 *(5.2-42.5)*	7.5 *(6.6-8.5)*	47.6 *(8.7-262.0)*	28.0 *(14.2-54.9)*

Note: Annual HOU and Building Type sample sizes may exceed the total sample size of 224. Self-reported annual HOU were gathered by space so sites that had areas of both high and low use will be represented in each bin. With regard to building type, two projects were performed in school districts for which visits to multiple building types were performed (services and other).

Table 5-2 presents EUL results by technology and by various sub samples and includes a two-tailed, 90% confidence interval around each result. Like the previous table, the top row provides overall EULs by technology, with subsequent rows presenting EULS by program size, annual hours of use and building type. Cells are shaded gray to illustrate statistically different results. While CFL bulb results by program size and LED exit results by building type were statistically different in the table above at the 80% confidence interval, they are not at the 90% confidence interval.

Table 5-2: Summary of EUL Results at 90% CI

		CFL bulbs	CFL Fixtures	HID	LED Exit	T8 Fixtures
Overall **(90% CI)**		**5.1** ***(4.1-6.3)***	**7.0** ***(6.2-7.9)***	**9.1** ***(8.0-10.3)***	**21.9** ***(11.1-43.1)***	**16.2** ***(12.0-22.0)***
Program Size	Large (n=92) (90% CI)	6.3 *(4.5-8.9)*	11.3 *(8.0-16.1)*	8.7 *(7.5-10.2)*	20.4 *(10.3-40.8)*	16.7 *(12.0-23.2)*
	Small (n=132) (90% CI)	4.4 *(3.4-5.8)*	5.9 *(5.2-6.8)*	9.6 *(7.9-11.8)*	25.3 *(9.7-66.2)*	14.2 *(8.7-23.3)*
Annual HOU Bin	High HOU (n=166) (90% CI)	6.9 *(3.2-14.8)*	25.4 *(3.8-170.5)*	10.2 *(8.5-12.2)*	N/A	13.6 *(9.9-18.6)*
	Low HOU (n=138) (90% CI)	4.7 *(3.5-6.4)*	9.5 *(7.2-12.6)*	12.1 *(7.4-19.8)*	N/A	22.3 *(13.7-36.3)*
Building Type	Retail/Wholesale (n=70) (90% CI)	3.2 *(1.9-5.3)*	5.2 *(4.1-6.6)*	11.2 *(7.9-15.8)*	12.0 *(4.9-29.6)*	11.0 *(8.1-14.8)*
	Services (n=106) (90% CI)	6.5 *(4.8-8.7)*	7.3 *(6.4-8.3)*	10.4 *(8.1-13.3)*	22.4 *(10.9-46.0)*	19.4 *(12.8-29.5)*
	Other (n=51) (90% CI)	5.6 *(3.4-9.5)*	14.8 *(3.5-63.1)*	7.5 *(6.4-8.9)*	47.6 *(5.0-456.5)*	28.0 *(11.6-67.1)*

Note: Annual HOU and Building Type sample sizes may exceed the total sample size of 224. Self-reported annual HOU were gathered by space so sites that had areas of both high and low use will be represented in each bin. With regard to building type, two projects were performed in school districts for which visits to multiple building types were performed (services and other).

Appendix A: Sample Site Survey Form

This appendix presents the core site survey form. Note that the area shaded in gray was merged onto the form before each site visit. We have placed example information into the form to illustrate this. The auditor used the forms during the walkthrough at each site.

1. Track Fixt Type: The fixture type information from the tracking system.
2. Track Location: The location from the tracking system.
3. Track Qty: The quantity from the tracking system.
4. Onsite Space Type: The location of the fixtures as noted by the auditor during the on-site.
5. Onsite Total: Total fixtures accounted for on-site; includes those installed and those accounted for by the not found event codes.
6. Onsite Installed: Total fixtures that were installed and operating at the time of the on-site visit.
7. App. Ann. Hrs.: Estimate of annual hours as estimated by the on-site contact.
8. # Occ. Sensor (OS): Auditor noted the quantity of fixtures that are controlled by occupancy sensors.
9. OS Setting (Man./Auto): Auditor noted if occupancy sensor(s) are on manual or automatic setting.
10. OS Loc. (Good/Poor): Auditor noted if the occupancy sensor(s) are installed in good or poor locations.
11. Removal Event Code: Used to designate why fixture was removed; using the codes below the table.
12. Removal Event Qty: The quantity removed due to the corresponding removal event.
13. Removal Event Year/Range: The year the removal event occurred in or a range of years if specific year is not offered. Also indicated if the respondent knew it was removed by a particular year or was installed through a particular year but could not provide a range or specific year. For instance, if the contact knew that the fixtures were there in 2004 but could not say for sure if they were there any ***later*** than that, it was written by the auditor as 'L2004'. If the contact only knew that the fixtures were no longer installed in 2006, but could not say for sure if they were removed ***earlier*** than that, it was written by the auditor as 'E2006'.

Example On-Site Form

Pre-Filled Prior to On-Site Visit			Auditor Input On-Site							Customer Inquiry On-Site					
Track Fixture Type	Track Location	Track Qty	Onsite Space Type	Onsite Total	Onsite Installed	App. Ann. Hrs.	# Occ. Sensor (OS)	OS Setting (Man./ Auto)	OS Loc. (Good/ Poor)	Not Found Event 1			Not Found Event 2		
										Code*	Qty	Year/ Range	Code*	Qty	Year/ Range
Fluorescent, (4) 48", T-8 lamp	*Main Sales Area*	*410*	Sales	410	410	5,824	0								
Fluorescent, (4) 48", T-8 lamp	*Bakery Prep By Circle*	*5*	Bakery Prep	5	5	8,760	0								
Fluorescent, (4) 48", T-8 lamp	*Bakery Circle*	*6*	Bakery Circle	6	6	8,760	0								
Fluorescent, (4) 48", T-8 lamp	*Frozen Aisles*	*25*	Frozen Aisles	25	25	5,824	0								
Fluorescent, (4) 48", T-8 lamp	*Main Stockroom*	*72*	Main Stock	72	0					R	72	2005			
Fluorescent, (4) 48", T-8 lamp	*Customer Service/Entry*	*32*	Customer Svc/Entry	32	26	8,760	6	Auto	Good	RIK	2	2007	RIK	4	2009
Fluorescent, (4) 48", T-8 lamp	*Produce Grid*	*28*	Produce	28	28	8,760	0								
Fluorescent, (4) 48", T-8 lamp	*Deli, Cheese, Bakery*	*122*	Deli, Cheese, Bakery	122	122	5,824	0								

* Not Found Event Codes: F = Equipment failure, D = Dissatisfied, R = Remodel, V = Location vacant/demolished, C = Change in use of space, U = Equipment upgraded, RIK= Replaced in Kind, T = Temporarily taken out of operation (indicate estimated reinstall date), N = Location not found & unknown by site contact, IEC = Inaccessible and estimated by site contact, IEA = Inaccessible and estimated by the auditor, I = Inaccessible and not able to be estimated, U = Upgraded to a higher efficiency measure (record what this upgraded measure is), NI = Never Installed according to contact, X = Don't know/Unsure, O = Other (specify). If inaccessible, auditor will try to get fixture type and quantity estimates for the inaccessible space from the site contact or estimate them based on other similar areas in the facility that are accessible.

In addition to visual inspection and customer reports, auditors opened up randomly selected fixtures to record the manufacturer and model numbers of T8s fixtures, CFL bulbs, CFL fixtures, and HID fixtures to inform the persistence assessment. When specific conditions were met, auditors checked two ballasts in the fixture type/space type combinations that had the largest quantity of program installations (so that the products checked would represent a large proportion of those installed). If these two ballast model numbers did not match up, the auditor checked additional ballasts until they could discern an approximate removal rate. Conditions under which ballast inspections were not performed included the following:

- When the customer would not allow the auditor to check the ballasts,
- When fixtures were deemed to be unsafe to open due to condition (very old fixtures, hazardous inspection conditions, unsafe wiring conditions, fixtures that are determined to be difficult to put back together correctly, ballast covers with screws intended for one use or that are damaged, fixtures that are dirty and might cause dust to become airborne, etc.),
- When fixtures locations did not lend themselves to inspection (such as areas of privacy or locations where it would otherwise disrupt business).
- When fixtures were more than 10 feet off the ground.

Appendix B: Building Type Categorizations

This appendix shows how each of the 26 building types (as agreed upon by the sponsors prior to the study) were categorized into the three groups presented throughout this report.

Building Type Categorizations

Other			
Heavy Industrial	Industrial Refrigeration	Light Industrial	Multifamily High Rise
Multifamily Low Rise	Other	Warehouse	
Retail/Wholesale			
Big Box	Fast Food	Full Service Restaurant	Grocery
Multi-Story Retail	Small Retail		
Services			
Assembly	Auto Repair	Community College	Dormitory
Hospital	Hotel	Large Office	Motel
Primary School	Religious	Secondary School	Small Office
University			

Appendix C: On-Site Recruitment Protocol

Northeast Energy Efficiency Partnership
C&I Lighting Persistence Recruitment Protocol

This document provides a protocol for the recruitment of the site visit work. The objective of this protocol is to contact sampled sites in a manner that either informs the persistence analysis via information from the recruitment contact itself or guides the future collection of information via an on-site or drive-by effort. At the recruitment stage, this means that we employ a system that rigorously tracks the outcome of the effort to particular final dispositions that lead to either further known action items or can be used as inputs to the survival analysis itself.

Recruitment Script

If contact name available

Good morning/afternoon. My name is____. I am calling on behalf of <program administrator/retail affiliate name>. May I speak with <contact name>?

According to our records, your company participated in an energy conservation program with <utility/retail affiliate name> in <installation year>. Through your participation, <qty> lighting products were installed at <location>. We are currently performing an assessment of these lighting products so I was wondering if it be possible for us to schedule a visit to your facility to observe the installed lighting?

KEMA

ON-SITE RECRUITMENT

Yes → Schedule a date and time for a visit. Note final disposition as "**Appointment scheduled**" below.

Date: ____________ Time: ________ Contact: _____________________

No → Can I ask you four quick questions regarding these lighting installations?

1. Since they were installed in <installation year>, have any of these products failed?"
   ___Yes
   ___No/Do not Know →**GOTO ON-SITE RECRUITMENT**

2. Approximately what percent of the original quantity are no longer in operation?
   _____%

3. What type of lighting was installed in their place and what proportion of the products removed were replaced by each?
   a. ____________________________________ - _____%
   b. ____________________________________ - _____%
   c. ____________________________________ - _____%

4. Approximately how many years after installation were they removed and why were they removed*? ______

   *If respondent provides removal rates by year, please note specific percentages by year:

% of total	*Year Removed*	*Why Removed? (Circle One & use as many rows as needed)*
____	________	*Remodel/Failure/Dissatisfaction/Razed/Other:* ________________ *If dissatisfaction, why?* __________________________________
____	________	*Remodel/Failure/Dissatisfaction/Razed/Other:* ________________ *If dissatisfaction, why?* __________________________________
____	________	*Remodel/Failure/Dissatisfaction/Razed/Other:* ________________ *If dissatisfaction, why?* __________________________________

Thank and Terminate. Record "**Appointment refused, basic disposition of lighting determined**" below.

If contact not available from file or if new contact needs to be established:

Good morning/afternoon. My name is______. I am calling on behalf of <utility/retail affiliate name>.

According to our records, your company participated in an energy conservation program with <utility/retail affiliate name> in <installation year>. We are currently performing an assessment of the lighting products installed through this program so I was wondering if I could speak with someone at your facility – such as a facility manager or building operator – that might be familiar with these products? Record contact name, ask to speak with contact, and **GOTO "*If contact name available*" script**.

Contact Name: ___________________

If knowledgeable facility contact cannot be reached: Record as "**No information able to be gathered, needs sample replacement**" below.

If no contact can be made using available tracking information: Use available information to perform an online search to gather information on whether site is still in operation under new management or company. Try to contact the "new company" using the "***If contact not available from file or if new contact needs to be established***" script above.

If no information is available on-line for "new company": Instruct auditor to "drive by" site address to see if the facility still exists. Record as "**Facility not able to be reached, needs drive-by**" below.

If facility exists on "drive by": Attempt recruitment on-site using "***If contact not available from file or if new contact needs to be established***" script. Ask contact recruitment questions and gather data per on-site protocol to the extent possible. If contact is unavailable, get contact information and attempt phone recruitment using "***If contact name available***" script.

If facility exists but is vacant on "drive by": Record as "***Facility is vacant*, needs sample replacement**" below.

If facility does not exist on "drive by": Attempt to find out when building was demolished from neighboring businesses. Reported demolition date: ________. Record as "***Site demolished, all products considered removed as of "demolition date".***"

Final Disposition:

___ Appointment scheduled.

___ Contact was reached and confidently reported full measure removal from site.

___ Facility not able to be reached, needs drive-by.

___ Appointment refused, basic disposition of lighting determined.

___ No information able to be gathered, needs sample replacement.

___ Facility is vacant, needs sample replacement

- **Note whether this site is believed to be short term vacancy: Yes / No.**
- **Note any percent of site is still functioning ____% and assessment of whether lighting appears to be in place ___________________________.**

___Site demolished, all products considered to have not persisted as of demolition date: ___________.

Appendix D: Technical Appendix

Confidence Interval for a Measure's EUL

Recall, it is only possible to calculate an approximate standard error of a measure's EUL estimate. This is because it is the log of a measure's EUL estimate that is directly obtained and the distribution of the log of a measure's EUL estimate is unknown.

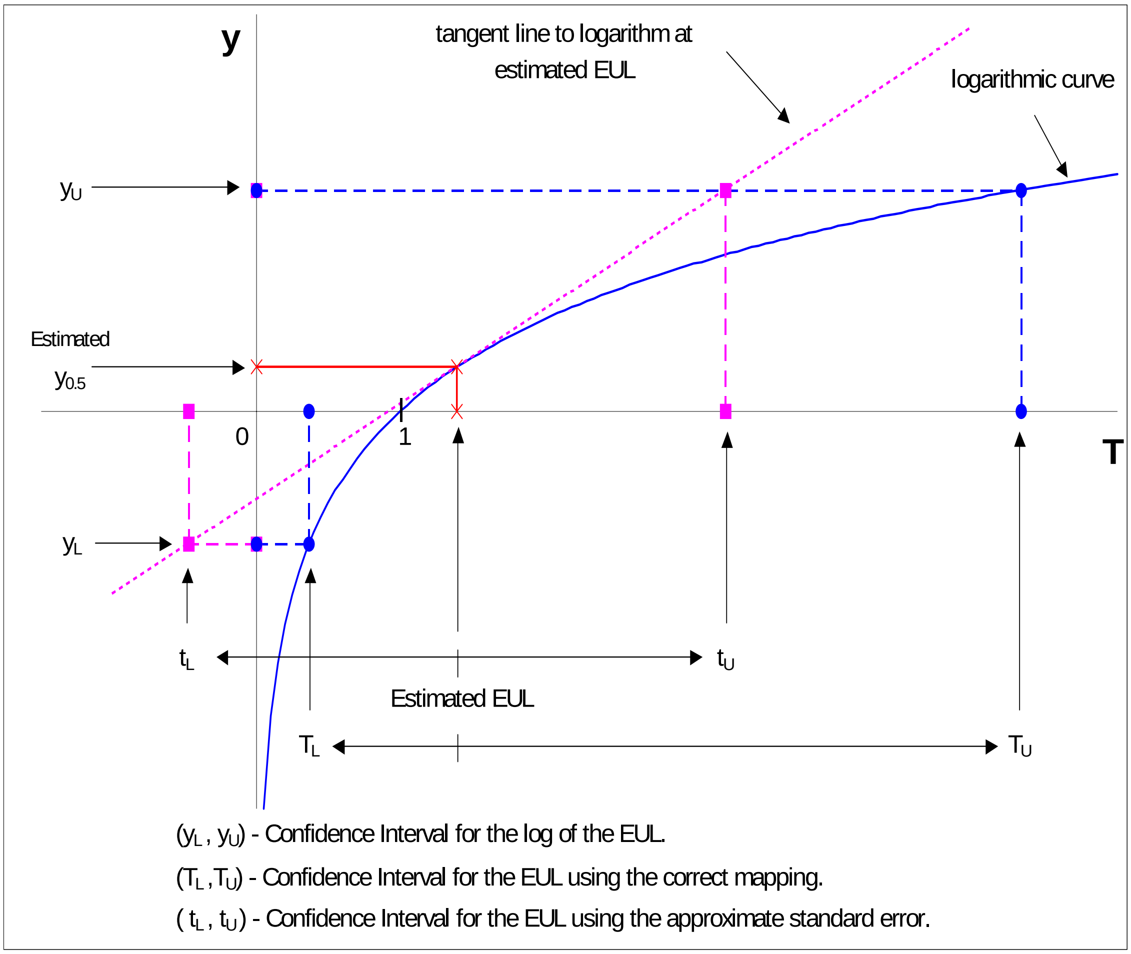
A confidence interval for a measure's EUL can be calculated using the approximate standard error (adjusted or unadjusted, whichever is appropriate) of the measure's EUL estimate. A confidence interval for a measure's EUL can also be obtained from the confidence interval for the log of the measure's EUL. The lower and upper bounds of the latter confidence interval for a measure's EUL equal the exponential of the lower and upper bound values of the confidence interval for the log of the measure's EUL, respectively. A confidence interval for the log of a measure's EUL is calculated using the standard error (adjusted or unadjusted, whichever is appropriate) of the log of the measure's EUL estimate.

The confidence interval for a measure's EUL based on the approximate standard error of the measure's EUL estimate is symmetric about the measure's EUL estimate. That is, the lower and upper bounds of this confidence interval are the same distance from the measure's EUL estimate. The confidence interval for the log of a measure's EUL is similarly symmetric about the log of the measure's EUL estimate. However, the confidence interval for a measure's EUL based on the confidence interval for the log of the measure's EUL is not symmetric about the measure's EUL estimate. This is because the exponential transformation is non-linear. Consequently, the confidence interval for a measure's EUL based on the approximate standard error of the measure's EUL estimate is less accurate than the confidence interval for the measure's EUL based on the confidence interval for the log of the measure's EUL.

The larger the approximate standard error of a measure's EUL estimate, the greater the consequences of the non-linearity of the logarithmic transformation and the less accurate the confidence interval for the measure's EUL based on the approximate standard error of the measure's EUL estimate. The non-linearity of the logarithmic transformation also explains why the confidence interval for a measure's EUL based on the approximate standard error of the measure's EUL estimate may contain negative values, which are clearly impossible. The confidence interval for a measure's EUL based on the confidence interval for the log of the measure's EUL will never contain negative values.

The two methods of calculating a confidence interval for a measure's EUL are illustrated in the figure below. This study calculates and reports the more accurate confidence interval for a measure's EUL obtained from the confidence interval for the log of the measure's EUL.

Figure 5-1: Two Methods of Calculating a Confidence Interval for the EUL



Confidence Interval for the Log of a Measure's EUL

In general, the bounds of a confidence interval for a parameter are calculated as the parameter estimate ± the standard error of the parameter estimate times the critical value from the appropriate distribution for the desired level of confidence. The standard error of the log of a measure's EUL estimate employed in the calculation of the confidence interval for the log of the measure's EUL is provided by SAS. This standard error is a function of the standard errors of the parameter estimates of the general linear regression model. If necessary, the standard error of the log of a measure's EUL estimate provided by SAS is adjusted by the square root of the design effect.

The log of a measure's EUL estimate is assumed approximately normally distributed. Therefore, the critical value employed in the calculation of a confidence interval for the log of a measure's EUL is approximated using the value from the Student distribution for the appropriate degrees of freedom and desired level of confidence. The degrees of freedom equals the effective sample size neff minus one, where neff is the number of units of the measure employed in the analysis divided by the design effect. The value of neff may be a non-integer.

Unadjusted Weibull Model Statistics

In the following listings, we present model statistics output directly from SAS. Note that these statistics are not adjusted for clustering and are shown for reference. Adjusted model statistics are provided later in this appendix.

Unadjusted Overall Model Statistics

CFL Bulbs

```
The SAS System

tech=CFLB

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                          Log(lower)
Dependent Variable                          Log(upper)
Number of Observations                           12819
Noncensored Values                                2292
Right Censored Values                             4748
Left Censored Values                              5042
Interval Censored Values                           737
Name of Distribution                           Weibull
Log Likelihood                            -10535.68802


Number of Observations Read       14505
Number of Observations Used       12819
Missing Values                     1686


                 Fit Statistics

-2 Log Likelihood                         21071.38
```

```
AIC (smaller is better)                 21075.38
AICC (smaller is better)                21075.38
BIC (smaller is better)                 21090.29


Algorithm converged.




          Analysis of Maximum Likelihood Parameter Estimates

                          Standard   95% Confidence     Chi-
Parameter     DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept      1   1.8391   0.0066   1.8261   1.8521 76500.1     <.0001
Scale          1   0.5852   0.0081   0.5696   0.6013
Weibull Scale  1   6.2910   0.0418   6.2095   6.3735
Weibull Shape  1   1.7087   0.0236   1.6630   1.7557
```

CFL Fixtures

```
The SAS System

tech=CFLF

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                        Log(lower)
Dependent Variable                        Log(upper)
Number of Observations                          4253
Noncensored Values                              2045
Right Censored Values                           2156
Left Censored Values                              50
Interval Censored Values                           2
Name of Distribution                         Weibull
Log Likelihood                          -2886.727104


Number of Observations Read        5072
Number of Observations Used        4253
Missing Values                      819


                 Fit Statistics

-2 Log Likelihood                       5773.454
AIC (smaller is better)                 5777.454
AICC (smaller is better)                5777.457
BIC (smaller is better)                 5790.165
```

```
Algorithm converged.



          Analysis of Maximum Likelihood Parameter Estimates

                          Standard   95% Confidence     Chi-
Parameter     DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept      1   2.0883   0.0088   2.0711   2.1055 56713.2     <.0001
Scale          1   0.3872   0.0070   0.3738   0.4011
Weibull Scale  1   8.0713   0.0708   7.9337   8.2112
Weibull Shape  1   2.5826   0.0466   2.4929   2.6755
```

LED Exit

```
The SAS System

tech=Exit

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                        Log(lower)
Dependent Variable                        Log(upper)
Number of Observations                          1959
Noncensored Values                               204
Right Censored Values                           1751
Left Censored Values                               4
Interval Censored Values                           0
Name of Distribution                         Weibull
Log Likelihood                           -746.155986


Number of Observations Read        2040
Number of Observations Used        1959
Missing Values                       81


                 Fit Statistics

-2 Log Likelihood                       1492.312
AIC (smaller is better)                 1496.312
AICC (smaller is better)                1496.318
BIC (smaller is better)                 1507.472


Algorithm converged.
```

```
         Analysis of Maximum Likelihood Parameter Estimates

                            Standard   95% Confidence     Chi-
Parameter     DF Estimate     Error        Limits       Square Pr > ChiSq

Intercept      1   3.3061    0.0912    3.1273   3.4849 1313.72     <.0001
Scale          1   0.6005    0.0385    0.5295   0.6809
Weibull Scale  1  27.2782    2.4882   22.8126  32.6181
Weibull Shape  1   1.6654    0.1068    1.4686   1.8885
```

HIDs

```
The SAS System

tech=HID

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                          Log(lower)
Dependent Variable                          Log(upper)
Number of Observations                            6743
Noncensored Values                                1270
Right Censored Values                             5439
Left Censored Values                                11
Interval Censored Values                            23
Name of Distribution                           Weibull
Log Likelihood                            -2246.235216


Number of Observations Read        7144
Number of Observations Used        6743
Missing Values                      401


                 Fit Statistics

-2 Log Likelihood                 4492.470
AIC (smaller is better)           4496.470
AICC (smaller is better)          4496.472
BIC (smaller is better)           4510.103


Algorithm converged.




         Analysis of Maximum Likelihood Parameter Estimates

                            Standard   95% Confidence     Chi-
Parameter     DF Estimate     Error        Limits       Square Pr > ChiSq
```

```
Intercept      1   2.3270   0.0104   2.3065   2.3474 49800.5     <.0001
Scale          1   0.3173   0.0066   0.3046   0.3306
Weibull Scale  1  10.2469   0.1068  10.0396  10.4585
Weibull Shape  1   3.1511   0.0658   3.0247   3.2828
```

T8s

```
The SAS System

tech=T8

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                        Log(lower)
Dependent Variable                        Log(upper)
Number of Observations                         85222
Noncensored Values                             13322
Right Censored Values                          71043
Left Censored Values                             705
Interval Censored Values                         152
Name of Distribution                         Weibull
Log Likelihood                          -44248.04378


Number of Observations Read       91204
Number of Observations Used       85222
Missing Values                     5982


                 Fit Statistics

-2 Log Likelihood                       88496.09
AIC (smaller is better)                 88500.09
AICC (smaller is better)                88500.09
BIC (smaller is better)                 88518.79


Algorithm converged.




          Analysis of Maximum Likelihood Parameter Estimates

                          Standard   95% Confidence     Chi-
Parameter     DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept      1   3.0145   0.0093   2.9962   3.0328  104023     <.0001
Scale          1   0.6254   0.0048   0.6160   0.6348
Weibull Scale  1  20.3795   0.1905  20.0096  20.7563
Weibull Shape  1   1.5991   0.0123   1.5752   1.6233
```

Unadjusted Model Statistics by Program Size

CFL Bulbs

```
The SAS System

tech=CFLB

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                           Log(lower)
Dependent Variable                           Log(upper)
Number of Observations                            12819
Noncensored Values                                 2292
Right Censored Values                              4748
Left Censored Values                               5042
Interval Censored Values                            737
Name of Distribution                            Weibull
Log Likelihood                             -10166.50415


Number of Observations Read       14505
Number of Observations Used       12819
Missing Values                     1686


tech=CFLB

      Class Level Information

Name      Levels    Values

size           2    1-Small 2-Large


                 Fit Statistics

-2 Log Likelihood                      20333.01
AIC (smaller is better)                20339.01
AICC (smaller is better)               20339.01
BIC (smaller is better)                20361.38


Algorithm converged.


       Type III Analysis of Effects

                         Wald
Effect       DF    Chi-Square    Pr > ChiSq
```

```
size           1      701.9826        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                    Standard   95% Confidence     Chi-
Parameter              DF Estimate     Error       Limits       Square Pr > ChiSq

Intercept               1   2.0420    0.0107    2.0210    2.0629 36531.9     <.0001
size          1-Small  1  -0.3519    0.0133   -0.3779   -0.3259  701.98     <.0001
size          2-Large  0   0.0000
Scale                   1   0.5460    0.0077    0.5312    0.5613
Weibull Shape           1   1.8315    0.0258    1.7816    1.8827
```

CFL Fixtures

```
The SAS System

tech=CFLF

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                         Log(lower)
Dependent Variable                         Log(upper)
Number of Observations                           4253
Noncensored Values                               2045
Right Censored Values                            2156
Left Censored Values                               50
Interval Censored Values                            2
Name of Distribution                          Weibull
Log Likelihood                           -2406.067657


Number of Observations Read        5072
Number of Observations Used        4253
Missing Values                      819


tech=CFLF

      Class Level Information

Name       Levels    Values

size            2    1-Small 2-Large


                 Fit Statistics

-2 Log Likelihood                       4812.135
```

```
AIC (smaller is better)                  4818.135
AICC (smaller is better)                 4818.141
BIC (smaller is better)                  4837.201


Algorithm converged.


       Type III Analysis of Effects

                         Wald
Effect       DF    Chi-Square    Pr > ChiSq

size          1      545.5066        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                  Standard   95% Confidence     Chi-
Parameter              DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept               1   2.5672   0.0260   2.5163   2.6182 9749.56     <.0001
size          1-Small   1  -0.6501   0.0278  -0.7047  -0.5956  545.51     <.0001
size          2-Large   0   0.0000
Scale                   1   0.3856   0.0070   0.3721   0.3995
Weibull Shape           1   2.5936   0.0471   2.5029   2.6876
```

LED Exit

```
The SAS System

tech=Exit

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                         Log(lower)
Dependent Variable                         Log(upper)
Number of Observations                           1959
Noncensored Values                                204
Right Censored Values                            1751
Left Censored Values                                4
Interval Censored Values                            0
Name of Distribution                          Weibull
Log Likelihood                           -743.4197431


Number of Observations Read        2040
Number of Observations Used        1959
Missing Values                       81


tech=Exit
```

```
      Class Level Information

Name      Levels    Values

size           2    1-Small 2-Large


                 Fit Statistics

-2 Log Likelihood                       1486.839
AIC (smaller is better)                 1492.839
AICC (smaller is better)                1492.852
BIC (smaller is better)                 1509.580


Algorithm converged.


       Type III Analysis of Effects

                       Wald
Effect       DF     Chi-Square     Pr > ChiSq

size          1         5.1162         0.0237


              Analysis of Maximum Likelihood Parameter Estimates

                                 Standard   95% Confidence     Chi-
Parameter                DF Estimate    Error       Limits        Square Pr > ChiSq

Intercept                 1   3.2376   0.0913   3.0586   3.4166 1257.09     <.0001
size          1-Small     1   0.2118   0.0936   0.0283   0.3953    5.12     0.0237
size          2-Large     0   0.0000
Scale                     1   0.5997   0.0385   0.5288   0.6802
Weibull Shape             1   1.6674   0.1071   1.4702   1.8910
```

HIDs

```
The SAS System

tech=HID

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                        Log(lower)
Dependent Variable                        Log(upper)
Number of Observations                          6743
Noncensored Values                              1270
```

Right Censored Values	5439
Left Censored Values	11
Interval Censored Values	23
Name of Distribution	Weibull
Log Likelihood	-2229.641467

Number of Observations Read	7144
Number of Observations Used	6743
Missing Values	401

tech=HID

Class Level Information

Name	Levels	Values
size	2	1-Small 2-Large

Fit Statistics

-2 Log Likelihood	4459.283
AIC (smaller is better)	4465.283
AICC (smaller is better)	4465.286
BIC (smaller is better)	4485.732

Algorithm converged.

Type III Analysis of Effects

Effect	DF	Wald Chi-Square	Pr > ChiSq
size	1	33.3481	<.0001

Analysis of Maximum Likelihood Parameter Estimates

Parameter		DF	Estimate	Standard Error	95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	2.2781	0.0124	2.2538	2.3025	33603.9	<.0001
size	1-Small	1	0.1023	0.0177	0.0676	0.1370	33.35	<.0001
size	2-Large	0	0.0000					
Scale		1	0.3111	0.0064	0.2987	0.3240		
Weibull Shape		1	3.2144	0.0666	3.0864	3.3477		

T8s

The SAS System

```
tech=T8

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                          Log(lower)
Dependent Variable                          Log(upper)
Number of Observations                           85222
Noncensored Values                               13322
Right Censored Values                            71043
Left Censored Values                               705
Interval Censored Values                           152
Name of Distribution                           Weibull
Log Likelihood                            -44175.44564


Number of Observations Read       91204
Number of Observations Used       85222
Missing Values                     5982


tech=T8

      Class Level Information

Name      Levels    Values

size           2    1-Small 2-Large


                 Fit Statistics

-2 Log Likelihood                       88350.89
AIC (smaller is better)                 88356.89
AICC (smaller is better)                88356.89
BIC (smaller is better)                 88384.95


Algorithm converged.


       Type III Analysis of Effects

                        Wald
Effect       DF    Chi-Square    Pr > ChiSq

size          1      150.9432        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                  Standard   95% Confidence     Chi-
```

```
Parameter              DF  Estimate    Error       Limits       Square Pr > ChiSq

Intercept               1    3.0461   0.0099    3.0266    3.0655 93760.5     <.0001
size          1-Small   1   -0.1602   0.0130   -0.1858   -0.1347   150.94     <.0001
size          2-Large   0    0.0000
Scale                   1    0.6262   0.0048    0.6169    0.6357
Weibull Shape           1    1.5969   0.0122    1.5730    1.6210
```

Unadjusted Model Statistics by Business Type

CFL Bulbs

```
The SAS System

tech=CFLB

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                        Log(lower)
Dependent Variable                        Log(upper)
Number of Observations                         12819
Noncensored Values                              2292
Right Censored Values                           4748
Left Censored Values                            5042
Interval Censored Values                         737
Name of Distribution                         Weibull
Log Likelihood                          -9263.297295


Number of Observations Read       14505
Number of Observations Used       12819
Missing Values                     1686


tech=CFLB

               Class Level Information

Name      Levels    Values

busi           3    1-Retail/Whole 2-Services 3-Other


                 Fit Statistics

-2 Log Likelihood                     18526.59
AIC (smaller is better)               18534.59
AICC (smaller is better)              18534.60
BIC (smaller is better)               18564.43
```

```
Algorithm converged.


       Type III Analysis of Effects

                          Wald
Effect       DF     Chi-Square    Pr > ChiSq

busi          2      2290.2836        <.0001


                  Analysis of Maximum Likelihood Parameter Estimates

                                            Standard   95% Confidence     Chi-
Parameter                    DF Estimate     Error       Limits       Square Pr > ChiSq

Intercept                     1   1.9217    0.0134   1.8954   1.9480 20507.1     <.0001
busi          1-Retail/Whole  1  -0.5727    0.0174  -0.6067  -0.5386 1086.73     <.0001
busi          2-Services      1   0.1335    0.0164   0.1013   0.1657   66.03     <.0001
busi          3-Other         0   0.0000
Scale                         1   0.5195    0.0070   0.5059   0.5335
Weibull Shape                 1   1.9249    0.0261   1.8745   1.9767
```

CFL Fixtures

```
The SAS System

tech=CFLF

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                         Log(lower)
Dependent Variable                         Log(upper)
Number of Observations                           4253
Noncensored Values                               2045
Right Censored Values                            2156
Left Censored Values                               50
Interval Censored Values                            2
Name of Distribution                          Weibull
Log Likelihood                           -2652.940628


Number of Observations Read        5072
Number of Observations Used        4253
Missing Values                      819


tech=CFLF

               Class Level Information

Name       Levels    Values
```

```
busi           3    1-Retail/Whole 2-Services 3-Other


                 Fit Statistics

-2 Log Likelihood                     5305.881
AIC (smaller is better)               5313.881
AICC (smaller is better)              5313.891
BIC (smaller is better)               5339.303


Algorithm converged.


       Type III Analysis of Effects

                        Wald
Effect       DF     Chi-Square    Pr > ChiSq

busi          2       414.4287        <.0001


                  Analysis of Maximum Likelihood Parameter Estimates

                                         Standard   95% Confidence     Chi-
Parameter                    DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept                     1   2.8313   0.0854   2.6639   2.9988 1098.23     <.0001
busi          1-Retail/Whole  1  -1.0503   0.0870  -1.2208  -0.8798  145.83     <.0001
busi          2-Services      1  -0.7095   0.0856  -0.8773  -0.5418   68.72     <.0001
busi          3-Other         0   0.0000
Scale                         1   0.3673   0.0066   0.3545   0.3806
Weibull Shape                 1   2.7225   0.0492   2.6277   2.8207
```

LED Exit

```
The SAS System

tech=Exit

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                         Log(lower)
Dependent Variable                         Log(upper)
Number of Observations                           1959
Noncensored Values                                204
Right Censored Values                            1751
Left Censored Values                                4
Interval Censored Values                            0
Name of Distribution                          Weibull
Log Likelihood                           -716.5060753
```

```
Number of Observations Read        2040
Number of Observations Used        1959
Missing Values                       81


tech=Exit

               Class Level Information

Name      Levels    Values

busi           3    1-Retail/Whole 2-Services 3-Other


                 Fit Statistics

-2 Log Likelihood                       1433.012
AIC (smaller is better)                 1441.012
AICC (smaller is better)                1441.033
BIC (smaller is better)                 1463.333


Algorithm converged.


       Type III Analysis of Effects

                         Wald
Effect       DF    Chi-Square    Pr > ChiSq

busi          2       48.2766        <.0001


                  Analysis of Maximum Likelihood Parameter Estimates

                                         Standard   95% Confidence     Chi-
Parameter                   DF Estimate     Error       Limits       Square Pr > ChiSq

Intercept                    1   4.0813    0.2460   3.5990   4.5635   275.16     <.0001
busi          1-Retail/Whole 1  -1.3797    0.2417  -1.8533  -0.9060    32.59     <.0001
busi          2-Services     1  -0.7554    0.2204  -1.1874  -0.3234    11.75     0.0006
busi          3-Other        0   0.0000
Scale                        1   0.5940    0.0379   0.5242   0.6731
Weibull Shape                1   1.6834    0.1074   1.4856   1.9075
```

HIDs

```
The SAS System

tech=HID

The LIFEREG Procedure
```

```
                 Model Information

Data Set
Dependent Variable                     Log(lower)
Dependent Variable                     Log(upper)
Number of Observations                       6743
Noncensored Values                           1270
Right Censored Values                        5439
Left Censored Values                           11
Interval Censored Values                       23
Name of Distribution                      Weibull
Log Likelihood                       -2057.263578


Number of Observations Read       7144
Number of Observations Used       6743
Missing Values                     401


tech=HID

               Class Level Information

Name      Levels    Values

busi           3    1-Retail/Whole 2-Services 3-Other


                 Fit Statistics

-2 Log Likelihood                4114.527
AIC (smaller is better)          4122.527
AICC (smaller is better)         4122.533
BIC (smaller is better)          4149.792


Algorithm converged.


       Type III Analysis of Effects

                       Wald
Effect       DF    Chi-Square    Pr > ChiSq

busi          2      305.7341        <.0001


                  Analysis of Maximum Likelihood Parameter Estimates

                                        Standard   95% Confidence     Chi-
Parameter                    DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept                     1   2.1360   0.0120   2.1125   2.1596 31601.6     <.0001
busi          1-Retail/Whole  1   0.3989   0.0286   0.3429   0.4549  194.95     <.0001
busi          2-Services      1   0.3215   0.0218   0.2788   0.3642  217.88     <.0001
```

```
busi           3-Other          0    0.0000
Scale                           1    0.3253    0.0071    0.3117    0.3395
Weibull Shape                   1    3.0739    0.0671    2.9451    3.2082
```

T8s

```
The SAS System

tech=T8

The LIFEREG Procedure

                 Model Information

Data Set
Dependent Variable                       Log(lower)
Dependent Variable                       Log(upper)
Number of Observations                        85222
Noncensored Values                            13322
Right Censored Values                         71043
Left Censored Values                            705
Interval Censored Values                        152
Name of Distribution                        Weibull
Log Likelihood                         -42235.03713


Number of Observations Read       91204
Number of Observations Used       85222
Missing Values                     5982


tech=T8

               Class Level Information

Name       Levels    Values

busi           3    1-Retail/Whole 2-Services 3-Other


                 Fit Statistics

-2 Log Likelihood                      84470.07
AIC (smaller is better)                84478.07
AICC (smaller is better)               84478.07
BIC (smaller is better)                84515.49


Algorithm converged.


       Type III Analysis of Effects

                       Wald
Effect        DF    Chi-Square    Pr > ChiSq
```

```
busi          2     3232.6383        <.0001


                  Analysis of Maximum Likelihood Parameter Estimates

                                                Standard   95% Confidence     Chi-
Parameter                     DF Estimate     Error       Limits        Square Pr > ChiSq

Intercept                      1   3.5570    0.0230    3.5119   3.6022 23844.8      <.0001
busi          1-Retail/Whole  1  -0.9357    0.0222   -0.9791  -0.8922 1782.89      <.0001
busi          2-Services      1  -0.3652    0.0216   -0.4076  -0.3227  284.67      <.0001
busi          3-Other         0   0.0000
Scale                          1   0.6174    0.0047    0.6082   0.6267
Weibull Shape                  1   1.6197    0.0124    1.5956   1.6442
```

Unadjusted Model Statistics by Load Factor

CFL Bulbs

```
The SAS System

tech=CFLB

The LIFEREG Procedure

                    Model Information

Data Set                    WORK._MODEL_LIFEREG_LOAD_DATA
Dependent Variable                             Log(lower)
Dependent Variable                             Log(upper)
Number of Observations                              12098
Noncensored Values                                   1651
Right Censored Values                                4748
Left Censored Values                                 4962
Interval Censored Values                              737
Name of Distribution                              Weibull
Log Likelihood                               -9931.763247


Number of Observations Read       12098
Number of Observations Used       12098


tech=CFLB

       Class Level Information

Name          Levels    Values

load_cat           2    1-Low 2-High


                 Fit Statistics
```

```
-2 Log Likelihood                        19863.53
AIC (smaller is better)                  19869.53
AICC (smaller is better)                 19869.53
BIC (smaller is better)                  19891.73


Algorithm converged.


       Type III Analysis of Effects

                          Wald
Effect        DF    Chi-Square    Pr > ChiSq

load_cat       1      240.9537        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                 Standard   95% Confidence     Chi-
Parameter           DF Estimate     Error       Limits       Square Pr > ChiSq

Intercept             1   2.1748   0.0224   2.1309   2.2186 9439.31     <.0001
load_cat      1-Low   1  -0.3744   0.0241  -0.4217  -0.3271  240.95     <.0001
load_cat      2-High  0   0.0000
Scale                 1   0.6700   0.0106   0.6496   0.6911
Weibull Shape         1   1.4925   0.0236   1.4469   1.5394
```

CFL Fixtures

```
The SAS System

tech=CFLF

The LIFEREG Procedure

                    Model Information

Data Set                     WORK._MODEL_LIFEREG_LOAD_DATA
Dependent Variable                              Log(lower)
Dependent Variable                              Log(upper)
Number of Observations                                2620
Noncensored Values                                     413
Right Censored Values                                 2156
Left Censored Values                                    49
Interval Censored Values                                 2
Name of Distribution                               Weibull
Log Likelihood                                -961.0535621


Number of Observations Read        2620
Number of Observations Used        2620
```

```
tech=CFLF

       Class Level Information

Name           Levels    Values

load_cat            2    1-Low 2-High


                 Fit Statistics

-2 Log Likelihood                      1922.107
AIC (smaller is better)                1928.107
AICC (smaller is better)               1928.116
BIC (smaller is better)                1945.720


Algorithm converged.


       Type III Analysis of Effects

                         Wald
Effect       DF    Chi-Square    Pr > ChiSq

load_cat      1       58.5925        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                 Standard   95% Confidence     Chi-
Parameter             DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept              1   3.3715   0.1334   3.1100   3.6329  638.69     <.0001
load_cat      1-Low    1  -0.9813   0.1282  -1.2326  -0.7300   58.59     <.0001
load_cat      2-High   0   0.0000
Scale                  1   0.3721   0.0152   0.3434   0.4033
Weibull Shape          1   2.6872   0.1101   2.4798   2.9118
```

LED Exit

```
The SAS System

tech=Exit

The LIFEREG Procedure

                    Model Information

Data Set                    WORK._MODEL_LIFEREG_LOAD_DATA
Dependent Variable                             Log(lower)
Dependent Variable                             Log(upper)
Number of Observations                               1850
Noncensored Values                                     99
Right Censored Values                                1751
```

```
Left Censored Values                                           0
Interval Censored Values                                       0
Name of Distribution                                     Weibull
Log Likelihood                                      -345.8053789


Number of Observations Read        1850
Number of Observations Used        1850


tech=Exit

    Class Level Information

Name          Levels    Values

load_cat           1    2-High


                 Fit Statistics

-2 Log Likelihood                       691.611
AIC (smaller is better)                 695.611
AICC (smaller is better)                695.617
BIC (smaller is better)                 706.657


Algorithm converged.


       Type III Analysis of Effects

                           Wald
Effect        DF     Chi-Square     Pr > ChiSq

load_cat       0


              Analysis of Maximum Likelihood Parameter Estimates

                                  Standard   95% Confidence     Chi-
Parameter            DF Estimate     Error       Limits       Square Pr > ChiSq

Intercept             1   2.9456    0.0789   2.7908   3.1003 1392.15     <.0001
load_cat      2-High  0   0.0000
Scale                 1   0.3114    0.0273   0.2623   0.3697
Weibull Shape         1   3.2111    0.2810   2.7050   3.8119
```

HIDs

```
The SAS System

tech=HID

The LIFEREG Procedure
```

```
                    Model Information

Data Set                    WORK._MODEL_LIFEREG_LOAD_DATA
Dependent Variable                             Log(lower)
Dependent Variable                             Log(upper)
Number of Observations                               6054
Noncensored Values                                    581
Right Censored Values                                5439
Left Censored Values                                   11
Interval Censored Values                               23
Name of Distribution                              Weibull
Log Likelihood                                -1229.38639


Number of Observations Read       6273
Number of Observations Used       6054
Missing Values                     219


tech=HID

       Class Level Information

Name          Levels    Values

load_cat           2    1-Low 2-High


                 Fit Statistics

-2 Log Likelihood                      2458.773
AIC (smaller is better)                2464.773
AICC (smaller is better)               2464.777
BIC (smaller is better)                2484.898


Algorithm converged.


       Type III Analysis of Effects

                         Wald
Effect       DF    Chi-Square    Pr > ChiSq

load_cat      1       26.3487        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                Standard   95% Confidence     Chi-
Parameter             DF Estimate    Error       Limits       Square Pr > ChiSq

Intercept              1   2.4210   0.0150   2.3915   2.4504 25893.4     <.0001
load_cat      1-Low    1   0.1665   0.0324   0.1029   0.2300    26.35     <.0001
```

```
load_cat       2-High  0    0.0000
Scale                  1    0.2654    0.0079    0.2503    0.2814
Weibull Shape          1    3.7684    0.1126    3.5540    3.9957
```

T8s

```
The SAS System

tech=T8

The LIFEREG Procedure

                    Model Information

Data Set                     WORK._MODEL_LIFEREG_LOAD_DATA
Dependent Variable                              Log(lower)
Dependent Variable                              Log(upper)
Number of Observations                               83627
Noncensored Values                                   11819
Right Censored Values                                71043
Left Censored Values                                   613
Interval Censored Values                               152
Name of Distribution                               Weibull
Log Likelihood                                -39111.44558


Number of Observations Read       84286
Number of Observations Used       83627
Missing Values                      659


tech=T8

       Class Level Information

Name           Levels    Values

load_cat            2    1-Low 2-High


                 Fit Statistics

-2 Log Likelihood                       78222.89
AIC (smaller is better)                 78228.89
AICC (smaller is better)                78228.89
BIC (smaller is better)                 78256.89


Algorithm converged.


       Type III Analysis of Effects

                          Wald
Effect        DF     Chi-Square     Pr > ChiSq
```

```
load_cat      1     1718.9419        <.0001


              Analysis of Maximum Likelihood Parameter Estimates

                                    Standard   95% Confidence     Chi-
Parameter            DF  Estimate     Error       Limits       Square Pr > ChiSq

Intercept             1    2.8269    0.0094    2.8085    2.8453 90366.0     <.0001
load_cat      1-Low   1    0.4953    0.0119    0.4718    0.5187 1718.94     <.0001
load_cat      2-High  0    0.0000
Scale                 1    0.5982    0.0049    0.5887    0.6078
Weibull Shape         1    1.6717    0.0136    1.6452    1.6987
```

Estimated Design Effect

In the table below we present design effects estimated under different strategies for dealing with the outlier site. The fourth column contains the design effect without any adjustment for the outlier site, while the fifth corresponds to the scenario in which the outlier is dropped from the analysis. In the last column the outlier site receives a lower weight by being assigned the average number of HID fixtures. The design effect used throughout the analysis is the one in which the outlier is downweighted.

Table 5-3: Design Effect under Different Strategies

Technology	Number of Sites	Number of Units	Keep Outlier	Drop Outlier	Downweight Outlier
CFL Bulb	73	14,505	324.9	324.9	324.9
CFL Fixture	81	5,072	67.9	67.9	67.9
LED Exit	105	2,040	26.6	26.6	26.6
HID	84	7,144	79.2	64.4	65.9
T8	193	91,204	531.9	540.6	531.9

Calculating EUL from the Model Coefficients

Each technology's EUL can be calculated from the model coefficients provided below by means of the following method. Let u_p be the p-th quantile of the underlying distribution. In the case of the Weibull distribution, u_p is given by:

$$u_p = \log(-\log(1 - p))$$

Since we are interested in the median lifetime, that is, the value at $p = 0.5$, we have:

$$\begin{aligned} u_{50} &= \log\left(-\log\left(1 - 0.50\right)\right) \\ &= -0.367 \end{aligned}$$

The predicted EUL from the Weibull distribution is then calculated by:

$$EUL = e^{x^T\beta + \sigma \cdot u_{50}}$$

where $\boldsymbol{X}$ is the matrix of covariates including the intercept, $\boldsymbol{\beta}$ is the vector of coefficients, σ is the scale coefficient, and u_{50} is the 50th quantile from the Weibull distribution calculated above.

According to the SAS documentation, in PROC LIFEREG the standard errors of the predicted values are computed numerically, via Taylor series expansion. Because there is no closed-form solution, we do not duplicate that exposition here. More details can be found in the online SAS documentation.

Example: Calculating Overall EUL for T8s

For the sake of illustration, suppose we want to calculate overall EUL for T8s. The coefficients for the fitted Weibull model are presented in the tables below. Because the only covariate in the overall model is the intercept, the predicted EUL is calculated from $\beta = 3.02$, $\sigma = 0.63$, and $u_{50} = -0.367$.

$$\begin{aligned} EUL_{T8} &= e^{x^T\beta + \sigma \cdot u_{50}} \\ &\approx e^{3.01 + 0.63 \cdot (-0.367)} \\ &\approx 16.2 \end{aligned}$$

Adjusted Weibull Model Statistics

The following tables provide model statistics adjusted with the design effects presented in the previous section. In each case, the adjustment to the standard error is simply the square root of the design effect. Note that the chi-square and p-value statistics are already adjusted with the design effect.

Table 5-4: Adjusted Model Statistics for Overall Model

Technology	Parameter	Estimate	Design Effect	Unadjusted Standard Error	Adjusted Standard Error	Chi-Square	Prob Chi-Square
CFLB	Intercept	1.84	324.9	0.007	0.120	235.44	0.000
CFLB	Scale	0.59	324.9	0.008	0.146		
CFLB	Weibull Scale	6.29	324.9	0.042	0.754		
CFLB	Weibull Shape	1.71	324.9	0.024	0.426		
CFLF	Intercept	2.09	67.9	0.009	0.072	835.84	0.000
CFLF	Scale	0.39	67.9	0.007	0.058		
CFLF	Weibull Scale	8.07	67.9	0.071	0.583		
CFLF	Weibull Shape	2.58	67.9	0.047	0.384		
Exit	Intercept	3.31	26.6	0.091	0.470	49.48	0.000
Exit	Scale	0.60	26.6	0.039	0.198		
Exit	Weibull Scale	27.28	26.6	2.488	12.821		
Exit	Weibull Shape	1.67	26.6	0.107	0.551		
HID	Intercept	2.33	65.9	0.010	0.085	755.66	0.000
HID	Scale	0.32	65.9	0.007	0.054		
HID	Weibull Scale	10.25	65.9	0.107	0.867		
HID	Weibull Shape	3.15	65.9	0.066	0.534		
T8	Intercept	3.01	531.9	0.009	0.216	195.59	0.000
T8	Scale	0.63	531.9	0.005	0.111		
T8	Weibull Scale	20.38	531.9	0.190	4.393		
T8	Weibull Shape	1.60	531.9	0.012	0.283		

Table 5-5: Adjusted Model Statistics for Model by Program Size

Technology	Parameter	Value	Estimate	Design Effect	Unadj Standard Error	Adjusted Standard Error	Chi-Square	Prob Chi-Square
CFLB	Intercept		2.04	324.9	0.011	0.193	112.43	0.000
CFLB	size	Small	-0.35	324.9	0.013	0.239	2.16	0.142
CFLB	size	Large	0.00	324.9				
CFLB	Scale		0.55	324.9	0.008	0.139		
CFLB	Weibull Shape		1.83	324.9	0.026	0.465		
CFLF	Intercept		2.57	67.9	0.026	0.214	143.69	0.000
CFLF	size	Small	-0.65	67.9	0.028	0.229	8.04	0.005
CFLF	size	Large	0.00	67.9				
CFLF	Scale		0.39	67.9	0.007	0.058		
CFLF	Weibull Shape		2.59	67.9	0.047	0.388		
Exit	Intercept		3.24	26.6	0.091	0.471	47.35	0.000
Exit	size	Small	0.21	26.6	0.094	0.482	0.19	0.661
Exit	size	Large	0.00	26.6				
Exit	Scale		0.60	26.6	0.039	0.198		
Exit	Weibull Shape		1.67	26.6	0.107	0.552		
HID	Intercept		2.28	65.9	0.012	0.101	509.90	0.000
HID	size	Small	0.10	65.9	0.018	0.144	0.51	0.477
HID	size	Large	0.00	65.9				
HID	Scale		0.31	65.9	0.006	0.052		
HID	Weibull Shape		3.21	65.9	0.067	0.541		
T8	Intercept		3.05	531.9	0.010	0.229	176.29	0.000
T8	size	Small	-0.16	531.9	0.013	0.301	0.28	0.594
T8	size	Large	0.00	531.9				
T8	Scale		0.63	531.9	0.005	0.111		
T8	Weibull Shape		1.60	531.9	0.012	0.282		

Table 5-6: Adjusted Model Statistics for Business Type Model

Technology	Parameter	Value	Estimate	Design Effect	Unadj Standard Error	Adjusted Standard Error	Chi-Square	Prob Chi-Square
CFLB	Intercept		1.92	324.9	0.013	0.242	63.11	0.000
CFLB	busi	Retail/Whole	-0.57	324.9	0.017	0.313	3.34	0.067
CFLB	busi	Services	0.13	324.9	0.016	0.296	0.20	0.652
CFLB	busi	Other	0.00	324.9				
CFLB	Scale		0.52	324.9	0.007	0.127		
CFLB	Weibull Shape		1.92	324.9	0.026	0.470		
CFLF	Intercept		2.83	67.9	0.085	0.704	16.19	0.000
CFLF	busi	Retail/Whole	-1.05	67.9	0.087	0.716	2.15	0.143
CFLF	busi	Services	-0.71	67.9	0.086	0.705	1.01	0.314
CFLF	busi	Other	0.00	67.9				
CFLF	Scale		0.37	67.9	0.007	0.055		
CFLF	Weibull Shape		2.72	67.9	0.049	0.406		
Exit	Intercept		4.08	26.6	0.246	1.268	10.36	0.001
Exit	busi	Retail/Whole	-1.38	26.6	0.242	1.245	1.23	0.268
Exit	busi	Services	-0.76	26.6	0.220	1.136	0.44	0.506
Exit	busi	Other	0.00	26.6				
Exit	Scale		0.59	26.6	0.038	0.195		
Exit	Weibull Shape		1.68	26.6	0.107	0.553		
HID	Intercept		2.14	65.9	0.012	0.098	479.51	0.000
HID	busi	Retail/Whole	0.40	65.9	0.029	0.232	2.96	0.085
HID	busi	Services	0.32	65.9	0.022	0.177	3.31	0.069
HID	busi	Other	0.00	65.9				
HID	Scale		0.33	65.9	0.007	0.058		
HID	Weibull Shape		3.07	65.9	0.067	0.545		
T8	Intercept		3.56	531.9	0.023	0.531	44.83	0.000
T8	busi	Retail/Whole	-0.94	531.9	0.022	0.511	3.35	0.067
T8	busi	Services	-0.37	531.9	0.022	0.499	0.54	0.464
T8	busi	Other	0.00	531.9				
T8	Scale		0.62	531.9	0.005	0.109		
T8	Weibull Shape		1.62	531.9	0.012	0.286		

Table 5-7: Adjusted Model Statistics for Load Factor Model

Technology	Variable	Value	Estimate	Design Effect	Unadj Standard Error	Adjusted Standard Error	Chi-Square	Prob Chi-Square
CFLB	Intercept		2.17	324.9	0.02	0.403	29.05	0.000
CFLB	load_cat	1-Low	-0.37	324.9	0.02	0.435	0.74	0.389
CFLB	load_cat	2-High	0.00	324.9				
CFLB	Scale		0.67	324.9	0.01	0.191		
CFLB	Weibull Shape		1.49	324.9	0.02	0.425		
CFLF	Intercept		3.37	67.9	0.13	1.099	9.41	0.002
CFLF	load_cat	1-Low	-0.98	67.9	0.13	1.056	0.86	0.353
CFLF	load_cat	2-High	0.00	67.9				
CFLF	Scale		0.37	67.9	0.02	0.126		
CFLF	Weibull Shape		2.69	67.9	0.11	0.907		
Exit	Intercept		2.95	26.6	0.08	0.407	52.43	0.000
Exit	load_cat	2-High	0.00	26.6				
Exit	Scale		0.31	26.6	0.03	0.140		
Exit	Weibull Shape		3.21	26.6	0.28	1.448		
HID	Intercept		2.42	65.9	0.02	0.122	392.90	0.000
HID	load_cat	1-Low	0.17	65.9	0.03	0.263	0.40	0.527
HID	load_cat	2-High	0.00	65.9				
HID	Scale		0.27	65.9	0.01	0.064		
HID	Weibull Shape		3.77	65.9	0.11	0.914		
T8	Intercept		2.83	531.9	0.01	0.217	169.91	0.000
T8	load_cat	1-Low	0.50	531.9	0.01	0.275	3.23	0.072
T8	load_cat	2-High	0.00	531.9				
T8	Scale		0.60	531.9	0.00	0.113		
T8	Weibull Shape		1.67	531.9	0.01	0.314		

KEMA

Estimated Surviving Proportions by Year

While the EUL provides a standard measure of lifetime, it is a single point estimate. It can also prove useful to know how the estimated surviving proportions decrease over time, especially for the period observed in the sample. Table 5-8 presents estimated surviving proportions over time since installation (in years) for each of the technologies in the study. For each technology, proportions are given for the Kaplan-Meier (K-M) estimator and for the Weibull model. Note that the Kaplan-Meier estimate is only available for the period observed within the sample.

Table 5-8: Estimated Surviving Proportion by Technology and Time

	Estimated Surviving Proportion									
Time (Years)	CFL Bulbs		CFL Fixtures		LED Exits		HIDs		T8s	
	K-M	Weibull	K-M	Weibull	K-M	Weibull	K-M	Weibull	K-M	Weibull
1	100%	96%	100%	100%	100%	100%	100%	100%	100%	99%
2	84%	87%	98%	97%	99%	99%	97%	99%	97%	98%
3	64%	75%	84%	93%	96%	98%	97%	98%	95%	95%
4	52%	63%	78%	85%	93%	96%	95%	95%	89%	93%
5	43%	51%	66%	75%	93%	94%	91%	90%	84%	90%
6	27%	40%	65%	63%	92%	92%	85%	83%	83%	87%
7	27%	30%	63%	50%	92%	90%	69%	74%	83%	83%
8	26%	22%	30%	38%	87%	88%	57%	63%	80%	80%
9	26%	16%	30%	27%	n/a	85%	52%	51%	80%	76%
10	n/a	11%	n/a	18%	n/a	83%	n/a	40%	79%	73%
11	n/a	7%	n/a	11%	n/a	80%	n/a	29%	78%	69%
12	n/a	5%	n/a	6%	n/a	78%	n/a	19%	n/a	65%
13	n/a	3%	n/a	3%	n/a	75%	n/a	12%	n/a	61%
14	n/a	2%	n/a	2%	n/a	72%	n/a	7%	n/a	58%
15	n/a	1%	n/a	1%	n/a	69%	n/a	4%	n/a	54%
16	n/a	1%	n/a	0%	n/a	66%	n/a	2%	n/a	51%
17	n/a	0%	n/a	0%	n/a	63%	n/a	1%	n/a	47%
18	n/a	0%	n/a	0%	n/a	61%	n/a	0%	n/a	44%
19	n/a	0%	n/a	0%	n/a	58%	n/a	0%	n/a	41%
20	n/a	0%	n/a	0%	n/a	55%	n/a	0%	n/a	38%